ELECTRIC POWER RESEARCH INSTITUTE

California Energy Commission
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August 17, 2012

California Energy Commission
1516 Ninth Street
Sacramento, CA 95814

Subject: Docket No: 12-EPIC-01, First Triennial Investment Plan for the Electric Program Investment Charge Program

This letter is intended to provide a summary of the positive benefits provided to California electricity ratepayers by engaging with the Electric Power Research Institute (EPRI) as an active part of the Electric Program Investment Charge (EPIC) investment framework. To define ratepayer benefits, we refer directly to the definition provided in the mandatory principle of the EPIC decision as, "greater reliability, lower costs, and increased safety." This letter also discusses EPRI's unique structure, the multiple forms of value EPRI can provide, and provides examples of successful past engagement in California research, development, and demonstration (RD&D). EPRI looks forward to engaging with the California Energy Commission (CEC) and investor-owned utilities (IOUs) through the EPIC framework.

EPRI Background:
EPRI was organized in 1973 to conduct research and development relating to the generation, transmission, distribution, and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. This focus aligns with the objective of the EPIC Applied R&D program of "supporting pre-commercial technologies and approaches that are designed to solve specific problems in the electricity sector." EPRI, its employees, officers and Board, are committed to sound principles of corporate governance that will support the Institute's public benefit mission. In fact, EPRI has been determined by the Internal Revenue Service to be a tax-exempt 501(c)3 organization created specifically to serve the public interest through energy and related research. EPRI's members represent nearly 90 percent of the electricity generated and delivered in the United States, and international participation extends to about 30 countries. EPRI's principal office is in Palo Alto, CA and has been since it began operations, and it currently has over 270 full-time employees based in California.

EPRI's organizational foundation and public-interest objectives provide strong alignment with the mandatory and complementary guiding principles of the California Electric Program Investment Charge (EPIC), particularly in providing ratepayer benefits as defined in the EPIC

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final decision: “greater reliability, lower costs, and increased safety.” EPRI appreciates California’s continued investment in electric RD&D, and looks forward to engaging with the CEC and utilities through the EPIC framework. As we show through this letter, the citizens and ratepayers of California would be well-served through CEC and utility collaboration and investment with EPRI.

Value EPRI Engagement Provides to California Ratepayers:
As the CEC and California IOUs develop their first triennial investment plan under the EPIC framework, EPRI requests that CEC and IOU engagement in EPRI’s Annual Research Portfolio (ARP) programs be considered as a distinct, non-competitive funding item included in the CEC Applied R&D investment plan. The EPIC final decision states that “In each investment plan, the administrators may propose a limited authorization for non-competitive bidding for particular purposes”, as such, EPRI requests that CEC and utility engagement in EPRI’s ARP program be funded through a non-competitive bidding process due to the many unique values that engagement with EPRI provides to the California ratepayers and the program administrators responsible for serving ratepayer interests. This engagement will ensure that substantial value is provided to California ratepayers, which may otherwise not be realized without CEC and IOU collaboration with EPRI’s ARP programs. Five particular areas of value are:

- Collaborative financial leverage resulting in shared costs and lower financial risks
- Minimizing duplication of existing industry R&D
- Ensuring ideas, results, and progress from R&D initiatives outside of California are brought into California, and that ideas, results, and progress from California R&D initiatives are implemented both inside and outside the state
- Collaborating with a research institute with a strong history of public benefit
- Alignment with EPIC Program objectives

Collaborative financial leverage:
Participation in EPRI ARP programs enable the funds from the California ratepayers to be leveraged with funds from other utilities and governmental organizations worldwide. This aligns with the CPUC’s statement in the EPIC final ruling that “we encourage the use and leveraging of matching funds whenever possible”. In total, EPRI currently receives approximately $380 million annually to fund and manage collaborative, public-benefit RD&D initiatives in the electricity sector.

Collaborative, applied R&D through EPRI provides an unparalleled benefit/cost ratio toward meeting the objectives of the EPIC ruling for California ratepayers. In fact, utility (or other organizational) participants receive an average 10-to-1 funding leverage in EPRI ARP programs. This means that on average for every one dollar each participant funds toward a program, there are an additional ten dollars of funding added from other program participants. Additionally, funders of EPRI ARP programs are provided the opportunity to have an advisory role to help guide the prioritization and resource allocation within the program as well as have access to the R&D results. For instance, EPRI’s Overhead Transmission program (P37) provides its nearly 50

utility funders with an advisory role and access to the results of over $8.25 million of applied R&D annually, while even the largest program participants each provide less than $750 thousand of annual funding toward the program. This equates to a funding leverage of 11 times the investment of the largest program funders, and an even higher level of funding leverage for smaller program participants with a lower price to participate. In many cases, participation prices for EPRI ARP programs are based on metrics associated with relevant utility asset ownership (for example, miles of overhead transmission lines, megawatts of hydropower generation capacity, etc.).

For the EPIC program, EPRI's collaborative funding model provides the best opportunity to leverage the California ratepayer dollars and meet the EPIC administrators' need to show success and metrics associated with "funding support from other entities for EPIC-funded research on technologies or strategies".

Minimize duplication of existing industry R&D:
The interests and objectives outlined in the EPIC final decision also align with the interests and objectives of governments and utilities outside of California with whom EPRI is already working closely. For instance, the mandatory EPIC objectives of "greater reliability, lower costs, and increased safety" align with the objectives of providing reliable, affordable, safe, and environmentally responsible electricity that are shared by nearly every utility and organization EPRI is engaged with. Because of the active advisory role that participants in EPRI ARP programs hold in guiding the priorities of research programs, these shared objectives are ensured to be brought into every program. Additionally, if the EPIC framework is utilized for the program administrators to fund EPRI ARP programs, the CEC and California IOUs would be able to help EPRI's programs to meet the mandatory and complementary principles of the EPIC program.

By engaging collaboratively through EPRI with industry experts and utilities throughout the world, the EPIC program administrators may be sure the projects and initiatives they invest in will be building upon progress that has already been made. Nearly every other major utility in the US participates in EPRI ARP programs – to not participate in them would make the state of California and its IOUs be an exception in the electricity sector and excluded from much of the progress in applied R&D which is collaboratively being made. The risk of not participating in the EPRI global R&D collaborative is that California may invest in R&D in an isolated fashion relative to the rest of the industry, which would increase the opportunity for redundant investment in areas that have already been addressed in the US or global community. This potential redundancy would directly reduce the ratepayer benefits that could be gained in California through the EPIC ratepayer investment. With EPRI's members representing nearly 90 percent of the electricity generated and delivered in the United States, and with international participation extending to approximately 30 countries, EPRI provides a strong resource for collaborative, applied R&D to benefit California ratepayers.

A Strong and Consistent Public Benefit Mission
EPRI, its employees, officers and Board, are committed to sound principles of corporate governance that will support the Institute's public benefit mission. EPRI is a tax-exempt 501(c)3 organization created specifically to serve the public interest and has a strong and consistent history of technical objectivity and independence. In order to consistently review EPRI's public mission, the founding organizations of EPRI established a public Advisory Council to oversee this mission. The Advisory Council consists of 30 individuals from academia, government, business (non-utility), environmental organizations, as well as ten (10) state public utility commissioners appointed by the president of the National Association of Regulatory Utility Commissioners (NARUC). The current roster of the Advisory Council is provided in Attachment A.

The relevance of the Advisory Council has increased, not diminished, in the years since EPRI's founding. The rationale for its establishment – ensuring public oversight of quasi-public funds, balancing shorter term operational needs against longer term research, maintenance of an objective and unbiased voice, and consideration of the environmental and social consequences of electricity generation and transmission – are at the forefront of issues faced today. These objectives for the Advisory Council clearly align with those of the EPIC program.

Alignment with EPIC Program
EPRI's ARP programs directly align with the mandatory and complementary EPIC principles, as well as the five elements that EPIC administrators must include in their investment plans (Grid operations / market design, Generation, Transmission, Distribution, and Demand-side management). To illustrate the direct connection that EPRI's programs have with these elements, a summary of EPRI's Annual Research Portfolio for 2013 is enclosed in Attachment B and the full listing is available online at: http://portfolio.epri.com/Default.aspx

Through its collaborative, thorough, and industry-wide applied R&D roadmapping efforts, EPRI consistently tracks barriers and issues in the industry that are being targeted by its research. This would provide direct benefit to EPIC administrators' need to clearly identify objectives for "barriers or issues resolved that prevented widespread deployment of technology or strategy" in their investment plans. To illustrate the alignment of EPRI's portfolio with the objectives and target areas noted in the EPIC decision for Applied R&D, Technology Demonstration and Deployment, and Market Facilitation, and as a recommendation for EPIC administrators to consider in the development of their initial investment plans, EPRI's new and collaboratively developed R&D roadmaps for Power Delivery & Utilization, Environment, and Generation, as well as an analysis of overarching electric sector R&D Challenges are enclosed in Attachments C, D, E, and F, respectively.

Historic Engagement with CEC and CA Utilities:
EPRI has a strong history of successful engagement with the CEC and California utilities in the areas of Applied R&D, Technology Demonstration and Deployment, and Market Facilitation. A

notable example is the engagement between the CEC, EPRI and partners at Ecos in providing technical support for the incorporation of energy-efficient external power supplies for consumer and office electronics into California's Title 20 Appliance Efficiency Regulations by the CEC, which in turn supported the incorporation of somewhat more stringent specifications into federal product standards that took effect in 2008.

In a cost/benefit assessment by an for the CEC by KEMA, Inc., seven projects were chosen by Public Interest Energy Research (PIER) staff as having high probability of generating energy and environmental benefits in a relatively short period of time. Of the seven chosen research projects, the external power supply work EPRI was involved in provided the best cost benefit ratio. As estimated by this assessment, an initial PIER investment of $577,000 yielded between $58,000,000 and $105,000,000 in benefits for the state of California. On a nationwide scale, the benefits ranged from $908,000,000 to $1,135,000,000.

The research above led to further PIER-funded research and specification development by EPRI and Ecos for internal power supplies, aimed primarily at desktop computers. The specification developed led to a utility funded incentive program called 80PLUS, administered by Ecos with technical support from EPRI. To date this program has added over 3000 power supply designs to the certified list. In addition, EPRI's test procedure was adopted by Intel, and eventually the rest of the computer industry as the de facto standard for power supply efficiency testing. In 2007, the 80PLUS specification was adopted by the EPA's Energy Star program, as part of the fourth version of their computer efficiency specification. In addition, this work is ongoing, developing similar specifications for servers and electronic storage devices. Several other categories are pending, demonstrating the ongoing benefits generated by the initial CEC collaboration with EPRI.

This is an excellent example of how CEC research results can be expanded to the rest of the U.S. through engagement with EPRI, as well as the numerous benefits that have been provided to California ratepayers through prior CEC-EPRI collaboration. This successful market transformation required more than just California's market to move forward, and EPRI's involvement provided the opportunity to engage many other US regions to help facilitate participation of organizations with interests outside of California, most notably the manufacturers. Similar benefits can be provided in future projects facilitated under the EPIC program through collaborative and engagement with EPRI, which can directly help EPIC administrators meet the need to show metrics and benefits associated with "effectiveness of information dissemination" and "adoption of technology, strategy, and research data by others" as stated in the EPIC final decision.

Additional examples of CEC-EPRI collaboration are included in Appendix A:

In addition to the extensive work directly between the CEC and EPRI, the California IOUs have joined their electricity sector peers and engaged EPRI through its Annual Research Portfolio for

much of the last four decades. This portfolio facilitates the creation of solutions for specific, near-term problems while addressing range of complex, interconnected, and long-range strategic challenges through collaborative research, development, and demonstration programs. In many cases, the California IOU investments in EPRI's collaborative RD&D structure have been made through their R&D budgets, which may nowbe consolidated within the EPIC framework. To continue to enable these investments in collaborative industry R&D, the EPIC program must provide a specific and sufficient budget amount for its administrators to engage in EPRI Annual Research Portfolio programs.

Key Contacts:

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Sincerely,

Arshad Mansoor
Senior Vice President, Research & Development

Attachments

- Attachment A – EPRI Advisory Council Roster
- Attachment B – EPRI 2013 Annual Research Portfolio Summary
- Attachment C – EPRI Power Delivery & Utilization Roadmap
- Attachment D – EPRI Environment Roadmap
- Attachment E – EPRI Generation Roadmap
- Attachment F – EPRI Electric Sector R&D Challenges

Appendix A:

These past CEC-EPRI project show strong alignment with the mandatory and complementary principles of the EPIC program as well its areas of focus (Grid operations / market design, Generation, Transmission, Distribution, and Demand-side management:

Smart Grid

- Developed in 2010 with the California Investor-Owned Utilities (IOUs) the "California Utility Vision and Roadmap for the Smart Grid of 2020" – this report, published in 2011, describes the utilities' shared vision of a more capable, robust, and efficient electricity infrastructure and presents a detailed roadmap to help achieve the State's energy and environmental policy goals
- Continuing joint collaboration with the California utilities and the CEC – for example, EPRI's participation in the "Emerging Technologies Coordination Committee" quarterly meetings (with the CPUC, CEC, SCE, PG&E, SDG&E and SMUD), and the biennial Emerging Technologies Summit
- Performed in 2009 an initial investigation for the CEC to clarify what a smart grid is to stakeholders in California. Developed a framework to show how the technological components—hardware, control algorithms, information technology, and communication networks—could be brought together to make a smart grid possible. Results are published in the report "Integrating New and Emerging Technologies into the California Smart Grid Infrastructure".
- Jointly collaborated with the California utilities, Department of Water Resources, and the CAISO in 2008-09 to develop and demonstrate a new methodology for valuing demand response to mitigate wholesale market settlement costs. The work is reported in "Decision Support for Demand Response Triggers: Methodology Development and Proof of Concept Demonstration".

Energy Storage and Distributed Energy Resources

- Assessment of California CHP Market and Policy Options for Increased Penetration (2004-2005): Determined the market size and effects of policy on Combined Heat and Power options. (Final report is available at http://www.energy.ca.gov/2005publications/CEC-500-2005-060/CEC-500-2005-060-D.PDF)
- Shaping a California Distributed Energy Resources Procurement (2004-2005): Examined the barriers to adoption for Distributed Energy Resources and determined how to develop win-win programs for DER integration with utilities. (Final report is available at http://www.energy.ca.gov/2005publications/CEC-500-2005-062/CEC-500-2005-062-D.PDF)
- CEC/DOE Energy Storage Collaboration: A suite of energy storage demonstrations begun in 2005, testing several energy storage systems in California locations. EPRI was responsible for data collection (as a sub to Sandia, which had the prime contract

from CEC); the collaboration website created by EPRI is at http://energystoragedemo.epri.com/cec/index.asp

- Compressed Air Energy Storage Scoping Study for California: A top-level scoping study conducted in 2008 identifying potential sites for CAES and analyzing their potential for use in energy storage applications. (Final report is available at http://www.energy.ca.gov/2008publications/CEC-500-2008-069/CEC-500-2008-069.PDF)
- Wind-Storage-Enhanced Transmission Research and Development Project Grant (PIR-07-010): A $481k project begun in 2008 facilitating the deployment of energy storage technologies to address the effects of wind generation on the grid, with EPRI as the prime and PG&E and SCE as subcontractors to EPRI.
- PG&E NAS Battery project: EPRI is working with PG&E (the prime contractor funded by CEC) to create an Engineer-of-Record report documenting experiences and lessons-learned from the installation of two NAS batteries at PG&E sites

Electric Transportation

- The Energy Commission participated in a landmark 2007 study by EPRI and the Natural Resource Defense Council, 'Environmental Assessment of Plug-In Hybrid Electric Vehicles. This was the first attempt to to quantified the net resulting energy compounds and emissions (i.e. CO2, CO, VOC, NOX, SO2, NH3, PM, and Hg) resulting from the expansion of electric transportation in a given geographic region.
- The Energy Commission was a founding sponsor of Plug-In 2008 (held in San Jose, CA) and has both sponsored and participated in all five of the annual events
- EPRI is currently working with the South Coast Air Quality Management District on a DOE Recovery Act program, with CEC co-funding, to develop and evaluate almost 300 plug-in hybrid medium duty commercial vehicles in real-world fleet application
- EPRI is currently administering a block grant from the CEC to demonstrate the retrofit of medium-duty commercial trucks with plug-in hybrid electric systems

Environmental & Climate Analysis

- EPRI's first contract under the PIER program was to identify and manage a multi-disciplinary team to examine potential climate impacts on California ecosystems, public health and the economy. This highly-leveraged effort significantly advanced the understanding of potential climate impacts in the state, culminating in a CEC report and summarized in the book, The Impact of Climate Change on Regional Systems: A Comprehensive Analysis of California, Smith and Mendelsohn eds., Edward Elgar 2006. The project also served to introduce CEC staff to over 20 leading researchers in the impacts community.

Power Quality / Energy Efficiency / Demand Response

- During the early years of the PIER program, EPRI and CEC collaborated on technology development projects, and produced co-branded reports (Ex: Development of Liquid Membrane Technology, http://my.epri.com/portal/server.pt?Abstract_id=000000000001006577)

- Field testing of equipment in food processing facilities to determine their sensitivity to power quality events
- Development and deployment of uninterruptible power supplies using ultracapacitors in place of lead acid batteries
- Development of test procedures and performance specifications for the sensitive equipment found in food processing plants - these documents were adopted by the California League of Food Processors, which led to increased productivity (less downtime)
- Assessment of Power Quality impacts for California – this work established the baseline for the levels of productivity increase possible through the type of standard development above
- Guidebook on Power Quality guidelines for energy savings products – this work helped ensure that deployment of energy savings devices would not adversely affect productivity
- Lab and field testing of harmonic filters to determine potential energy savings.
- Assessment of the Impacts Of Power Factor Correction in Computer Power Supplies On Commercial Building Line Losses – this work led to the Energy Star specification on computer efficiency
- Battery charger test procedure – EPRI developed the test procedure used for battery chargers associated with CA Title 20 regulations
- Industrial power supply energy savings potential assessment – this work identified significant energy savings opportunities in adjustable speed drives, dry type transformers, welding equipment, industrial rectifiers, industrial process heating, and industrial motors
- Assessment of energy saving potential in uninterruptible power supplies
- Assessment of energy savings potential in consumer/commercial electronics and motor driven appliances - this work is on-going and includes lab testing and evaluation of low and high-end computing, home audio systems, induction cooking, adjustable speed drives in appliances, and assessment of energy savings potential through requirement of power factor correction for all consumer and commercial electronics
- Assessment of the energy potential in active harmonics cancellation in commercial and industrial settings, both through product testing and evaluation of new, emerging technologies and techniques
- Market research into the most promising approaches for industrial, agricultural, food, and water demand response, in concert with the California League of Food Processors and the Silicon Valley Manufacturing Group
- Development of demand response estimating software tools
- Assessment of the energy saving potential of Retrofit Energy Saving Devices including application guidelines for electric power users

- Demonstration of a productivity-enhancing ultracapacitor technology at an California-based Intel manufacturing facility
- Development of DC power distribution systems for data centers
- Industrial facility assessments for the food processing industry
- A Guidebook "Power Quality Guidelines for Energy-Efficient Device Application" promoting the successful implementation of energy efficient technologies
- A State-wide assessment of PQ in California industries targeting productivity enhancement opportunities
- Response to many energy efficiency, power quality, and productivity-related inquiries through participation in the EPRI Power Quality Knowledge project

Carbon Capture & Sequestration

- The WestCarb Regional Carbon Sequestration program through which EPRI has worked with support from the CEC (as well as funding from the US Department of Energy and EPRI member utilities from outside of California) on carbon dioxide capture and storage issues as well as with utility organizations – this work for CEC includes drilling stratographic wells and developing data in geologic formation in areas that supply power to California

Advanced Cooling and Water Conservation

- During the early years of the PIER program, EPRI and CEC collaborated on research covering a variety of initiatives addressing the technical barriers, costs and other challenges related to water conservation in power plants, and included projects such as: the use of degraded water sources for cooling towers; commercial and near-commercial technologies for water conservation; design and operations guidelines for air cooled condensers; wind effects on air cooled condensers; and evaporative cooling to reduce air cooled condenser energy penalties – this work helped enable these technologies in CA and the broader United States. EPRI has continued the work in advanced cooling and water conservation, with new efforts in developing the next generation of cooling technologies (thermosyphon coolers, green chillers, dewpoint depression) and energy efficient water and wastewater treatment technologies.

ELECTRIC POWER RESEARCH INSTITUTE

Electric Power Research Institute, Inc.
Advisory Council
2012

2013	**David G. Victor*, Chairman**	University of California San Diego
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2014	**Barry Worthington**	United States Energy Association

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2014	**Susan Ackerman***	Oregon Public Utility Commission
2014	**Kenneth W. Anderson, Jr.**	Public Utility Commission of Texas
2014	**Garry A. Brown**	New York State Public Service Commission
2014	**David C. Coen**	Vermont Public Service Board
2015	**Philip B. Jones**	Washington Utilities and Transportation Commission
2015	**Jon W. McKinney**	Public Service Commission of West Virginia
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2015	**Robert F. Powelson**	Pennsylvania Public Utility Commission
2014	**Harold D. Williams**	Maryland Public Service Commission
2013	**David A. Wright**	Public Service Commission of South Carolina

Terms expire at the August Advisory Council Meeting. This roster is as of August 5, 2012.

* Member of the Executive Committee of the Advisory Council.

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

2013 RESEARCH PORTFOLIO

RESEARCH OFFERINGS TO SHAPE THE FUTURE OF ELECTRICITY

A LINE OF SIGHT ON THE HORIZON

EPRI's portfolio of collaborative research, development, and demonstration programs solves specific, near-term problems while addressing a range of complex, interconnected, and long-range strategic challenges, including *how we can:*

Extend the operating life of today's assets

Long-Term Operations

Produce ever more electricity using ever decreasing amounts of water

Water Resource Management

Deploy renewable energy resources and integrate them with the grid

Renewable Resources and Integration

Many of the big answers to the big questions lie just beyond our line of sight — just beyond the horizon. Right now the horizon represents the limit of what we can see, but it's just the beginning of what we can discover.

The limit of what we can see;
the beginning of what we can discover.

Manage power more efficiently along the delivery chain

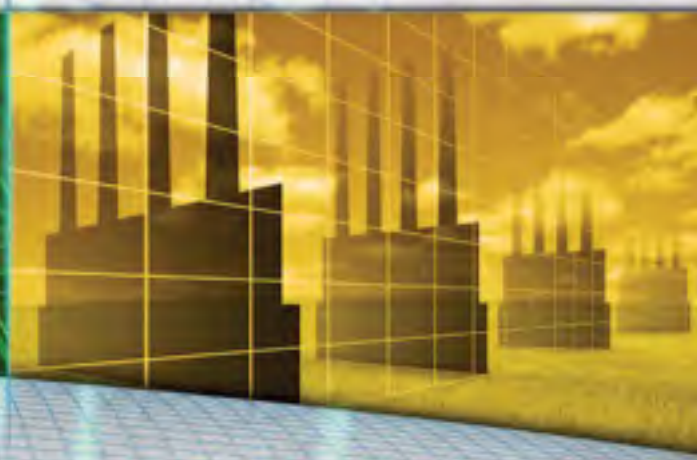
Energy Efficiency

Economically and technologically create the smart grid

Smart Grid

Deploy capital, manage costs, and navigate markets and mandates to achieve near-zero emissions

Near-Zero Emissions



TECHNOLOGY INNOVATION

Shaping the future through innovation

Introduction

The Technology Innovation Program (TI) leads early-stage RD&D to maintain a full pipeline of promising concepts, new knowledge, and potential breakthroughs. Experts across EPRI, its members, and the science and technology community scan horizons, anticipate opportunities, and marshal resources to focus applied innovation on strategic challenges. Collaboration with universities, national laboratories, and other institutions leads the industry in new directions. Insights and pre-commercial technologies transition into EPRI's sectors for further development and real-world application.
TI's five program elements are:

- **Innovation Scouting** monitors progress in other industries and around the world to identify high-value opportunities for collaborative RD&D for the electricity enterprise.
- **Thought Leadership** identifies strategic RD&D priorities and applies "technology readiness levels" to accelerate innovations from idea to application through EPRI's portfolio.
- **Polaris Initiative** provides seed funding to explore promising concepts, leading to follow-on work through TI and EPRI's research sectors.
- **Strategic Programs** make up the core of the TI portfolio to advance scientific knowledge and technological capabilities in 15 critical areas.
- **Breakthrough Technologies** represent potentially transformative advances being fast-tracked toward full-scale demonstration.

Strategic Programs

- **Carbon Capture**: Establish basic knowledge of solvent, sorbent, and membrane capture mechanisms. Accelerate scale-up testing of technologies offering lower energy penalties and costs.
- **Concrete**: Enhance understanding of aging and degradation. Improve inspection, nondestructive evaluation, condition assessment, and asset management for structures at nuclear plants and other facilities.
- **Energy Efficiency**: Develop advanced motor, space conditioning, and other end-use technologies, as well as building performance systems that offer increased efficiency and improved demand-response capability.
- **Future Plant Emissions**: Assess multimedia emissions and environmental and health risks for advanced generation, carbon capture, and pollution control systems to inform technology development and policymaking.
- **Grid Transformation**: Develop a framework, specifications, and advanced modeling, analysis, management, and protection tools to revolutionize operations and planning and enable seamless delivery of smart grid functions.
- **Low-Dose Radiation**: Conduct health effects studies and synthesize worldwide knowledge to develop updated risk models and advance the scientific basis for future exposure standards associated with nuclear plant operations.
- **Materials – Fossil & Nuclear Generation**: Develop advanced materials, improved condition assessment and asset management tools, and new component fabrication methods for existing and future plants.
- **Near-Zero Emissions**: Design and test fuel cleaning, energy conversion, and back-end control systems to help achieve fuel neutrality and maintain coal as an economically and environmentally acceptable supply option.
- **Nondestructive Evaluation**: Advance inspection and condition assessment for critical components and high-impact damage mechanisms to reduce maintenance costs and improve asset management at nuclear and fossil plants.
- **Nuclear Fuel Cycles & Generation Technologies**: Assess resource utilization, cost, safety, security, and waste management for open and closed fuel cycles. Determine potential of advanced fission, fusion, and hybrid systems.

How we respond to the challenges we face today, will define the horizon of tomorrow.

Arup Assar

- **Power Electronics**: Design and test solid-state devices offering higher capacity, increased efficiency, faster response, and reduced size and costs for power delivery, renewables integration, and end-use applications.
- **Renewables**: Develop biomass, wind, solar, geothermal, water, and grid integration technologies to reduce costs and environmental impacts and enable widespread deployment in central station and distributed applications.
- **Sensors & Operations**: Design and test real-time monitoring systems to improve availability, reliability, and performance of transformers, transmission lines, steam piping, turbine blades, coal gasifiers, and other components.
- **Smart Grid Health & Safety**: Evaluate radio-frequency emissions, field exposures, and possible health effects from advanced meters and other technologies to address public concerns and facilitate smart grid deployment.
- **Water Use & Availability**: Develop cooling, treatment, and energy conversion technologies for increasing water efficiency at power plants, reducing operational and environmental impacts, and facilitating siting of new capacity.

Breakthrough Technologies

Transmission Line Robot for Condition-Based Maintenance: The autonomous robot's on-board systems promise high-fidelity, lower-cost monitoring, while enhancing compliance with reliability and vegetation management standards. Commercial demonstration of a robot capable of traveling along overhead circuits and delivering actionable data is planned for 2014 on a new transmission line.

Handheld, Real-Time, 3-D Imaging for Component Inspection: Integrating advanced acoustic transducers and signal processing methods with computer mouse technology is expected to transform ultrasonic imaging from an expensive, niche inspection method to a mainstream nondestructive evaluation solution for a broad range of power plant components. By the end of 2014, the system is scheduled for field test validation and should be ready for commercial licensing.

Sequestration Resins for Treatment of Nuclear Plant Coolants: Novel resins target key transition-metal impurities in coolant systems and lock them within their chemical structures, promising at least a three-fold increase in removal rates, which could help compress outage schedules, decrease radiation exposure, and reduce costs. Demonstrations of sequestration resin technology at boiling and pressurized water reactor plants are scheduled for completion in 2012–13, followed by commercial licensing.

Erosion-Resistant Alloy Development via Functionally Graded Manufacturing: Powder metallurgy methods are expected to allow precise control of materials composition in order to increase damage resistance during component manufacturing rather than through post-fabrication treatment. Demonstration of damage-resistant nuclear plant valves is planned for 2013, paving the way for reduced lead times and costs and improved in-service performance in a range of nuclear and fossil generation applications.

Multifunctional Nanoparticles for Reducing Cooling Tower Water Consumption: Incorporating nanoparticles in coolants has the potential to improve thermal properties, reducing by as much as 20% the water consumption in closed-cycle steam-condensing systems at nuclear, fossil, and other power plants. Multifunctional nanoparticle technology is on track for early demonstration in 2015 to help power producers meet increasingly stringent water use restrictions while avoiding or lowering costs of major cooling system retrofits.

Near-term carbon capture and storage (CCS) technology is projected to reduce net energy output from coal-fired power plants by about 30% and increase their cost of electricity by 60–80%. EPRI is leading a global search for next-generation technologies based on first-of-a-kind computational models. These models quantify the fundamental properties that enable low-energy capture, accelerating the screening of candidate sorbents, solvents, and membranes. Among a database of more than 2.7 million sorbent formulations, for example, hundreds with breakthrough potential for reducing parasitic energy consumption have been identified. Modeling insights help focus exploratory research by universities, national laboratories, and other CCS developers on promising materials, as well as guide innovation scouting by EPRI.

ENVIRONMENT AND RENEWABLE ENERGY

Bringing together technology research and analysis with health/physical sciences to make the production and use of electricity sustainable for current and future generations

Air Quality

Rulemaking for air pollutants and regional haze continues to be a key issue for fossil power plant owners and operators. EPRI's Air Quality programs provide comprehensive scientific information to electric utilities, policymakers, regulators, and other stakeholders on the impacts of air quality on public health, visibility, and the environment. This research develops tools that help deliver scientifically based, cost-effective air quality management plans.

42 Air and Multimedia Toxics Health and Risk Assessment

91 Air Quality Assessment of Ozone, Particulate Matter, Visibility, and Deposition

92 Assessment of Air Quality Impacts on Human Health

Energy and Environmental Analysis

Electric utilities face unprecedented uncertainties from new environmental regulations and future energy and climate policies. Outcomes of these regulatory and policy actions will drive decisions about retrofitting plants with additional or new equipment or retiring them. Further uncertainty is added by changing fuel markets; increasing renewable resources; cost, performance, and availability of key generation and emission control technologies; uncertain economic and demand growth; and availability of capital. EPRI's Energy and Environmental Analysis programs integrate analyses of critical energy, environmental, and economic issues facing the electricity industry.

102 Global Climate Policy Costs and Benefits

103 Energy and Environmental Policy Analysis and Company Strategy

178 Technology Assessment, Market Analysis, and Generation Planning

Land and Groundwater

Management of contaminants and other by-products of electricity production, such as fly ash, is key to reducing the environmental footprint of electric sector operations. EPRI's Land and Groundwater programs provide tools and perform scientific analyses to assess and remediate contaminated soil and groundwater while developing management practices to prevent future releases.

49 Coal Combustion Products: Environmental Issues

50 Manufactured Gas Plant Site Management

59 Power Plant Multimedia Toxics Characterization

Occupational Health and Safety

Workplace injuries affect employee health, productivity, and job satisfaction and increase the cost of doing business. EPRI's Occupational Health and Safety program helps electric power companies reduce the number of workplace injuries, improve employee health, and control labor-related costs. The research provides rigorous analysis of injury and illness trends, designs cost-effective ergonomic interventions, and anticipates new exposures and health issues focused on the electricity sector.

62 Occupational Health and Safety

It is a profound mistake to think that everything has been discovered; as well think the horizon is the boundary of the world.

ANTOINE MERIN LEMIERRE

Renewable Energy

EPRI's Renewable Energy programs help improve the performance, availability, and cost-effectiveness of renewable technologies. Demonstrations optimize operating efficiency, reduce overall costs, and facilitate deployment of large-scale renewable generation. Technology development research helps find market opportunities and guides decisions on renewable assets. The research also examines environmental impacts of renewable energy development on land use, vegetation management, species and ecosystem interactions, and human health and safety. This research provides strategies to minimize such impacts and mitigate environmental barriers to renewable energy development.

84 Renewable Energy Economics and Technology Status
186 Wind
187 Solar
188 Biomass
189 Geothermal
190 Waterpower

T&D Environmental Issues

A safe, clean, and reliable power grid is critically important to the function of the electric industry, particularly as the grid is upgraded and expanded with new "smart" technologies. EPRI's T&D Environmental Issues programs work to understand and reduce scientific uncertainties associated with exposures to electric and magnetic fields and radio-frequency energy to help protect the health of both the public and utility workers. The research also develops cost-effective vegetation management on rights-of-way and examines environmentally acceptable options for service center, substation, and other infrastructure spill and cleanup issues.

51 T&D and ROW Environmental Issues
60 Electric and Magnetic Fields and Radio-Frequency Health Assessment and Safety

Water and Ecosystems

A primary challenge for power plant owners and operators is to ensure adequate availability of fresh water supplies for operations such as cooling. At the same time, protecting aquatic life during water withdrawal and discharge is paramount. EPRI's Water and Ecosystems programs develop information and tools to establish sustainable water use, water quality and fish protection, watershed management, and ecological impact assessments. The programs also research innovative water conservation technologies and options and use of alternative water sources.

53 Water Quality and Watershed Protection
54 Fish Protection at Steam Electric Power Plants
55 Water Availability and Resource Risk Management
56 Effluent Guidelines and Water Quality Management

Anticipating power plant owner scrutiny of coal combustion products, disposal and effluent discharges, ash pond closure strategies will be required over the next several years. Innovative solutions are needed for improving pond closure processes, land use once the pond is closed, and cost-effective remediation. EPRI's current research focuses on the potential for static liquefaction of the ponded ash during and after closure. Other research under consideration includes guidelines for construction of landfill facilities over closed ponds, which has the advantages of lower costs and environmental benefits compared to greenfield developments, and groundwater monitoring and remediation.

GENERATION

Making today's fossil generating fleet cleaner, more efficient, and more reliable and developing tomorrow's advanced generation technologies and emissions controls

Advanced Coal Plants, Carbon Capture and Storage

EPRI's Advanced Coal Plants programs help accelerate the development and commercial application of advanced coal-based power generation, including CO_2 capture technologies. New plant concepts and designs address technical risks, economic and environmental performance, and the challenges of deploying these new technologies. The programs also develop information needed to demonstrate the permanence and environmental safety of CO_2 storage. The goal is cost-effective coal-based generation with near-zero emissions and carbon capture and storage.

66 CoalFleet for Tomorrow - Future Coal Generation Options

165 CO_2 Capture and Storage

Combustion Turbines

Life-cycle costs, premature wear, failure risks, and environmental performance are critical issues affecting plant performance, reliability, and cost. EPRI's Combustion Combustion Turbines programs provide techniques and emerging technologies to quantify risk and reduce operations and maintenance costs, while maintaining reliability and performance. The goal is to effectively manage the risks, costs, and availability of these complex, increasingly important, and widely used assets.

79 Combined-Cycle Turbomachinery

88 Combined-Cycle HRSG and Balance of Plant

Environmental Controls

EPRI's Environmental Controls programs develop technologies that provide new control solutions for NOx, SOx, particulates, mercury, and other hazardous air pollutants (HAPS, organic and inorganic). The programs also optimize combustion to reduce the need for downstream control, which minimizes impacts on power plant operations and performance, and improve heat rate as a first-order effort to reduce CO_2 emissions. Predictive tools, databases, and monitoring technologies, guidelines, and practices help members reduce risk and objectively evaluate and implement technology options to achieve environmental performance goals at least cost.

71 Combustion Performance and Emissions Control

73 Post-Combustion NOx Control

75 Integrated Environmental Controls

76 Particulate and Opacity Control

77 Continuous Emissions Monitoring

78 Coal Combustion Product Use

The manager has his eye on the bottom line; the leader has his eye on the horizon

WARREN BENNIS

Major Component Reliability

Safety and availability loss due to failures are two key issues driving R&D on major fossil power plant components, especially in older plants. EPRI's Major Component Reliability programs provide data on critical equipment/material degradation mechanisms, conduct materials-related R&D for advanced generation technologies, and develop information for life-management strategies for steam turbines/generators. The programs help utilities balance the risks and costs of the largest, most costly equipment and focus on using proven technologies to create solutions.

63 Boiler Life and Availability Improvement Program
65 Steam Turbines-Generators and Auxiliary Systems
104 Generation Maintenance Applications Center (GenMAC)

Materials and Chemistry

Today's fossil power plants increasingly are adopting market-driven operating strategies such as cycling, pushing for maximum output during peak price periods, and frequent fuel switching to take advantage of spot market opportunities. These practices can accelerate material damage in major power block components. Safety and availability loss due to failures are two key issues driving R&D in EPRI's Materials and Chemistry programs, which includes flow-accelerated corrosion (FAC) mechanisms, materials selection guidance, corrosion mitigation methods, and repair and welding technologies needed to improve equipment performance and reliability, as well as advanced materials for new plants.

64 Boiler and Turbine Steam and Cycle Chemistry
87 Fossil Materials and Repair

Operations and Maintenance

Maintaining the availability of existing plants is critical to the future generation portfolio. Plant operators must continuously improve operations performance and shift from a reactive to a proactive approach to maintenance to achieve their reliability goals. EPRI's Operations and Maintenance programs address the need to improve operational effectiveness and safety, reduce maintenance costs, and provide technical support for the next generation of plant employees. The programs focus on providing an integrated solution that addresses the needs for processes, technologies, and skilled people.

68 Instrumentation, Controls, and Automation
69 Maintenance Management & Technology
108 Operations Management & Technology

Power Plant Water Management

Thermal electric power generation uses substantial amounts of water to provide cooling for thermal power plants, which currently deliver the majority of U.S. and global power generation. Power plants also discharge wastewater, which can be contaminated with metals and other dissolved and suspended solids. As a limited resource with competing demands, water is becoming more strategically important to the electric power industry. EPRI's Power Plant Water Management research is focused on ensuring the continued ability to generate electricity under increasing challenges to reduce water use and contamination.

185 Water Management Technology

Natural gas is the preferred fuel for many new power generation assets, but most of today's U.S. gas fleet has not yet been used extensively. These combined-cycle units are expected to provide more generation and very high reliability, but many were not designed for today's rapid load changes and cycling operations. EPRI's combustion turbine/combined-cycle research spans the entire plant. Current projects include guidelines for equipment-specific performance assessments, performance issue diagnostics, and identification of corrective actions, as well as a comprehensive maintenance basis to determine critical components and identify the most effective tasks to ensure that overhauls are scheduled and unanticipated breakdowns do not occur.

NUCLEAR

Developing safe, reliable, economical, and environmentally responsible technologies that enable the long-term operation of existing nuclear plants and the deployment of advanced nuclear power plants

Advanced Nuclear Technology

New nuclear power plants that incorporate advanced light water reactor technology must overcome a number of regulatory, economic, technical, and social challenges prior to licensing, construction, and successful start-up. By building on industry operating experience and EPRI's Advanced Nuclear Technology research, new nuclear plants can realize multiple benefits, including improved designs for long-term operation, optimized fabrication and construction practices, and reduced project risk. Longer-term research focuses on advanced nuclear design concepts, such as small modular reactors, and on issues that can potentially limit nuclear growth.

Chemistry, Low-Level Waste, and Radiation Management

Nuclear power plants implement and maintain detailed chemistry, low-level waste, plant effluent management, and radiation protection programs to safeguard workers, local populations, and the environment and to improve plant operation and maintenance. These programs must evolve in response to emerging science, changing regulations, and field experience. EPRI's Chemistry, Low-Level Waste, and Radiation Management research incorporates these developments into technical guidance and tools designed to improve waste management practices, reduce radiation exposure, minimize corrosion, and enhance plant decommissioning.

Equipment Reliability

Nuclear power plants rely on a large number of pumps, valves, circuit breakers, and other mechanical, electrical, and instrumentation and control equipment to operate safely, reliably, and cost-effectively. Equipment reliability depends on successful implementation of carefully designed engineering, operations, maintenance, repair, and replacement practices by properly trained plant personnel. EPRI's Equipment Reliability research includes technical, programmatic, and human performance factors in the development of tools, techniques, and practices that can increase overall plant reliability and safety.

Fuel Reliability

Safe, economical plant operation depends on fuel reliability. Fuel failures and operational issues can cost tens of millions of dollars per event and result in unnecessary radiation exposure. EPRI's Fuel Reliability research develops the technical basis for avoiding these problems by investigating their root causes, analyzing failed fuel rods, and developing fuel reliability guidelines. Research examines nuclear fuel performance to ensure that fuel assemblies function as intended under limiting conditions, such as changing water chemistry. Longer-term research assesses the viability of advanced fuel concepts that could provide more time for mitigating actions during accident conditions.

Long-Term Operations

All nuclear plant owners must decide at some point whether to seek life extensions for existing facilities or replace them with new generation sources. EPRI's Long-Term Operations research informs decisions on whether life extension for a given nuclear plant is technically sound and whether the benefits and costs of modernization and advanced technology could justify investment for long-term operations. Research activities focus on identifying and overcoming key technical barriers, investigating cost-effective modernization approaches, informing potential regulatory issues, capitalizing on public and private sector R&D investments around the world, and transferring interim results to operating plants.

Materials Degradation/Aging

The long-term performance and structural integrity of nuclear power plant components can be enhanced through improved understanding of materials properties, corrosion mechanisms, water chemistry interactions, and plant operation and management practices. EPRI's Materials Degradation/Aging research helps nuclear plant owners and operators maximize useful plant life, employ cost-based and risk-based decision making; develop technologies to address materials degradation and aging; anticipate and avoid safety events; and improve plant capacity, reliability, and availability.

The horizon leans forward, offering you space to place new steps of change.

Maya Angelou

Nondestructive Evaluation and Material Characterization

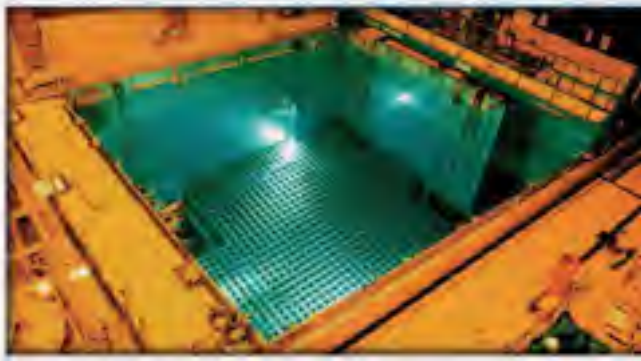
Nondestructive evaluation enables nuclear power plant operators to identify, locate, and characterize material degradation before it can affect structural integrity. EPRI develops and qualifies nondestructive evaluation technologies and practices that address new materials, new diagnostic capabilities, new regulatory standards, and new challenges that arise from operating experience. EPRI's Nondestructive Evaluation and Material Characterization research guides strategic decisions on whether and when to replace components, repair them, or continue their operation. Research results are also used to inform regulatory actions related to pre-service and in-service inspections.

Risk and Safety Management

Risk and safety assessment techniques provide information that enables nuclear plant owners to make technically sound design, maintenance, and operational decisions, contributing to safer and more cost-effective plant operation. Continuous refinement of risk and safety models and application approaches is necessary to ensure that decisions based on these models reflect industry operating experience and current computational advances. EPRI's Risk and Safety Management research helps quantify risks from within the plant's systems and from external hazards, including earthquakes, floods, fires, tornadoes, and security threats. The Fukushima Daiichi accident has increased EPRI research activities related to risk and safety management, accelerating and initiating efforts in areas such as probabilistic risk assessment for seismic events and external floods, severe accident management guidelines, and spent fuel pool risk assessment.

Used Fuel and High-Level Waste Management

Nuclear power's long-term viability depends on safe, cost-effective management of used fuel and high-level waste. An integrated solution that encompasses centralized interim storage, permanent geologic disposal, and closing the fuel cycle is achievable, but requires significant research and technology development. EPRI's Used Fuel and High-Level Waste Management research examines complex scientific and technical issues affecting waste management, including advanced fuel cycles, used fuel transportation, geologic repositories, extended on-site storage, and spent fuel pool behavior. This research informs regulatory decisions on waste management and provides insight into technical advances required to develop an integrated solution.



Because final disposal facilities for used nuclear fuel and high-level nuclear waste do not yet exist, nuclear plants will be storing this material on site or at central storage locations for decades. Stakeholders need confidence that the safety functions associated with extended storage are maintained. EPRI is leading a collaborative research program that will develop the technical bases to ensure the safe extended storage of used fuel. Research also will investigate nondestructive evaluation techniques for assessing the integrity of the stainless steel canisters for used fuel and high-level waste and the development of industry procedures for replacing aging storage systems as necessary.

Advanced Nuclear Technology: photo courtesy of TVO Equipment Reliability: photo courtesy of AREVA Materials Degradation/Aging: photo courtesy of NRC

POWER DELIVERY & UTILIZATION

Developing technologies and approaches to facilitate higher levels of grid reliability, efficient use of energy, and grid transformation

Transmission Lines and Substations

Transmission asset owners are being challenged in several ways. They seek to get maximum value from existing assets by extending their operating life. They are looking to specify new components and materials that are expected to serve reliably for an extended term and also to apply engineering experiences in the design of substations and transmission lines that can serve longer while attaining higher availability and reliability.

Research in EPRI's Transmission Lines and Substations programs can lead to understanding the fundamental aging and degradation processes of materials and components. Combined with a fleet management approach, this research may help in the design of cost-effective maintenance programs, the application of mitigation options, and the definition of priorities for asset replacement strategies. Research can also lead to improved live line working conditions, improved switching, safety, and reliability.

35 Overhead Transmission

36 Underground Transmission

37 Substations

162 HVDC Transmission

Grid Operations and Planning

Transmission operators will need to operate the grid reliably as a higher penetration of variable renewable resources, such as wind and solar, come online. This requires some fundamental changes to the planning and operations processes. For planning, it will be necessary to create the models and define the requirements for the development of analysis tools that have the capability to evaluate multiple scenarios for both deterministic and probabilistic approaches. For operations, it will be necessary to understand possible sources of flexibility, such as demand response, and how to adapt existing tools and processes to manage the resource-specific characteristics.

The research in EPRI's Grid Operations and Planning programs is helping to resolve these issues and can also lead to moving analysis from offline studies to online analysis using high-volume, low-latency information from synchrophasors. This real-time approach may help to improve system performance, initiate rapid control actions in response to fast changing conditions, and mitigate the effects of impending emergencies.

39 Grid Operations

40 Grid Planning

173 Bulk Power System Integration of Variable Generation

Distribution

Electricity distribution companies face a number of challenges, ranging from maintaining existing assets to meeting new load requirements. This includes connecting to distributed renewable resources, providing the energy for charging of electric vehicles, and enabling customers to actively participate in managing their energy uses through smart grid technologies. EPRI's Distribution programs can help distribution planning and operations transform from using paper-based processes to simulation- and model-based processes that integrate the various new and existing control strategies for operating the distribution grid.

174 Integration of Distributed Renewables

180 Distribution Systems

Long-Term Operations Water Resource Management Renewable Resources and Integration Energy Efficiency Smart Grid Near-Zero Emissions

We have always held to the hope, the belief, the conviction, that there is a better life, a better world, beyond the horizon.

FRANKLIN ROOSEVELT

Energy Utilization

End-use efficiency offers utilities a potential demand-side resource to maintain reliability and affordable service while reducing emissions and saving resources. Realizing this potential as well as meeting existing efficiency goals requires new, highly efficient end-use technologies. Research in EPRI's Energy Utilization programs helps to substantiate the expected energy savings, performance, and possible grid impact. Testing consists of controlled laboratory setups to determine performance, followed by field demonstrations to verify the expected savings, and finally early deployments to assess the readiness for rollout in efficiency programs. Emerging technologies are only one factor in achieving the anticipated savings. Another would be understanding consumer behavior and how that could make demand-response programs successful.

Electric vehicles are an emerging technology that requires utilities to prepare to serve an enthusiastic public. Research can assist utilities in understanding grid impacts and supply availability of various charging options, from smart to fast charging, as well as consumer expectations of the charging infrastructure.

18 Electric Transportation

170 End-Use Energy Efficiency and Demand Response

182 Understanding Electric Utility Customers

Cross-Cutting Technologies

As utilities are implementing smart grid technologies, interoperability and cyber security standards are still evolving. Mature, uniform standards to enable interoperability are needed for efficient end-to-end electric power system interactions. In addition, the increasing automation and communication capabilities of the power grid may pose cyber security, resiliency, and privacy challenges. EPRI's IntelliGrid and cyber security programs are working with standards-making bodies to develop the necessary technical requirements for information infrastructure technology standards, and to provide verification testing and technology demonstrations of interoperable operations.

Developing and deploying integrated storage systems decouples energy supply from demand and offers a substantial opportunity to improve the reliability of the electric grid. For transmission and distribution storage applications, research is required to establish guidelines for grid deployment and operation to enable effective grid integration. This can improve system reliability and facilitate greater utilization of off-peak renewable resources.

1 Power Quality

94 Energy Storage

161 IntelliGrid

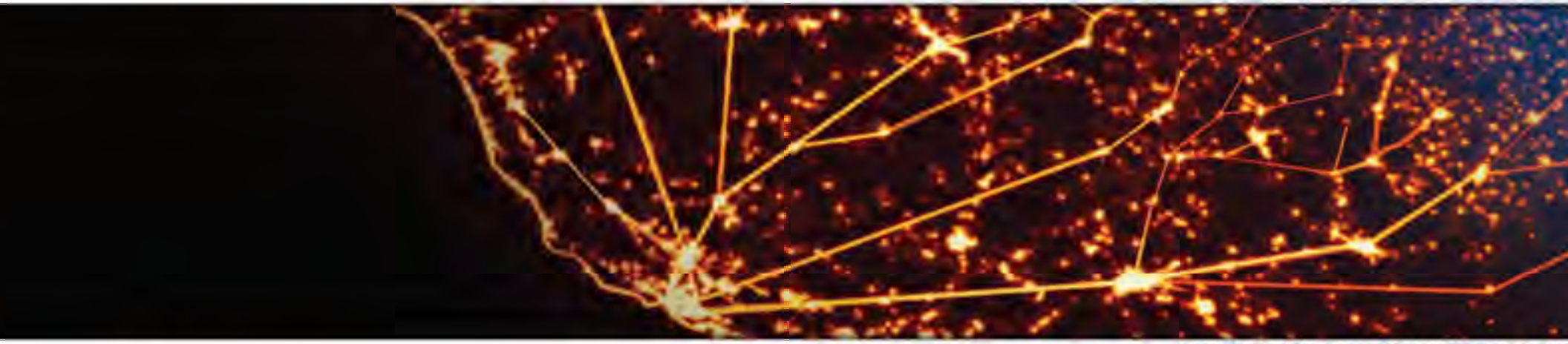
183 Cyber Security and Privacy

No portion of the electric power grid is changing more significantly and rapidly than the electric distribution system. The design and operation of this system has become much more complex. Increasing penetrations of customer-owned resources, especially highly variable wind and solar technologies, have added uncertainty to operation of the distribution system. Changes are needed to ensure that power fluctuations do not result in unacceptable voltage levels for distribution customers.

The heart and soul of the future distribution system will be the integration of monitoring, grid analytics, and control applications into an effective distribution management system. Grid analytics convert sensor and AMI data to information. The future distribution system must be able to perform data mining, that is, convert that data into actionable information.

HOW TO PARTICIPATE

EPRI offers scientific expertise and innovative technology to help utilities and all participants in the electricity sector provide safe, reliable, economic, and environmentally sustainable electricity to the public.



Benefits of Participation

If you participate in the EPRI RD&D program, you will have the opportunity to:

- Identify and solve critical and emerging industry issues.
- Stay in the forefront of driving technology innovation.
- Gain access to a comprehensive, timely, high-value RD&D portfolio.
- Collaborate and network with industry peers through advisory councils and committees.
- Transfer technology through the support of our researchers and technical advisors.

Getting the Most from Your Participation

To realize the greatest value from EPRI's programs, you may want to:

- Participate in advisory meetings to help shape the direction of our research.
- Access and apply leading-edge results within your company.
- Discuss your emerging or ongoing needs with an EPRI Technical Advisory Services representative.
- Obtain an epri.com login ID to gain access to EPRI's intellectual property and products.

Contact EPRI

To discuss options and solutions for your needs:

- Call EPRI at 800.313.3774 and press 4 to connect with EPRI's Customer Assistance Center.
- Send an e-mail to askepri@epri.com, and an EPRI representative will contact you.
- Complete and submit an online interest form at portfolio.epri.com.

All education is a continuous dialogue – questions and answers that pursue every problem on the horizon.

William O. Douglas

The Electric Power Research Institute, Inc.
(EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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EPRI | ELECTRIC POWER RESEARCH INSTITUTE

POWER DELIVERY & UTILIZATION SECTOR ROADMAPS

February 2012

WHY ROADMAPS?

Working closely with over 1,400 industry and public advisors and the Board of Directors, EPRI in 2010 identified six overarching strategic issues that offer both opportunities and challenges to the continued delivery of reliable, affordable and environmentally responsible electricity. These six overarching strategic issues are:

1. Energy Efficiency (End-to-End)
2. Long-Term Operations
3. Near-Zero Emissions
4. Renewable Resources and Integration
5. Smart Grid
6. Water Resource Management

Of course, the overall research agenda for the power industry is broader than these six strategic issues. The roadmaps for the Power Delivery and Utilization (PDU) research address the broader range of issues that must be addressed for the electric delivery system and end use energy applications. This is perhaps the most dynamic of all the power system research sectors as we work on next generation technologies for the grid (the "smart grid"), integration of renewables and other distributed resources, addressing changing loads like electric vehicles, enabling a broader group of end users to participate in markets and the operation of the grid, and finally to make the entire infrastructure as efficient as possible.

ROLES

EPRI takes a collaborative approach to roadmapping, as it does to all R&D. This process involves the full range of EPRI technical staff, EPRI's utility and public advisors and other sector stakeholders, particularly government, universities and other sector organizations. Their respective roles and responsibilities are:

- EPRI's **sector and program advisors** ("sector advisors"), working with EPRI's **technology staff and R&D leaders**, are primarily involved in the "what" of the roadmaps: what are the missing technologies and what is needed to address the strategic issues? What action plans, including scope, schedule and budget, are needed to overcome those challenges? The PDU roadmaps in this document are primarily the result of this process.
- The **Public Advisory Council** comments to EPRI on "whether" the prioritized research is both relevant and balanced in terms of serving the public interest. The Advisory Council's role is particularly critical, as its membership includes public utility commissioners who are keenly aware of the needs of the sector's customers – electricity ratepayers – and the balance that must be achieved to deliver electricity that is reliable, environmentally responsible and affordable. The Council provides essential linkage among EPRI, its Board, National Association of Regulatory Utility Commissioners (NARUC) and other public stakeholders and so holds a crucial role in the roadmapping process.
- Besides the Public Advisory Council, we will be sharing the PDU roadmaps with a wide variety of stakeholders (DOE, PSERC, NEETRAC, international research organizations, NIST, etc.) for comment and input. These experts will ensure that the roadmaps capture broad, industry views, not just EPRI's outlook, and will help to define where an EPRI role in addressing a particular R&D Challenge is appropriate. This will enable efficient resource allocation.
- The **Research Advisory Committee** (RAC) oversees the "when" and "where" of the roadmaps, as well as preparation of the roadmaps for EPRI's Technology Innovation program. "When" means establishing priorities, based on recommendations from EPRI staff and the sector advisors. "Where" means rigorously determining which R&D challenges are appropriate for the EPRI portfolio, and which are better left to others. "Where" also encompasses oversight of cross-cutting research questions that do not fall neatly into a single facet of the utility's business model or EPRI's research sectors.
- Finally, the **Board of Directors** sets EPRI's strategic direction, making the "why" determination: why is it critical that EPRI, its stakeholders and the industry commit resources to specific R&D activities? And if it is critical, the Board must lead in developing the strategic plan for how the necessary resources will be marshaled.

SECTOR ROADMAP

The attached roadmaps represent a bottoms-up view of the future states, gaps, and action plans necessary to close the gaps, as well as expected values and avoided risks when closing the gaps. They are aligned with the work performed within the Power Delivery and Utilization sector and at this stage may be closely aligned with what EPRI staff and the program and sector advisors perceive EPRI's role to be. In the upcoming review and vetting phases it is expected that they will be expanded to include industry input by other stakeholders and planned efforts by other research organizations.

The roadmaps are organized by technical areas that correspond to important elements of the PDU research organization. As mentioned above, the research agenda within PDU encompasses much more than the six strategic issues that will be tracked at the executive level. However, many of the PDU research priorities align with one or more of the six strategic issues as well:

1. Energy Efficiency (End-to-End)
   - Distribution Area – Capacity and Efficiency Roadmap
   - Efficiency Area – end use technologies road maps including Heating Ventilation and Air Conditioning, Water Heating, Power Electronics Roadmap, Lighting, Integrated Buildings, Data Centers, And Industrial Heating And Waste Heat Recovery, As Well As Motors And Drives.
   - Efficiency Area – demand response technologies roadmaps Including Control Technologies for Dynamic Energy Management and Integrated Buildings
   - Efficiency Area – Customer Behavior and Load Research
2. Long-Term Operations (where presently this issue mostly refers to the long term operations of nuclear power plants - similar R&D issues are required to extend the life of transmission and distribution assets)
   - Transmission and Substations Area – Effective Inspection, Assessment And Maintenance
   - Transmission and Substations Area – Condition Monitoring And Automation
   - Distribution Area – Asset Management
   - Energy Storage
3. Renewable Resources and Integration
   - Grid Operations and Planning – Integration Of Supply Side and Demand Side Resources and Technologies
   - Energy Storage
   - Distribution Area – Integration of Renewable Energy
4. Smart Grid
   - IntelliGrid Research Area – Interoperability
   - IntelliGrid Research Area – Communications
   - Cyber Security Area – Assess and Monitor Risk
   - Cyber Security Area – Protective Measures to Reduce Risk
   - Cyber Security Area – Reducing Cyber Security Risk for Legacy Systems
   - Cyber Security Area – Manage Incidents
   - Cyber Security Area – Technology to Support Privacy
   - Cyber Security Area – Cyber Security and Compliance for Instrumentation and Control Systems
   - Transmission and Substations Area – Condition Monitoring and Automation
   - Grid Operations and Planning – All Roadmaps
   - Distribution Area – System Responsiveness, Flexibility and Smart Grid
   - Distribution Area – Integration of Renewable Resources
   - Efficiency Area – Efficiency Area – Demand Response Technologies Roadmaps Including Control Technologies For Dynamic Energy Management and Integrated Buildings

The following timeline shows key milestones between August 2011 and November 2012, but as noted above, an effective technology roadmap is iterative and dynamic. It is a process that derives its value from extensive discussion and collaboration.

Aug/Sept 2011	EPRI and sector advisors identify R&D Challenges, and RAC maps those Challenges to the six strategic issues. EPRI, sector advisors and RAC prioritize "top R&D Challenges" for each of the six strategic issues, without regard to whether the Challenge is one that EPRI is best suited to address.
Sept/Oct 2011	The public Advisory Council reviews the top R&D Challenges for each issue, commenting on whether the public interest is met and the objectives of reliability, environmental responsibility and affordability are appropriately balanced.
Nov 2011	Joint Board/RAC meeting to achieve Board concurrence with roadmap visions and process. Discuss the top R&D Challenges for each issue area and priority Challenges for each issue. Board advice to RAC on strategic considerations.
Jan/Feb 2012	Sector advisors define action plans for the R&D Challenges (with the top challenges receiving priority attention), map existing EPRI research to the R&D Challenges and identify the top R&D Challenges (1) where EPRI should play a role; or (2) where EPRI is not engaged, or not sufficiently engaged, to provide a timely solution.
March 2012	RAC validates the action plans and identification of the top R&D Challenges, with particular attention to whether cross-cutting issues areas have been sufficiently developed (i.e., R&D needs have not fallen through a crack because they don't fit neatly into a particular EPRI sector). RAC also develops a Technology Innovation roadmap describing the role of EPRI and the electricity industry in early stage research that could result in step changes in technology adoption across the six strategic issues.
April 2012	Board receives a report on development of action plans and identification of the top Challenges for EPRI attention. The public Advisory Council receives a similar report and continues its commentary on the public interest and the balance of the objectives in terms of reliability, environmental responsibility and affordability.
June 2012	International Innovation Summit at Ente Nazionale per l'Energia eLetrtrica (ENEL) R&D Center at Pisa, Italy: Technology Innovation (TI) roadmap and international R&D priorities discussed.
August 2012	Summer Seminar tentative working theme: Moving the Dial on Innovation. Board receives a report from RAC on the TI roadmap.
Sept 2012	EPRI and Sector advisors finalize scope/schedule for EPRI's R&D Challenges. RAC finalizes TI roadmap scope, schedule and budget for the TI R&D Challenges.
Oct 2012	Report out to the Board on the Challenges EPRI should address. Board aligns on the priorities and plans for marshaling the resources to address them.
Nov 2012	It is expected by November 2012; PDU will have vetted and documented industry roadmaps for all our technology areas, and that these roadmaps are the basis for continuing to identify research opportunities and driving the direction both EPRI and the industry needs to go to meet our shared vision.

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GRID OPERATIONS AND PLANNING

VISION

The future transmission grid will be highly automated, will be flexible in connecting all energy sources, will facilitate active participation by all grid-connected participants, and will provide transmission services at affordable prices. It will be capable of satisfying customized requirements for reliability, market operations, power quality, and service-level agreements.

The transmission grid will be planned and operated in compliance with applicable reliability, safety, and security standards and criteria, and automated processes and tools will be available to demonstrate and document compliance.

Planners and operators will have guidelines and techniques that will enable them to include markets, economics, public policy, environmental and societal considerations, and cost-allocation issues in their assessments, plans and daily operating decisions.

Communication processes will enable information transfer to stakeholders about evolving technologies, markets, economics, customer service, and public policy issues related to the grid operations and planning function.

The future transmission grid will demonstrate the following characteristics:

1. It will provide for high levels of reliability while minimizing the impacts of system disturbances through the use of smart technologies and advanced measurements and controls (self-diagnosis and self-healing).
2. It will be robust, secure, and highly resilient to cyber attacks and other hazards, including natural disasters.
3. It will enable the integration of diverse energy sources, including variable generation and storage devices.
4. It will facilitate the active participation of all transmission-connected entities, customers, and market participants through demand-response programs.
5. It will be scalable and flexible to satisfy the diverse reliability, quality, and security needs of customers.
6. It will leverage and integrate existing technologies and emerging intelligent technologies and techniques to provide for predictive maintenance, optimal levels of asset utilization, and greater efficiencies.

DRAFT: INTEGRATION OF SUPPLY-SIDE AND DEMAND-SIDE RESOURCES AND TECHNOLOGIES

FUTURE STATE COMPONENTS

The transmission grid will enable the integration of diverse arrays of energy sources and demand options (such as wind generation, solar generation, demand response, and storage).

The following attributes, examples, and initiatives further describe this future state:

- Energy storage, controllable demand-response programs, and plug-in vehicles will be integrated and leveraged in operating the grid reliably and efficiently.
- Load and generation forecasting techniques and validated models will enable grid operators and planners to incorporate uncertainties associated with variable generation resources and customer demand-response characteristics.
- The impact of geographic diversity of supply-side and demand-side resources and technologies will be incorporated in developing long-term and near-term grid reinforcement and operational plans.
- Criteria and techniques will assist grid operators and planners in determining the necessary amount and type of balancing resources (operating reserves)—including adequacy and ramping—to integrate variable generation.

GAPS

- Planners and operators will need probabilistic and deterministic planning techniques to consider the variable and uncertain production patterns of variable generation and to assess necessary upgrades to the transmission grid.
- Planners and operators will require metrics for system flexibility, methods to evaluate sources of flexibility for investment (existing and emerging), and case studies to analyze extreme events and demonstrate flexibility requirements over time relative to increasing variable generation (VG).
- Validated, non-proprietary models are required for new supply-side and demand-side devices and technologies (wind plants, solar PV plants, storage devices, demand response, plug-in electric vehicles, and so on).
- Analytical approaches will be required to represent new demand-side technologies and resources in studies (demand response, storage devices, plug-in electric vehicles, and so on). Tools and processes will be required to update models based on actual system and component performance.
- Advanced forecasting techniques must be fully integrated into both long-term planning (capacity and transmission) and real-time operating practices (visualization, determination of operating reserve, and stochastic unit commitment) and into EMS and other situational-awareness tools.
- Industry needs to continue to participate in NERC Integration of Variable Generation Task Force (IVGTF) activities to upgrade planning and operating practices and also inform FERC NOPR development regarding OATT and market reforms for variable generation.
- EPRI grid operations and planning projects should be coordinated with IntelliGrid, Distribution (DG integration), and Generation (impacts of cycling and retirements) programs.
- Planners and operators will require metrics for system flexibility and methods to evaluate sources of flexibility for investment (existing and emerging) to accommodate the large-scale integration of variable generation.

ACTION PLAN

The integration of new resources (such as wind and solar generation) and technologies (such as storage and demand response) at transmission and distribution levels has accelerated in recent years and is expected to continue to grow in future. It is the role of grid operators and planners to ensure reliable integration of these resources/technologies at the bulk electric system level.

To achieve this Future State, RD&D will need to be directed in four principal areas: (1) Situational Awareness; (2) Study Scope, Tools, and Techniques; (3) Forecasting; and (4) Resource Adequacy and Flexibility. The following RD&D activities focus on enabling and emerging technologies, processes, and tools that will support grid operators and planners in achieving this Future State.

Situational Awareness

Real Time Visualization: Provide real time visualization of supply-side and demand-side resources/technologies/devices in control centers to meet the needs of grid operators. This will require appropriate levels of details, integrated with other EMS information, on wind and solar generation, distributed

energy resources, demand response (DR), storage, plug-in electric vehicles, and so on.

Modeling

Models: Develop models of supply-side and demand-side resources/technologies/devices needed for conducting simulation studies. The industry needs validated, non-proprietary power-flow and dynamics models for wind generators, solar PV plants, storage devices, demand response, plug-in electric vehicles, distributed energy resources, and so on. In some instances, three-phase models to conduct electromagnetic transient studies (such as sub-synchronous resonance (SSR) study) are also needed.

Study Scope, Tools, and Techniques

Risk-Based Study Processes/Tools: Develop risk-based study processes/tools that incorporate variability and uncertainty of VG and DR.

Frequency Response Assessment Studies: Develop processes, modeling, and tools to perform simulation studies for evaluating frequency response of an interconnected network. Such studies will require time-domain simulations that incorporate mid-term and long-term dynamics. Because the scope of such studies extends beyond that of typical transient-stability simulations, efforts will be needed to identify appropriate software and to identify and develop appropriate modeling. In addition, industry needs metrics to measure what constitutes adequate frequency response (primary and secondary) during the time scale that ranges from seconds to tens of minutes.

Distributed Energy Resources: Develop study tools, modeling, and processes to assess impact of distributed energy resources on the bulk electric system.

Forecasting

Forecasting Tools for DR and VG: Develop/enhance tools to forecast VG and DR for a day-to-day operation timeframe as well as for a long-term planning timeframe. These tools need to incorporate customer behavior for demand response and to represent the changing generation mix. Grid operators and planners will need to coordinate this activity with generation and distribution experts familiar with VG and DR variability and uncertainty.

Forecasting Tools for Operating Reserve Requirements: Develop tools that can forecast day-ahead operating reserve requirements, including system ramping capability and needs. These efforts should also include developing analytical techniques such as "stochastic unit commitment" that can optimize dispatch schedules. This activity will need to be coordinated with the generation sector of the industry.

Adaptable Forecasting Tools: Develop adaptable, self-learning forecasting tools that can continuously analyze historical data and integrate the learning into forecasting algorithms and continuously update VG and DR forecasting. Grid operators and planners will need to coordinate this activity with generation and distribution experts familiar with VG and DR variability and uncertainty.

Sophisticated/Integrated Forecasting Tools: Develop interfaces to integrate forecasting tools with tools, applications, and processes used by grid planners and operators for their core activities. Grid operators and planners will need to coordinate this activity with generation and distribution experts familiar with VG and DR variability and uncertainty.

Resource Adequacy and Flexibility

Impact of Cycling on Conventional Generation: Develop tools to assess impact of cycling on conventional generating units. The variability of wind and solar generation is expected to result in added cycling (ramping up/down) of conventional generators. Tools and techniques are needed to assess the impact of cycling on equipment life, overall cost and the resulting effect on how conventional generators will be committed and dispatched as capacity and frequency-regulating resources. This activity will need to be coordinated with the generation sector of the industry.

Adequacy and Flexibility of the Generation Fleet: Develop tools and techniques to evaluate the adequacy and flexibility of the generation fleet to meet electricity demand and to provide frequency-regulation services such as governing, AGC, and operating reserves. These tools and techniques are critical in light of the evolving generation mix, with increasing penetration of variable generation and growing retirement of conventional generation. The industry also needs metrics for measuring adequacy and flexibility for resources to meet demand and provide frequency-regulation services. Evaluations of system adequacy and flexibility requirements can also help in prioritizing investments for these resources. Overall, these tools and techniques have the potential to help grid planners in securing adequate resources to meet demand and grid operators in securing adequate resources to prepare for reliable operation under contingency conditions.

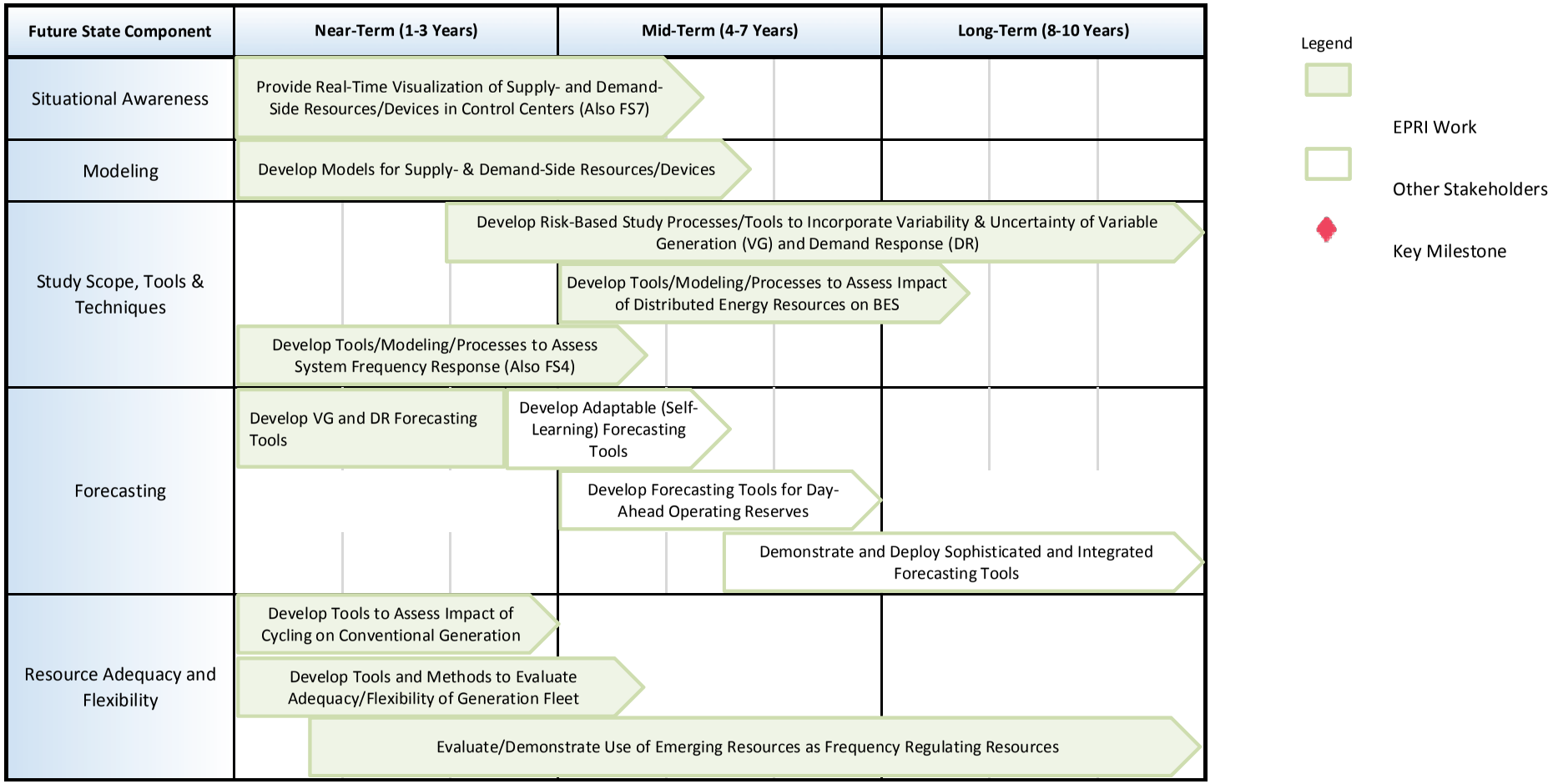
Utilizing Emerging Resources: Evaluate/demonstrate the use of emerging resources (such as storage, demand response, and plug-in electric vehicles) for frequency-regulation service. As penetration of VG increases and the retirement of conventional generation proceeds, it will be prudent to assess the feasibility of utilizing new resources as operating reserves.

The above activities are arranged in technology tracks in the following roadmap. The roadmap shows the five principal technology tracks of: (1) Situational Awareness; (2) Modeling; (3) Study Scope, Tools, and Techniques; (4) Forecasting; and (5) Operating Reserve Resources. In each track, the associated activities related to the grid operations and planning function are summarized in the boxes.

VALUE AND RISK

The integration of new resources (such as wind and solar generation) and technologies (such as storage and demand response) at transmission and distribution levels has accelerated in recent years and is expected to continue to grow in future. This growth is driven by economics as well as public policies. The above efforts and the companion roadmap will help the grid operators and planners in facilitating the integration.

The integration of novel resources and technologies will require significant resources, and change in current practices and processes. If not pursued adequately, the economic and public benefits offered by these resources and technologies will not be derived.


Future State Component
Near-Term (1-3 Years)
Mid-Term (4-7 Years)
Long-Term (8-10 Years)
Situational Awareness
Provide Real-Time Visualization of Supply- and Demand-Side Resources/Devices in Control Centers (Also FS7)
Modeling
Develop Models for Supply- & Demand-Side Resources/Devices
Study Scope, Tools & Techniques
Develop Risk-Based Study Processes/Tools to Incorporate Variability & Uncertainty of Variable Generation (VG) and Demand Response (DR)
Develop Tools/Modeling/Processes to Assess Impact of Distributed Energy Resources on BES
Develop Tools/Modeling/Processes to Assess System Frequency Response (Also FS4)
Forecasting
Develop VG and DR Forecasting Tools
Develop Adaptable (Self-Learning) Forecasting Tools
Develop Forecasting Tools for Day-Ahead Operating Reserves
Demonstrate and Deploy Sophisticated and Integrated Forecasting Tools
Resource Adequacy and Flexibility
Develop Tools to Assess Impact of Cycling on Conventional Generation
Develop Tools and Methods to Evaluate Adequacy/Flexibility of Generation Fleet
Evaluate/Demonstrate Use of Emerging Resources as Frequency Regulating Resources
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

Grid operators and planners will have simulation study tools, techniques, and models capable of incorporating reliability, power quality, safety, and security standards and criteria, as well as market, economics, public policy, and environmental aspects.

The following attributes, examples, and initiatives further describe this future state:

- Tools, techniques, and technologies will enable grid operators and planners to: 1) increase power flows on new and existing transmission lines, while maintaining high reliability and minimizing costs; 2) reduce transmission line losses; 3) manage safe and efficient use of right of way by multiple entities, such as pipelines and telephone lines; and 4) manage the right of way for the public.
- The needs and processes to conduct stability studies and advanced transmission studies (such as transient voltage recovery, harmonics, and sub-synchronous resonance) will be well understood and documented. The processes for such studies will be seamlessly integrated into the processes used to conduct other routine studies.
- Common information modeling (CIM) will be fully functional across the industry for the grid operations and planning function.
- Tools, techniques, and processes will enable grid operators and planners to consider multiple development and operational scenarios (such as off-peak and shoulder-peak), changing characteristics of load (non-passive), and new resources (such as wind, solar, PEV, demand-side, and storage).
- Grid planners and operators will have the ability to seamlessly transfer data from real-time energy-management systems (EMSs) to off-line simulation-study tools to facilitate off-line studies, and to seamlessly transfer the results of off-line simulation studies to an EMS environment for display and to facilitate real-time contingency-analysis studies.
- All operators within an interconnection will be able to readily exchange EMS models and data among themselves.
- Fast simulation techniques will enable grid operators and planners to efficiently conduct off-line and real-time contingency-analysis studies.
- Automated processes will facilitate validation of component simulation models (such as a generator-excitation system model) by comparing routinely available field data with simulation results.
- Interactive tools will enable the planners and operators to conduct off-line and real-time contingency-analysis studies through plug-and-play modules consisting of software programs to analyze the power system, power system models, and the associated geographic information.

GAPS

- Planners and operators will need tools and fast simulation techniques that can accommodate and evaluate a multitude of scenarios, options, and resources (generation, demand side, transmission, new technologies, and so on).
- Planners and operators will need guidelines for using deterministic and probabilistic planning techniques and to incorporate system flexibility into planning criteria and metrics.
- Methods will be required to perform studies that capture primary and secondary frequency responses (speed governing, AGC, and operating reserves).
- Increased consideration of advanced technologies (e.g. HVDC and FACTS devices) will require that validated and non-proprietary models be integrated into day-to-day planning and operations. Automated tools are required for validating models (power flow, stability, and detailed three-phase models for transient studies).
- Study tools and models are required to capture mid-term and long-term dynamics in simulation studies, and to be seamlessly integrated with other tools.
- Planners and operators will also need methods and rules-based techniques (Artificial Intelligence) to make increased use of sensor information (synchrophasors, dynamic thermal circuit rating, and so on) into planning and operation models and analysis.
- EPRI grid operations and planning efforts and projects should be coordinated with EPRI Distribution, Transmission and Substations, IntelliGrid, and Generation programs.

ACTION PLAN

The integration of new resources (such as wind and solar generation) and technologies (such as storage and demand response) at transmission and distribution levels has accelerated in recent years and is expected to continue to grow in future. It is the role of grid operators and planners to ensure reliable integration of these resources/technologies at the bulk electric system level.

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Transmission Efficiency and Utilization: Demonstrate and deploy technologies to improve the efficiency and utilization of transmission assets. It should be noted that within the EPRI GOP area, EPRI Program P172 (Efficient Transmission Systems) is designed to help utilities analyze and develop strategies and implement technologies to increase transmission efficiency and utilization.

Advanced Computing Techniques: Develop a roadmap and specifications to employ advanced computing techniques in GOP applications. Advanced computing technologies may be deployed to accelerate data analysis and computer simulation tasks and to enhance the analysis conducted by grid planners and operators. The overall objective of this activity is to apply advanced computing techniques to enhance the functionality of current tools and techniques used by GOP staff.

Advanced Computing Techniques: Demonstrate the use of advanced computing techniques in GOP applications. This represents the implementation of the roadmap developed in the above activity.

Distributed Energy Resources: Develop study tools, modeling, and processes to assess impact of distributed energy resources on the bulk electric system.

Forecasting

Forecasting Tools for DR and VG: Develop/enhance tools to forecast VG and DR for a day-to-day operation timeframe as well as for a long-term planning timeframe. These tools need to incorporate customer behavior for demand response and to represent the changing generation mix. Grid operators and planners will need to coordinate this activity with generation and distribution experts familiar with VG and DR variability and uncertainty.

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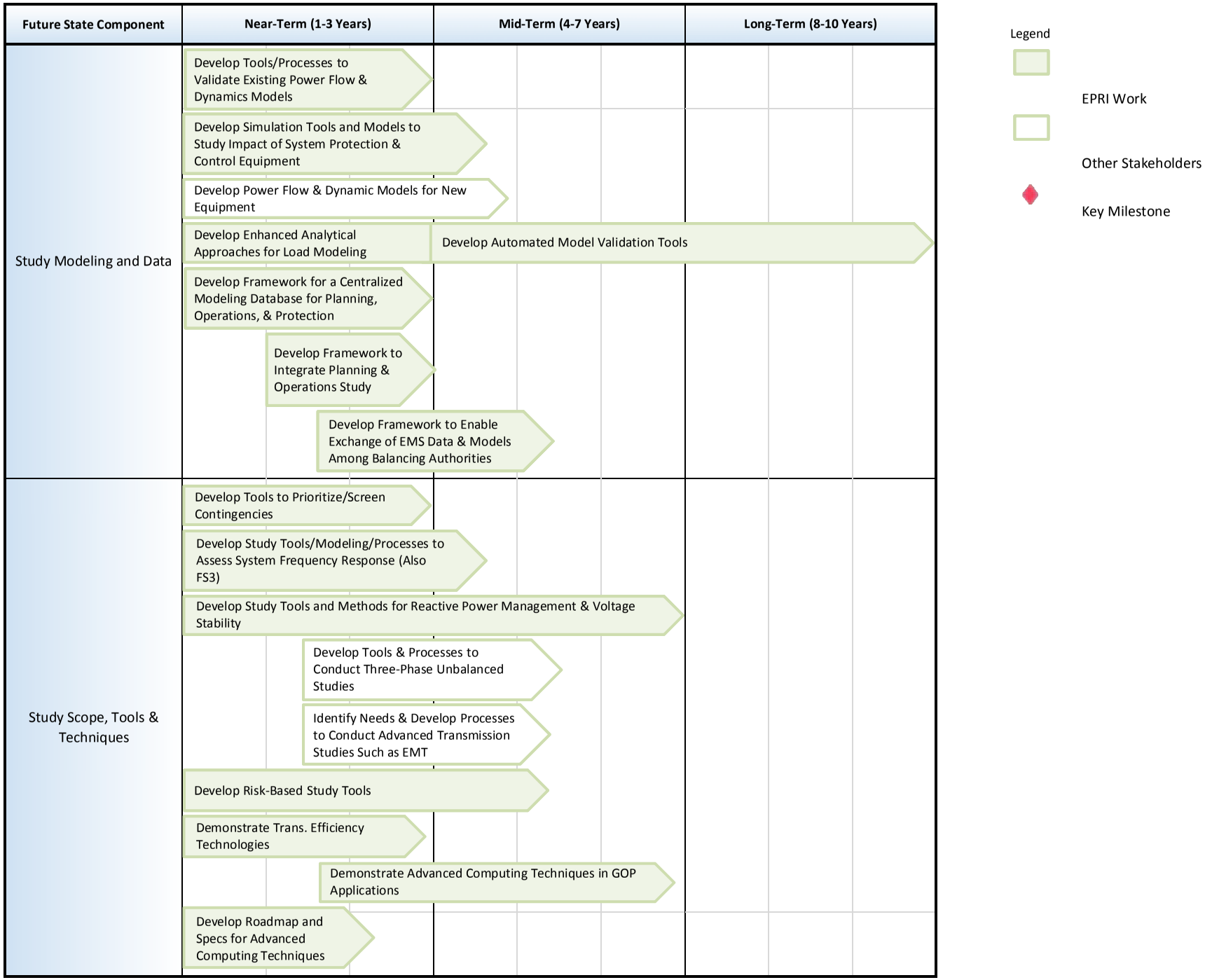
The above activities are arranged in technology tracks in the following roadmap. The roadmap shows the five principal technology tracks of: (1) Situational Awareness; (2) Modeling; (3) Study Scope, Tools, and Techniques; (4) Forecasting; and (5) Operating Reserve Resources. In each track, the associated activities related to the grid operations and planning function are summarized in the boxes.

VALUE AND RISK

With the grid undergoing significant transformation, the efforts outlined in the above action plan will be necessary and valuable to the grid operators and planners in meeting the reliability, economic, power quality, security and public policy requirements and challenges.

The above action plan will require significant commitment from gird operators and planners to spend money on developing new tools, techniques and processes, and to spend time on demonstrating and deploying the newly developed tools. Without such commitment, the full potential of the grid, in terms of its reliability, security, power quality, etc., cannot be realized.


Future State Component
Near-Term (1-3 Years)
Mid-Term (4-7 Years)
Long-Term (8-10 Years)
Study Modeling and Data
Develop Tools/Processes to Validate Existing Power Flow & Dynamics Models
Develop Simulation Tools and Models to Study Impact of System Protection & Control Equipment
Develop Power Flow & Dynamic Models for New Equipment
Develop Enhanced Analytical Approaches for Load Modeling
Develop Automated Model Validation Tools
Develop Framework for a Centralized Modeling Database for Planning, Operations, & Protection
Develop Framework to Integrate Planning & Operations Study
Develop Framework to Enable Exchange of EMS Data & Models Among Balancing Authorities
Study Scope, Tools & Techniques
Develop Tools to Prioritize/Screen Contingencies
Develop Study Tools/Modeling/Processes to Assess System Frequency Response (Also FS3)
Develop Study Tools and Methods for Reactive Power Management & Voltage Stability
Develop Tools & Processes to Conduct Three-Phase Unbalanced Studies
Identify Needs & Develop Processes to Conduct Advanced Transmission Studies Such as EMT
Develop Risk-Based Study Tools
Demonstrate Trans. Efficiency Technologies
Demonstrate Advanced Computing Techniques in GOP Applications
Develop Roadmap and Specs for Advanced Computing Techniques
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

Decision-support tools will be available to system operators to help them contain disturbances and restore the system efficiently following a major disturbance or blackout.

The following attributes, examples, and initiatives further describe this future state:

- Special protection schemes and intentional islanding schemes will be leveraged to minimize the impact of system disruptions and to assist system operators in restoration efforts.
- Simulators will be available for use in real-time and off-line environments to facilitate tabletop exercises and restoration-related simulation studies and training.
- Real time simulation and protection schemes will respond to system disturbances to mitigate the impacts and also proactively develop the restoration steps to efficiently restore the system based on the particular disturbance.
- Synchrophasor data will assist restoration by pinpointing failures and causes and by continuing to provide information regarding situational awareness even when the state estimator does not function.

GAPS

- Operators need enhanced analytical techniques and tools to provide support during emergency and system-restoration conditions, including guidance on an optimal system-restoration path as the restoration progresses using available resources (lines, loads, and blackstart generation sources).
- Increased use of special protection schemes and analytical techniques are required to develop intentional islanding schemes (such as Intelligent Separation Schemes) to minimize the impact of system disruptions and assist system operators in restoration efforts.
- Increased use of synchrophasor data may also assist restoration by pinpointing failures and causes and by continuing to provide information regarding situational awareness even if the state estimator does not function.

ACTION PLAN

Addressing system emergencies and restoring the system after blackouts are some of the critical responsibilities of system operators. Normally, grid operators work jointly with grid planners to develop decision-support tools to deal with these situations.

To achieve this Future State, RD&D will need to be directed in three principal areas: (1) Prevention; (2) Mitigation; and (3) Restoration. The following RD&D activities focus on enabling and emerging technologies, processes, and tools that will support grid operators and planners in achieving this Future State.

Prevention

Real-Time Contingency Analysis (RTCA) Tools: Enhance RTCA tools to speed up the analysis process. This will help operators in promptly arriving at mitigation measures that can help in addressing impending contingencies or system emergencies.

Operator Training Simulators: Enhance operator training simulators to simulate what-if scenarios involving system emergencies, mitigation measures, and restoration procedures.

Sensor Technologies: Develop sensor technologies that can enhance an operator's situational awareness. As an example, synchrophasor technology has the potential to enhance situational awareness of an operator because it can provide high-resolution, synchronized data across a wide area of a power system and early warning of evolving stability issues.

Mitigation

Safety Nets: Develop intelligent automatic separation schemes as safety nets to mitigate potential impact of system emergencies. The industry needs analytical techniques that can help in developing such schemes.

Decision-Support Tools for System Emergency: Develop and demonstrate tools that can help operators in addressing system emergencies.

Restoration

Decision-Support Tools for System Emergency and Restoration: Develop and demonstrate tools and methods that help operators in restoring the system following a blackout. The industry needs tools that can help operators identify optimal restoration paths and their sequence when the system is being restored in a step-by-step fashion following a major blackout.

Guidelines for Blackstart Requirements: Develop tools and methods that can provide guidelines for the locations, and the corresponding MW amounts, of blackstart resources required across a system. These efforts will include the development of analytical methods that can identify blackstart

requirements when the system is being restored in a step-by-step fashion following a major blackout.

New Blackstart Resources: Investigate the potential of new resources (such as storage) to provide blackstart service. Demonstrate the blackstart capability of these resources.

The above activities are arranged in technology tracks in the following roadmap. The roadmap shows three tracks: (1) Prevention; (2) Mitigation: and (3) Restoration. In each track, the associated activities that are under the purview of grid operators and planners are shown in abbreviated form in the boxes. In each track, the associated activities related to the grid operations, and planning function are summarized in the boxes.

VALUE AND RISK

The technology development efforts mentioned in the above action plan are essential for grid operators and planners in addressing system emergencies, preventing or mitigating consequences, and restoring the system effectively. The potential value to be derived from these R&D efforts could be measured in substantial financial savings to the society.

Increasing complexity in operating the power system calls for investment in developing these technologies, without which potential risk of degradation in system availability is possible.

Future State Component	Near-Term (1-3 Years)	Mid-Term (4-7 Years)	Long-Term (8-10 Years)
Prevention	Enhance Real-Time Contingency Analysis Tools		
	Enhance Operator Training Simulators		
	Deploy Sensor Technologies (e.g., Synchrophasor) to Enhance Operator Situational Awareness		
Mitigation	Develop Safety Nets & Intelligent Separation Schemes		
	Develop and Demonstrate System Emergency Decision Support Tools		
Restoration	Develop and Demonstrate Restoration Decision Support Tools		
	Develop Guidelines for Blackstart Requirements	Investigate and Demonstrate New Blackstart Resource (e.g., Storage)	

Legend

- EPRI Work
- Other Stakeholders
- Key Milestone

FUTURE STATE COMPONENTS

The transmission grid will be capable of self-healing by automatically detecting, analyzing, and responding (through automated controls) to operating conditions.

The following attributes, examples, and initiatives further describe this future state:

- Local, centralized, and hierarchical control strategies will be leveraged to facilitate the automatic detection, analysis, and response to system disturbances.
- Grid operators will be able to enable auto-pilot operation of certain functions, if desired, while still having full visualization of current system conditions, expected future conditions, and the ability to intervene as necessary.

GAPS

- Demonstration projects are required to evaluate the use and benefits of more complex control strategies, including centralized controls that can monitor and activate multiple controls across a wide area (such as voltage control or system restoration).
- It is also necessary to investigate the impact of renewable generation and demand-side technologies on voltage-support requirements, including advancement of EPRI and industry tools and techniques as appropriate/necessary, and the use of demonstration projects on member company systems.
- The use of synchrophasor data to improve the overall effectiveness of advanced control schemes should also be investigated.
- The existing communication infrastructure and technologies may not be adequate for effectively operation of advanced hierarchical controls and control strategies.
- Distributed data processing capability will be required for effective operation of local and distributed controls.

ACTION PLAN

Well designed automated controls capable of detecting, processing power system information, and responding to processed information can help the grid operator in addressing system emergencies by mitigating system impact, which in turn can aid system restoration efforts.

To achieve this Future State, RD&D will need to be directed in one principal area: Automatic Response and Grid Controls. The following RD&D activities focus on enabling and emerging technologies, processes and tools that will support grid operators, and planners in achieving Future State 6.

Automatic Response and Grid Controls

Advanced Automated Controls Using Sensor Data: Develop advanced automated controls that use high-volume, low-latency data such as synchrophasors. As mentioned in the flowchart for Future State 2, grid operators and planners will benefit from the development of advanced controls that can take automatic corrective actions to improve system performance or to mitigate the effects of impending emergencies.

Adaptive Protection and Control: Explore the development and application of adaptive protection and control equipment and strategies. Such protection equipment can be programmed for flexible settings, instead of fixed settings, depending upon system conditions, which can help in optimizing system performance. This activity will need to be coordinated with protection and control engineers in the industry.

Advanced Voltage-Control (AVC) Technology: Demonstrate and deploy the AVC technology. It should be noted that Program P172 provides opportunities to EPRI members to demonstrate this technology on their systems.

Intelligent Automated Separation Schemes: Develop and demonstrate intelligent automated separation schemes.

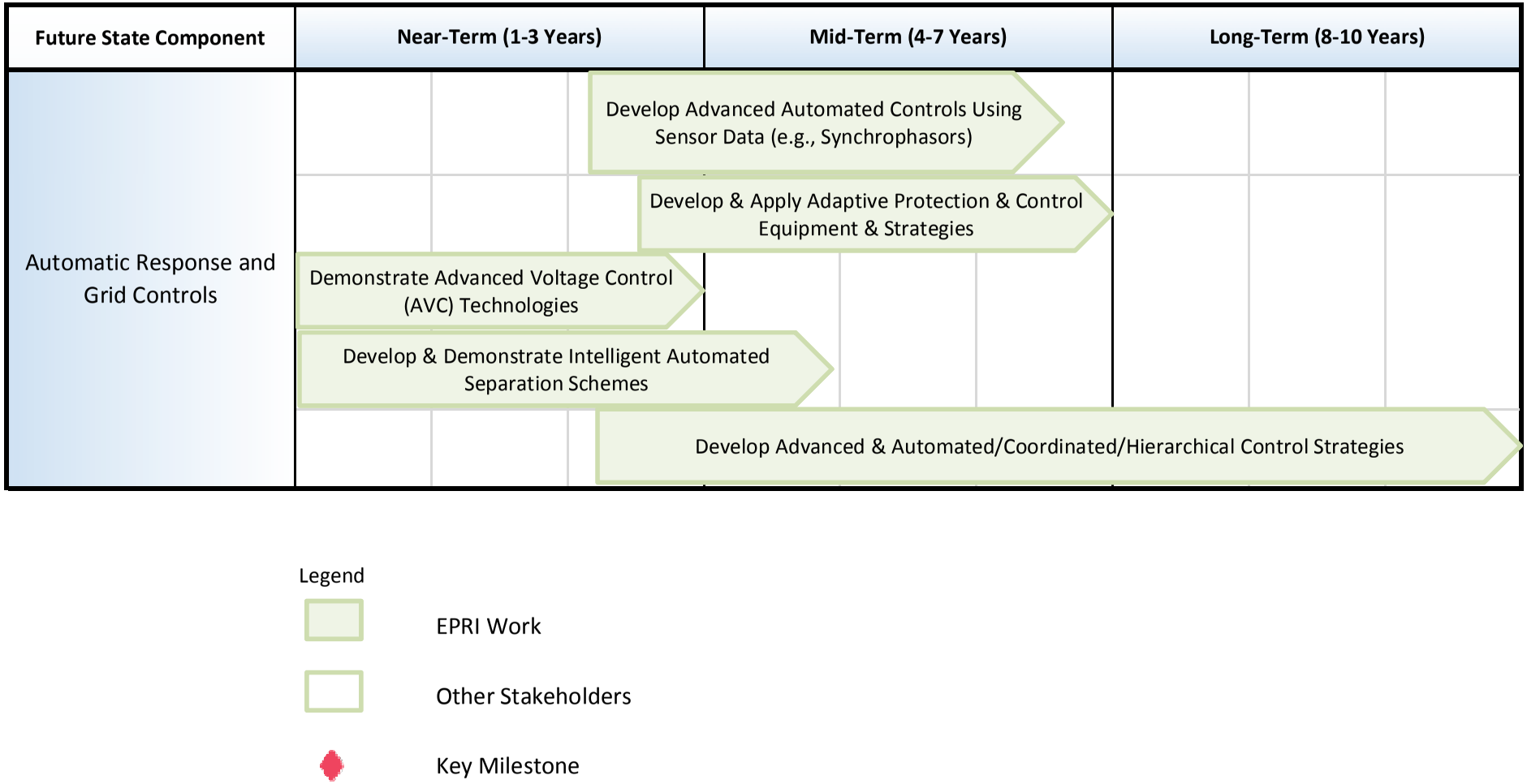
Advanced Control Strategies: Develop and demonstrate automated/coordinated/hierarchical controls and control strategies. This will require some groundbreaking research and involvement from industry visionaries. The long-term goal is to develop advanced controls and advanced hierarchical control strategies over a wide area to improve self-healing of the transmission grid.

The above activities are arranged in technology tracks in the following roadmap. The roadmap shows one track, namely Automatic Response and Grid Controls. In this track, the associated activities related to the grid operations and planning function are summarized in the boxes.

VALUE AND RISK

The efforts mentioned above to develop advanced controls will improve the self healing nature of the grid, thus augmenting the function of grid operators.

With the increased complexity in operating the power system, the risk to the system can be minimized by developing sound controls and control strategies. These R&D efforts are somewhat technically complex, which poses a risk that the industry may not take them on.


Future State Component
Near-Term (1-3 Years)
Mid-Term (4-7 Years)
Long-Term (8-10 Years)
Automatic Response and Grid Controls
Develop Advanced Automated Controls Using Sensor Data (e.g., Synchrophasors)
Develop & Apply Adaptive Protection & Control Equipment & Strategies
Demonstrate Advanced Voltage Control (AVC) Technologies
Develop & Demonstrate Intelligent Automated Separation Schemes
Develop Advanced & Automated/Coordinated/Hierarchical Control Strategies
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

A full set of applications, tools, and systems will be available to provide the visualization and situational awareness required by system operators, customers, and regulators.

The following attributes, examples, and initiatives further describe this future state:

- Grid operators will have sufficient real-time information to enhance situational awareness and "look ahead" capability to enhance their decision-making. Tools will determine the appropriate (MW and Mvar) margins to display for operators based on the location and system conditions. Real-time tools, including mitigation strategies, will be available to guide the operator in decision-making to steer through security situations.
- Synchrophasor data will be available to facilitate instant diagnosis of the performance of the entire system, which will then be displayed, based on the needs of the operators.
- Applications, tools, and systems will enable grid operators to identify in real-time potential areas of voltage instability and the corresponding dynamic and static reactive-power requirements by area, to avoid instability. For each potential voltage-security or collapse scenario identified in off-line studies, synchrophasor data will calculate margins available in real time before a voltage collapse can occur. Specific operating steps (responses) will be automatically presented to the operators based on potential problems identified by synchrophasor data.
- Information about the health of critical equipment will be available for use by operators to identify potential equipment problems and incorporate this information in real-time contingency analysis to arrive at potential mitigation strategies.

GAPS

- Enhanced situational-awareness tools and analytical techniques are required to support the system operators in several areas, including: reserve monitoring (reactive reserve and operating reserve); alarm-response procedures; proactive operating procedures; operating guides (mitigation plans); load-shed capability; system reassessment and re-posturing; and blackstart capability in real-time.
- Tools and applications may also use sensor data (PMU, DCTR, and so on) to calculate available MW margins in real time and assessment of voltage-stability margins across a wide area. Algorithms will be required to interpret the data and provide information regarding asset and system health in a usable form for operators, asset managers, and planners. This information should include suggested mitigation measures.
- To improve wide-area visibility, it will be necessary to develop vendor-neutral interfaces that will enable the exchange of EMS models, transfer of real-time data to simulation programs, and information and data exchange data between all operators and control centers within an interconnection.

ACTION PLAN

It is essential for the grid operator to know the present conditions within and around their power system and to have an indication of system conditions anticipated during the next few hours.

To achieve this Future State, RD&D will need to be directed in four principal areas: (1) Grid Monitoring and Sensors; (2) Decision Support and Visualization Tools; (3) Real-Time Tools for Voltage and Frequency Control and Support; and (4) Analysis of Monitored Data. The following RD&D activities focus on enabling and emerging technologies, processes, and tools that will support grid operators and planners in achieving this Future State.

Grid Monitoring and Sensors

Real-Time Visualization of Supply-Side and Demand-Side Resources and Technologies: Provide real-time visualization of supply-side and demand-side resources/technologies/devices in control centers to meet the needs of grid operators. This will require information and appropriate level of detail related to wind and solar generation, distributed energy resources, demand response, storage, plug-in electric vehicles, and so on to be integrated with other EMS information.

Synchrophasor Technology Applications: Develop synchrophasor technology-based applications that provide wide-area high-resolution, synchronized real-time monitoring of power system performance.

Decision Support and Visualization Tools

Advanced Visualization Techniques: Develop advanced human-centric visualization techniques. Tools and techniques are needed to display information in control centers that is succinct and intuitive for operators. Operators also need comprehensive visualization techniques to display operating boundaries for guidance on security limits and margins.

Alarm-Management Techniques: Develop advanced techniques to manage the alarm data received from the system by converting the data to information displayed succinctly for the operators.

State Estimation Using Synchrophasor Technology: Enhance State Estimator solution techniques by incorporating synchrophasor data.

Equipment Health Information: Develop processes and tools to integrate real-time health information of critical equipment in control centers.

Dynamic Thermal Circuit Rating (DTCR) Technology: Develop and demonstrate processes and tools to deploy DTCR technology in system operations and market practices and processes.

Real-Time Tools for Voltage and Frequency Control and Support

Voltage Stability: Develop and demonstrate tools/processes for real-time assessment of voltage stability and stability margins. The industry needs analytical tools to assess voltage stability performance and calculate stability margins in a real-time environment. Also, tools and processes are needed to display this information in control centers.

Reactive-Power Management: Develop study tools and methods to assess voltage stability and to manage reactive-power resources to mitigate stability problems. Also, tools and processes are needed to display this information in control centers. This activity will take on an additional importance due to: a) retirement of conventional generators, which provide robust dynamic voltage support; and b) large-scale integration of variable generation, which may not provide as robust voltage support as provided by conventional generation.

Frequency Response: Develop and demonstrate tools/processes for real-time assessment of frequency response. The industry needs processes and tools that can promptly analyze system frequency response to events such as generator or line trips and display the information succinctly for the operator to assess adequacy of the frequency response.

Management of Operating Reserve Resources: Develop and demonstrate tools/processes for real-time management of operating reserve resources. This will require the combined use of the following tools indicated in the flowchart for Future State 3: all the tools mentioned under the "Resource Adequacy and Flexibility" track and the forecasting tools for operating reserve requirements mentioned under the "Forecasting" track.

Analysis of Monitored Data

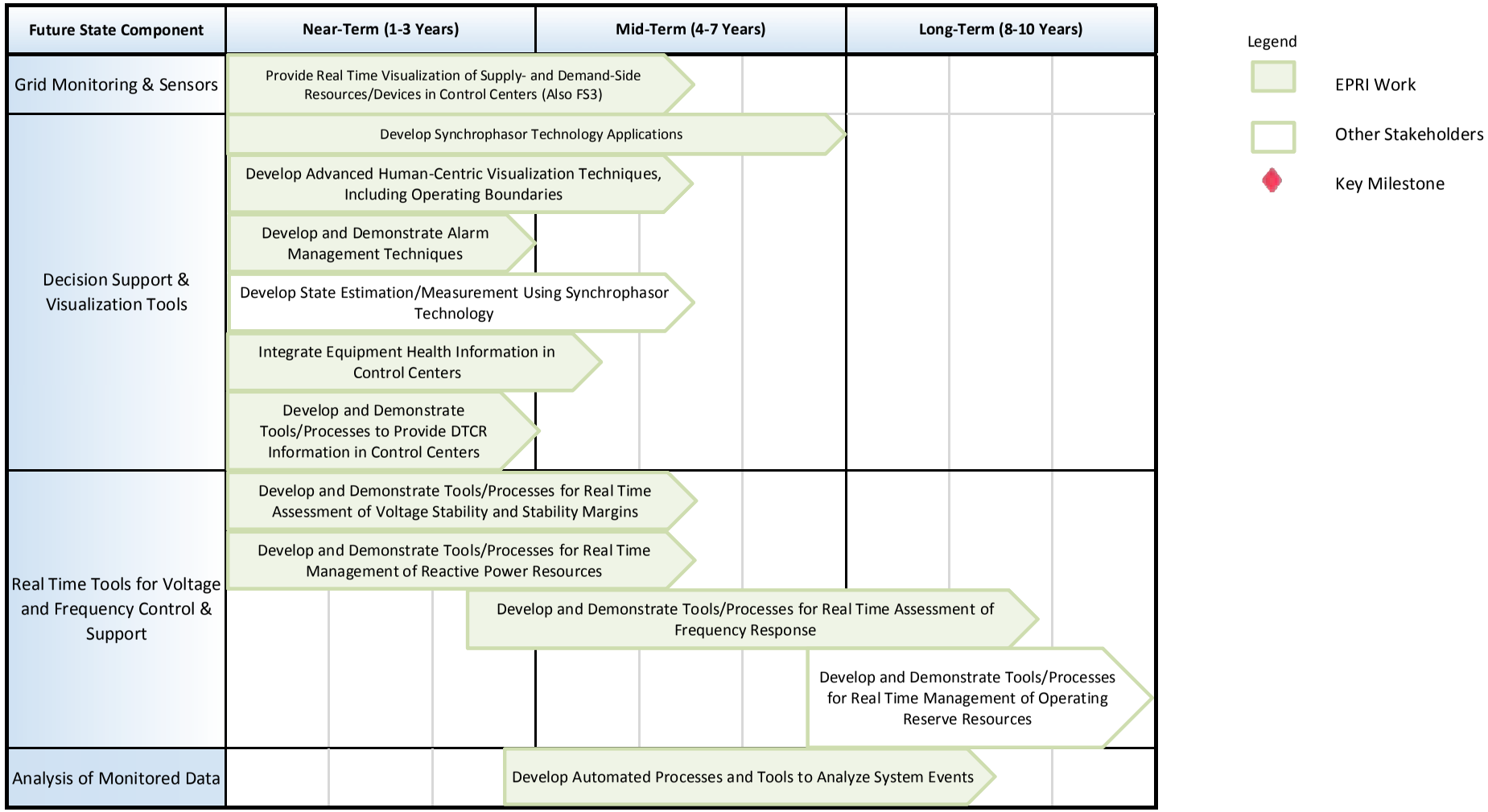
Automated System-Event Analysis: Develop automated processes and tools to analyze system events. The industry needs such tools to be able to quickly identify the signature of an event and act to mitigate its effect. Eventually, such tools and processes can help in real-time postmortem of major disturbances.

The above activities are arranged in technology tracks in the following roadmap. The roadmap shows four tracks: (1) Grid Monitoring and Sensors; (2) Decision-Support and Visualization Tools; (3) Real-Time Tools for Voltage and Frequency Control and Support; and (4) Analysis of Monitored Data. In each track, the associated activities related to the grid operations and planning function are summarized in the boxes.

VALUE AND RISK

The lack of situational awareness was found to be one of the primary causes for the 8/14/03 blackout. The efforts mentioned in the above action plan are essential to enhance the knowledge of an operator of power system conditions and to support the operator's decision-making.

Without such efforts, risk of emergencies and blackout could increase, especially in light of increasingly larger operational footprints.


Future State Component
Near-Term (1-3 Years)
Mid-Term (4-7 Years)
Long-Term (8-10 Years)
Grid Monitoring & Sensors
Provide Real Time Visualization of Supply- and Demand-Side Resources/Devices in Control Centers (Also FS3)
Decision Support & Visualization Tools
Develop Synchrophasor Technology Applications
Develop Advanced Human-Centric Visualization Techniques, Including Operating Boundaries
Develop and Demonstrate Alarm Management Techniques
Develop State Estimation/Measurement Using Synchrophasor Technology
Integrate Equipment Health Information in Control Centers
Develop and Demonstrate Tools/Processes to Provide DTCR Information in Control Centers
Real Time Tools for Voltage and Frequency Control & Support
Develop and Demonstrate Tools/Processes for Real Time Assessment of Voltage Stability and Stability Margins
Develop and Demonstrate Tools/Processes for Real Time Management of Reactive Power Resources
Develop and Demonstrate Tools/Processes for Real Time Assessment of Frequency Response
Develop and Demonstrate Tools/Processes for Real Time Management of Operating Reserve Resources
Analysis of Monitored Data
Develop Automated Processes and Tools to Analyze System Events
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

The future workforce will have access to interactive training in power system fundamentals, power system analysis, safety, security, public policy, economics, and the latest IT techniques and approaches.

The following attributes, examples, and initiatives further describe this future state:

- Handheld, portable, and virtual devices will be available to facilitate interactive power system training.
- A comprehensive training database, including documented institutional knowledge and nationally funded training material (such as the University of Illinois material), will be available to facilitate training of grid operators and planners.
- Interactive tools used in the performance of routine operational and planning analysis will be adaptive to the level of user experience to provide additional intelligence and analysis of system conditions and development of mitigation measures.

GAPS

- Industry will require processes and techniques to capture the knowledge and experience of retiring staff and succession plans, including assessment of impacts of retirements.
- Standardized curricula and recruiting strategies with community colleges, apprenticeship programs, and universities may be developed to inform individuals of career possibilities. Industry needs to seek grant funding (EPA, DOE, and Job Training & Partnership Act) and create a standard evaluation for assessing new employees regarding their previous knowledge and skills.
- EPRI GOP efforts should be coordinated with the industry and other areas of EPRI (Distribution, Generation, and Transmission and Substations).

ACTION PLAN

As the GOP workforce transforms due to retirement of experienced staff, industry will need to pay particular attention to developing the skills of those entering the workforce.

To achieve this Future State, activities will need to be directed in three principal areas: (1) Skills; (2) Training Tools; and (3) Training Database. A large portion of these activities are not specifically related to RD&D, but they represent process improvements and mechanisms that will assist in the development of the future workforce.

Skills

Inventory of Industry Skill-Set Requirements: Create an inventory of industry skill-set requirements (through IEEE, PSERC, EPRI, and other entities).

Update of Industry Skill-Set Requirements: Update skill-set requirements as needed to reflect industry changes.

Loss of Institutional Knowledge: Develop processes to track the loss of institutional knowledge (such as EMTP expertise).

Training Tools

Electromagnetic Transients (EMT) Studies: Develop training material to conduct EMT studies for digital simulation of transients involving electromagnetic and electromechanical phenomena. These studies are typically conducted using programs such as Electromagnetic Transients Program (EMTP), PSCAD software and Alternative Transients Program (ATP).

Knowledge Capture and Transfer Tools: Develop knowledge capture and transfer tools. Develop on-the-job and coop training programs.

Syllabi and Courses: Develop and evergreen syllabi and courses for technical training with universities and Web trainers.

Courses for Mandatory Training: Develop courses for mandatory training such as that required by NERC.

Operator Training Simulators: Develop digital/operator training simulators, real-time digital simulators, and the corresponding training modules.

Training Database

Training Material: Develop training material on industry skill sets (need-based).

National Training Database: Develop national database of training material.

The above activities are arranged in technology tracks in the following roadmap. The roadmap shows three tracks: (1) Skills; (2) Training Tools; and (3) Training Database. In each track, the associated activities that are related to the grid operations and planning function are summarized in the boxes.

VALUE AND RISK

The efforts outlines in the above action plan are designed to address the growing workforce concerns and depletion of skill sets in the power industry.

A risk exists that the workforce and skill sets may deplete if industry-wide efforts to develop training tools and databases are not pursued and especially if training activities continue to take low priority as has been the case for decades.

Future State Component	Near-Term (1-3 Years)	Mid-Term (4-7 Years)	Long-Term (8-10 Years)
Skills	Create and Inventory of Industry Skill Sets	Update Skill Set Requirements and Evergreen the Process	
	Develop Processes to Track the Loss of Institutional Knowledge (e.g., EMTP Expertise)		
Training Tools	Develop Training Material for Electromagnetic Transients Studies		
	Develop Knowledge Capture and Transfer Tools Develop On-the-Job and Coop Training Programs		
	Develop and Evergreen Syllabus and Courses for Technical Training with Universities and Web Trainers		
	Develop Courses for Mandatory Training (NERC, etc.)		
	Develop Digital/Operator Training Simulators & Real-Time Digital Simulators and Corresponding Training Modules		
Training Database	Develop Training Materials on Industry Skill Sets (Needs Based)		
	Develop National Database of Training Materials		

Legend

EPRI Work

Other Stakeholders

Key Milestone

TRANSMISSION AND SUBSTATIONS RESEARCH AREA

VISION

The core vision of the Transmission and Substations Area is:

*Extract the Maximum from **Existing Assets** and Construct High Performance **New Assets***

- The **Life Expectancy** and **Utilization** of *Existing Assets* should be **Maximized**
- *New Assets* should have **Superior Life Expectancy** and **Maintainability**

The key drivers which impact this vision include:

- *Safety*
- *Effective use of Capital and Maintenance Budgets*
- *High Level of Reliability*
- *Environmental and Societal Responsibility*

This strategic vision guides the research performed in the Transmission and substations Area Programs:

- Underground Transmission Lines
- Overhead Transmission Lines
- Substations
- High Voltage Direct Current Transmission Systems (HVDC)

Roadmaps for 6 *Future States* are documented in the following sections. The *Components* and *Gaps* identified in each *Future State* are remarkably similar between Overhead Transmission, Underground Transmission, Substations and HVDC assets. The *Action Plans* however differ significantly. The following *Future State* sections reflect this.

FUTURE STATE COMPONENTS

Inspection and assessment provides the basis for any effective asset management approach. It is vital not only for managing aging assets, but also plays a role in selecting new components and designs as well maintaining a high level of safety. It is at the core of operating transmission assets at a high reliability.

1. Inspection and assessment tools, methods and intervals will be based on a fundamental understanding of component-specific degradation and failure mechanisms and will be performed at optimal intervals and at the least cost.
2. Inspection and Assessment approaches and technologies will predict a component's time to failure, providing the utility with the opportunity to decide to "run-to-failure," or to plan and budget for life-extending maintenance or replacement.
3. Inspections will have minimal impact on system availability. Manual (human) processes will be minimized to collect and interpret data.
4. Utilities will have the knowledge, tools and techniques to develop and implement maintenance, condition assessment, life extension and fleet management programs based on a sound technical basis.
5. Advances in sensors, monitoring hardware and intelligent microprocessor relays will provide utilities with a robust foundation to incorporate real time information in their asset management decision support.
6. Utilities will have access to, and confidence in, component specific remediation techniques and technologies that can be easily applied.
7. Utilities will have the knowledge, tools and techniques to locate faults and determine the root cause.
8. Utilities will have effective techniques and resources to train new staff as well as capture and transfer the tribal knowledge resident in mature staff.

GAPS

1. Understanding of Degradation and Failure Modes

A fundamental understanding of how components degrade and fail is vital to many aspects of developing and applying new inspection and assessment technologies as well as selecting remediation approaches. Industry wide databases which enable knowledge of the performance of components across many entities and environments are also required.

2. Condition Assessment Technologies

Technologies which can be used to assess the condition of components in the field are increasing in importance as transmission assets age. These required technologies range from rounds inspection tools to on-line monitoring. Tools and techniques which do not require outages or live line work are preferred, e.g., robotics, standoff technologies. Analytical methodologies are required to translate condition data into actionable information.

3. Optimal Remediation Methods

Methods and materials to remediate assets that are aged or have been identified as high risk will be needed as the transmission assets age. Utilities need to have the confidence and tools to select, specify and apply these remediation approaches.

4. Fleet Management Analytics

Algorithms, tools and methodologies are needed to evaluate an entire fleet of components and identify populations for replacement or remediation. These tools will also support spares policies and feedback to the specification of new components.

5. Knowledge Capture and Transfer

The knowledge that has been amassed in the transmission industry over the past decades by utility staff, equipment experts and vendors needs to be captured and effectively transferred to a new generation of technical staff.

ACTION PLAN

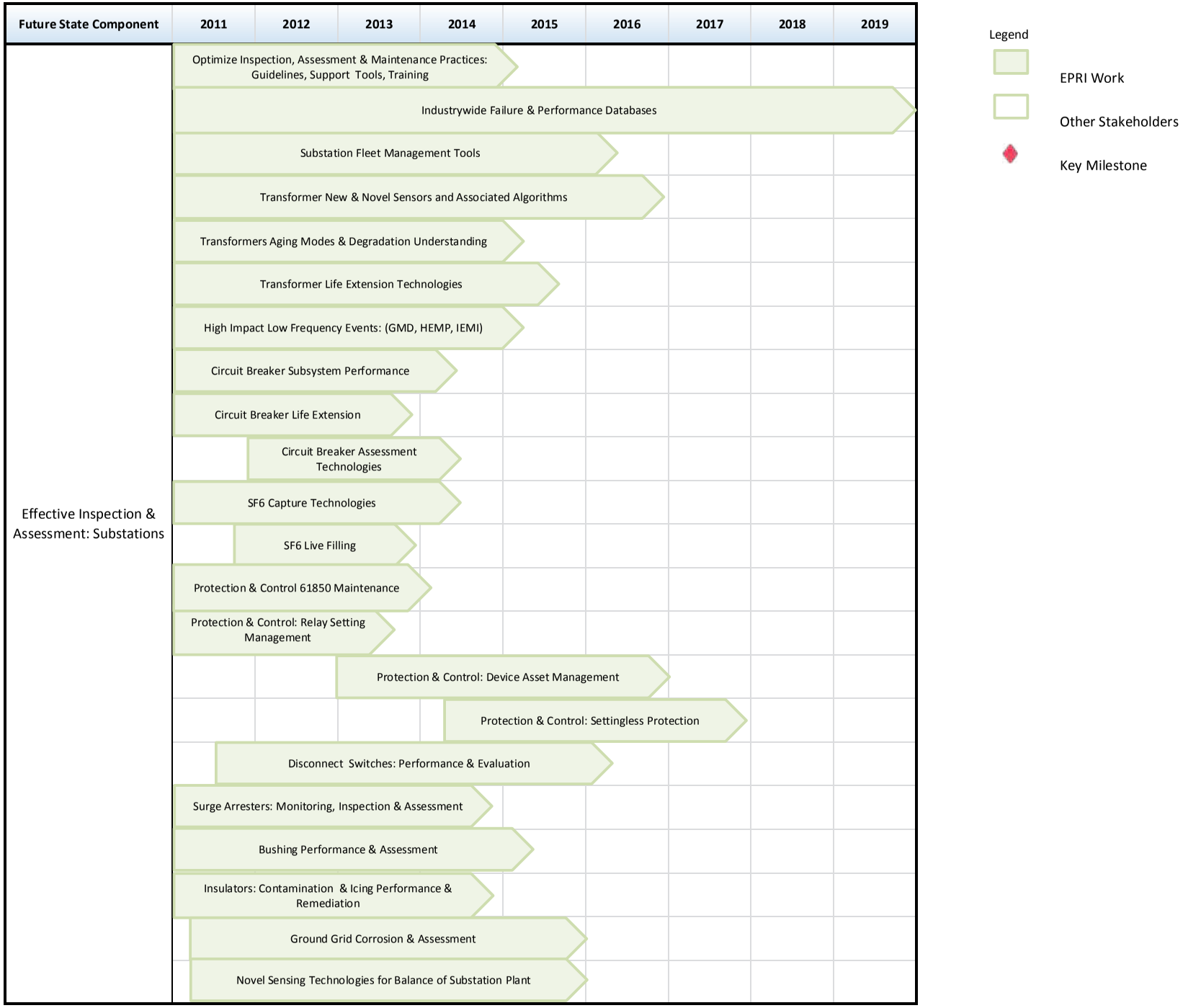
Although the *Future States* and *Gaps* are similar across Overhead, Underground, Substations and HVDC programs, the action plans are quite different. A graphical representation of the action plans for each of the programs is shown in the following pages.

VALUE AND RISK

The value of research to enable effective inspection and maintenance of transmission and substation assets lies in ability of the asset owners and operators to manage their transmission assets at a high level of reliability, availability and safety.

The risk of not understanding the condition of transmission assets and applying effective remediation are multi-fold:

- Maintenance and capital budgets may increase significantly as the transmission fleet ages and require intensive maintenance or replacement utilizing traditional approaches.
- The performance of transmission assets will degrade resulting in a reduction of reliability and potentially safety.
- If inspection, assessment and remediation approaches are utilized which are not well researched and evaluated there is a potential for poor decisions being made resulting in undesirable consequences.


Future State Component
2011
2012
2013
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2016
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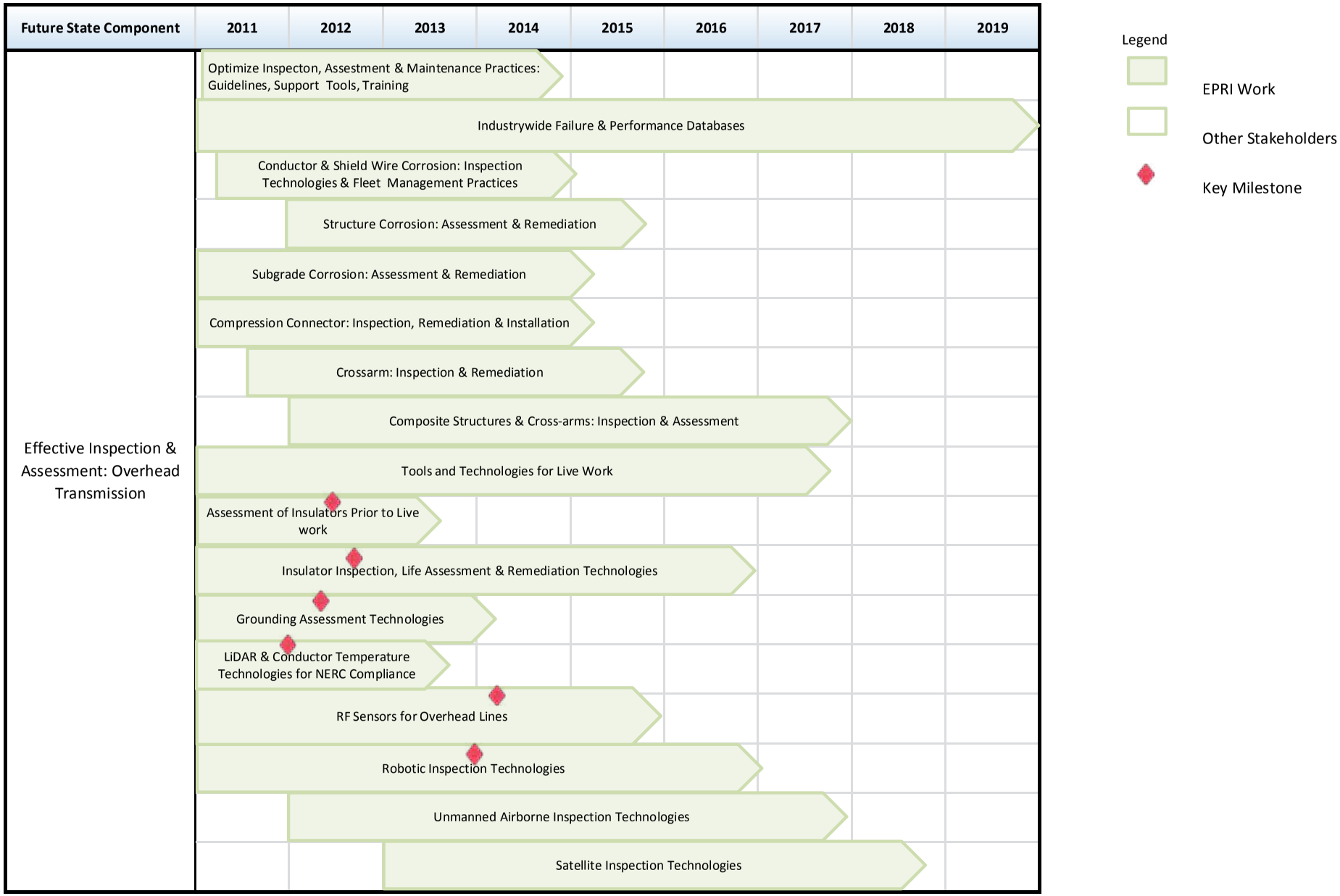
2018
2019
Effective Inspection & Assessment: Substations
Optimize Inspection, Assessment & Maintenance Practices: Guidelines, Support Tools, Training
Industrywide Failure & Performance Databases
Substation Fleet Management Tools
Transformer New & Novel Sensors and Associated Algorithms
Transformers Aging Modes & Degradation Understanding
Transformer Life Extension Technologies
High Impact Low Frequency Events: (GMD, HEMP, IEMI)
Circuit Breaker Subsystem Performance
Circuit Breaker Life Extension
Circuit Breaker Assessment Technologies
SF6 Capture Technologies
SF6 Live Filling
Protection & Control 61850 Maintenance
Protection & Control: Relay Setting Management
Protection & Control: Device Asset Management
Protection & Control: Settingless Protection
Disconnect Switches: Performance & Evaluation
Surge Arresters: Monitoring, Inspection & Assessment
Bushing Performance & Assessment
Insulators: Contamination & Icing Performance & Remediation
Ground Grid Corrosion & Assessment
Novel Sensing Technologies for Balance of Substation Plant
Legend
EPRI Work
Other Stakeholders
Key Milestone


Future State Component
2011
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2019
Effective Inspection & Assessment: Overhead Transmission
Optimize Inspecton, Assestment & Maintenance Practices: Guidelines, Support Tools, Training
Industrywide Failure & Performance Databases
Conductor & Shield Wire Corrosion: Inspection Technologies & Fleet Management Practices
Structure Corrosion: Assessment & Remediation
Subgrade Corrosion: Assessment & Remediation
Compression Connector: Inspection, Remediation & Installation
Crossarm: Inspection & Remediation
Composite Structures & Cross-arms: Inspection & Assessment
Tools and Technologies for Live Work
Assessment of Insulators Prior to Live work
Insulator Inspection, Life Assessment & Remediation Technologies
Grounding Assessment Technologies
LiDAR & Conductor Temperature Technologies for NERC Compliance
RF Sensors for Overhead Lines
Robotic Inspection Technologies
Unmanned Airborne Inspection Technologies
Satellite Inspection Technologies
Legend
EPRI Work
Other Stakeholders
Key Milestone

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Effective Inspection & Assessment: Underground Transmission	New Sensor Technology for Cables								
	Corrosion: Detection & Remediation								
	Diagnostic Methods for Cables								
	Industrywide Performance and Failure Database								
	Life Expectancy & Condition Assessment								
	Robotic Inspection on Vaults & Cables								

Legend

- EPRI Work
- Other Stakeholders
- Key Milestone

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Effective Inspection & Assessment: HVDC	Live Working Tools & Technologies								
	Life Expectancy of Composite Insulators								

FUTURE STATE COMPONENTS

1. Utilities will have the tools to specify and assess new and existing materials/components/designs for failure modes, reliability and life expectancy in a rapidly changing manufacturing environment.
2. New materials will be developed that are easier to apply, reliable, cost effective and enable real-time in-service assessment (predictive) of material condition and risk.
3. Materials and components will have a minimal effect on the environment.
4. Tools and techniques will enable the confident selection, specification, installation and maintenance of new component technologies.
5. Components will be safe and friendly to work practices.

GAPS

1. Understanding of Degradation and Failure Modes

A fundamental understanding of how new and emerging components and materials degrade and fail is vital.

2. Development of New Materials and Components

More cost effective and reliable materials and components with equivalent or higher performance and life expectancy are required.

3. Effective Selection, Specification and Application

Utilities need to be able to select, specify and apply both existing and new technologies confidently in a wide range of conditions to ensure the optimal performance and an appropriate life expectancy. Historically it may have been possible to rely on high quality products from vendors that meet the application. As utilities procure new technologies with unknown long term performance, and vendors of mature technologies are more globally diverse, the importance of relevant tests and specifications has increased.

4. Effective Inspection and Remediation

Although the performance of new components and materials is vital, it is also important that when they reach end of life, that inspection and monitoring technologies exist to identify high risk units, manage the fleet and perform remediation. In addition it needs to ensure that these new materials and components do not pose a barrier to live working techniques.

5. Increasing Powerflow in Existing Assets

There is an increasing demand to increase the powerflow through existing assets and rights of way. Technologies, new components and rating methodologies are needed to address this gap.

ACTION PLAN

Although the *Future States* and *Gaps* are similar across Overhead, Underground, Substations and HVDC programs, the action plans are quite different. A graphical representation of the action plans for each of the programs is shown in the following pages.

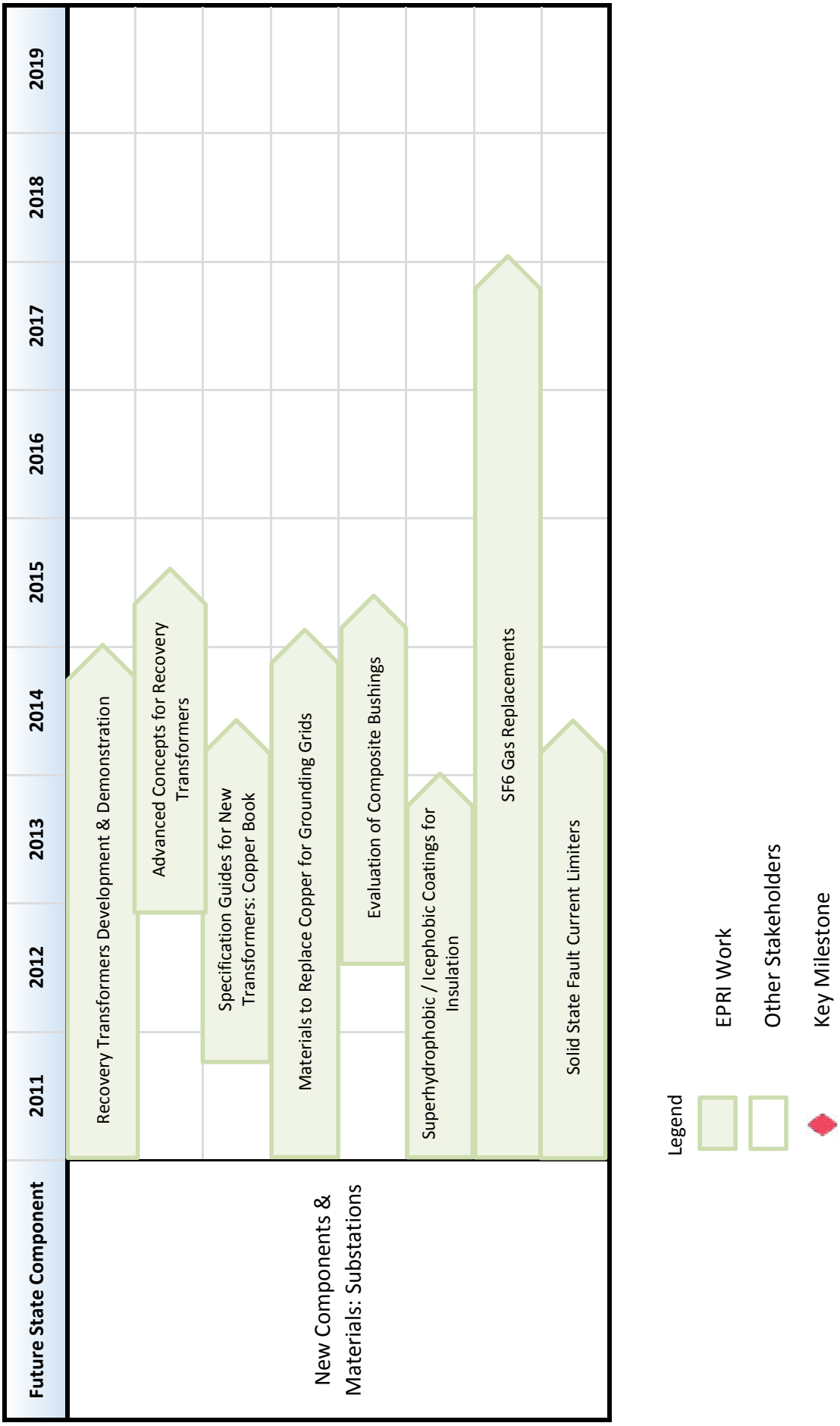
VALUE AND RISK

The value of developing and comprehensively evaluating new components and materials as well as addressing application, operation, inspection and assessment includes:

- Access to lower cost and more reliable assets which will have a longer life expectancy. Which in-turn will reduce capital and maintenance budgets.
- More environmentally compatible new materials and components.
- Components and materials that have the potential to increase the powerflow through existing rights of way
- Materials and components that can potentially be applied to existing assets that will either increase performance or extend life.
- Access to new components which can potentially reduce the capital and O&M costs.

Risks that may emerge if new materials and components are not developed or fully evaluated prior to application with all the tools required for their entire life cycle:

- The powerflow through existing rights of way will be limited to present levels.
- New materials and components maybe applied which have not been fully evaluated which may result in a reduction in the reliability, safety and life expectancy of the transmission system.
- New materials and components that have not been fully evaluated may result in increased maintenance expenditures due to unforeseen challenges.


Future State Component
2011
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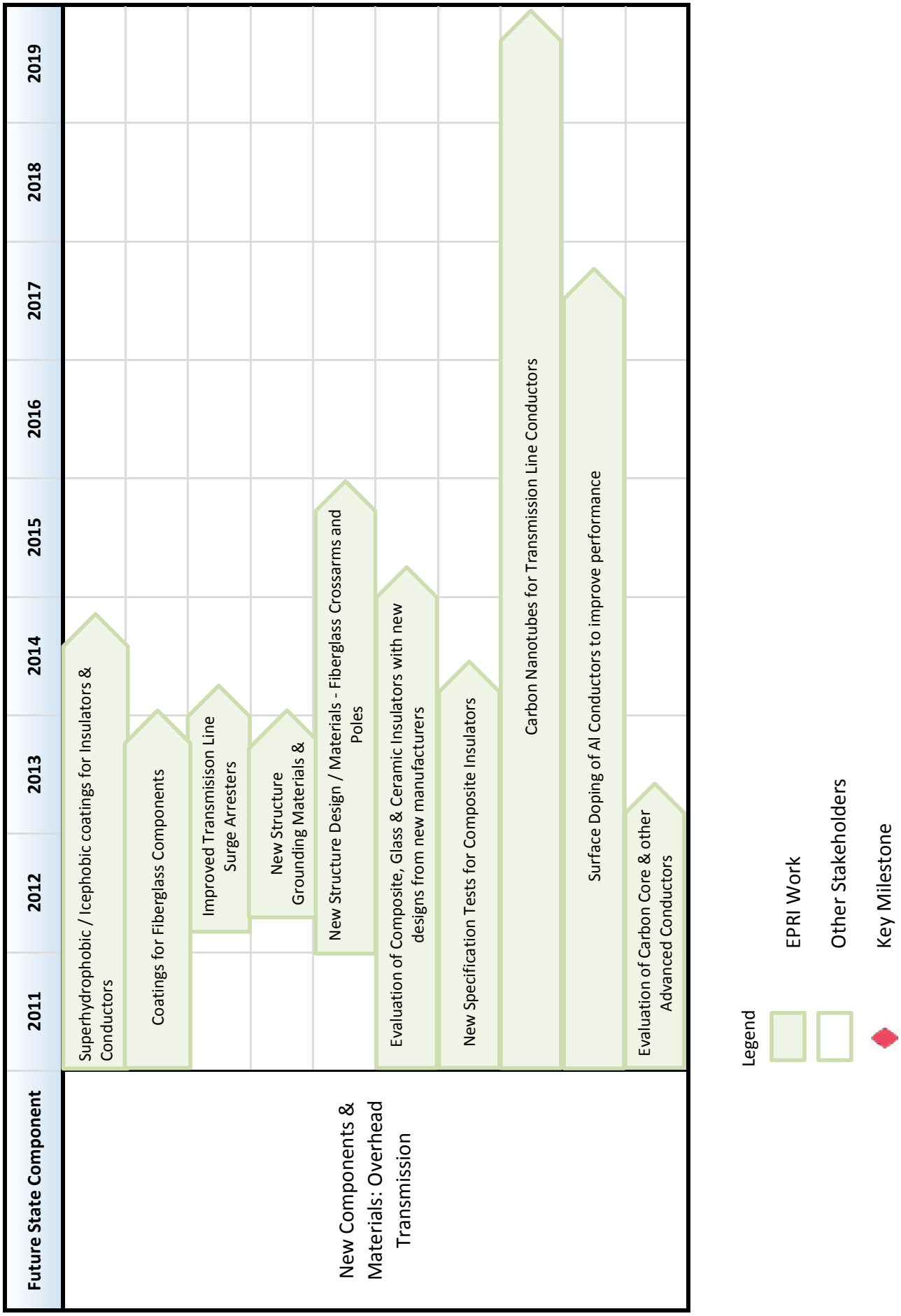
2019
New Components & Materials: Substations
Recovery Transformers Development & Demonstration
Advanced Concepts for Recovery Transformers
Specification Guides for New Transformers: Copper Book
Materials to Replace Copper for Grounding Grids
Evaluation of Composite Bushings
Superhydrophobic / Icephobic Coatings for Insulation
SF6 Gas Replacements
Solid State Fault Current Limiters
Legend
EPRI Work
Other Stakeholders
Key Milestone


Future State Component
2011
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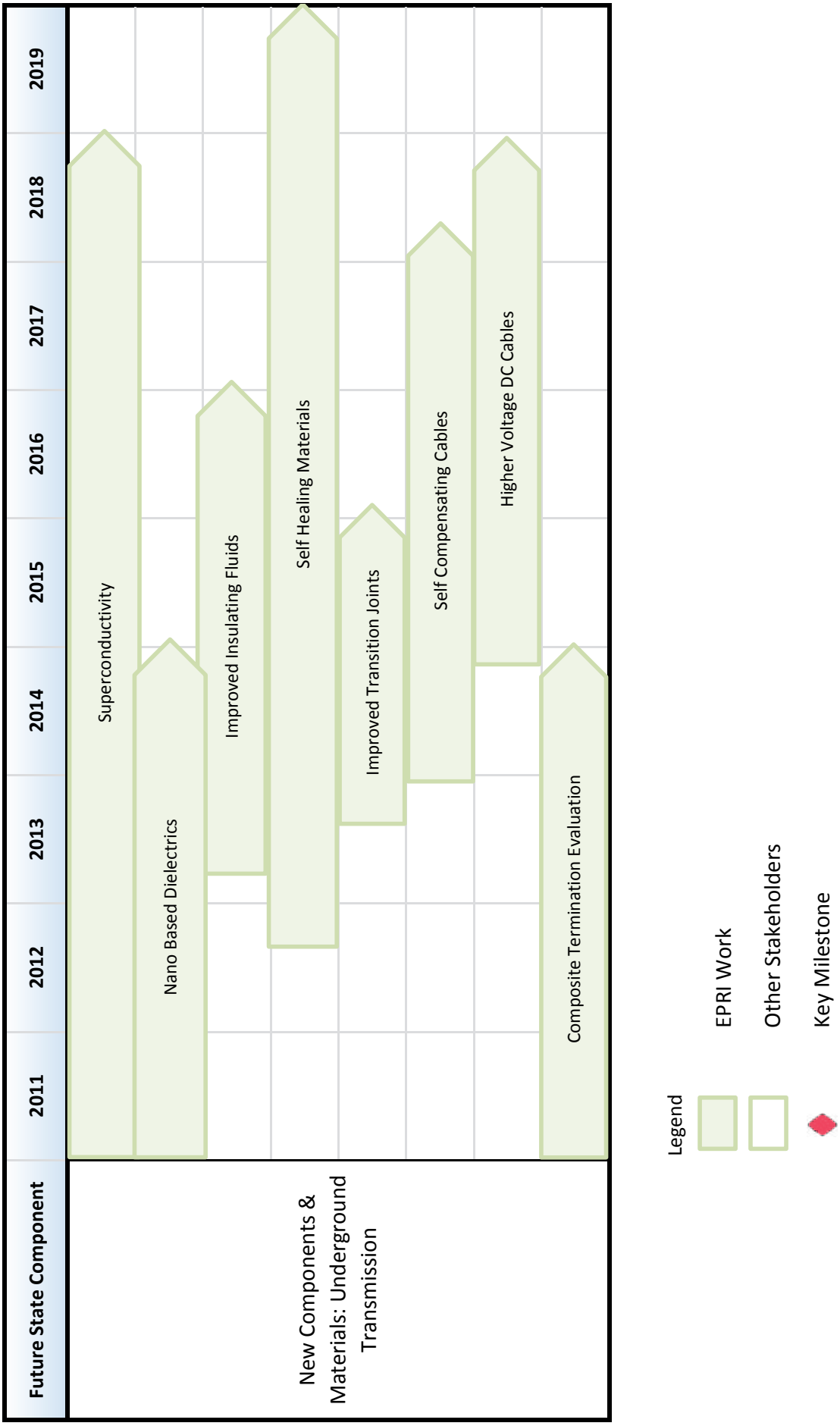
2019
New Components & Materials: Overhead Transmission
Superhydrophobic / Icephobic coatings for Insulators & Conductors
Coatings for Fiberglass Components
Improved Transmisison Line Surge Arresters
New Structure Grounding Materials &
New Structure Design / Materials - Fiberglass Crossarms and Poles
Evaluation of Composite, Glass & Ceramic Insulators with new designs from new manufacturers
New Specification Tests for Composite Insulators
Carbon Nanotubes for Transmission Line Conductors
Surface Doping of Al Conductors to improve performance
Evaluation of Carbon Core & other Advanced Conductors
Legend
EPRI Work
Other Stakeholders
Key Milestone


Future State Component
2011
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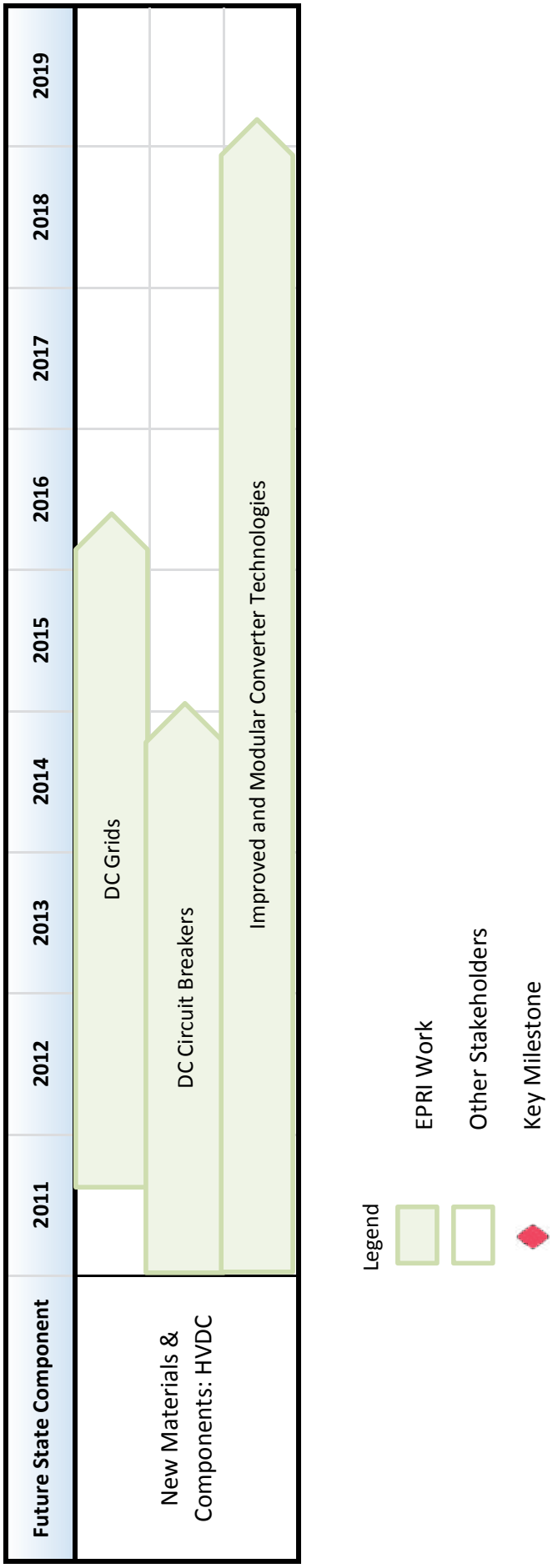
2019
New Components & Materials: Underground Transmission
Superconductivity
Nano Based Dielectrics
Improved Insulating Fluids
Self Healing Materials
Improved Transition Joints
Self Compensating Cables
Higher Voltage DC Cables
Composite Termination Evaluation
Legend
EPRI Work
Other Stakeholders
Key Milestone


Future State Component
2011
2012
2013
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2018
2019
New Materials & Components: HVDC
DC Grids
DC Circuit Breakers
Improved and Modular Converter Technologies
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

1. Techniques and technologies will enable safe and efficient work practices on and around transmission lines (energized and de-energized).
2. Designs and components will be safe and friendly to work practices.
3. Utilities will have effective techniques and resources to train new staff as well as capture and transfer the tribal knowledge resident in mature staff.

GAPS

1. Improved Field Practices and Tools

New tools ranging from hotsticks, to robotics, to software will result in field personnel being more effective and efficient while maintaining safety. As scheduled outages are less frequency and more costly, live work will become more important requiring improved tools and practices.

2. Condition Assessment Technologies

Technologies which can be used to assess the condition of components in the field are increasing in importance as transmission assets age. These required technologies range from rounds inspection tools to on-line monitoring. Tools and techniques which do not require outages or live line work are preferred, e.g., robotics, standoff technologies.

3. Optimal Remediation Methods

Methods and materials to remediate assets that are aged or have been identified as high risk will be needed as the transmission assets age. Utilities need to have the confidence and tools to select, specify and apply these remediation approaches. Many of these techniques will have to be implemented under energized conditions as the availability of outages will continue to be challenging.

4. Knowledge Capture and Transfer

The knowledge that has been amassed in the transmission industry over the past decades by utility staff, equipment experts and vendors needs to be captured and effectively transferred to a new generation of technical staff. Good practices should be shared between different entities. Increased application of live working techniques will require a new generation of personnel to be trained.

ACTION PLAN

Although the *Future States* and *Gaps* are similar across Overhead, Underground, Substations and HVDC programs, the action plans are quite different. A graphical representation of the action plans for each of the programs is shown in the following pages.

VALUE AND RISK

By developing and implementing new and effective field practices personnel will be more optimally utilized reducing capital and maintenance budgets.

Techniques which can be applied energized conditions without compromising safety or reliability will enable maintenance actions in a timely fashion due to the limited availability of outages. This in-turn will result in increased reliability.

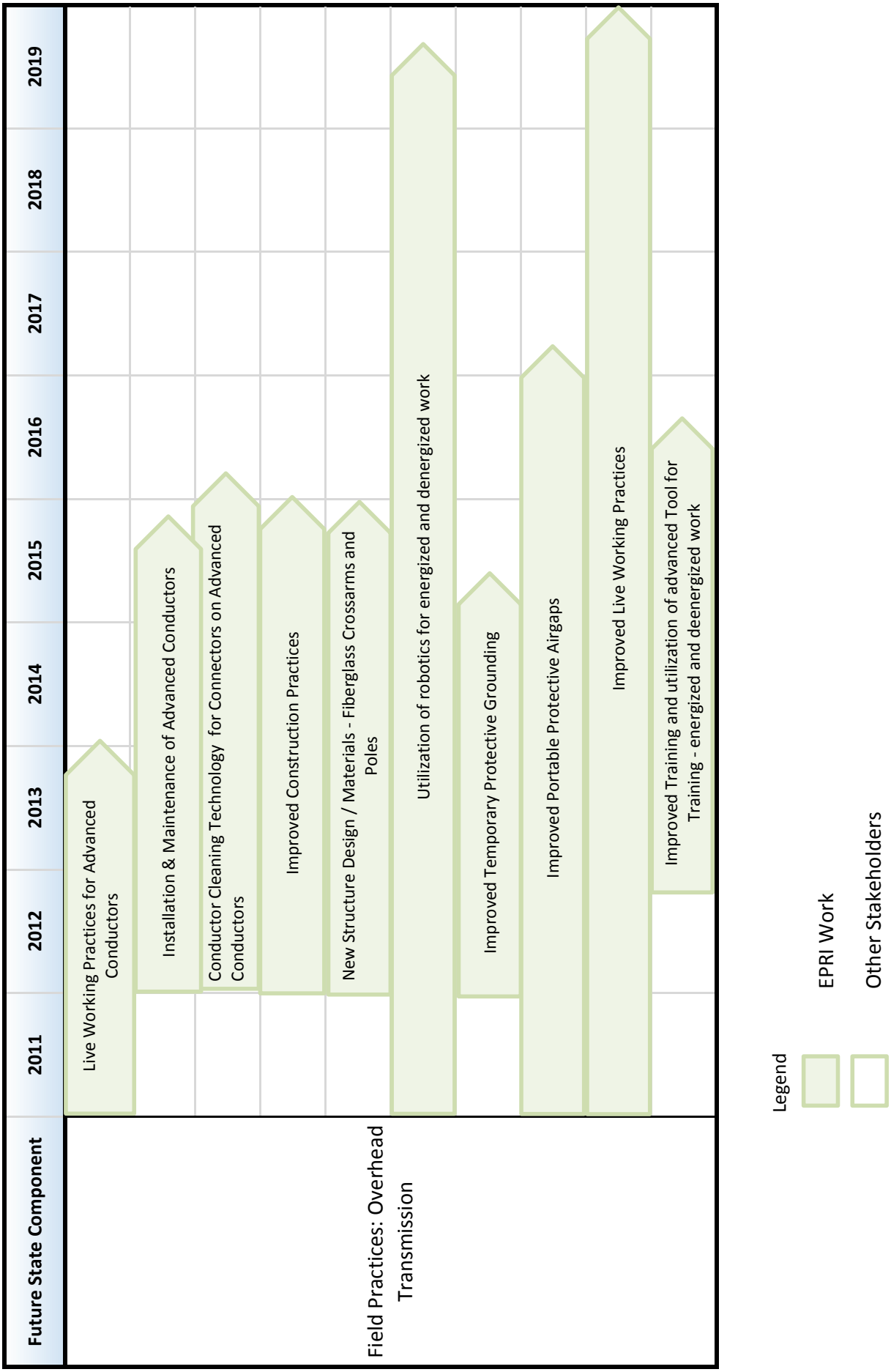
If methods to capture and transfer knowledge from the existing workforce to the new employees are not developed and implemented the reliability and safety of the power system may be impacted due to the lack of availability of skilled personnel.

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Field Practices: Substations			Improved Ground Grid Audits						
	Improved Switching Safety: Practices, Sharing & Training								
	Improved Application, Testing and Maintenance of 61850								

Legend

EPRI Work

Other Stakeholders


Future State Component
2011
2012
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2018
2019
Field Practices: Overhead Transmission
Live Working Practices for Advanced Conductors
Installation & Maintenance of Advanced Conductors
Conductor Cleaning Technology for Connectors on Advanced Conductors
Improved Construction Practices
New Structure Design / Materials - Fiberglass Crossarms and Poles
Utilization of robotics for energized and denergized work
Improved Temporary Protective Grounding
Improved Portable Protective Airgaps
Improved Live Working Practices
Improved Training and utilization of advanced Tool for Training - energized and deenergized work
Legend
EPRI Work
Other Stakeholders

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Field Practices: Underground Transmission			Improved Electrical Practices in Manholes						
			Improved Pulling Practices for Cables						

Legend

EPRI Work

Other Stakeholders

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Field Practices: HVDC		HVDC Live Work Practices & Tool							

Legend

EPRI Work

Other Stakeholders

FUTURE STATE COMPONENTS

1. Designs that maximize powerflow along the right of way while reducing losses and allowing multiple entities to utilize the right of way, e.g., pipelines, cell phones, etc.
2. Designs that can accept and fully utilize new components with enhanced performance.
3. Designs and components that are safe and friendly to work practices.
4. Utilities will have effective techniques and resources to train new staff as well as capture and transfer the tribal knowledge resident in mature staff.

GAPS

A fundamental understanding of how specific components are manufactured, degrade and fail is vital to select the most appropriate components, apply them effectively in design and install them for maximum reliability. This selection should be based industry wide databases of component performance, testing and modeling. The following gaps have been identified:

1. Development of New Materials and Components

More cost effective and reliable materials and components which are required. Confidence is needed on how to select, specify, install, inspect, assess and remediate these new materials and components for their entire anticipated life.

2. Effective Selection, Specification and Application

Utilities need to be able to select, specify and apply both existing and new technologies in a wide range of conditions to ensure the optimal performance and life expectancy. Historically it may have been possible to rely on high quality products and guidance from vendors. As utilities procure new technologies with unknown performance the need exists to develop appropriate specifications and testing. Utilities are also procuring mature technologies from non-traditional vendors, although these products meet industry standards, they do not always meet the performance of historical products. This has increased the importance of developing effective tests and specifications as well as design and installation practices.

3. Improved Design and Construction Tools

Specialized tools need to be continually developed and improved to support both designers and construction personnel. The tools range from field hardware to modeling software. These tools need to improve the productivity of personnel while maintaining a high level of reliability for both traditional and emerging designs. Many of these specialized tools do not exist or need improvement.

4. Reference Information

Reference guides are necessary to document and transfer all the characteristics, fundamental concepts, performance criteria and effects of the various design and construction options of transmission assets.

ACTION PLAN

Although the *Future States* and *Gaps* are similar across Overhead, Underground, Substations and HVDC programs, the action plans are quite different. A graphical representation of the action plans for each of the programs is shown in the following pages.

VALUE AND RISK

New well evaluated designs and construction techniques will enable lower cost assets to be constructed which enable increased power flow, increased reliability and reduced maintenance which are more compatible with the environment. In turn these benefits will result in reduced capital and maintenance budgets.

The risk of not developing these new technologies is that the industry will be limited by the performance and powerflow of multi-decade old designs and practices.

If new technologies are not thoroughly developed and effectively evaluated prior to widespread application the potential exists for reduced safety and reliability of the transmission system due to unforeseen performance issues. This in turn will impact maintenance budgets.

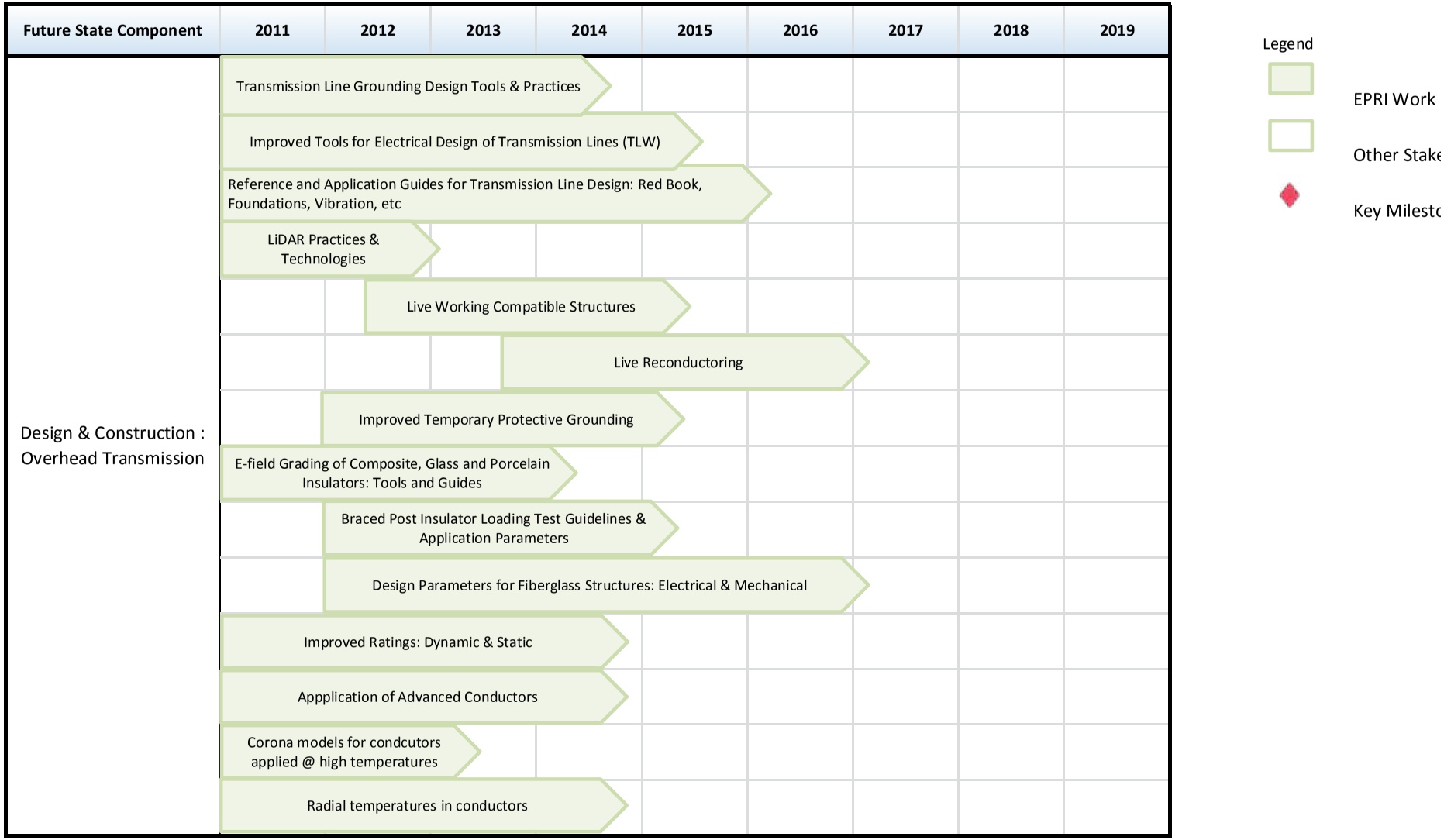
Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Design & Construction: Substations		Rating Calculations: Transformers, CT, Buswork, etc.							
			Improved Ground Grid Designs						
	Designing Protection & Control accounting for 61850								
			Mechanical Forces under Fault Current Conditions						

Legend

EPRI Work

Other Stakeholders

Key Milestone


Future State Component
2011
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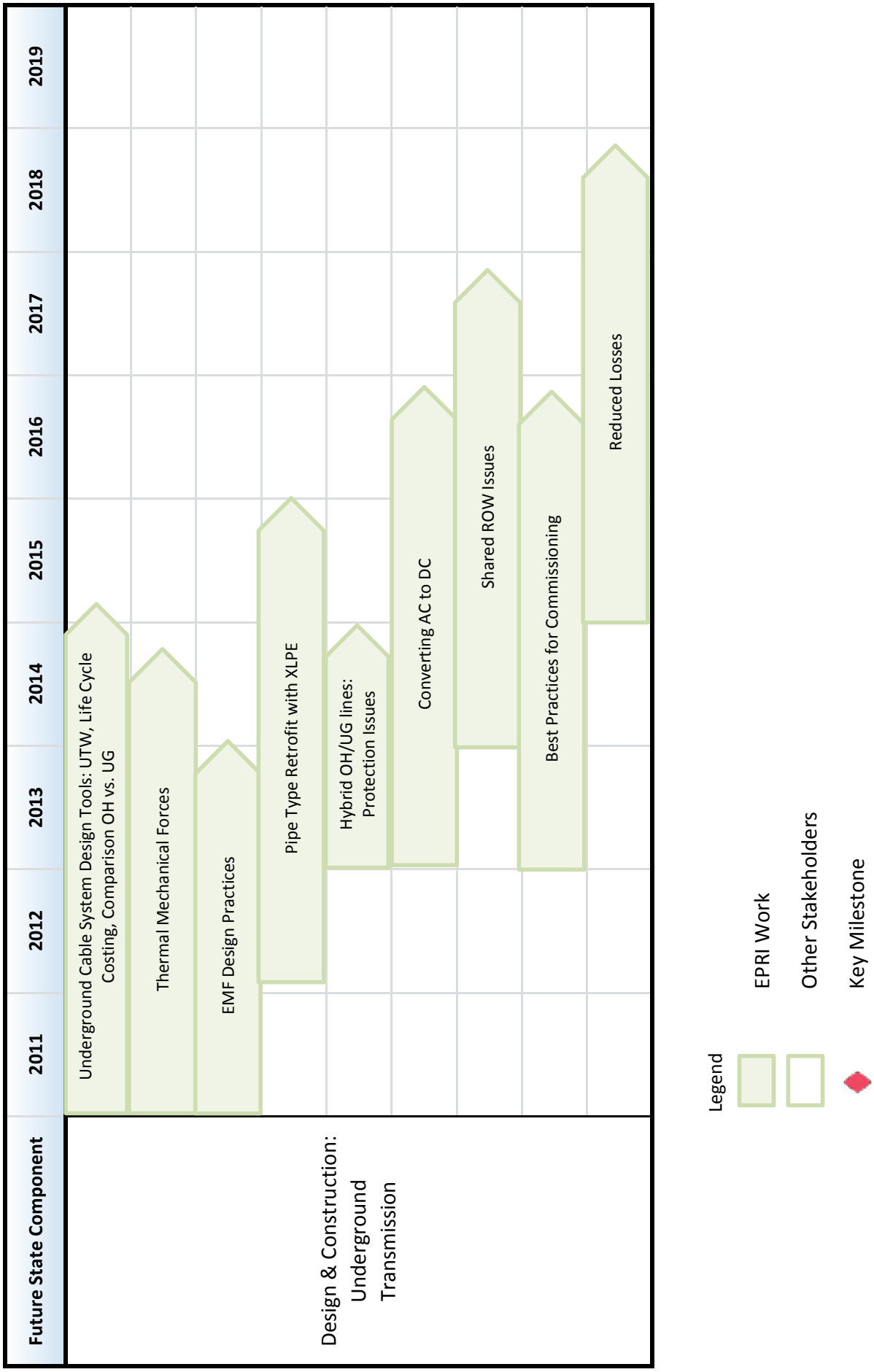
2019
Design & Construction : Overhead Transmission
Transmission Line Grounding Design Tools & Practices
Improved Tools for Electrical Design of Transmission Lines (TLW)
Reference and Application Guides for Transmission Line Design: Red Book, Foundations, Vibration, etc
LiDAR Practices & Technologies
Live Working Compatible Structures
Live Reconductoring
Improved Temporary Protective Grounding
E-field Grading of Composite, Glass and Porcelain Insulators: Tools and Guides
Braced Post Insulator Loading Test Guidelines & Application Parameters
Design Parameters for Fiberglass Structures: Electrical & Mechanical
Improved Ratings: Dynamic & Static
Appplication of Advanced Conductors
Corona models for condcutors applied @ high temperatures
Radial temperatures in conductors
Legend
EPRI Work
Other Stake
Key Milestc


Future State Component
2011
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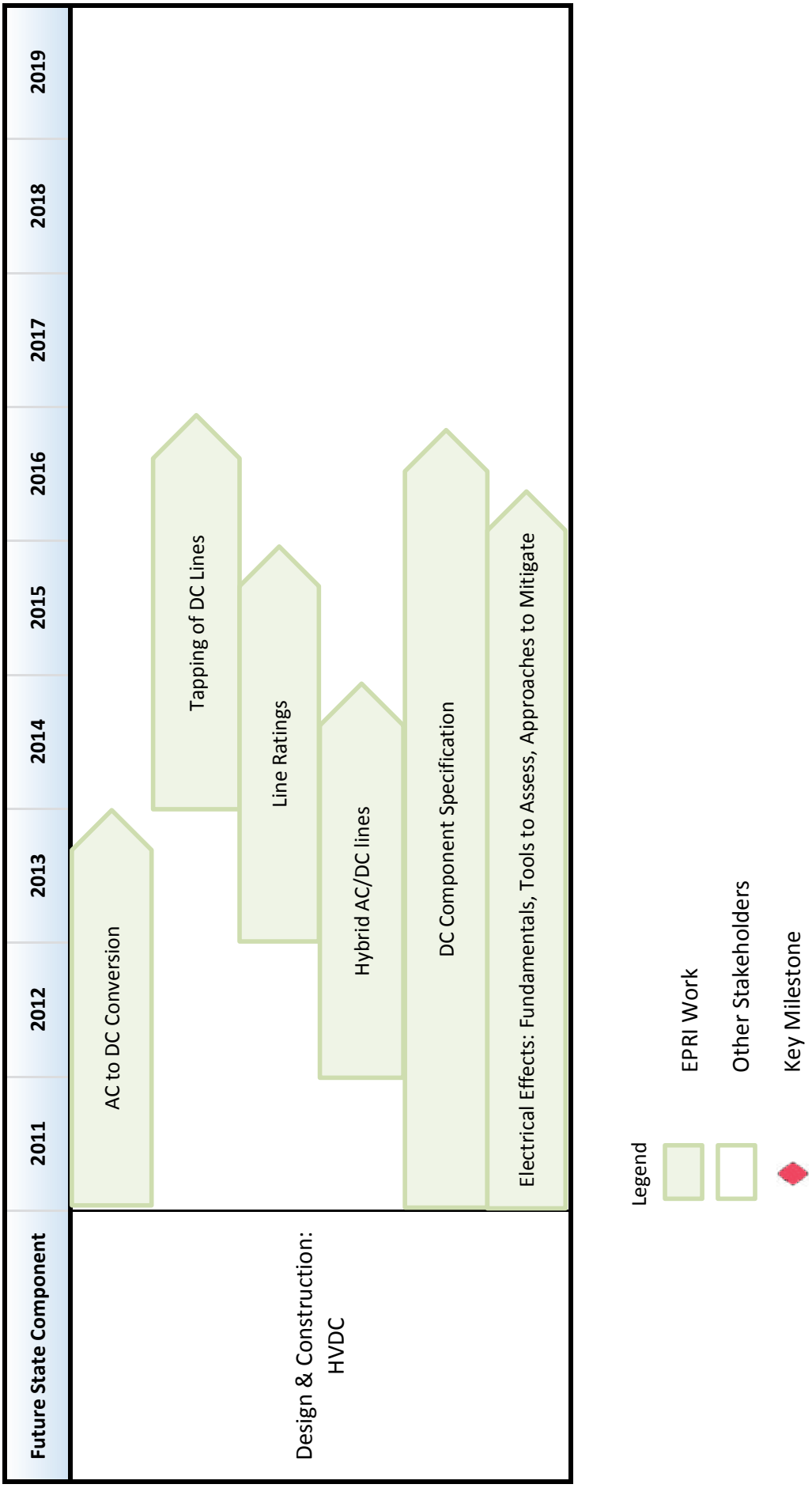
2019
Design & Construction: Underground Transmission
Underground Cable System Design Tools: UTW, Life Cycle Costing, Comparison OH vs. UG
Thermal Mechanical Forces
EMF Design Practices
Pipe Type Retrofit with XLPE
Hybrid OH/UG lines: Protection Issues
Converting AC to DC
Shared ROW Issues
Best Practices for Commissioning
Reduced Losses
Legend
EPRI Work
Other Stakeholders
Key Milestone


Future State Component
2011
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2018
2019
Design & Construction: HVDC
AC to DC Conversion
Tapping of DC Lines
Line Ratings
Hybrid AC/DC lines
DC Component Specification
Electrical Effects: Fundamentals, Tools to Assess, Approaches to Mitigate
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

1. The condition and operating parameters of transmission assets will be available to drive informed decision making which may lead to reduction in risk and equipment failure.
2. Field crews, subject matter experts, asset managers, operators and executives will have access to the pertinent information in an automated manner.
3. Sensing, protection and control functions will be less complex and require less maintenance.
4. An integrated approach to protection and control will be implemented accounting for inputs not only within the asset being protected, but also from other assets and other geographical locations.
5. Utilities will apply electronic devices with confidence expecting a long life and minimal maintenance.

GAPS

A fundamental understanding of how components degrade and fail is the perquisites of automation and condition monitoring. As such the following gaps need to be closed.

1. Power-harvesting and Storage

Sensing and associated technologies require energy which can be harvested from the environment. Harvesting technologies need to be developed and assessed so that they can be applied with confidence. The energy from most harvesting sources is intermittent requiring local storage capability. The ability of storage devices to operate over a wide range of conditions with multi-decade life is required.

2. Information Communication Infrastructure

Communication from new and tradition electronic devices needs to be addressed. The last link to sensing technologies is often a challenge due to the nature of the environment, e.g., installed at high voltage. Interoperability standards which enable a wide range of devices from multiple vendors to easily communicate and integrate are required with minimal maintenance.

3. Algorithms

Algorithms are required to convert the data collected to information that can be acted on by different stakeholders. These algorithms need to be robust and repeatable and work in a near real time environment.

4. Visualization and Alarms

Visualization tools are needed which provide data and information to different stakeholders in the appropriate format so that they can make informed decisions for their job function.

ACTION PLAN

Although the *Future States* and *Gaps* are similar across Overhead, Underground, Substations and HVDC programs, the action plans are quite different. In addition a significant effort is needed in the data integration and IT infrastructure area which is under The IntelliGrid Program. A graphical representation of the action plans for each of the programs is shown in the following pages.

VALUE AND RISK

The value of performing the research and ensuring that the industry has robust tools include an increase in reliability, extension of asset life, a reduction in costs and a potential increase in powerflow through existing assets.

The risk of not performing the research include the lack of technologies to address emerging asset health issues, a lack of knowledge of the status of transmission assets and the possible proliferation of solutions that are stand alone, difficult to maintain and have a limited life.

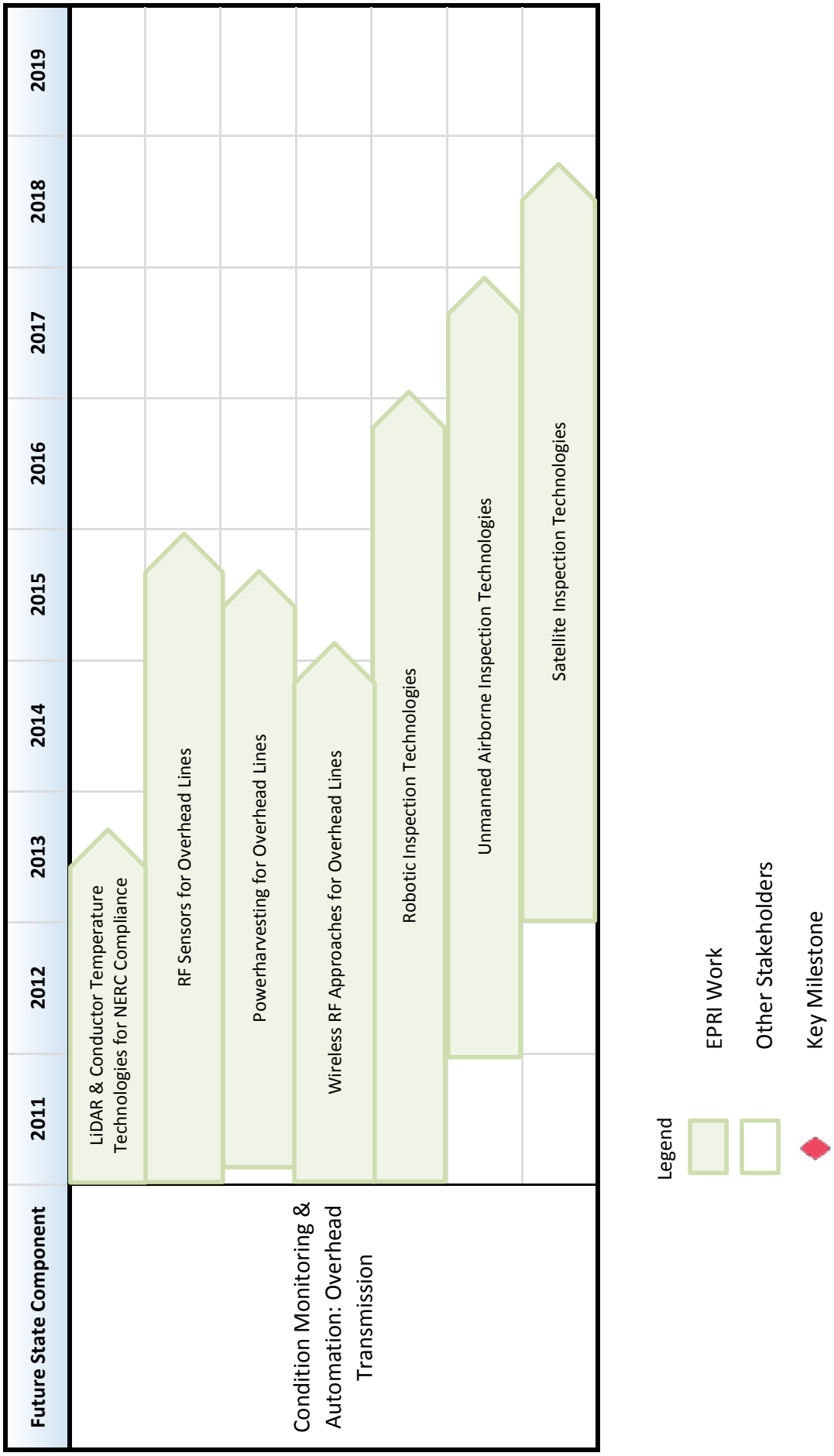
Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Condition Monitoring & Automation: Substations	Novel Sensing Technologies for Balance of Substation Plant								
	Transformer New & Novel Sensors and Associated Algorithms								
	Substationwide Sensing Technologies: RF, Antenna Array, Swept Frequency								
	Substation Fleet Management Tools								
	Surge Arresters: Monitoring, Inspection & Assessment								
	Insulators: Contamination & Icing Performance Sensors & Algorithms								
	Powerharvesting for Substation Sensor Application								
	Point to Point RF & Wireless Mesh Communication Applications								
	Protection & Control 61850 Maintenance								
		Protection & Control: Settingless Protection							

Legend

EPRI Work

Other Stakeholders

Key Milestone


Future State Component
2011
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Condition Monitoring & Automation: Overhead Transmission
LiDAR & Conductor Temperature Technologies for NERC Compliance
RF Sensors for Overhead Lines
Powerharvesting for Overhead Lines
Wireless RF Approaches for Overhead Lines
Robotic Inspection Technologies
Unmanned Airborne Inspection Technologies
Satellite Inspection Technologies
Legend
EPRI Work
Other Stakeholders
Key Milestone

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Condition Monitoring & Automation: Underground Transmission	New Sensor Technology for Cables								
	Diagnostic Methods for Cables								
	Robotic Inspection on Vaults & Cables								

Legend

- EPRI Work
- Other Stakeholders
- Key Milestone

FUTURE STATE:

1. Knowledge, technologies and tools to allow increased powerflow on new and existing transmission assets while maintaining high reliability and low costs.
2. Reduction of transmission line losses.
3. Enable safe and efficient use of right of way by multiple entities, e.g., pipelines, cell phones, etc.
4. Managed use of right of way for the public

GAPS

1. Understanding of Degradation and Failure Modes of Transmission Assets Operated at Higher Utilization Level

A fundamental understanding of how components degrade and fail under higher power transfer is required. Higher power transfer can result in increased heating and/or increased electric fields which in-turn impacts degradation mechanisms and rates.

2. Development of New Materials and Components

More cost effective and reliable materials and components which enable high power flow and utilization of the right of way are required. These new materials will most probably have different aging characteristics under high temperatures and electric field. Confidence is needed on how to select, specify, install, inspect, assess and remediate these new materials and components for their entire anticipated life.

3. Effective Designs, Selection, Specification and Application for Increased Utilization

Utilities need to be able to design, select, specify, apply, operate, inspect and assess both existing and new technologies and approaches confidently in a wide range of conditions to ensure the optimal performance and an appropriate life expectancy.

4. Knowledge Capture and Transfer

The knowledge that has been amassed in the transmission industry over the past decades by utility staff, equipment experts and vendors needs to be captured and effectively transferred to a new generation of technical staff.

5. Increasing Powerflow in Existing Assets

Both static and dynamic rating technologies and methodologies are needed to increase the powerflow through existing rights of way. In addition the number of circuits and services which reside on a right of way needs to be increased with minimal impact on reliability, availability or safety. The impact of the effect of this increased utilization on health effects and sensations needs to be fully understood and mitigation options developed.

ACTION PLAN

Although the *Future States* and *Gaps* are similar across Overhead, Underground, Substations and HVDC programs, the action plans are quite different. A graphical representation of the action plans for each of the programs is shown in the following pages.

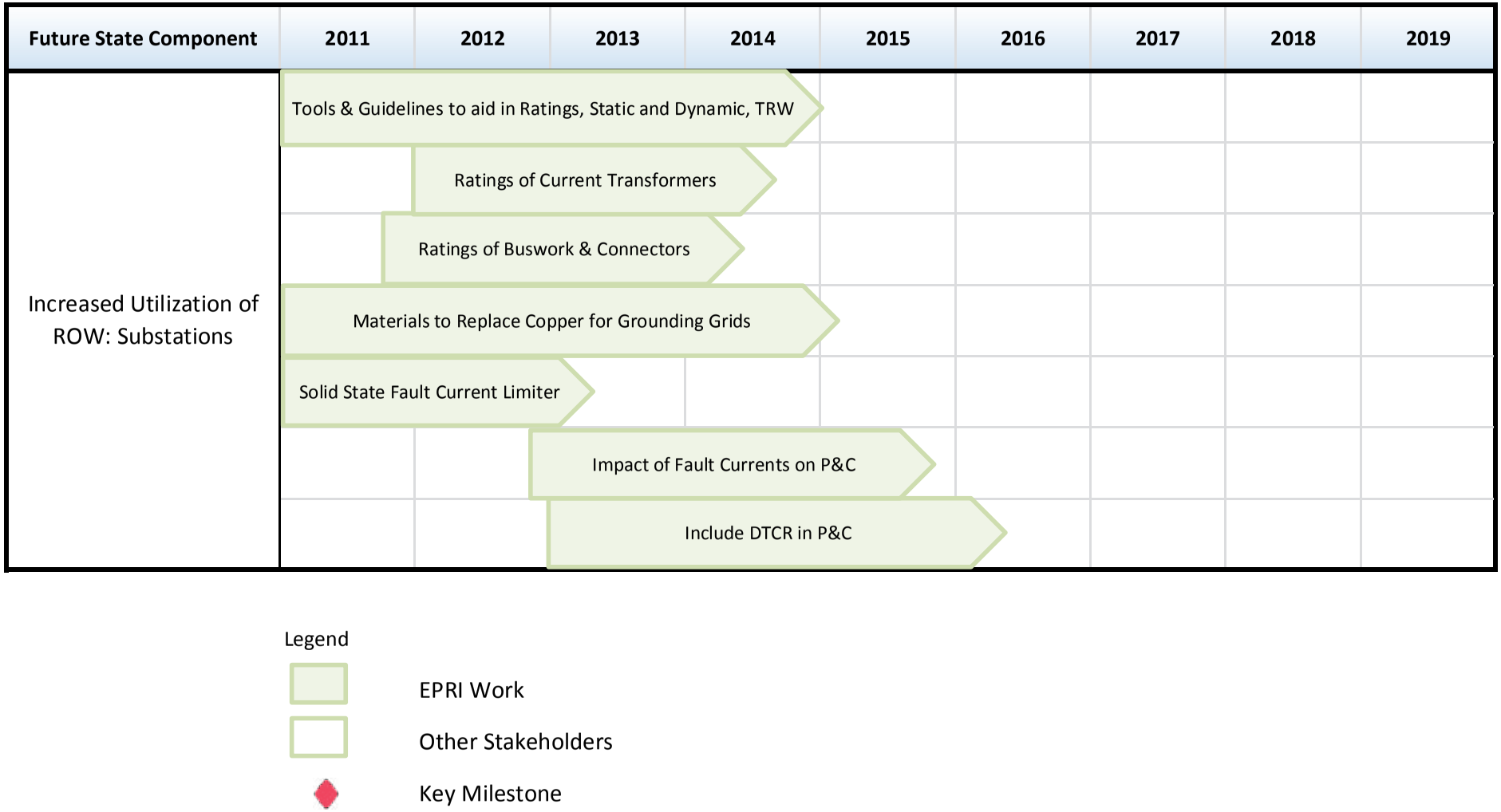
VALUE AND RISK

The value of increasing the utilization of the rights of way include:

- Increased powerflow through existing rights of way can potentially decrease both the time and cost to strengthen the transmission system and connect new loads or generation.
- By utilizing the rights of way for other applications apart from the transmission of electricity utilities can potentially increase revenue or increase the acceptance of transmission assets by the public.

If research is not performed approaches or components maybe be utilized which do not have the expected performance, either long or short term expected. This in-turn may results in reduced reliability and increased maintenance costs.

Situating other assets on transmission rights of way without a thorough understanding of performance under all operational conditions can potentially impact reliability or safety of either the transmission, or the co-located systems.


Future State Component
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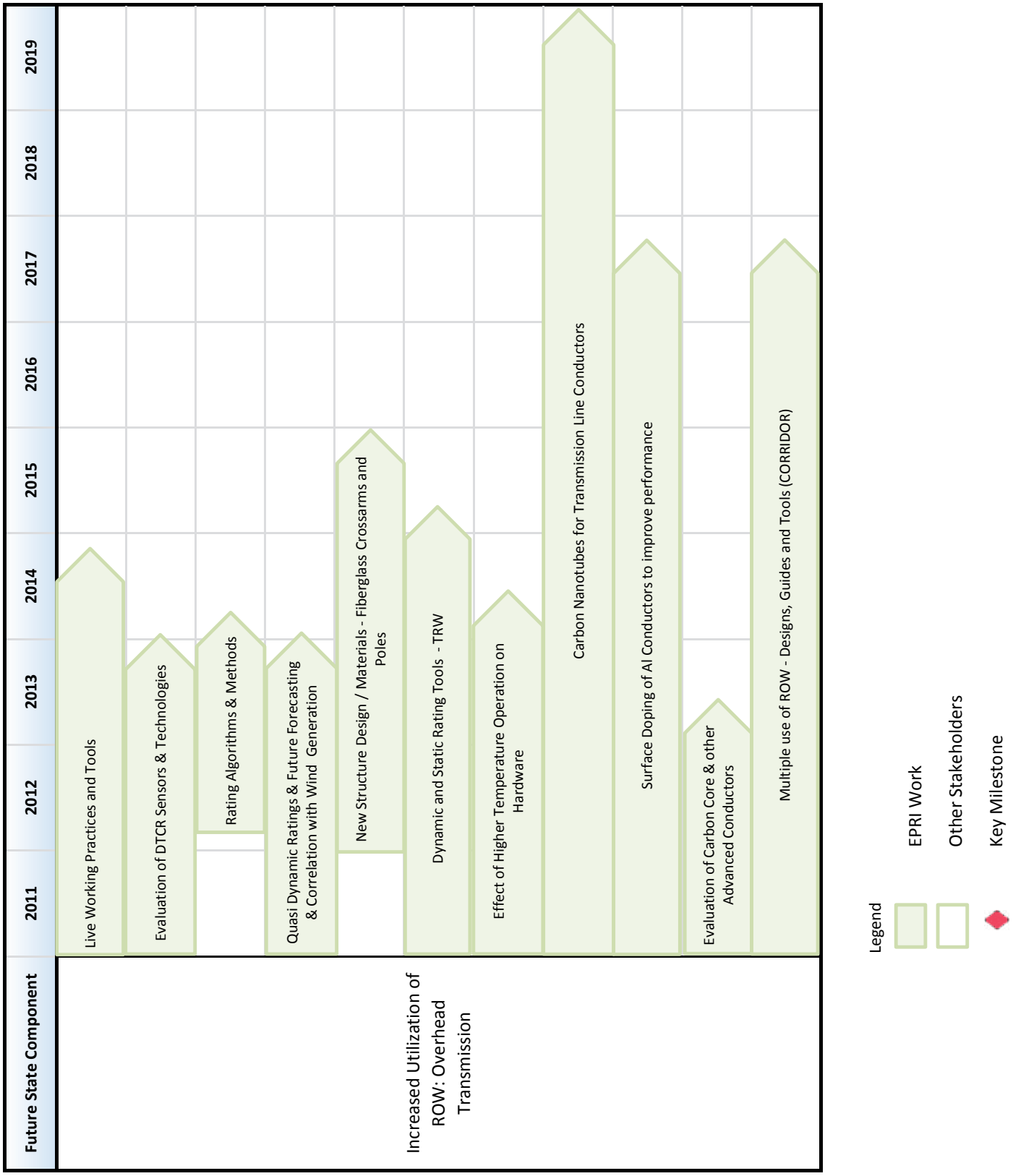
Increased Utilization of ROW: Substations
Tools & Guidelines to aid in Ratings, Static and Dynamic, TRW
Ratings of Current Transformers
Ratings of Buswork & Connectors
Materials to Replace Copper for Grounding Grids
Solid State Fault Current Limiter
Impact of Fault Currents on P&C
Include DTCR in P&C
Legend
EPRI Work
Other Stakeholders
Key Milestone


Future State Component
2011
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2019
Live Working Practices and Tools
Evaluation of DTCR Sensors & Technologies
Rating Algorithms & Methods
Quasi Dynamic Ratings & Future Forecasting & Correlation with Wind Generation
New Structure Design / Materials - Fiberglass Crossarms and Poles
Dynamic and Static Rating Tools - TRW
Effect of Higher Temperature Operation on Hardware
Carbon Nanotubes for Transmission Line Conductors
Surface Doping of Al Conductors to improve performance
Evaluation of Carbon Core & other Advanced Conductors
Multiple use of ROW - Designs, Guides and Tools (CORRIDOR)
Increased Utilization of ROW: Overhead Transmission
Legend
EPRI Work
Other Stakeholders
Key Milestone

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Increased Utilization of ROW: Underground Transmission	Dynamic Ratings: Sensing Systems & Approaches								
	Dynamic Ratings: Tools and Approached (TRW)								
			Improved Cooling of Pipe Type Cables						

Legend

- EPRI Work
- Other Stakeholders
- Key Milestone

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Increased Utilization of ROW: HVDC	AC - DC Conversion								
		DC Ratings: Dynamic & Static							
		Multiple Use of the ROW							

Legend

- EPRI Work
- Other Stakeholders
- Key Milestone

DISTRIBUTION SYSTEMS

VISION

Utility distribution systems continue to be challenged by an aging infrastructure, conventional designs, and increased demands for power. Electricity distribution companies are under pressure to improve reliability and system performance, while dealing with the ongoing challenges of an aging infrastructure, conventional designs, and increasing customer demands for higher reliability and power quality. Budget and investment constraints require electric utilities to manage their distribution systems ever more efficiently. In addition, present expectations require that distribution systems support increased automation, new load types, increased distributed generation and storage, increased demand-side controls, environmentally friendly (green) technologies, and so on.

The Electric Power Research Institute (EPRI) distribution infrastructure programs focus on addressing these challenges and providing guidance to help utilities manage their distribution assets, reduce operations and maintenance costs, and improve system reliability and performance. In addition, EPRI research results provide guidance on deploying infrastructure technology (monitoring, communications, computing, and information management) to support advanced applications, automation, and systems integration that will enhance system operations and maintenance and enable applications to manage demand response and energy efficiency.

EPRI's distribution infrastructure programs consist of projects that address the short- and long-term needs of its members. Short-term research includes such things as identifying and documenting leading industry practices, developing reference guides and guidebooks, establishing and facilitating interest groups, and providing testing and analysis services. Longer-term research includes such things as developing new technologies, assessing the impacts and efficacy of emerging technologies and developing longer-term solutions for effective cable fleet management.

In close collaboration with its members, EPRI has developed a strategic plan to articulate the objectives of EPRI research for the next 10 years and to ensure that the focus of its research is, and remains, aligned with those objectives. This roadmap provides a high level summary view of the strategic plan and the reader is encouraged to review the full Distribution Strategic Plan (1022335) for the details.

FUTURE STATE COMPONENTS

In close cooperation with utility funders EPRI has identified future state components for the distribution system of the future. The components (Figure 1-1) are consolidated descriptions of the desired state of the electric distribution system 10 years from now. They are defined as follows:

1. Capacity and Efficiency: The electric distribution system infrastructure is *economically* designed, built, maintained and operated such that utility assets *efficiently* meet or exceed customer and regulatory expectations of *capacity*.

2. System Responsiveness and Smart Grid: The system is flexible, able to respond to changing system conditions, able to communicate real time information, easily and efficiently accommodates varied generation and load types, easily accommodates the installation of new equipment and equipment types, and supports system and end-use energy-efficiency and demand-response initiatives

3. Reliability and Power Quality: The electric distribution system is designed, built, maintained and operated in a manner that meets or exceeds customer and regulatory requirements and expectations of *reliability, availability, and quality*.

4. Safety, Environmental and Regulatory: The electric distribution system is designed, built, maintained, and operated in a manner that is *safe* to the public and to employees, is *environmentally responsible*, meets or exceeds *regulatory requirements*, and protects the *security* of crucial grid infrastructure and information.

5. Asset Management: Utilities have processes and technology in place to nimbly manage the *performance and health of the system and system assets* and to aid them in making *optimal operation and investment decisions*.

6. Institutional Knowledge and Industry Practice: Utilities have access to industry-wide institutional *knowledge, information, and practices*.

Figure 1-1 illustrates a desired state of the electric distribution system 10 years from now. The consolidated future state descriptions were developed collaboratively with the members of the Distribution Advisory Council. Each consolidated future state description includes a list of the original future state descriptions that were combined to develop the consolidated statement, as well as the specific barriers and challenges to achieving each future state. The barriers and challenges are the gaps that must be addressed in order to achieve the desired future state and, thus, are the focus of the EPRI distribution research portfolio.

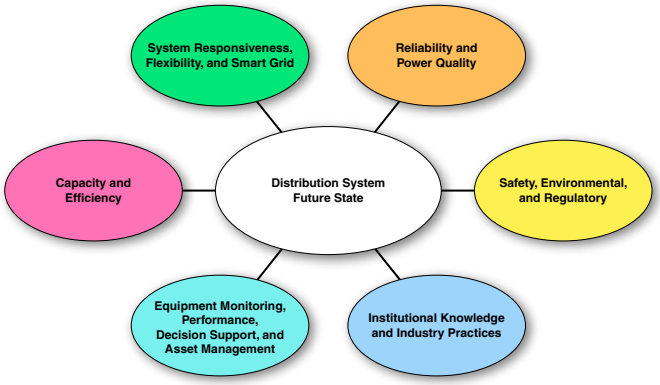


Figure 1-1 Future State Components

GAPS

The electric industry—and the electric distribution system, in particular—will face considerable challenges during the next decade, including an ever-increasing demand for energy, an increased focus on environmental protection, the expected rapid increase of renewable and nonrenewable distributed generation sources, new and varying load types, and increased end-use efficiency initiatives. These challenges are exacerbated by an aging infrastructure and traditional design, maintenance, and operating philosophies. Some of the key challenges for the industry include the following:

- The need to ensure interoperability of Smart Grid technologies to reduce cost and the risk of technology obsolescence
- The need to ensure cyber security, particularly in light of Smart Grid applications
- The need to reduce carbon footprint, slow the growth of peak demand, and accelerate deployment of efficient end-use technologies such as plug-in hybrid electric vehicles and distributed energy resources
- The need to ensure distribution reliability in the face of increasing deployment of intermittent generation and demand response
- The need to increase visibility and awareness of grid operation to minimize the probability of blackouts
- The need to automate condition-based inspection and maintenance
- The need for continued safety of workers and the public

ACTION PLAN

For 2012, EPRI has divided the distribution research portfolio into 10 project sets, each supporting one or more of the strategic categories. The research portfolio has been structured to provide utilities with knowledge to support Smart Grid implementation and tools for planning, design, maintenance, operation, and analysis of the distribution system.

EPRI has aligned this new research portfolio structure with the strategic direction defined by the future states, such that it will be a sustainable structure into the future. Individual research projects in the portfolio will be developed and prioritized based on industry needs, using the strategic planning process

VALUE AND RISK

Achieving a future state distribution system as described in the vision statement and detailed in the consolidated future state descriptions is critical to the industry being able to continue to provide reliable, safe, and cost-effective distribution services to customers. The potential risks and costs of inaction by electricity distributors in the face of inevitable changes during the next 10–20 years are significant. The risks of inaction include potential system outages resulting from the inability to reconfigure the system to meet changing load requirements and having to resort to traditional methods such as rolling blackouts to respond to situations in which load needs exceed available distribution capacity.

The costs of inaction in achieving the desired future states include over-expenditure in traditional distribution system expansion because utilities are unable to take advantage of existing capacity in adjacent feeders due to a lack of technology to understand real-time system loading conditions on feeder sections and to effectively swap load between feeders.

Increasing overall energy demands will be coupled with increased conservation initiatives by individual energy users, increased use of demand-side controls to manage loads, and the implementation of smaller, distributed renewable and nonrenewable generation resources. These changes will require not only growth of the distribution infrastructure but also the ability to understand changing system conditions in real time and reconfigure the system to best accommodate these conditions.

To successfully respond to these changes, electricity distributors must invest in monitoring and control technologies, a robust communications infrastructure, intelligent algorithms that can quickly assess system conditions and recommend optimal alternatives, and automated designs that can efficiently and automatically reconfigure the system as needed. Without an investment in these technologies, current distribution system designs will be unable to adapt to these changes.

For demand-side management initiatives to be considered part of the overall distribution supply plan, utilities must be able to reduce the system load on individual circuits and circuit sections at peak times. From the customers' point of view, to optimally apply or enable load reduction techniques, they must receive pricing or other signals so that they can weigh the economics of implementing these alternatives. Without the appropriate infrastructure, utilities will either underestimate the impact of demand reduction and be caught with an overbuilt distribution infrastructure and excess distribution capacity at peak times or overestimate the impact of demand reduction and be caught with too little distribution capacity to meet demand at peak loads.

Without specific knowledge of loading at different points along a circuit, a utility cannot effectively use sectionalizing to change the available capacity of a circuit or circuit section to meet loading needs. This issue will be further exacerbated by the implementation of new, distributed energy resources that will vary the available generation capacity at any one time. Some of this generation is likely to be less predictable and not able to be scheduled. Without technology that can understand transient system configuration, load needs, and available supply, utilities will either over-build the system to be able to address these unpredictable eventualities at considerable cost or under-build it and be unable to meet customer needs in certain places and under certain conditions.

Without a concerted effort by the industry to anticipate and respond to impending challenges, the distribution system, as it exists today, will be unable to continue to supply reliable, fairly priced distribution services and overcome the challenges that will arise during the next 10 to 20 years.

Industry leaders and the EPRI Distribution Advisory Council understand that they must overcome these challenges, and they are taking steps to do just that. The research projects described in this plan will play a key role in supporting the industry in its efforts to adapt to the changing environment and to implement emerging technologies that will meet the needs of both the short- and the long-term futures.

FUTURE STATE COMPONENTS

The electric distribution system infrastructure is *economically* designed, built, maintained and operated such that utility assets *efficiently* meet or exceed customer and regulatory expectations of *capacity*.

The following detailed future state descriptions have been consolidated into the capacity and efficiency consolidated future state description shown above:

- Infrastructure has adequate capacity to meet peak loads in accordance with planning criteria.
- Distribution system losses (per unit of power delivered) are lower than today
- New distribution system equipment requires minimal maintenance, has limited environmental impact, and is available at a reasonable cost
- Utilities will use new technologies to increase the utilization of existing structures, conduit and duct bank systems.
- Utilities will use techniques and technologies, such as voltage conservation, to achieve demand conservation objectives

GAPS

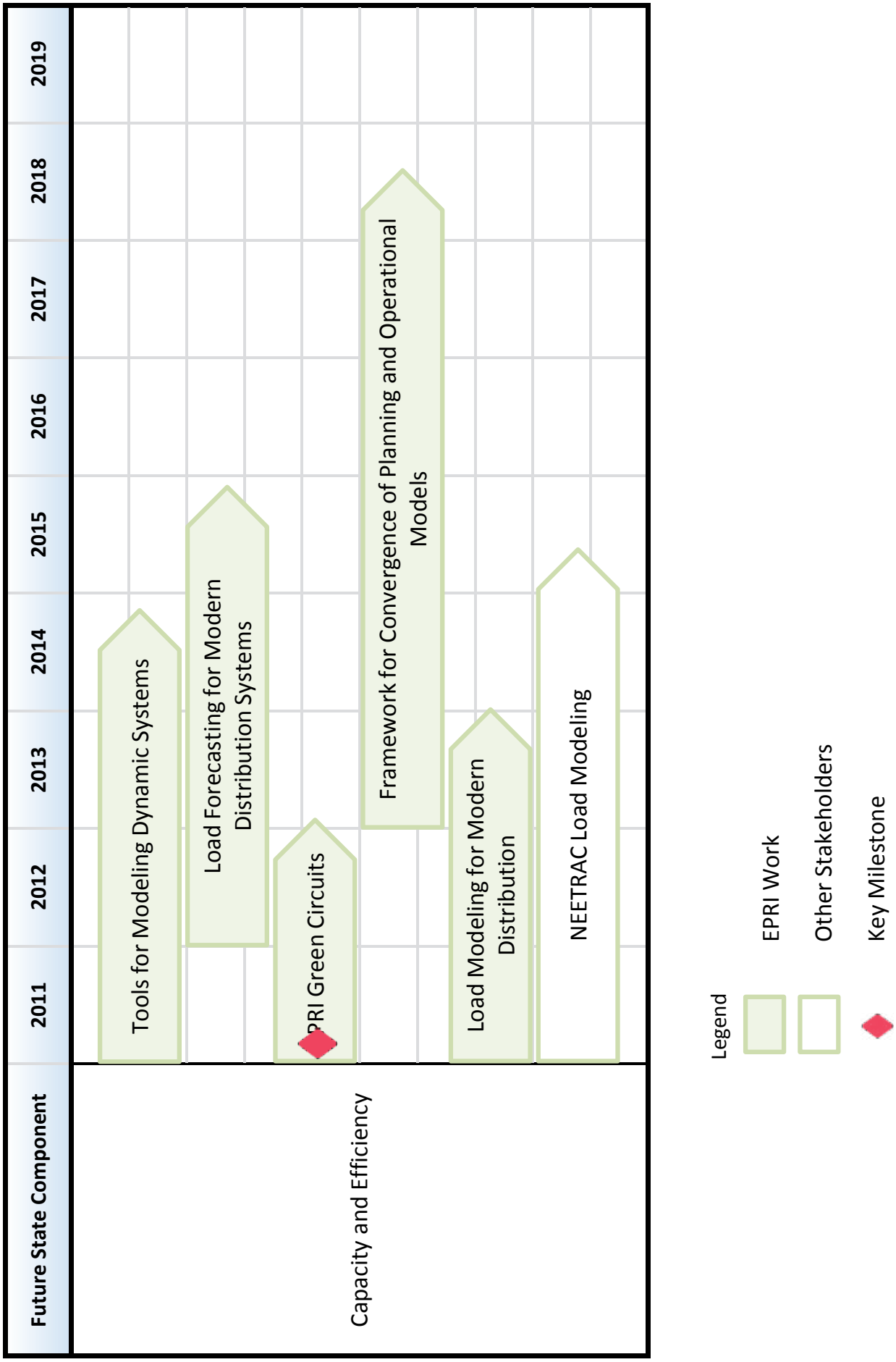
- Tools to more accurately estimate load additions.
- Improved forecasting methodologies to better/more accurately anticipate load growth.
- Method to normalize "weather adjustment" in the planning process (criteria).
- Demonstrate that investment plans maximize value in order to justify funds.
- Cheaper methods for replacing/augmenting/reinforcing existing infrastructure to meet customer capacity requirements.
- Method for minimizing distribution heating (I^2R) through operations and control (phase balancing, and so on).

ACTION PLAN

Offer a research project set focused on modern tools for planning and design of distribution systems, new analysis methods, new modeling approaches, and incorporation of distributed resources into the planning process. Planning and design of electric distribution systems are undergoing dramatic changes in the world of the smart grid. In the past, distribution planning focused on maintaining acceptable electrical conditions in the steady state during peak load conditions and minimum load conditions. With the growing penetration of distributed energy resources (including highly variable renewable generating resources), there is a need to analyze and plan for dynamic operating conditions that can occur at any time throughout the year. The rapid growth of small-scale distributed generation (such as rooftop solar) has created the potential for a considerable number of "zero net energy" homes, which presents a major challenge for short- and long-term load forecasting.

VALUE AND RISK

Modern tools are needed to evaluate and mitigate the impact of these fundamental changes to the distribution system characteristics. Planning tools must be able to evaluate distribution performance over annual profiles with many factors affecting load levels and characteristics.


Future State Component
2011
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Capacity and Efficiency
Tools for Modeling Dynamic Systems
Load Forecasting for Modern Distribution Systems
EPRI Green Circuits
Framework for Convergence of Planning and Operational Models
Load Modeling for Modern Distribution
NEETRAC Load Modeling
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

The system is flexible, able to respond to changing system conditions, able to communicate real time information, easily and efficiently accommodates varied generation and load types, easily accommodates the installation of new equipment and equipment types, and supports system and end-use energy-efficiency and demand-response initiatives

The following detailed future state descriptions have been consolidated into the system responsiveness, flexibility, and Smart Grid consolidated future state description shown above:

- Utilities are prepared to accommodate distributed generation, storage, and plug-in hybrid electric vehicles.
- All intelligent distribution devices support plug and play capability.
- The distribution system is designed with devices to manually or automatically respond to meet changing system conditions (demand needs, fault conditions, and so on).
- Utilities use the Smart Grid infrastructure to accomplish core distribution tasks

GAPS

- Distribution designs/protection schema that address anticipated increasing distributed generation, storage and PEVs.
- Unsure of the capacity implications of new generation types.
- Operators need to be able to control and dispatch distributed generation, if part of total capacity plan.
- Distribution and generation integration planning.
- Distribution designs and protection that accommodates microgrids.
- Consider distributed generation and storage in the design of the Smart Grid.
- The public and local agencies do not understand the implications of new generation on the distribution system.
- Need to be able to influence the design and regulation of distributed generation and storage on the distribution system.

ACTION PLAN

EPRI research develops and evaluates advanced distribution system applications for reliability improvement, system optimization, asset management, and distributed resource integration. These applications involve implementation of monitoring equipment (sensors), communications infrastructure, and advanced protection and control functions. The results will support utilities in the migration to distribution management systems with model-based management of the system. The Distribution Management System (DMS) of the future will need to integrate many functions to optimize system performance, reduce losses, optimize voltage and VAR control, improve reliability through system reconfiguration and fast restoration, and integrate distributed resources. The plan builds on the analytical capabilities of the Open Distribution Simulator Software (OpenDSS) software for analytical assessment of advanced distribution management functions and also works with member utilities to demonstrate advanced functions for development of application guidelines and identification of gaps in the technologies.

VALUE AND RISK

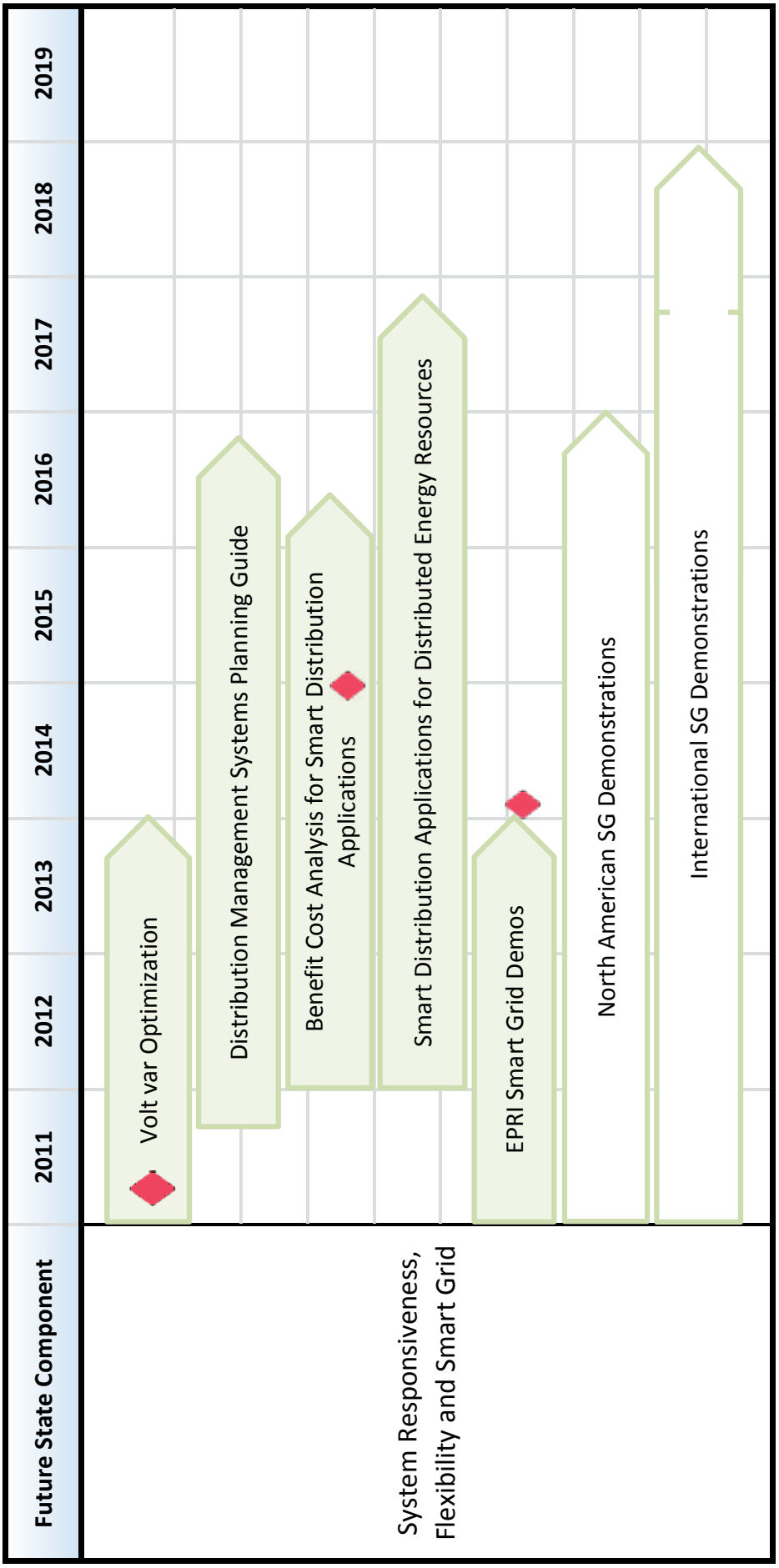
Results can be used to help specify voltage optimization systems as part of overall smart distribution development, develop the business cases for voltage optimization functions, and evaluate performance of systems being implemented.

The results will provide the resources for needs assessment, business case development, and specification of advanced system reconfiguration functions that could be implemented as part of a distribution management system including:

- Performance assessment for advanced reconfiguration functions
- Benefits that can be achieved with advanced reconfiguration functions
- Requirements for advanced reconfiguration functions
- Provide a foundation for implementing voltage optimization systems as a function of distribution system characteristics and existing infrastructure.

Many challenges are impeding the implementation of Smart Grid technologies, including existing distribution system designs and conditions that are not yet ready to support smart applications, the need for plans for an orderly application of smart technologies, standards and protocols for the

technologies, the need for plans and methods for investment cost allocation, and justification for capital investments by utilities. In addition, new load and generation types are being added to the grid, creating an urgent need for the dynamic system response enabled by smart applications.


Future State Component
2011
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2018
2019
System Responsiveness, Flexibility and Smart Grid
Volt var Optimization
Distribution Management Systems Planning Guide
Benefit Cost Analysis for Smart Distribution Applications
Smart Distribution Applications for Distributed Energy Resources
EPRI Smart Grid Demos
North American SG Demonstrations
International SG Demonstrations
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

The electric distribution system is designed, built, maintained and operated in a manner that meets or exceeds customer and regulatory requirements and expectations of *reliability, availability, and quality*.

The following detailed future state descriptions have been consolidated into the system reliability and power quality consolidated future state description shown above:

- Distribution infrastructure meets customer and regulatory system performance expectations (frequency, quality).
- Utilities have access to technology that enables them to accurately predict and respond to storm damage.
- Utilities have access to technology and automation that enables them to quickly locate, troubleshoot, diagnose, sectionalize, and remedy the causes of outages on the distribution system (duration).

GAPS

- Customer expectations of quality and service are continually changing and vary widely.
- Understanding customer expectations of service.
- Methods to match customer needs and expectations to both system performance and the cost of achieving that performance (quality, time, and performance).
- Understanding the initial and life cycle costs of various design alternatives, and correlate that with different levels of reliability delivery.
- New system designs that provide improved reliability.
- Methods to predict failures/end of equipment life.
- Equipment with improved life (better able to resist deterioration, loading, and so on).
- Methods to identify susceptible areas to develop hardening plans.
- Methods to identify and determine location of incipient faults.
- Understanding the impact of climate change on service reliability.
- Understanding the cost of an outage to justify investment.
- Predictive event damage models based on expected weather conditions.
- Post-storm assessments.

ACTION PLAN

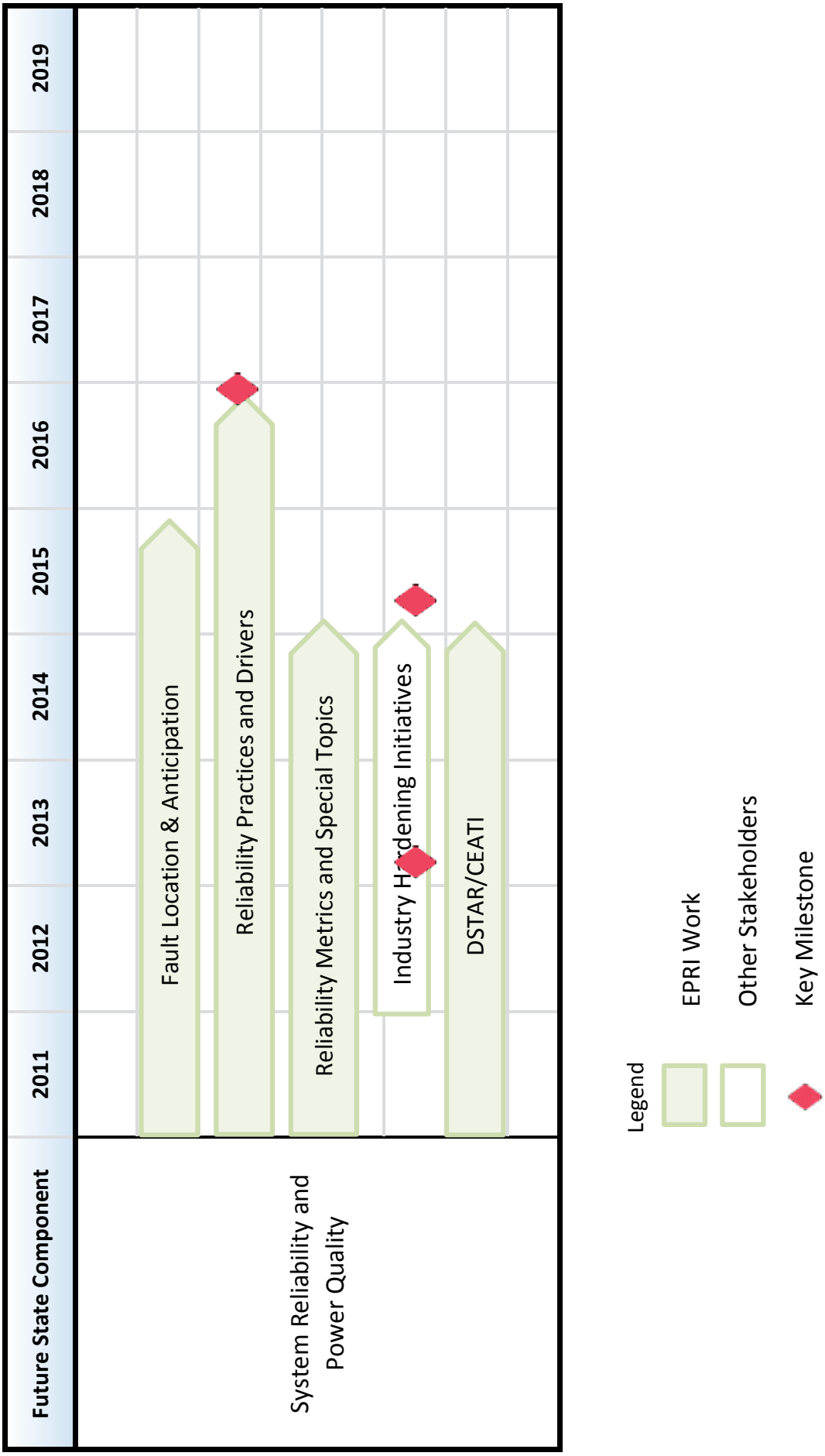
EPRI has developed and tested systems to make fault location systems easier for utilities to install and use. Such systems allow operators to view the estimated location of a fault, which helps operators direct crews to do switching and locate faults faster. These systems also locate temporary faults, so that problem locations can be identified before permanent faults occur. Along these lines, current research is extending the algorithms for locating incipient faults. The main goal in 2011 is to test the performance of this system based on a larger library of field events and then to investigate ways that the effectiveness can be improved through combinations of technologies such as:

- Integration of fault indicator data with substation-based fault location
- Advanced meters and triangulation
- Integration of data from automated feeder devices such as reclosers, switches, capacitors, and regulators

VALUE AND RISK

Much of the existing distribution infrastructure lacks the technology (sensors, fault indicators, and so on) to facilitate troubleshooting and diagnosis of outages. Consequently, the process for troubleshooting outages is often lengthy and labor intensive. For example, current techniques for locating faults in underground systems include using trial and error to find the location of a problem and rely on potentially destructive techniques such as direct current high potential testing. System maps that are used by troubleshooters as an aid might not reflect real-time field conditions. When a problem is diagnosed, utility operators often do not have instant knowledge of the available capacity on adjacent feeder sections during peak periods or knowledge of the load to be sectionalized in order enable real-time sectionalizing decisions to minimize the impact of the outage to customers. Utilities require technologies to quickly diagnosis system conditions and reconfigure the system to maintain or restore service, or minimize the impact of the outage.

In addition, the increased application of distribution generation and the application of demand response initiatives as additional tools to meet capacity requirements will further challenge the distribution system. A key industry issue is the need to ensure reliability with increasing penetration of intermittent generation and demand response.


Future State Component
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System Reliability and Power Quality
Fault Location & Anticipation
Reliability Practices and Drivers
Reliability Metrics and Special Topics
Industry Hardening Initiatives
DSTAR/CEATI
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

The electric distribution system is designed, built, maintained, and operated in a manner that is *safe* to the public and to employees, is *environmentally responsible*, meets or exceeds *regulatory requirements*, and protects the *security* of crucial grid infrastructure and information.

The following detailed future state descriptions have been consolidated into the safety, environmental, and regulatory consolidated future state description shown above:

- Practices for maintaining and operating infrastructure continue to be safe and conform to all regulatory requirements.
- Utilities have safeguards in place to ensure security on the grid infrastructure and all crucial information and control systems.
- Utilities have an acceptable strategy for addressing proposed infrastructure attachments (antennas, communication devices, foreign attachments, and so on) to the distribution system.

GAPS

- Impending changes to the National Electrical Safety Code, National Fire Protection Association standard 70E, and Occupational Safety and Health Administration regulations will have potential implications for utilities, particularly in confined spaces.
- Need more effective oversight of impending or anticipated changes.
- Work rules and clearance procedures might have to be modified with the application of additional automation.
- Regulatory environments might change significantly with Smart Grid.
- Each state regulatory agency operates independently, making it a challenge to implement industry-wide practices.
- The inherent nature of electrical distribution systems can cause potential hazards.
- Need legislative and/or regulatory support to obtain required vegetation clearance.
- Need to educate customers and regulators to understand issues of stray voltage.

ACTION PLAN

Arc Flash

There is an industry need to better evaluate many of the design, technology, and process options to reduce arc flash hazards. Arc flash hazard reduction and mitigation involve system protection and device coordination, equipment design and specification, work procedures, and protective clothing and equipment. Each of these aspects can play a role in reducing arc flash hazards. Moreover, certain regulatory guidelines, including the National Electrical Safety Code (NESC) Section 410 and Occupational Safety and Health Administration (OSHA) 1910.269 and 1926 Subpart V, continue to evolve. This research will help guide that evolution and help utilities comply.

Protective clothing has advanced significantly in the last decade, and further advances are expected. More work is needed to evaluate clothing performance in practical use and in arc flash scenarios that may be encountered by utility workers.

Neutral to Earth Voltage

EPRI collaborative research provides the latest techniques for understanding and dealing with virtually all related concerns at readily accessible human and animal contact locations. The goal is to utilize new technology to more readily understand source and coupling mechanisms for arc detection and the more traditional for contact and stray voltage.

In addition, the wealth of material developed in prior years will be maintained on the contact voltage website to support staff training, industry awareness, regulatory inquiries, and overall understanding of related subjects.

VALUE AND RISK

Arc Flash

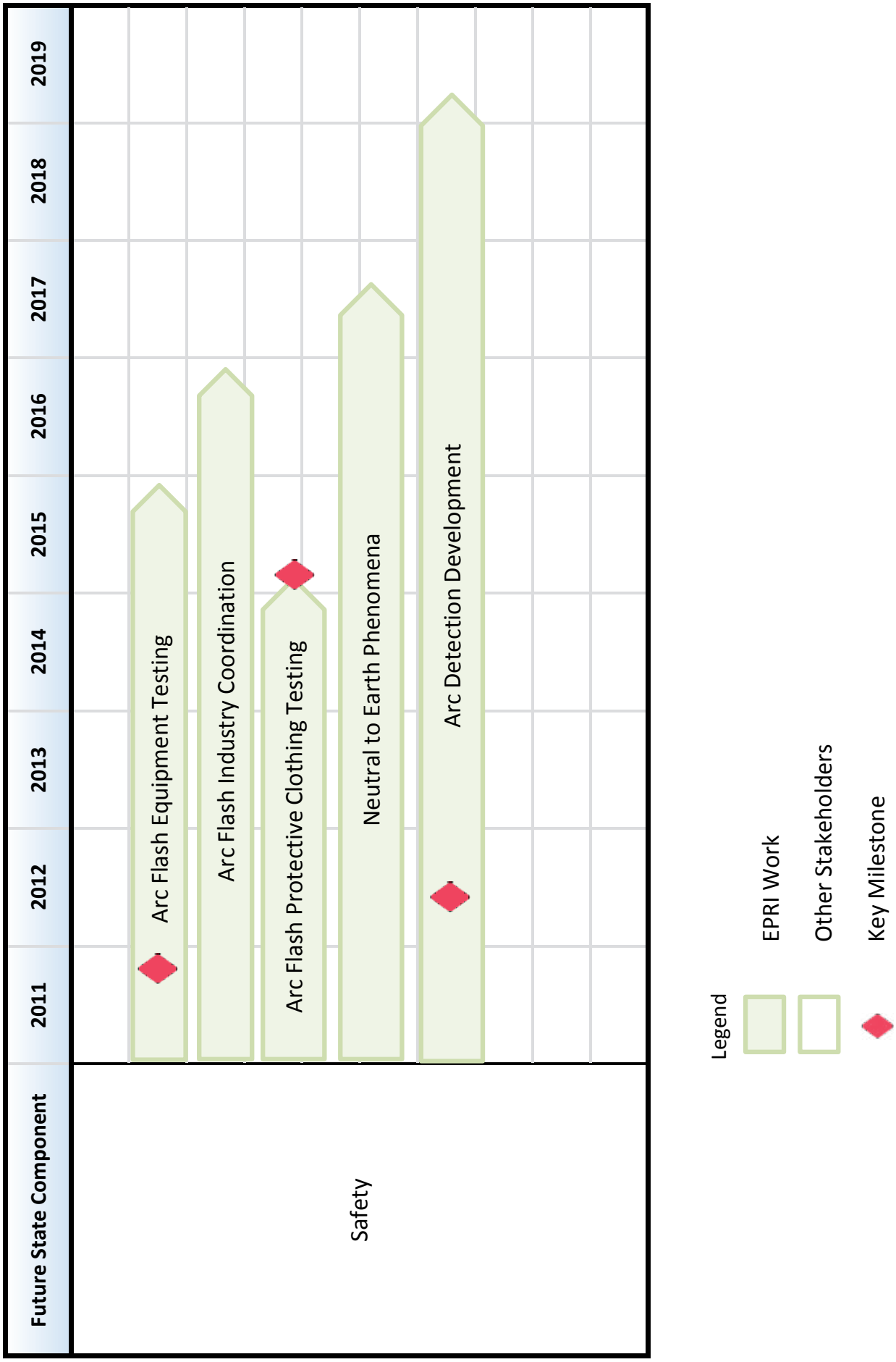
EPRI research work has provided the industry considerable experimental data on incident energies from a variety of arc flash hazards. EPRI will build on this research by coordinating with other industry groups, including the IEEE 1584 and the American Society for Testing and Materials (ASTM) working groups. This work expands on earlier results to address the following:

- Case studies of approaches for addressing arc flash hazards
- Targeted testing of equipment
- Testing of fabrics and clothing systems

- Improved worker and public safety
- More efficient implementation of arc flash programs
- Validation of predictive modeling and simulation tools
- Better industry standards

Neutral to Earth Voltage

Results can be used to develop comprehensive methodologies and processes for handling customer complaints and regulatory inquiries about elevated neutral to earth (NEV) and urban stray voltage; prioritize and standardize the means by which members repair or provide mitigation solutions for identified voltage concerns and how they support customer-initiated remediation; and develop training tools and standardized investigation procedures for their staff that result in a well-defined, structured process from the initial complaint to final follow-up.


Future State Component
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2019
Safety
Arc Flash Equipment Testing
Arc Flash Industry Coordination
Arc Flash Protective Clothing Testing
Neutral to Earth Phenomena
Arc Detection Development
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

Utilities have processes and technology in place to nimbly manage the *performance and health of the system and system assets* and to aid them in making *optimal operation and investment* decisions.

The following detailed future state descriptions have been consolidated into the equipment monitoring, performance, decision support, and asset management consolidated future state description shown above:

- The distribution system is fully and accurately modeled in electronic systems and available to engineers, operators, and field personnel. In urban network systems, mapping includes meshed secondary systems.
- Utilities have remotely installed devices in place to perform real-time, on-line condition assessments, minimizing manual inspections wherever possible.
- Utilities have a defined process for assessing equipment condition and performance to predict failures and equipment life cycles in order to develop optimal maintenance, replacement, and reinforcement plans.
- Utility engineers and control room operators have access to electrical information down to the customer level and tools to perform real-time analyses.
- Utilities can assess the health of underground cable systems in place, without damaging the cable and without taking it out of service.

GAPS

- High costs of moving from paper systems to geographic information systems.
- Integration with supervisory control and data acquisition.
- Tying asset register with geographic information systems to perform analyses (life cycle cost, condition assessment, and so on).
- Costs of sensors prohibits broad application.
- Need to develop new diagnostic methods to ascertain equipment condition.
- Lack of information and history about asset condition and performance.
- Processes for analyzing asset condition and performance data to develop risk failure probabilities and predictions.
- Processes to take information and use it to determine optimal inspection, maintenance and investment strategies.
- Easy to access views/reports of distribution loading conditions for Operators that can be used to make decisions.
- Develop easy to access views/reports that can be used by Engineers for planning analyses
- Need to develop common equipment characteristics, parameters, and metrics among utilities.
- Need to understand how differences in the way a piece of equipment is used (environment, configuration, and so on) from one utility to the next.
- Need to define failure modes for distribution equipment.

ACTION PLAN

EPRI research is designed to help utility asset managers by providing component reliability and infrastructure inspection-assessment information and knowledge. Laboratory testing is combined with actual field data to build an industry database and provide a better understanding of component reliability, equipment remaining life, fleet populations, and life cycle cost. This work focuses on components on an individual basis and also on component systems (overhead capacitor installations, for example) and builds and maintains an industry database. Laboratory testing is combined with utility survey and field data to enhance the database and provide a better understanding of individual component reliability and operational parameters that affect reliability. The laboratory component of this work features a multi-stress accelerated aging method that includes electrical, mechanical, ultra-violet, salt fog, and flammability testing.

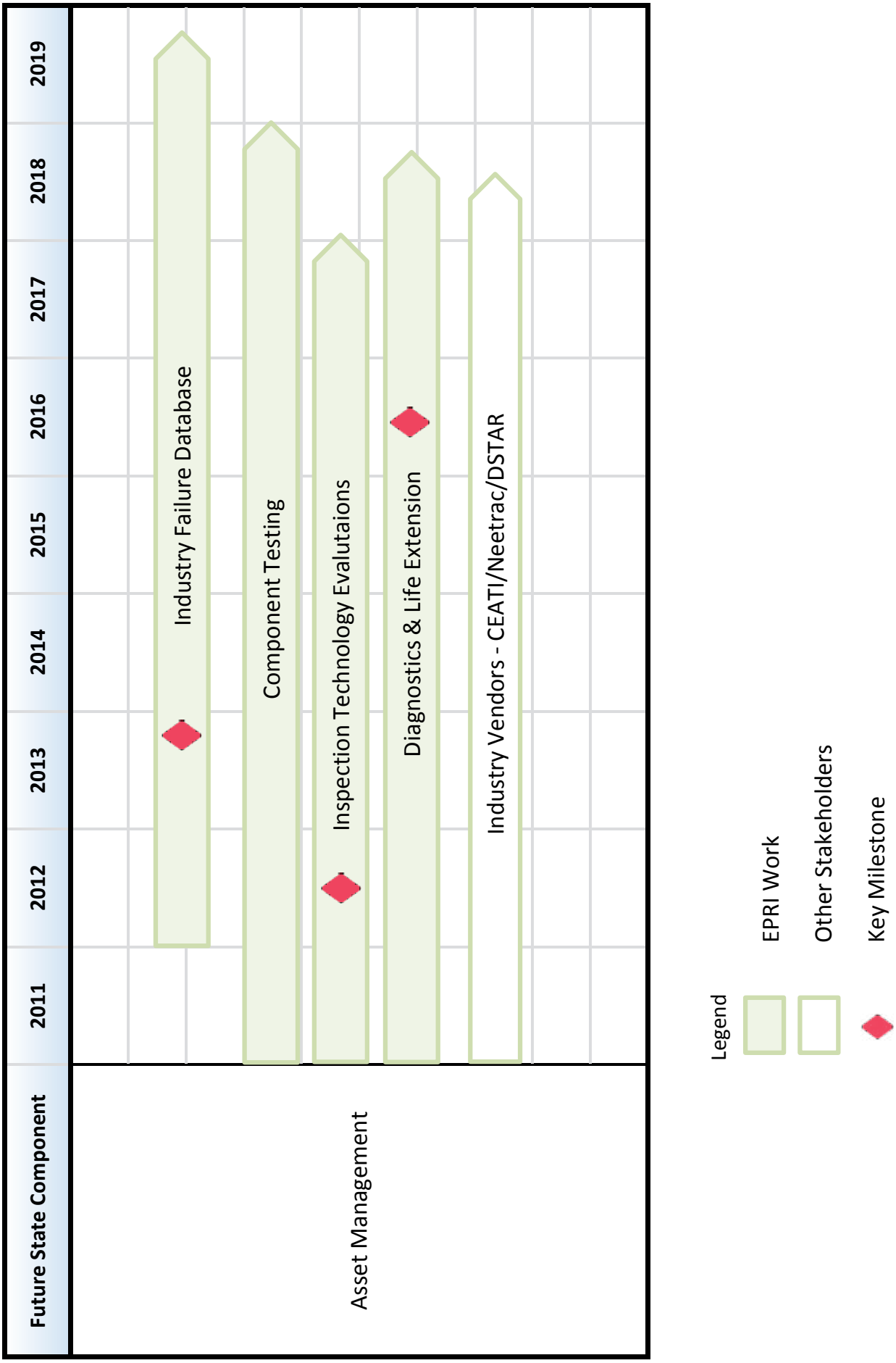
This work will also provide distribution utilities with the necessary information to accurately perform meaningful inspections that will enhance distribution system reliability and operations. This information includes improved methods for performing basic inspections and the development and implementation of new inspection technologies

VALUE AND RISK

Quantifying distribution component reliability can be challenging for utilities, especially without a formal analysis program. The issue becomes more difficult when manufacturers make design and material changes that can have impacts on reliability. Improved understanding of component reliability

can be gained through a framework of testing and data collection. This information can then be used to support the fundamental cycle of asset management including evaluating component design, selecting the right component for the task, assuring proper component installation, performing focused inspection and assessment, and prioritizing replacements.

Outages that are caused by failing infrastructure are costly for utilities and end-use customers. Routine inspection programs are one tool that utilities can use to reduce failures on their circuits and minimize customer outages. By identifying problems that need repair before they develop into failures, inspection programs can be a cost-effective method for enhancing the quality, reliability, and safety of electric service


Future State Component
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2017
2018
2019
Asset Management
Industry Failure Database
Component Testing
Inspection Technology Evalutaions
Diagnostics & Life Extension
Industry Vendors - CEATI/Neetrac/DSTAR
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

Utilities have access to industry-wide institutional *knowledge, information, and practices*.

The following detailed future state descriptions have been consolidated into the institutional knowledge and industry practices consolidated future state description shown above:

- Utility engineers and asset managers have access to industry-wide information about equipment performance, condition, and failure modes that can be used to make investment and maintenance decisions.
- Utility institutional knowledge is documented, available, and transferable

GAPS

- The effort to gather this information and make it understandable to people outside one's company is labor intensive.
- Need to understand legal ground rules with respect to vendor identification
- The workforce is aging; utilities are losing experience as people retire.
- Utilities are challenged to find ways to do more with less.
- Need to capture the institutional knowledge and best practices that are held by the experienced workforce.
- Need to bring new resources into the pipeline before the loss of experienced resources to ensure adequate on-the-job training.
- Need to partner with educators to reestablish the power engineering and craft worker training programs.
- Power engineering programs need transmission and distribution hardware training focus in their programs.
- There is a lack of available, experienced resources (both contractor and native).
- Need to share institutional knowledge with educators.
- Need better use of computers and web technology for capturing and sharing knowledge.

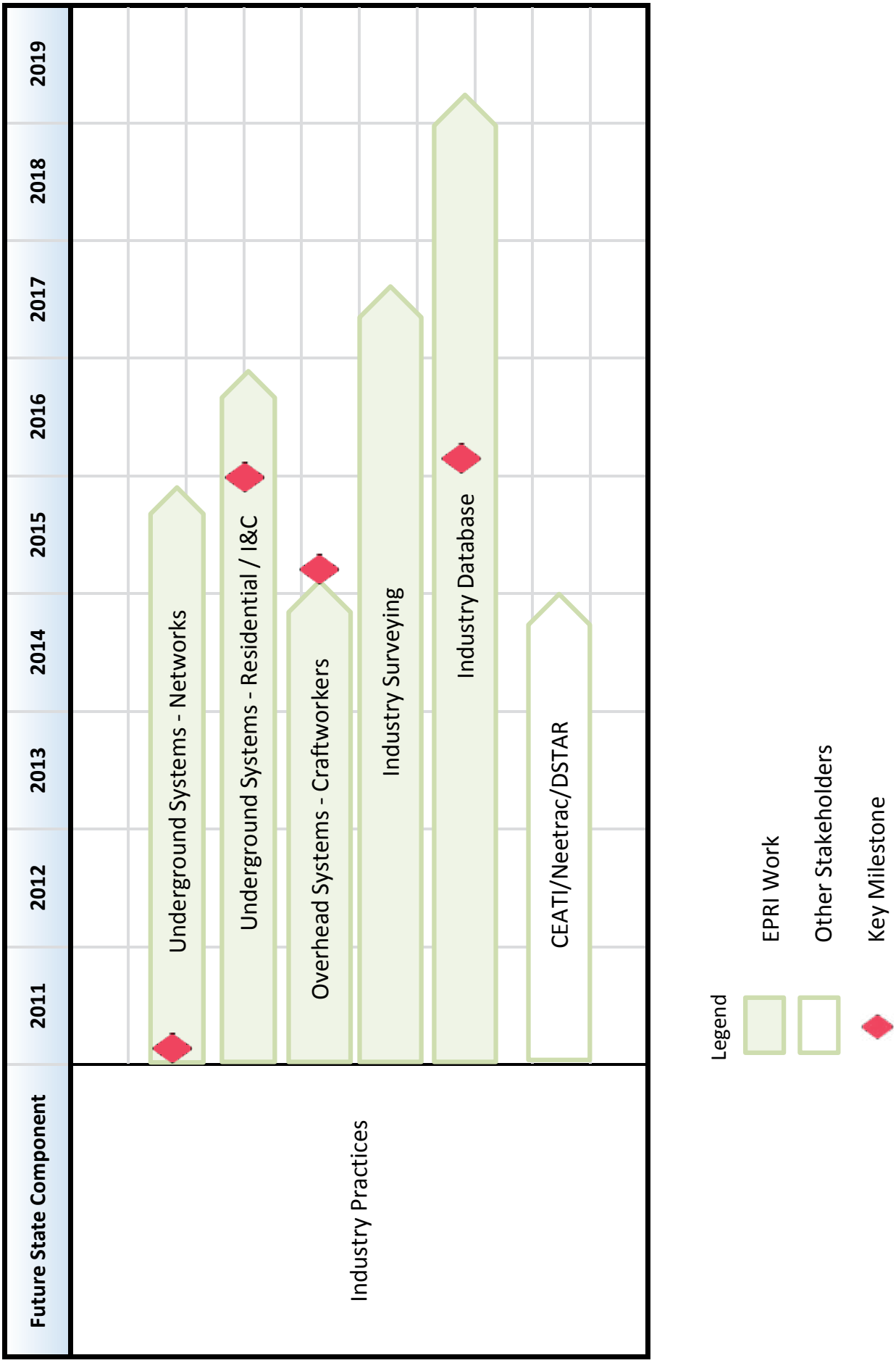
ACTION PLAN

This research focuses on distribution systems and uses a research approach where an EPRI project team visits a utility and immerses itself in the utility operation, collecting practice information firsthand from utility planners, engineers, operators, and field work crews. The research results are published in reports that summarize key practices and are populated in an online dynamic industry data repository. The data repository enables research participants to identify, analyze, and compare peer company approaches to managing urban underground distribution systems.

- Improve the reliability of distribution systems through the identification and application of alternative, optimal reliability practices.
- Improve the safety of utility activities involving construction and operation of distribution systems through the identification and application of alternative, optimal safety practices.
- Improve the efficiency associated with planning, designing, engineering, constructing, and operating distribution systems through the identification of alternative, optimal management practices.

VALUE AND RISK

Distribution systems are a crucial part of the industry and deliver high levels of reliability and customer service. However, distribution systems also present challenges, such as high costs for construction and maintenance, and require unique skill sets for effectively managing distribution systems, typically held by a few key individuals. Moreover, the loss of experienced engineering staff to mergers and attrition has left many utilities with a gap in the expertise needed for optimal planning, design and engineering, construction, and operation and maintenance of distribution systems.


Future State Component
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2019
Industry Practices
Underground Systems - Networks
Underground Systems - Residential / I&C
Overhead Systems - Craftworkers
Industry Surveying
Industry Database
CEATI/Neetrac/DSTAR
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

The existing electric distribution system is ready to accommodate a reasonable demand for deployment of renewable generation. Practices to establish hosting capacities, procedures for making interconnections and methods for mitigating problems are well established. Operating the distribution system with distributed renewable generation does not compromise system *reliability, power quality or safety*.

The following are key components for achieving this future state:

- Distribution planners have the data, experience and needed modeling tools to plan for different renewable deployment scenarios.
- Methods to determine feeder hosting capacities for variable distributed generation are available.
- Distribution operators know what distributed resources are connected to their systems, are able to forecast and manage variability and can employ mitigation strategies when needed.
- Distributed PV systems include power and communication interfaces that are able to provide grid support
- Communication protocols and interfaces are available for distribution management systems can take advantage of advanced functions available from electronic inverters.
- Effective business models for utility ownership and operation of distributed PV are available.
- Utilities that own and operate distributed PV systems have established practices to minimize operation costs and avoid downtime.

GAPS

- Lack of understanding of the nature of solar PV variability relative to wind variability. What are typical ramp rates? Ramp magnitude/duration? Diversity benefits?
- Need to define and utilization control options in power electronics interface of PV and small wind turbines for grid support.
- Need for the development and validation of steady-state, dynamic, and short-circuit models solar and wind plants in planning studies
- Need for development of new planning and operation methods and tools that consider the variability of output across time

There are some gaps specific to the integration of high levels of distributed renewable generation resources into the distribution system, which will require nimble management processes, use of highly automated and flexible distributed smart devices, and workforce training to uphold safety and reliability standards. A future grid network with increasing distributed generation will need to have the following attributes:

- Communication, metering, and power interfaces of distributed renewables to provide grid support including the required communications protocols for integration.
- Smart technologies (e.g., inverters, energy storage devices), advanced measurements and controls (i.e., self diagnosis and self healing).
- Existing and emerging intelligent technologies and techniques to provide for proactive maintenance, optimal levels of asset utilization, and greater efficiencies.

These gaps are mapped against a timeline for R&D objectives for distributed renewable integration to provide a roadmap for the activities over the next 10 years.

ACTION PLAN

Closing these R&D gaps will require that the industry invest resources in developing and implementing new processes, tools, techniques and technologies. To guide industry efforts, a 10-year plan or roadmap is developed for the distribution system integration research areas. Roadmaps present the near-term, mid-term and long-term R&D activities needed to reach the vision articulated in the research gaps.

EPRI will work collaboratively with industry and other research institutions including universities and national labs to provide analysis and development of advanced planning and operating methods. EPRI will also prototype software tools and technologies that implement these advanced methods and conduct demonstrations with our members. Once methods and tools are validated, EPRI will work with commercial vendors to ensure the tools are further developed and maintained such that all industry can access and utilize them.

For the distributed renewable integration activities are related to helping integrate distributed renewable resources into the distribution system and the program applies many technologies and approaches that are part of the smart grid. In addition it also researches key safety concerns caused by introduction of active generation on customer premises and along the distribution feeders.

VALUE AND RISK

Value to industry is derived by addressing the key drivers:.

1. Changing end-user preferences for electricity from clean and diversified generation sources, state renewable portfolio standards and potential for a federal climate policy.
2. A significant growth trend for distributed PV is bringing operational concerns and the need for new methods in distribution planning and design to maintain grid reliability and safety.
3. Utilities recognizing the need to extend communications and to define functional interactions from substation to customer-sited DER.
4. Growing interest of utilities in ownership models, risk and economic analysis, better decision making techniques and development of strategies for engagement.
5. New opportunities for rate base recovery and leveraging the value of the utility distribution system to support renewable distributed generation.

The increased application of distribution generation and the application of demand response initiatives as additional tools to meet capacity requirements will further challenge the distribution system. As the composition of the system changes utilities will maintain the responsibility to meet demand with increasing efficiency, reliability and quality.

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Integration of Distributed Renewables: Distribution ready for high penetration	Create planning and analysis tools to evaluate distributed integration								
			Develop methods to incorporate output forecasts into						
		Develop alternative methods and estimations tools to be used instead of the one-side fits all 15% rule							
					Develop guidelines to managing the system performance, reliability, & economic priorities with PV				
Distributed generation provides grid support		Develop guidelines to managing the system performance, reliability, & economic priorities with PV							
		Test controls, protections, & failure modes in inverters							
				Develop standards for communications with distribution renewables					
Utilities manage distributed assets and depend on them as generators		Develop guidelines to managing the system performance, reliability, & economic priorities with PV							
		Understanding of strategic business approach to distributed asset management				Develop models for asset management and cost effective O&M based on			

Legend

EPRI Work

Other Stakeholders

Key Milestone

POWER QUALITY RESEARCH AREA

VISION

EPRI research in the power quality area focuses on presenting a vision for the role that PQ can and should play in enhancing the three principal performance metrics for electric utilities: enterprise economic performance for the enterprise, the system performance of the modern grid, and improving customer satisfaction for all electric power users. This effort has identified a number of key technical foundations for power quality research including **improving and benchmarking grid PQ performance** including managing the increasing impact of harmonics, flicker, and other PQ phenomena on both transmission and distribution feeders. The research effort also seeks to **manage and extract the maximum value from data resources** including analysis tools, visualization tools and platforms, and data integration methods. Understanding and improving **system compatibility between the grid and loads** including understanding the contribution of new and changing loads on grid performance is a central focus. Capturing and leveraging EPRI's extensive power quality expertise is the primary focus of **PQ knowledge development and education activities** through training, customized web content, and accessible/readable documents developed for a broad audience.

FUTURE STATE COMPONENTS

Utilities and the public need to understand the true level of quality performance of their transmission and distribution networks, and to identify methods and actions that may improve the quality. New and changing loads require additional benchmarking efforts of current and past grid performance and it will be necessary to forecast future PQ levels based on changing grid configurations and load mixes.

Today there is a need to redefine the acceptable levels of power quality for key phenomena such as harmonic content, voltage sags and others and develop a set of metrics that can be applied at the transmission and distribution level. Benchmarking power quality will lead to a better understanding of the existing levels of quality provided to consumers and will form the expectations of the levels of quality in the future. In addition the ability to conduct comprehensive PQ benchmarking has gained feasibility as monitoring systems have become more versatile and cost effective.

It will be required that we understand today's level of PQ for a wider variety of phenomena in order to have a basis for comparison as the grid and load characteristics continue to chance.

Using PQ technical and informational resources to improve and benchmark grid performance will require:

- Analyzing power quality measurements will be more sophisticated in order to facilitate useful benchmarking of grid PQ as the impacts of the Smart Grid begin to take hold.
- Tools to estimate future power quality levels based on changing grid configurations and load compositions
- Methodologies will exist for quantifying and qualifying the impact of PQ and other performance phenomena beyond simplistic counting of events
- The distribution system "harmonics problem" will have a set of clearly defined solutions.

GAPS

There are both technical and implementation gaps between the modernized electricity system characterized above and the current state. Technical and implementation gaps need to be addressed simultaneously.

Technical gaps for achieving improvement and benchmarking of grid PQ performance are:

- A unified framework is needed for benchmarking current PQ performance
- More sophisticated methods are needed for assessing the impact of PQ phenomena on grid performance, beyond simple counting of events or simple amplitude measurements
- A unified framework is needed for estimating future PQ levels – and harmonics in particular – for different circuit designs and configurations and for different and changing mixes of loads served

ACTION PLAN

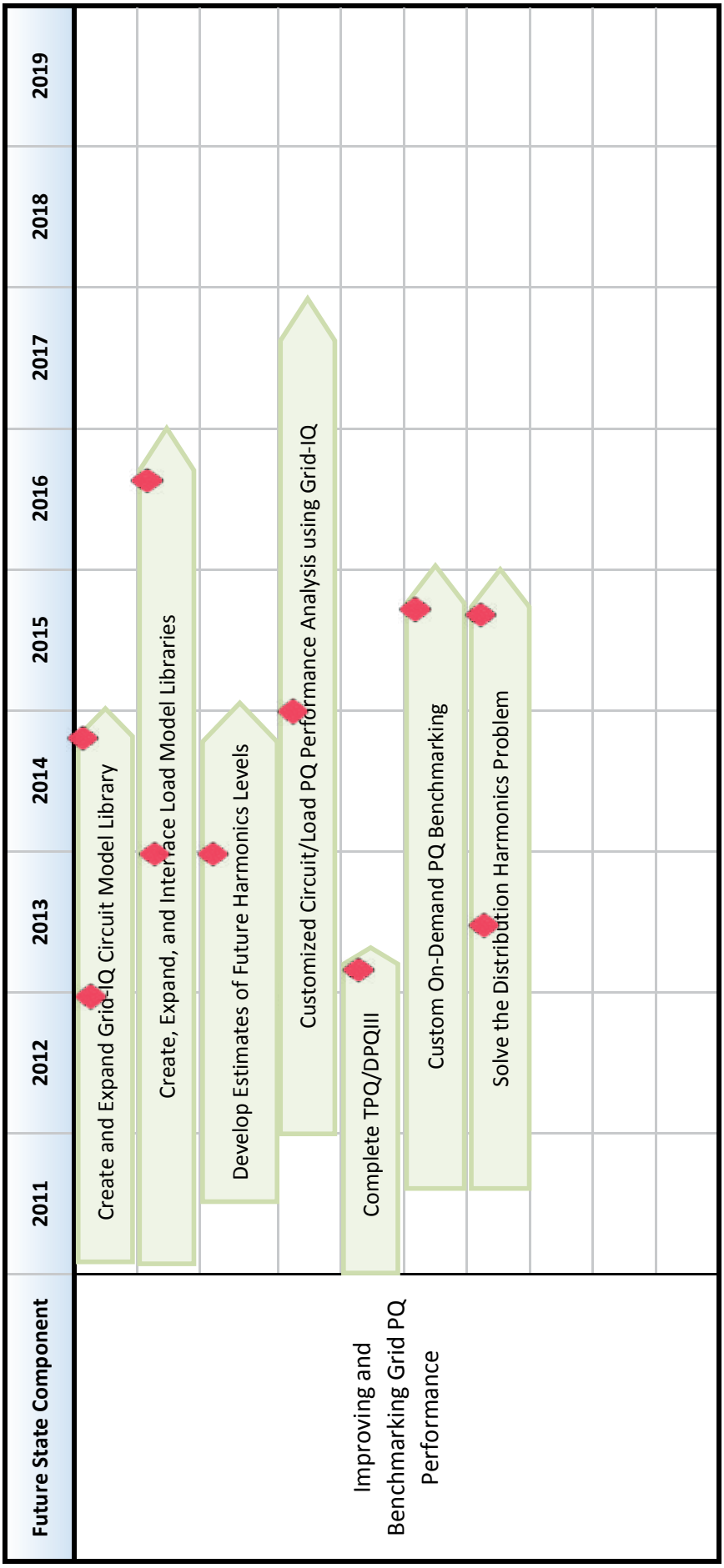
EPRI PQ research area has begun important initiatives to address these gaps:

- ***EPRI GridIQ Framework:*** The GridIQ Framework intends to allow rigorous estimation and modeling of the impact of new loads and circuit configuration on grid PQ. This framework will incorporate models for existing as well as emerging and rapidly growing loads (CFLs, PHEV chargers, PV installations, etc.) and combine the models into a system model library.
- ***EPRI Power Quality Diagnostic System tools:*** The Power Quality Diagnostic System (PQDS) is designed to help engineers and technicians develop solutions for power quality problem and assess the economics simplifying the calculation required to determine the costs and the expected performance of corrective measures, when compared to a base case.
- ***Transmission and Distribution Benchmarking:*** This benchmarking effort is designed to increase our knowledge of grid performance in a number of important ways including:
  - Stratification of data to allow finer resolution of performance for different circuits, grid configurations, load served, etc.
  - Addition of transmission-level statistics
  - Addition of multiple phenomena beyond voltage sags including harmonics, flicker, etc.

VALUE AND RISK

Electric utilities cannot achieve economic and grid-performance excellence by continuing to pursue the "reactive" approach to power quality, i.e., waiting for problems to manifest and solving them retroactively. The emergence of new and changing loads, the impacts of automated grids, and the

need to extract greater value from existing infrastructure make a proactive approach to PQ necessary. A proactive approach not only reduces long-run costs, but also improves economic performance, grid performance, and customer satisfaction. Enabling better management decisions through trending analysis, estimation of future PQ levels, and recommendations for proactive prevention and mitigation presents a new paradigm for power quality management.


Future State Component
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Create and Expand Grid-IQ Circuit Model Library
Create, Expand, and Interface Load Model Libraries
Develop Estimates of Future Harmonics Levels
Customized Circuit/Load PQ Performance Analysis using Grid-IQ
Complete TPQ/DPQIII
Custom On-Demand PQ Benchmarking
Solve the Distribution Harmonics Problem
Improving and Benchmarking Grid PQ Performance
Legend
EPRI Work
Other Stakeholders
Key Milestone

DRAFT: MANAGING AND EXTRACTING MAXIMUM VALUE FROM DATA RESOURCES

FUTURE STATE COMPONENTS

Power quality data bases have historically been among the largest data repositories maintained by electric utilities. Whereas most of grid is monitored at 50/60 Hz and RMS levels, power quality has long focused on capturing waveforms, harmonics and high frequency signals on power lines

Extracting useful information from these data streams will not happen on its own. In fact, if history offers any lesson, unless the utility industry recognized and addresses this issue today, we will have huge, but inaccessible, silo'd, and awkwardly structured data stores that add cost, but little real- or near-time value.

Key elements of extracting the maximum value from PQ data resources include:

- The availability of waveform data is expected to proliferate with the installation of smart meters and intelligent electronic devices (IEDs)
- Visualization of grid events will be integrated across different data repositories including OMS, GIS, maintenance, DFR, and other IED data sources
- Visualization of data will be distributed and accessible across a wide variety of field-deployable devices
- Analysis tools for extracting valuable information from wave form data will provide real- or near-time information that will help to improve grid and economic performance.

GAPS

Gaps to achieving these future states include:

- Integration methodologies and plans for defining wave form data needs and sources across increasingly diversified systems
- Creating infrastructure to allow real- and near-time analysis of wave form data to provide immediate and actionable information,
- Development of versatile platforms to allow visualization of PQ and other grid performance data for a much broader utility-internal audience
- Creating interoperability standards for easy interchange of data
- Creating analysis algorithms not only for PQ phenomena, but also for other grid and equipment performance issues such as fault location, equipment health assessment, etc.

ACTION PLAN

EPRI PQ research area has begun important initiatives to address these gaps:

Updated Power Quality Data Analysis and Visualization: EPRI has developed software tools and analysis algorithms for gathering, visualizing, and extracting information from PQ data, primary among them being PQView. Featuring data-management tools that can quickly characterize the data, PQView includes statistical analysis and plotting tools that can provide single- or multiple-site power systems analyses. Key to extending this functionality will be updating PQView to become a modern, multi-platform data visualization and analysis system.

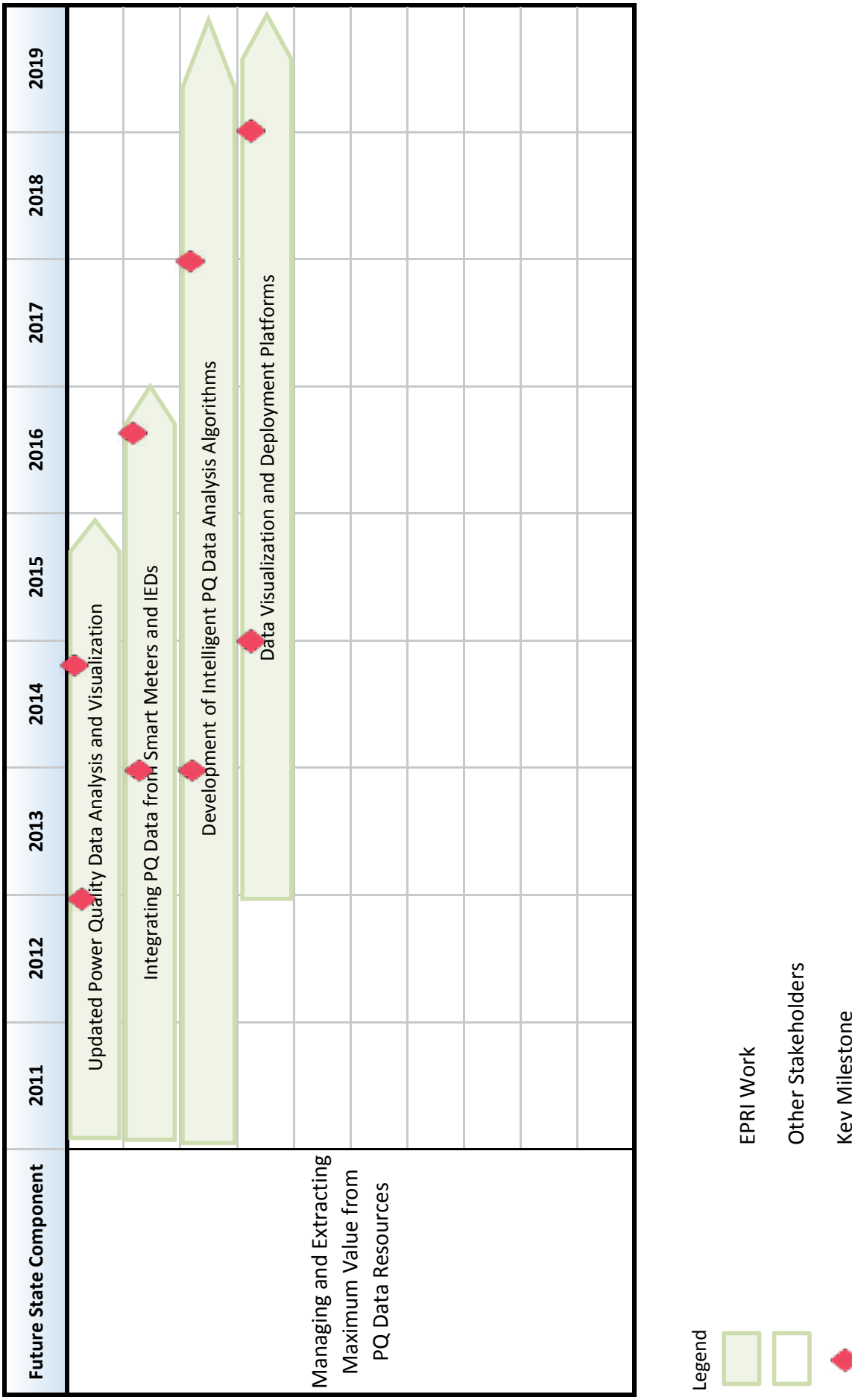
Integrating PQ Data streams from Smart Meters and IEDs for power quality applications: While expectations run high that wave form data from Smart Meters may be of great benefit to the utility industry, early results have not been encouraging. To address this EPRI will conduct an assessment of the possible and likely usage of Smart Meter data for PQ applications and define requirements for metering data to serve as power quality data source.

Development of intelligent PQ data analysis algorithms: Algorithms that analyze data form existing data resources and repositories and extract real and actionable information including fault location, incipient equipment failures, assessment of equipment health and longevity, detection of system impending malfunctions or failure, and correlation of system events with captured data.

Data visualization and deployment platforms: Creation of portable applications – for iPhone, Droid, and similar devices – for wider deployment and value of data resources.

VALUE AND RISK

A key differentiator among electric utilities is how well they manage data and how well they extract value from existing and emerging data sets. The intelligent acquisition, storage, analysis, and knowledge deployment resulting from increasingly diverse data sets is a fundamental challenge for successful implementation of smart T&D. EPRI's Power Quality research area has been at the forefront of data-based research, identifying new ways to manage and analyze data and bringing real value to electric utilities. Innovative ways of analyzing, displaying, and accessing data are urgently needed.


Future State Component
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Managing and Extracting Maximum Value from PQ Data Resources
Updated Power Quality Data Analysis and Visualization
Integrating PQ Data from Smart Meters and IEDs
Development of Intelligent PQ Data Analysis Algorithms
Data Visualization and Deployment Platforms
Legend
EPRI Work
Other Stakeholders
Key Milestone

DRAFT: SYSTEM COMPATIBILITY BETWEEN THE GRID AND LOADS

A key focus of power quality is the ability of electric power supplied to the end user to successfully – and consistently – power utility customer loads. This implies a partnership between the utility and the customer – reasonably clean power for the former, and reasonably tolerant loads for the latter.

Both players in this partnership need standards, guidelines, tools, and resources if compatibility is to be achieved at the lowest societal cost.

GAPS:

Key elements of achieving compatibility include:

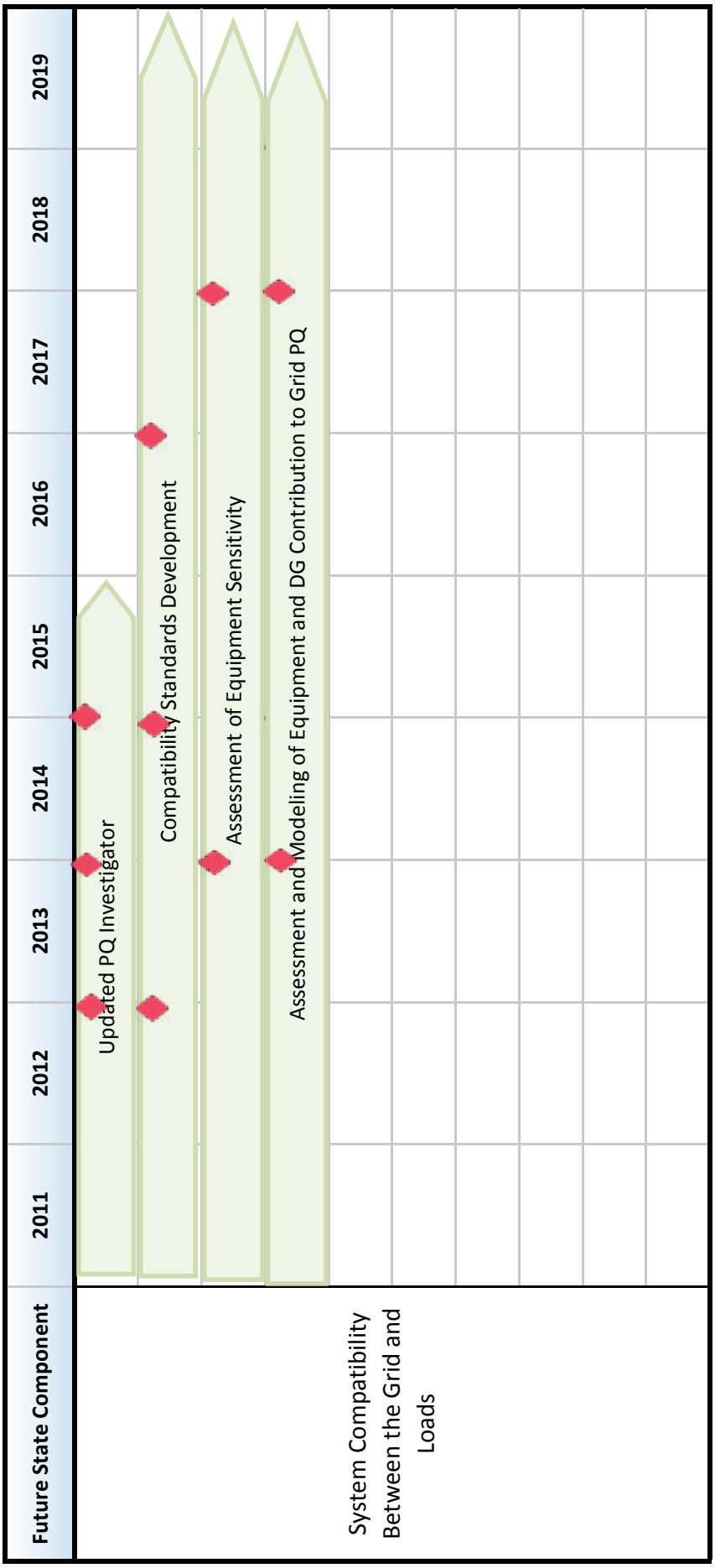
- Meaningful standards exist for both grid PQ and end use device sensitivity
- Expert tools exist for solving compatibility issues when they occur
- End use device testing identifies issues before process interruptions occur
- The contribution of end use loads to grid PQ levels – and harmonics in particular – is well understood
- The sensitivity of new and changing loads to an increasingly complex grid is well understood

ACTION PLAN

- Active participation of EPRI in meaningful compatibility standards development efforts such as the planned updated SEMI F47 equipment compatibility standard.
- Continued development of the Power Quality Investigator, which enables utility engineers to work with end-use customers to analyze their processes for susceptibility to voltage variations. This needs to include a compilation of background information on various industries, processes, equipment, and components in manufacturing based on experience in facility audits and solving PQ problems.
- On-going end-use equipment compatibility and PQ-contribution testing including CFLs, LED, and other lighting technologies; electric vehicle charging; rooftop PV and other inverter-based systems; evolving residential electronics; and grid-connected electronic systems such as Smart Meters, data accumulators, etc.
- Creation of a load model library of new and changing end-use technologies to enable estimation of future PQ levels for harmonics, flicker, and other PQ phenomena.

VALUE AND RISK

It has been many decades since the electric utility industry has seen such rapid change in both the technology of the grid and the composition/behavior of the load being served. Understanding of both is critical to improved economic performance, grid performance, and customer satisfaction. The EPRI PQ program is assembling and deploying a large, diverse, and growing load model library for the purposes of understanding and estimating future grid PQ levels so that good management decisions can be made today. More and better PQ analysis tools are needed to enable quick response to utility customer PQ issues.


Future State Component
2011
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2019
System Compatibility Between the Grid and Loads
Updated PQ Investigator
Compatibility Standards Development
Assessment of Equipment Sensitivity
Assessment and Modeling of Equipment and DG Contribution to Grid PQ
Legend
EPRI Work
Other Stakeholders
Key Milestone

INTELLIGRID RESEARCH AREA

VISION

"Smart Grid" is a high level concept that infuses information and communications technologies with the electricity grid to increase performance and provide new capabilities. Each utility will create its own Smart Grid over time through investments made in back office systems, communications networks and intelligent electronic devices (IED's). These investments will be substantial; EPRI estimates that the net 20 year investment needed to realize the smart grid in the U.S. is between $338 and $476 billion.

The smart grid vision includes the idea that the utility's meters, sensors, control devices, and software applications will be able to exchange information, and to do this with sufficient timing and data volume to enable a wide range of applications. These applications will likely vary from utility-to-utility, and may include wide area protection and control, integration of bulk and distributed renewable generation, equipment health monitoring, volt / var optimization, fault location, load management, a range of diverse energy rate options for consumers, and enhanced information to consumers.

Two key technical foundations of the smart grid are the **Communications** networks that provide connectivity to the IEDs and the **Interoperability** standards that enable devices and systems from multiple vendors to exchange information.

It is envisioned that utility communication systems will grow, both in terms of the coverage of the system and the number of devices reached. It is also anticipated that utilities will migrate from multiple, single purpose communications networks to fewer, unified networks, each of which can support multiple applications.

It is envisioned that the intelligent power system of the future will be realized as a system-of-systems, with cleanly defined interfaces that allow individual domains and industry segments to evolve independently. Independent domains could include, for example, energy trading markets, bulk grid operations, distribution operations, the automotive industry, the customer / home automation industry, the industrial controls industry, etc.

Although individual utilities will build their smart grids in different ways and on different schedules, it is envisioned that these smart grids will be capable of co-operating harmoniously. To achieve this vision, utilities will need the methods, tools and information for effective **Smart Grid Planning and Implementation**.

The following sections describe critical "gaps" that are preventing the industry from realizing the smart grid vision and actions needed to address these gaps. Gaps and actions are segmented into the followings areas:

- Interoperability,
- Communications,
- Smart Grid Planning and Implementation

DRAFT: INTEROPERABILITY

Interoperability is the ability of two devices or systems to exchange information and use that information to perform their functions. The vision of the smart grid is that millions of devices in different domains and with different owners will be able to exchange information. For the smart grid vision to be widely adopted, this exchange of information needs to happen with minimal integration cost and difficulty. Therefore, interoperability is critical.

The key to interoperability is standards. In order for devices and systems to communicate easily, they must speak the same language. Standards abound in the utility space. They have different, albeit sometimes overlapping domains. Some standards are mature and others are emerging.

FUTURE STATE COMPONENTS

The interoperability-related characteristics of the envisioned modernized electricity system include:

- Data standards will have been developed for critical smart grid applications including demand response, DER integration, PEV integration, PMU networks, AMI, etc.
- Multiple standards that address common applications or adjacent applications are increasingly being harmonized. For example, Standards for DER integration have converged with those for other utility applications (e.g., SCADA, AMI, DR).
- Reference architectures and associated interface standards (at many layers) will have been developed.
- Standard certification services will be available
- End to end interoperability testing services will be available
- Training and implementation support services will be available
- Interoperability standards support cyber security
- Strategies for migrating from one standard to another are well understood and support if available to utilities

GAPS

There are both technical and implementation gaps between the modernized electricity system characterized above and the current state. Technical and implementation gaps need to be addressed simultaneously.

Technical gaps for achieving interoperability are:

- Existing standards for smart grid applications are incomplete and have not been broadly adopted by utilities, vendors, and third party device manufacturers.
- Key smart grid standards need to be harmonized.
- Reference architectures and associated interface standards that will enable interoperability between equipment from different vendors does not exist.
- The tools and techniques to enable standard certification have not been fully developed.
- End to end interoperability test procedures do not exist
- Cyber security is not uniformly addressed by standards

Gaps in the adoption of interoperability standards are:

- Utilities often don't understand the risks and benefits of adopting a key standard
- It is often difficult and costly for utilities to implement a standard
- There is a lack of reference and training material for standards implementation.
- Lack of staff adequately skilled to conduction training on a broad scale.

ACTION PLAN

Realizing interoperability in the smart grid is a huge undertaking that involves the active involvement of all stakeholders. It requires the development and adoption of standards, reference architectures and certification and testing procedures. It is an on-going process that engages many organizations including the federal government, standards development organizations, user's groups, etc. Each organization in this "community" of stakeholders has its own role and activities; however, all of these activities need to be coordinated and harmonized to realize the smart grid vision.

Key members of the smart grid interoperability "community" include:

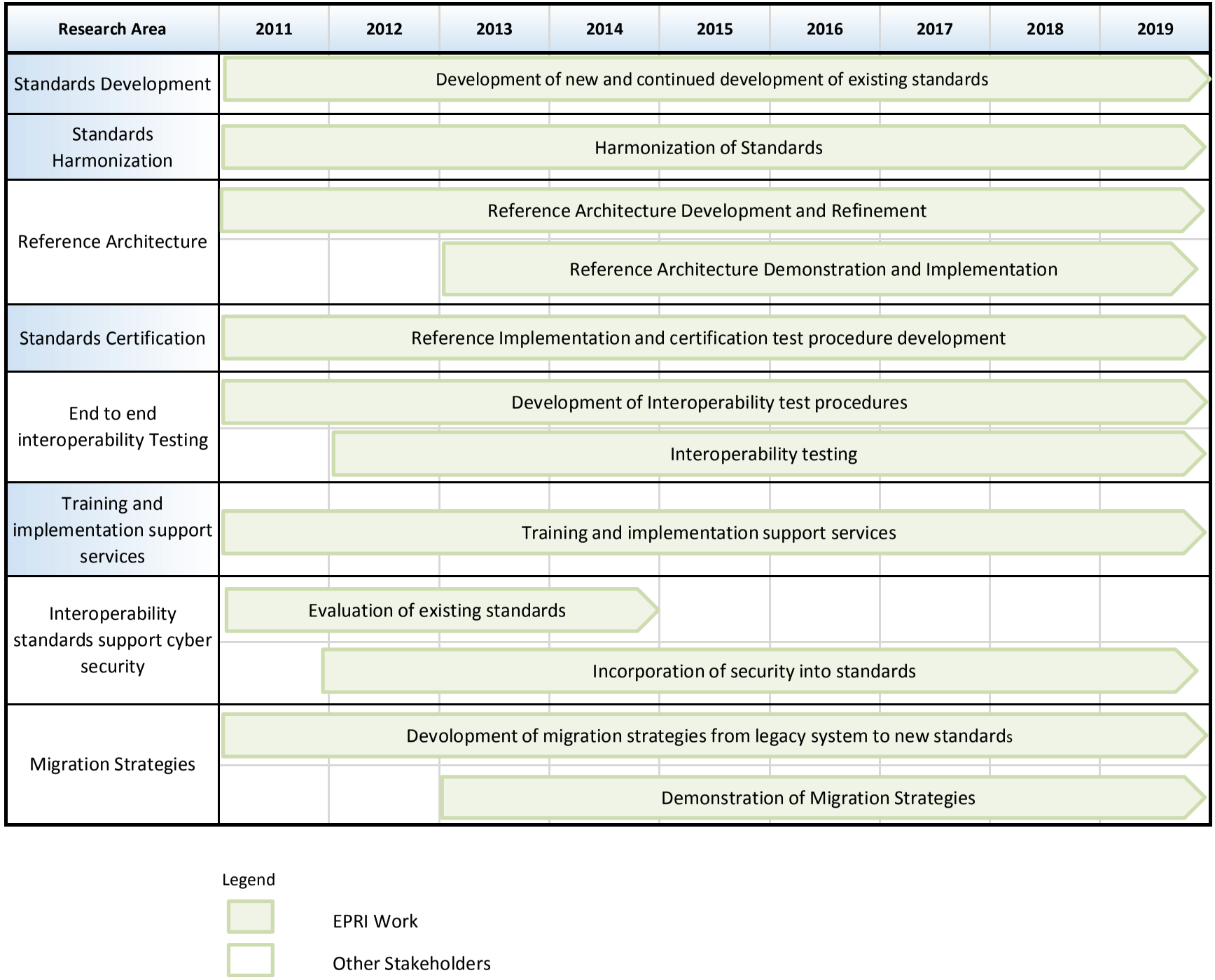
- **The Smart Grid Interoperability Panel (SGIP)** engages stakeholders from the entire Smart Grid Community in a participatory public process to identify applicable standards, gaps in currently available standards, and priorities for new standardization activities for the evolving Smart Grid.

- **Standards Development Organizations (SDO)** develop standards following a collaborative process
- **User's Groups** develop implementation agreements and requirements, offer training, provide certification testing for specific standards and create communities to foster adoption. User's Groups often gather business requirements which are then shared with SDOs for inclusion in future editions of any given standard

A parallel effort is needed to provide outreach and training to electric utilities on migration strategies and the implementation of emerging standards.

VALUE AND RISK

For utilities, standards based interoperability will dramatically reduce both capital and life cycle costs when deploying AMI systems, demand response, asset monitoring and wide area monitoring and control, and when integrating distributed generation. It will reduce the risk of vendor lock in and early obsolescence of equipment and systems. It will enable data and information to be shared with the people and individuals who need it.


Research Area
2011
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Standards Development
Development of new and continued development of existing standards
Standards Harmonization
Harmonization of Standards
Reference Architecture
Reference Architecture Development and Refinement
Reference Architecture Demonstration and Implementation
Standards Certification
Reference Implementation and certification test procedure development
End to end interoperability Testing
Development of Interoperability test procedures
Interoperability testing
Training and implementation support services
Training and implementation support services
Interoperability standards support cyber security
Evaluation of existing standards
Incorporation of security into standards
Migration Strategies
Devolopment of migration strategies from legacy system to new standards
Demonstration of Migration Strategies
Legend
EPRI Work
Other Stakeholders

Communications technologies are evolving rapidly driven largely by communications carriers and equipment suppliers. The smart grid vision is that millions of devices - on the transmission system, in substations, on the distribution system and within the consumer premises – will be able to exchange information to increase grid performance and functionality and to provide consumers with information and services. To realize this vision, a utility's communications reach will need to be as ubiquitous and pervasive as its electric grid.

Currently, electric utilities operate many communications networks each one designed for a single purpose such as advanced metering, SCADA, equipment monitoring, etc. As more devices are added with new capabilities, these networks become difficult to manage and scale. Going forward, communications networks will tend to be higher performance, more integrated and unified.

FUTURE STATE COMPONENTS

Key communications-related characteristics of the envisioned modernized power system are:

- Industry communications requirements (both near-term and long-term) are well understood.
- The performance (including, reliability, robustness, availability, security and privacy), costs and risks of current and emerging communications technologies, private network vs. public carrier infrastructure, licensed vs. unlicensed RF spectrum, etc. are well understood so that utilities can knowledgeably select the technology that best meets their needs.
- The electric utility industry is represented on communications standards development to influence technology development to better meet industry needs.
- Information on the health effects of wireless communications is available for utilities and society.
- Strategies for integrating and managing new communication networks with legacy systems are well understood.

GAPS

There are several communications-related "gaps" between the envisioned modernized power system characterized above and the current state.

Communications system requirements for electric utility applications

An initial set of requirements has been developed for the Home Area Network (HAN), but these need to be reassessed regularly as our understanding of the applications and human behavior grow. Requirements for the Field Area Network (FAN) and within substations need to be developed.

Characterization of existing and emerging technologies and approaches

Electric utilities have many choices to make when deploying communications networks, including:

- Technology (LTE, WiMAX, Wi-Fi, ZigBee, HomePlug, etc.)
- Frequency (licensed, unlicensed, lightly licensed)
- Private network vs. commercial carrier

The best approach will vary depending up application, topology, population, density, etc. Utilities need unbiased information on the performance, risks and costs of the different technologies and approaches.

Integration and management of new communications networks with legacy systems

New technologies will always need to co-exist with existing systems. Cost effective approaches for integrating new communications networks with legacy systems need to be developed and demonstrated. Similarly, cost effective approaches for managing communications networks comprised of different technologies of different generations need to be developed and demonstrated.

Electric utility influence in new standards and technology develop

Electric utility representation has been largely absent in the communications standards development bodies. As utility communications requirements are better understood, they need to be contributed to Standards Development Organizations so that new standards and technologies can better meet industry needs.

Impact of EMF on human health

As the electric utility industry increases its use of wireless communications, it is important to understand the effect of electromagnetic fields on human health.

ACTION PLAN

Communications system requirements for electric utility applications

Many organizations are working to develop requirements for utility applications including EPRI, Open SG, the Smart Grid Interoperability Panel (SGIP), standards development organizations and user's groups. It is critically important that requirements are vetted broadly by stakeholders.

Characterization of existing and emerging technologies and approaches

Both laboratory testing and field demonstrations are needed to characterize current and emerging technologies and approaches. A series of field demonstrations are needed for both HAN and FAN technologies.

Integration and management of new communications networks with legacy systems

Approaches for integration and management used by other industries need to be evaluated, adapted and demonstrated by utilities.

Electric utility influence in new standards and technology develop

Participation in communications standards development can come from EPRI, industry trade associations, Utility Telecommunication Council, utilities, etc.

Impact of EMF on human health

Characterize the EMF produced by utility equipment.

VALUE AND RISK

Communications is the backbone of the smart grid. It has to potential to enhance the performance and functionality of the grid and to better inform and engage consumers. The challenge for utilities is selecting the communications technologies that securely and cost effectively meets both their near-term and long-term needs. Uninformed decisions could lead to early obsolescence or long-term vendor lock-in.

Research Area	2011	2012	2013	2014	2015	2016	2017	2018	2019
Communications requirements	Home Area Network Requirements Development								
	Field Area Network Requirements Development								
Characterization of existing and emerging technologies and approaches	HAN Technology Characterization								
	FAN Technology Characterization								
	Evaluation: licensed vs. unlicensed spectrun								
	Evaluation: private network vs. public carrier								
Integration and management of new communications networks with legacy systems	Network management identification, adaption and demonstration								
		Evaluation of the Internet for HAN applications							
Electric utility influence in new standards and technology develop	Standards development & User's Group participation								
Impact of EMF on human health	EMF characterization of utility field equipment								

Legend

- EPRI Work
- Other Stakeholders
- Key Milestone

"Smart Grid" is a high level concept that infuses information and communications technologies with the electricity grid to increase performance and provide new capabilities. Each utility will have its own unique smart grid vision and will build towards this vision through investments in back office systems, communications networks and intelligent electric devices (IED's).

The smart grid has been referred to as a "system of systems" because each of the individual investments must be integrated together to enable data from one system to be shared with another and communications networks to support multiple applications. The systems engineering aspect of the smart grid makes its planning implementation extremely complex.

A utility must have a positive business case for each investment or a collection of investments. This is complicated because many of the applications are not well proven and the full costs and benefits are uncertain.

FUTURE STATE COMPONENTS

Key planning and implementation-related characteristics of the envisioned modernized power system are:

- There are well accepted strategies and best practices for building out the smart grid
- Accurate, unbiased information on costs, benefits and risks are available for applications such as advanced metering, demand response, volt / var optimization, etc.
- The utility workforce has the skills to operate and maintain new technologies and systems
- Electric utilities have the processes and governance structure in place to manage change

GAPS

There are several planning and implementation-related "gaps" between the envisioned modernized power system characterized above and the current state.

Strategies and best practices for building out the smart grid

The industry lacks the methods and tools necessary for planning, designing and implementing the smart grid. Specific gaps are:

- Smart Grid roadmap development guides and best practices
- Use cases and requirements for smart grid applications

Accurate cost / benefit / risk information from actual smart grid implementations

Many of the applications and technologies being deployed by utilities are unproved and the actual costs, benefits and risks of the deployments are unclear. Actual realized information is scarce. Many utilities and regulators are waiting for the results of early adopters before they move forward with investments.

Change management processes for both utilities and their customers

Many of the applications and technologies associated with the smart grid (communications networks, back office systems, advanced meters, distributed generation, dynamic pricing, demand response, etc.) are going to require substantial change both within the utility and for customers. It has been shown repeatedly that making changes without proper planning and communications can result in serious backlash that can have severe consequences for a company.

Workforce training

Along with the new technologies and processes associated with the smart grid are new skill sets required by utility workers such as enterprise architects, cyber security specialists, communications experts, etc.

ACTION PLAN

Strategies and best practices for building out the smart grid

EPRI and several other companies have been working with utilities to develop company-specific smart grid roadmaps that define the smart grid vision for the company and define the investments that a company needs to make over time to realize the vision. EPRI has been working with several utilities to conduct smart grid demonstrations. DOE has also been funding smart grid demonstrations. Lessons learned and best practices from these projects needs to be captured and broadly disseminated.

Accurate cost / benefit / risk information from actual smart grid implementations

EPRI and DOE has jointly developed a cost / benefit methodology for smart grid demonstration projects. This methodology is being applied to the EPRI and DOE sponsored demonstration projects. Realized cost / benefit data needs to be broadly disseminated.

Change management processes for both utilities and their customers

Best practices from other industries needs to be identified and shared with electric utilities. Lesson's learned and best practices from electric utilities needs to be captured and broadly disseminated.

Workforce training

Lesson's learned and best practices from electric utilities needs to be captured and broadly disseminated.

VALUE AND RISK

Planning and designing the smart grid is extremely complex and requires skills that are new for the utility industry. The methods, tools and forums that EPRI provides will help utilities better manage the complexity.

Although many business cases have been developed for smart grid applications, realized cost / benefit information from actual implementations is scarce. This information will be critical for utilities to have when selecting the smart grid applications and technologies to implement.

Research Area	2011	2012	2013	2014	2015	2016	2017	2018	2019
Strategies and best practices for building out the smart grid	Smart grid roadmap methodology and best practices								
	Smart grid deployment best practices								
Accurate cost / benefit / risk information from actual smart grid implementations	Realized costs / benefits from early deployments								
Change management processes for both utilities and their customers	Change management lessons learned & best practices								

Legend

EPRI Work

Other Stakeholders

CYBER SECURITY AND PRIVACY FOR THE ELECTRIC SECTOR

VISION

Cyber/physical security and data privacy have become increasingly critical priorities for electric utilities. The evolving electric sector is more dependent on information technology and telecommunications infrastructures to ensure the reliability and security of the electric grid. Cyber security measures must be designed and implemented to protect the electric grid from attacks by terrorists and hackers and non-malicious cyber security events such as user errors. The cyber security measures must also strengthen the resilience of the electric grid against natural disasters and inadvertent threats such as equipment failures.

There are many challenges to securing the electric sector. Real-time cyber threats frequently evolve faster than the industry's ability to develop and deploy countermeasures. Additionally, the landscape is complicated by large deployments of legacy equipment and protocols, computationally constrained devices, and an increasing variety of communications technologies and protocols. These challenges combined with a lack of cyber security metrics make it difficult to assess the cyber security risk in real-time.

The changing regulatory environment also increases the uncertainty associated with making investments in cyber security and privacy and can often focus resources more on compliance than security. As noted by the Government Accountability Office (GAO), the "existing federal and state regulatory environment creates a culture within the utility industry of focusing on compliance with cyber security requirements, instead of a culture focused on achieving comprehensive and effective cyber security."

Other government agencies and industry leading organizations have also recognized this potential threat and have called for industry action to prevent cyber security threats, to protect the developing smart grid, to respond to cyber security threats, as well as to prepare for prompt recovery after a cyber security event.

The Energy Sector Control Systems Working Group recently released their "Roadmap to Achieve Energy Delivery Systems Cybersecurity" (hereafter referred to as the Energy Cybersecurity Roadmap) that identifies several strategic areas of focus to achieve resilient energy delivery systems by 2020.

- Assess and monitor risk
- Develop and implement new protective measures to reduce risk
- Reduce cyber security risk for legacy systems
- Manage incidents
- Develop technology to support privacy
- Reduce the cost of security and compliance for instrumentation and control systems

The EPRI Cyber Security and Privacy Roadmap builds on this work and includes additional key objectives that will help asset owners and operators meet their cyber security and privacy challenges.

FUTURE STATE COMPONENTS

Assessing and monitoring the cyber security posture for energy delivery systems is vital to understanding and managing cyber security risk. New metrics, methodologies, and tools are required to support real-time risk monitoring and decision making. Additionally, increased cyber interoperability and integration across vendors and domains will greatly enhance the need for cyber event management and situational awareness.

GAPS

There are several barriers to achieving this goal. First, there is a lack of agreed upon metrics for measuring cyber security posture and risk. Second, there is a lack of interoperable standard information security objects to represent events such as alerts and alarms. Third, the network security management standards for transmission and distribution systems are not fully developed. Finally, there is a lack of tools to support cyber security situational awareness for power delivery systems.

ACTION PLAN

This area focuses on key technical issues associated with assessing and monitoring risk for power delivery systems. *The Energy Cybersecurity Roadmap* identifies three key priorities: risk factors and levels, risk methodologies and tools, and security state monitoring.

Risk factors and levels focus on:

- Metrics to describe security posture
- Terms and measures for testing and baselining security
- Quantifying trustworthiness and risk
- Characterizing a set of threat scenarios and metrics for assessing risk

Risk methodologies and tools focus on:

- Risk assessment tools that include methodologies for assessing vulnerabilities, frameworks for prioritizing control measures, and means for justifying costs
- Tool sets for asset owners to assess and benchmark risk
- Engineering decision making tools for optimizing security
- Data driven ability to determine how and which vulnerabilities and threats should be addressed

Security state monitoring focuses on:

- Real-time security status visualization tools to baseline security states and compare security posture after implementation of new solutions
- Modeling and simulation tools that have dynamic automated capabilities to inform risk management decisions
- Real-time security state monitoring of new and legacy system applications
- Developing and deploying sensor systems with mechanisms to detect and report anomalous activity
- Visualization technologies that integrate and correlate multiple data streams
- Network management/control at mesh-network (smart grid) scale (millions of devices)
- Develop tools for visualizing smart grid functions at transmission control centers

The EPRI Cyber Security and Privacy program will engage with current work being performed at organizations such as DHS, NIST, DOE, NERC, and academic institutions for this effort. EPRI will focus on supporting these objectives by developing security management architectures, supporting the standardization and interoperability of security, and creating tools for security visualization.

VALUE AND RISK

The ability to assess and monitor risk is a fundamental component of cyber security situational awareness. The increased complexity of the electric sector requires real-time awareness of what cyber events are occurring and the tools to display them to an operator in a meaningful way.

The process of achieving real-time situational awareness requires detailed data from a variety of vendors, operating environments, and system levels. This represents a very complex task that will require cooperation from multiple stakeholders across the electric sector domains.

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Risk Factors and Levels	Metrics to Describe Security Posture								
	Terms and Measures for Testing and Baselining Security								
	Characterizing Threat Scenarios								
	Metrics for Attack Surface								
	Quantifying Trustworthiness								
Risk Methodologies and Tools	Tools to Assess and Benchmark Risk								
	Frameworks for Prioritizing Control Measures								
	Decision Making Tools for Optimizing Security								
Security State Monitoring	Interoperable Security Objects Across Vendors and Domains								
	Network Security Management for TX and DX								
	Tools for Cyber Security Situational Awareness								

Legend

EPRI Work

Other Stakeholders

Key Milestone

FUTURE STATE COMPONENTS

Increasing the security of next-generation energy delivery systems will require a combination of new security architectures, tools and procedures that provide end-to-end security and support defense-in-depth features. These technologies and their communications protocols must support strong protective measures such as device and application authentication, access control, cryptography, and redundancy and fail over mechanisms for continued operation.

GAPS

There are several gaps that must be overcome to introduce effective protective measures for energy delivery systems. As next-generation technologies and applications are introduced, new security architectures are required to protect a much more complex and interconnected grid. Additionally, a variety of communication and cyber security standards are being implemented, making it difficult to ensure end-to-end security. Finally, the number of devices that must be protected demands that cyber security solutions be scalable.

ACTION PLAN

This action plan builds on several priorities that have been identified by the *Energy Cybersecurity Roadmap*. These priorities are divided into three areas: resilience testing and validation, systems, and access and communications.

Resilience testing focuses on:

- Developing tools and test-beds to evaluate candidate architectures and protocols
- Acceptance testing capability for evaluating the security robustness of next-generation energy delivery systems
- Security certifications programs

The systems area focuses on the development of technologies to support capabilities such as:

- Non-bootable patching (hot patching) capability
- Safe harbor designs to prevent cascading failures
- Secure change management across widely distributed systems

The access and communications area focuses on:

- Techniques to provide explicit, managed communications trust
- Cryptographic key management methods scalable to millions of devices
- Trusted platform modules and trusted network connections for real-time communications that are nonproprietary
- White list capabilities for applications and communications

EPRI has also identified a cross-sector need to improve the procurement process, including:

- Generic method for identifying cyber security requirements and controls needed by "categories" of data flow, component, or system with some high level specification language or guidance
- Generic method and specification language for identifying vendor cyber security capabilities (i.e., "Tier") to meet the requirements
- Generic approach for performing risk assessment, cost/benefit analysis, and applying compensating controls for less than fully-compliant vendors
- Generic cyber security specification language, including a mapping of the language to specific cyber security guidelines and compliance requirements

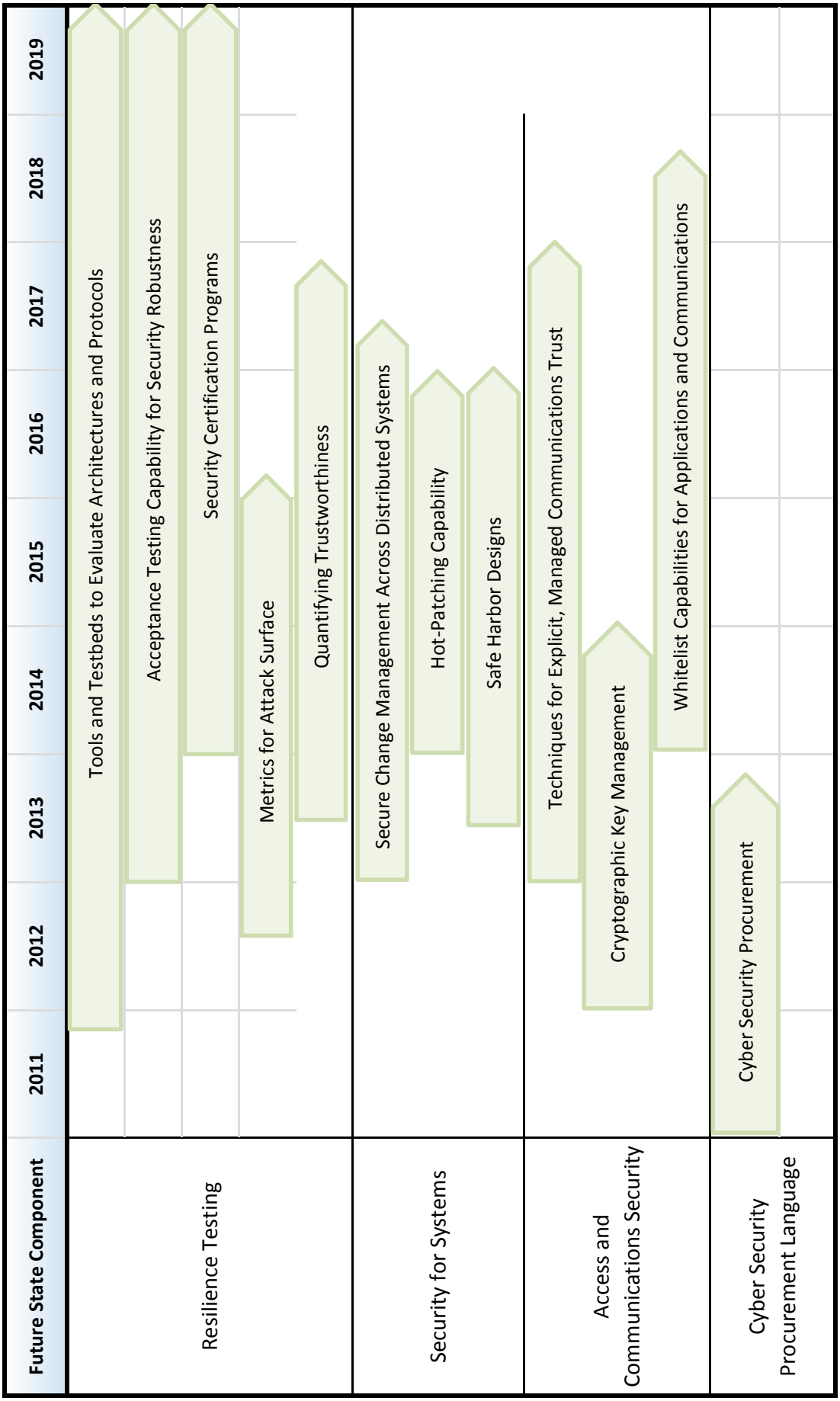
The EPRI Cyber Security and Privacy Program will focus on several research objectives to support these priorities. In the near-term, EPRI will focus on enhancing our substation test bed capabilities and developing tools to support security testing of end-user devices. EPRI will also engage both vendors and utilities to improve the procurement process. In the longer term, EPRI will focus on techniques for the live verification of firmware and the development of high-assurance architectures.

VALUE AND RISK

Secure architectures and supporting technologies must be developed and tested to protect next-generation energy delivery systems. This will allow security to be 'built-in' to devices and systems from the beginning, rather than added on later.

There are several risks that will make implementing new protective measures difficult. First, changes to standards to promote increased security can take years to be approved and adopted. Second, new technologies must not interfere with the operation of real-time systems by surpassing latency and bandwidth constraints. Third, the increased number of nodes and interconnections between systems greatly

increases the overall system's complexity, making it difficult to determine the level of protection. Fourth, the constantly changing environment of new threats and vulnerabilities adversely impacts deployed technology.


Future State Component
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Resilience Testing
Tools and Testbeds to Evaluate Architectures and Protocols
Acceptance Testing Capability for Security Robustness
Security Certification Programs
Metrics for Attack Surface
Quantifying Trustworthiness
Security for Systems
Secure Change Management Across Distributed Systems
Hot-Patching Capability
Safe Harbor Designs
Access and Communications Security
Techniques for Explicit, Managed Communications Trust
Cryptographic Key Management
Whitelist Capabilities for Applications and Communications
Cyber Security Procurement Language
Cyber Security Procurement
Legend
EPRI Work
Other Stakeholders
Key Milestone

DRAFT: REDUCING CYBER SECURITY RISK FOR LEGACY SYSTEMS

FUTURE STATE COMPONENTS

While there are significant efforts to upgrade the infrastructure and equipment of the electric sector, a large base of "legacy" systems will continue to be used for the foreseeable future. Reducing the risk of legacy systems will require the development of mitigation strategies and of technical solutions to support protection mechanisms such as encrypted communication links, secure access control for IEDs, and detailed logging and monitoring that is performed across all devices to support audits and event analysis.

GAPS

In this context, legacy systems are defined as those that are non-cyber aware, or incompatible/non-compliant with current security policies or guidelines. There is a significant installed base of serial-connected devices that perform a critical function for the bulk electric system (i.e., protection relays). Further, security guidelines are being revised, and device updates (firmware) are not always available to bring the IEDs within compliance to the revisions.

Many of these IEDs were developed and produced before there was a sense of urgency and concern regarding cyber security in the electric sector. Some IED "gateways" have been produced to address some of these gaps, but this is not a comprehensive solution in itself.

ACTION PLAN

The EPRI Cyber Security and Privacy program will address these gaps by:

- Creating cyber security mitigation strategies for legacy systems
- Developing transition strategies for legacy systems (covering pure legacy and mixed environments)
- Assessing of substation security solutions (remote access)

VALUE AND RISK

Many devices in the substation and in the field could be considered "legacy" in some fashion due to the rapidly changing technology of the electric grid. This effort will address numerous gaps to reduce the cyber security risk associated with these systems.

EPRI will leverage its experience and relationships with the vendor community, cyber security working groups, and standards bodies to gather the necessary requirements to enhance the cyber security features of current and future product offerings.

Further, EPRI is well situated to perform evaluations of various security solutions and architectures with the use of the Smart Grid Integration Lab. This lab will support an end-to-end network from the customer to the control center (including mixed environments of legacy and non-legacy devices) to evaluate emerging threats, mitigation approaches and migration strategies.

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Reduce Legacy System Risk	Cyber Security Mitigation Strategies for Legacy Systems								
	Transition Strategies for Legacy Systems								
	Assessing Substation Security Solutions								

Legend

EPRI Work

Other Stakeholders

Key Milestone

FUTURE STATE COMPONENTS

Cyber security research for energy delivery systems has primarily focused on the prevention and detection of cyber incidents. While these efforts are important for the protection of control systems, they do not prepare for the eventuality of a cyber incident. Energy delivery systems must also be resilient to cyber incidents and continue to perform critical functions while under duress and during the recovery process.

GAPS

To support cyber resiliency for energy delivery systems, several technical gaps need to be addressed. Unlike traditional IT systems, control systems are expected to be available and functioning 24/7/365. When a cyber incident occurs, systems cannot simply be quarantined or removed from service. Instead, fail-safe and fail-secure techniques must be developed and deployed, as well as tools to model and understand the ramifications of different response scenarios. Systems must also be capable of adapting to different and variable trust levels for components to maintain overall system functionality.

ACTION PLAN

The *Energy Cybersecurity Roadmap* identifies several research priorities for monitoring risk and supporting cyber resiliency for the electric sector:

- Using both cyber- and physical- state information in developing automated and assisted response capabilities
- Software architectures that can isolate the impact of exploited vulnerabilities
- Adaptive intrusion prevention system for more robust application to network and application
- Develop capabilities to measure the degree of resilience, including the cyber/physical impacts of a cyber incident

In the near-term, the EPRI Cyber Security and Privacy Program will support these priorities by examining risk management for cyber-physical attacks and supporting table-top exercises for responding to incidents. In the medium-term, EPRI will focus on decision support tools for responding to cyber incidents, tools and techniques to support cyber security forensics and techniques for verification of firmware/software integrity. At a later stage, EPRI will focus on developing architectures to dynamically address varying trust levels.

VALUE AND RISK

Cyber resiliency for energy delivery systems will increase the sector's ability to respond and recover from cyber incidents (malicious or non-malicious) in a more intelligent and predictive manner.

A combination of basic and applied research will be required to address the technical complexity of this issue. Additionally, vendors will be required to add several new features, capabilities, and (occasionally) hardware to their products.

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Manage Incidents			Adaptive Intrustion Prevention						
			Tools for Real-Time Cyber Security Forensics						
					Architectures for Dynamic Trust Levels				
				Cyber Decision Response Tools for Operators					

Legend

EPRI Work

Other Stakeholders

Key Milestone

FUTURE STATE COMPONENTS

Communications technology enables the bidirectional flow of information throughout the smart grid. The granularity, or depth and breadth of detail, captured in the information collected and the interconnections created by the smart grid are factors that contribute to the increased privacy concerns about the smart grid.

GAPS

More detailed data may be generated and aggregated through smart grid operations than previously collected with monthly meter readings. Although many of the tools and techniques that are applicable to cyber security are also applicable to privacy, there are differences in the requirements. The unique requirements related to privacy will require new tools and countermeasures. Currently, there is a lack of standard tools and techniques to perform analyses on aggregated data or to share the aggregated data with third-parties while ensuring that privacy concerns and privacy laws are not violated. Aggregated data will be used for planning and forecasting.

ACTION PLAN

This effort will build upon the work that is being done by the Smart Grid Interoperability Panel (SGIP) Cyber Security Working Group (CSWG), the American Bar Association Privacy Working Group, the Privacy by Design effort in Ontario, the North American Electric Standards Board (NAESB) Data Privacy Task Force, the European Commission task force on data handling, data safety, and consumer protection, and the National Institute of Standards and Technology (NIST) priority action plan on standardized energy usage data format. These programs are developing privacy use cases and recommending privacy practices. The technology required to store, aggregate, analyze, and protect energy usage data (and other personally identifiable information) needs to be identified and evaluated.

VALUE AND RISK

Currently, technology has focused on cyber and physical security requirements to address threats and vulnerabilities. Some of the technology also may be used to address privacy requirements. This effort will assess technology to achieve the following:

- Provide an assessment of technology that may be used in the storage, anonymization, aggregation, and/or analysis of privacy-protected energy usage data
- Develop models and heuristics for data aggregation and data anonymization
- Provide proposed alternative logical architectures for the privacy protection of energy usage data
- Include in the logical architectures the sharing of energy usage data with third-party service providers

The advocates of privacy rights represent a small but very vocal group. If privacy concerns for smart grid applications are not addressed, there is a risk that technology deployment could be slowed down by the threat of litigation or public relations problems. Additionally, the risks associated with violating state laws have already led to multiple vendors to leave the energy management service market.

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
End-User Privacy		Tools and Techniques to Support End-User Privacy							

Legend

EPRI Work

Other Stakeholders

Key Milestone

DRAFT: CYBER SECURITY AND COMPLIANCE FOR INSTRUMENTATION AND CONTROL SYSTEMS

FUTURE STATE COMPONENTS

Information technology (IT) security policies and practices are well-established and evolving; with professionals working to secure business networks while constantly increasing workplace productivity. Although industrial control systems (ICS) share much of the same type of computing technologies as business networks, security policies and practices must consider a different type of productivity requirement – safety and efficiency of process control. Control engineers are required to maintain, upgrade, and secure control systems while also optimizing their end use by plant operators. Cyber security standards compliance requirements must be met with efficient, continually improving cyber security program implementation that includes the use of technologies that are proven to improve security.

GAPS

Cyber security standards have been produced as a result of continual threats to business and process control networks. Many standards have been drafted, undergone revision, and are being enforced for compliance. In recent years, electric utilities have established cyber security programs to ensure compliance with the critical infrastructure protection (CIP) standards requirements of the North American Electric Reliability Corporation (NERC) and related requirements in the international community.

Compliance with these standards is not easy, and requires IT staff and control engineers to work together to implement and maintain a cyber security program for control systems. As part of establishing and maintaining a cyber security program, a variety of security strategies and technologies are needed to mitigate risk and react to new vulnerabilities while improving program efficiency.

ACTION PLAN

There are two priorities that need to be focused on to address these gaps. The first is examining various technologies and strategies for securing instrumentation and control systems. The focus is on solutions implemented within the fossil power industry, but solutions from other industries will also be considered. For each solution topic, it is necessary to study how the technology works, implementation options and best practices, field installations, and capabilities/limitations.

The second priority focuses on programmatic elements of a cyber security effort, and should develop industry best practices for the following:

- Program requirements
- Program elements
- Design and initiation
- Implementation and maintenance
- Standards compliance preparedness

This effort should also map various standards and guidance to NERC CIP – (ANSI/ISA99, NIST, ISO, etc.)

VALUE AND RISK

Cyber security strategies and technologies will reduce vulnerabilities of power plant control systems to malicious attacks that could cause disruption to electricity generation and damage to equipment. Technology-assisted early detection and prevention of cyber attacks will support reliable, safe, environmentally sound, and economic operation of critical generating units. Best practices based guidance will help utilities manage the growing cyber security program requirements without compromising key functionality and benefits of modern instrumentation and control systems.

There are a few risks associated with security and compliance of instrumentation and control systems:

- There is not a one-size-fits-all approach for selecting various technologies or designing/implementing a program
- Cultural barriers must be considered as part of a mindset biased towards security
- Functionality and ease-of-use considerations for operators might prohibit specific technologies from being implemented
- Already under-staffed generating units must deal with securing control systems while already struggling to keep up with workload

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Cyber Security for Instrumentation and Control Systems	Security Solutions for I&C Systems								
		Cyber Security Best Practices for I&C Systems							

Legend

- EPRI Work
- Other Stakeholders
- Key Milestone

ELECTRIC TRANSPORTATION AND ENERGY STORAGE

VISION

Electric transportation and energy storage have been recognized for over a century as important opportunities in improving the value of electricity to society. The electrification of transportation may result in reduced emissions, increased energy efficiency, greater reliability, and ultimately lower costs to consumers and businesses. Energy storage can be an effective method of adding stability, control, and reliability to the grid. Historically, these opportunities have been limited by the lack of cost-effective storage options that could compete with fossil fuels in the same applications. The availability of lower-cost, longer lived storage technologies, as well as changing economics for traditional transportation and grid technologies, has once again brought these opportunities to the fore.

But while the underlying technologies have come within reach, there is still some to go before electric transportation and energy storage options can match the reliability and cost-effectiveness of traditional options, which have had a hundred year head start. There is a need for continued research into the real world performance of storage technologies, as well as the path by which cost can be decreased through manufacturing scale experience, and how the opportunity will develop as the technology improves. The EPRI programs in Electric Transportation and Energy Storage are designed to facilitate the development of these technologies in ways that maximize the opportunities for the electric power enterprise and for society.

FUTURE STATE COMPONENTS

Transportation accounts for nearly 72% of petroleum consumption in the U.S., the majority of which is consumed by light-duty vehicles. While the efficiency of gasoline and diesel vehicles is improving, these gains are not sufficient to overcome both population increases and rising per capita vehicle usage. Plug-In electric vehicles, which include both battery electric vehicles and plug-in hybrid electric vehicles, represent a significant opportunity to reduce petroleum consumption, improve local air quality, and reduce CO_2 emissions.

- Plug-in electric vehicles will be widely available and represent a substantial portion of the vehicle fleet. By 2030, as many as 70 million plug-in vehicles may be on the road in the U.S. alone. The total cost of ownership of an electric vehicle will be significantly lower vehicles powered solely by gasoline or diesel fuels.
- Non-road electric transportation applications in commercial and industrial settings will have reach nearly full adoption due to significant economic and air quality benefits
- The electric power infrastructure will have adequate generation, transmission, and distribution capacity to meet all electric transportation requirements, without a substantial upgrade in capacity.
- Charging of plug-in vehicles will be accomplished in a safe and reliable fashion, primarily through residential and workplace charging, with regional networks of public chargers primarily for safety purposes.
- Smart grid-enabled plug-in vehicles will be widely used as grid resources, providing ancillary services and load control through managed charging; backup power to residences; and possibly even serving as energy storage resources.

GAPS

Plug-in electric vehicles have higher upfront costs than traditional vehicles, due to advanced battery and electric-drive component costs. Electricity is a significantly lower cost transportation fuel than gasoline, diesel, or any of the other alternatives. Plug-in vehicles can produce additional economic value through load management or the provision of ancillary services

- Data and understanding of electric drive technologies and systems, and their application. Many electric drive systems, such as plug-in vehicles, are relatively new and there is still relatively little information about how they perform, how they will be used, and what effects they will have.
- Methods for fully assessing and addressing the impacts on the electric grid from the substantial increase in load as the result of adoption of electric drive technologies.
- Definition and understanding of the equipment required to charge plug-in vehicles in a safe and cost-effective manner. Products such as plug-in vehicles can be widely deployed only with the appropriate infrastructure, which in some cases may not exist today.
- Identification and development of technologies that allow PEVs to be used as grid resources.

ACTION PLAN

Automotive manufacturers and their suppliers are a critical component in the success of plug-in electric vehicles. Collaboration is important to reduce vehicle costs and streamline the delivery of electricity to the vehicles.

- Collaborate with automotive manufacturers and drivers to assess present vehicle performance and usage, and create reasonable projections for future performance and assessments of costs and benefits of transportation electrification, which in turn will determine probable rates of market adoption as well as grid impacts
- Develop a sound methodology for assessing the impacts on the electric grid, as well as tools that can be used to determine how best to address such impacts
- Test and characterize electric vehicle supply equipment (EVSE) to determine the safest, most reliable, and most efficient ways in which vehicle charging can be accomplished
- Collaborate with industry in the development of appropriate standards and protocols for optimal performance and integration of vehicle, EVSE, and the grid
- Develop best practices for using plug-in vehicles as a grid resource

VALUE AND RISK

When the action plans are realized, the following values will result:

- Electric drive technologies will create opportunities for reduced emissions, increased efficiency, greater reliability, and lower lifetime costs to consumers and business

- The electric power infrastructure will enable opportunities for value creation through electric drive technologies, while maintaining high reliability, high asset utilization, and overall cost-effectiveness.
- A network of charging resources and technologies will enable the implementation of electric drive technologies in a safe, reliable, and cost-effective way.
- Plug-in vehicles will be available to utilities and system operators as aggregated grid assets, creating opportunities to lower the cost of operation and increase asset utilization without substantially increasing capital investment.

If the action plans are not realized, the following risks may occur:

- Increased distribution investment will offset increased asset utilization and other benefits of plug-in vehicles.
- Timely, accurate and verified information, technologies and best practices on electric drive technologies may not be available, creating uncertainty and inefficiency and possibly creating missed opportunities.
- Utilities may undertake costly deployment of infrastructure and other technologies by promoting non-standard approaches or by over-building, potentially resulting in 'stranded assets'
- Tools and information required to adapt to rapid changes in the industry may not be available to those who need it, leaving them unprepared to adapt
- The lack of information and tools may bias stakeholders to decide towards the status quo, meaning that substantial opportunities could be missed for improving efficiency, reducing emissions, and enhancing energy independence in the transportation sector.

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Plug-in Electric Vehicle (PEV) Technology	Vehicle Performance and Modeling								
	Battery Performance and Cost								
			Battery Post-Vehicle Secondary Use						
	Vehicle Power Train Research								
Plug-In Electric Vehicle Applications	Fleet Vehicle Applications for Electric Vehicles								
	Non-road Applications for Electrification								
		Consumer Use of Electric Vehicles							
Electric Vehicle Supply Equipment (EVSE)	EVSE Performance and Efficiency								
		EVSE and Smart Charging							
		Advanced EVSE: Fast Charging							
Grid Impacts of Vehicle Electrification	Distribution Impacts of PEVs								
		PEV Adoption and Load Forecasting							
Environmental, Economic, and Policy Issues	Enviromental Assessment of PEVs								
	Economic Assessment of PEVs								
	Policy Developments in PEVs								

Legend

- EPRI Work
- Other Stakeholders
- Key Milestone

FUTURE STATE COMPONENTS

Energy storage can be used in conjunction with other tools to reduce costs, increase reliability, and improve performance of the distribution network. To accomplish this, utilities must have access to cost-effective grid storage products that have a track record of safety and reliability, as well as well-understood performance.

Utilities also need analysis tools that enable the use of storage to effectively maintain the performance and reliability of the grid.

By "distribution level storage", we mean any storage system operating for localized or distribution level operation, rather than the operation of the bulk grid. Distribution level storage can include storage connected at the substation, on a feeder, or at the edge of the grid, possibly extending to some of the applications of storage that is installed on the customer side of the meter.

GAPS

The use of storage today is limited primarily by the high capital cost of storage technologies, which makes the use of alternative solutions more cost-effective than storage in most cases. Even in those cases where the use of storage is economically feasible, the relative scarcity of ready-to-connect storage products makes it a less attractive option for most utilities.

To address these limitations, the following technical gaps should be addressed:

- Storage technologies are generally too expensive, do not have long life, and are highly inefficient. For instance, today's lead-acid batteries cost over $300/kWh capacity and last less than 5 years in a cycling application. A system built from these batteries cannot be expected to release more than 65 to 70% of the energy used to charge them. This means that batteries are not cost-effective in the vast majority of utility applications.
- Grid storage product development is in its infancy. Even where batteries can be used cost-effectively on the grid, there are very few cost-effective products with a good track record on the market.
- Utilities do not have common procedures for siting, permitting and other grid deployment activities for storage, resulting in delays, higher expense, and sometimes costly mistakes.
- Present analytic tools do not accurately reflect the way storage is used or the way in which its direct benefits can be calculated, resulting in severe undervaluation of the technology in analyses, despite the fact that users who already own systems such as pumped hydro value them highly.

ACTION PLAN

- Define targets for storage technology performance and work with other research organizations to explore new storage technologies that have the potential to meet those targets
- Facilitate development of workable storage products through definition of common functional requirements, duty cycles, specifications, test plans
- Develop best practices for grid deployment of storage
- Create validated analytic tools and methodologies, with transparent data sets and models, that calculate the value of storage in specific distribution contexts with reasonable accuracy

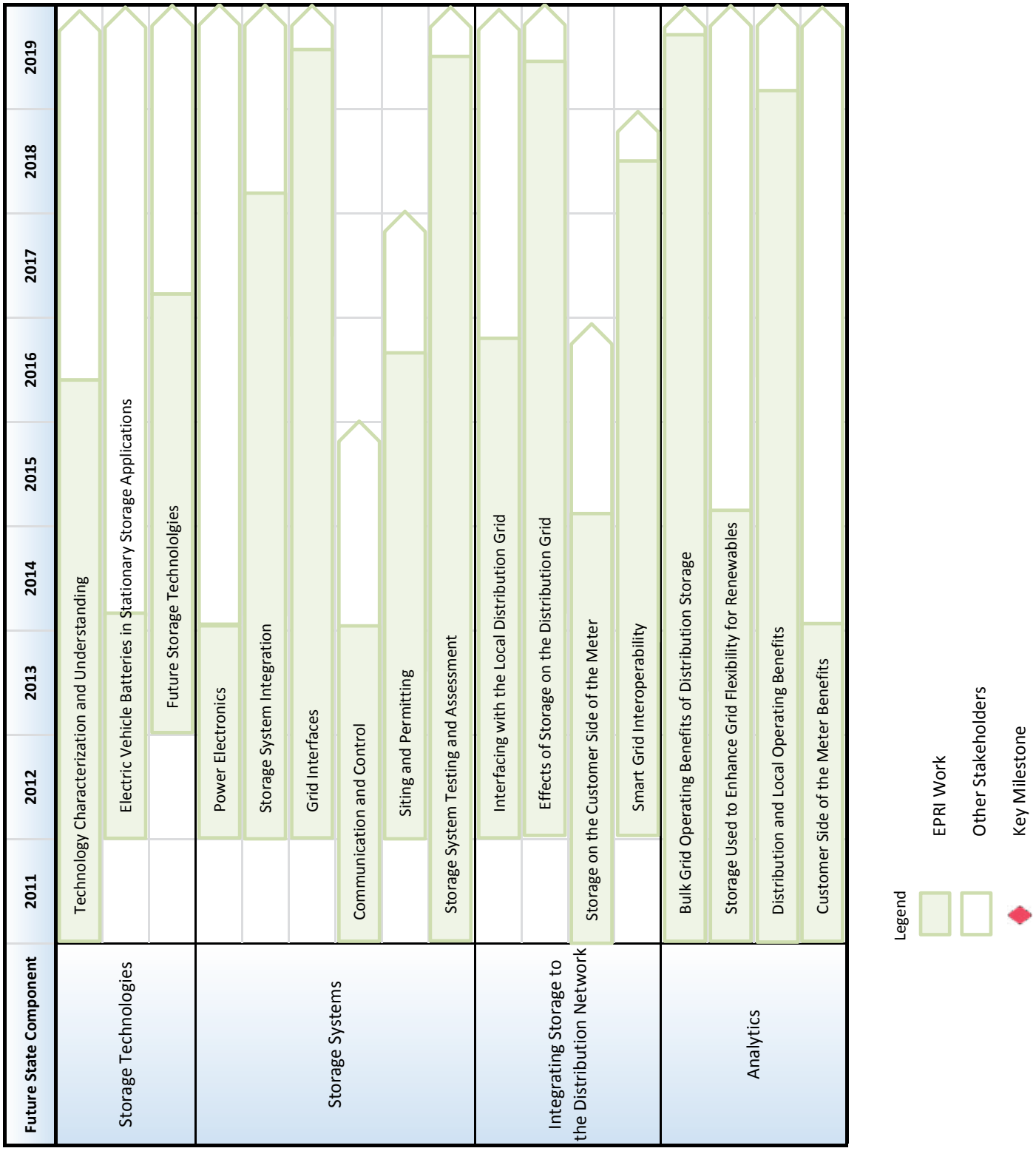
VALUE AND RISK

When the action plans are realized, the following values will result:

- Utilities will have practical options for distributed energy storage that will improve the reliability and flexibility of the distribution network.
- Utilities will have practical options to energy storage through the existence of a number of technologies that directly address the storage requirements in utility contexts.
- Utilities will have access to safe, reliable, "grid-ready" storage products with a reasonable track record that can meet utility needs
- Utilities will have common practices towards grid deployment that will reduce the cost and risk of storage deployment.
- Utilities and public utility commissions will have validated, transparent methodologies to help determine where storage is likely to be most valuable, and how it should be sized and deployed
- The owners of storage systems will be able to justify them economically through the proper allocation of indirect and residual benefits

If the research activities are not carried out, the following risks are evident:

- Timely, accurate and verified information on storage technologies and best practices may not be available, increasing uncertainty and inefficiency in selection and use of storage products
- Utilities may undertake costly deployment of storage infrastructure through promotion of non-standard approaches or through over-building, potentially resulting in 'stranded assets'
- Only a small number of "grid-ready" storage technologies and products may be available, limiting the options utilities have when implementing energy storage and possibly resulting in higher costs and reduced societal benefits
- Tools and information required to adapt to rapid changes in the industry may not be available to those who need it, leaving them unprepared to adapt
- The lack of information and tools will bias most stakeholders to decide towards the status quo, meaning that substantial opportunities may be missed to cost-effectively improve stability, control, and reliability on the grid.


Future State Component
2011
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Storage Technologies
Technology Characterization and Understanding
Electric Vehicle Batteries in Stationary Storage Applications
Future Storage Technololgies
Storage Systems
Power Electronics
Storage System Integration
Grid Interfaces
Communication and Control
Siting and Permitting
Storage System Testing and Assessment
Integrating Storage to the Distribution Network
Interfacing with the Local Distribution Grid
Effects of Storage on the Distribution Grid
Storage on the Customer Side of the Meter
Smart Grid Interoperability
Analytics
Bulk Grid Operating Benefits of Distribution Storage
Storage Used to Enhance Grid Flexibility for Renewables
Distribution and Local Operating Benefits
Customer Side of the Meter Benefits
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

Energy storage is an important potential flexibility resource for the bulk grid. With the potential to act as either load or generation, bulk storage can add substantial control to both sides of the energy balancing equation.

In principle, storage can also be used to shift energy generated at times of low demand to times of high demand, improving the utilization of renewable generation as well as other less controllable generation such as nuclear and combined cycle gas plants.

To accomplish this well, utilities must also have the analysis tools and, where applicable, an understanding of market structures that enable the use of storage to effectively maintain the reliability of the grid.

By "bulk storage", we mean any storage system operating to affect bulk-level operations for the grid, rather than local or distributed operations. Bulk storage can include large-scale systems such as compressed-air energy storage (CAES) and pumped hydro, as well as smaller systems used to provide flexibility to the grid (either through direct control or through market mechanisms)

GAPS

The capital cost of storage at present is very high. This, together with the relative inefficiency of the charge-discharge process, limits the ability to cost-effectively use storage to shift energy in time.

Bulk storage makes more sense as a flexibility resource on the grid, providing services such as frequency control, spinning reserve, and black start. However, storage is still expensive enough to limit these uses in most cases.

To address these limitations, the following technical gaps should be addressed:

- Storage technologies must be made much more inexpensive, ideally created from low-cost, ubiquitous materials, through simple construction technologies.
- Storage technologies must be long-lived. While technologies such as pumped hydro and CAES have the potential to be used for decades, many other technologies proposed for bulk storage use do not have such lifetimes.
- Storage technologies must be more efficient. Today's technologies have round trip efficiencies of less than 75%; many proposed technologies have efficiencies of less than 50%.
- Present analytic tools do not accurately reflect the way storage is used or the way in which its direct benefits can be calculated, resulting in severe undervaluation of the technology in analyses, despite the fact that users who already own systems such as pumped hydro value them highly.
- Present market mechanisms do not account for indirect and residual benefits of storage, such as reduced cycling loads on generators.

ACTION PLAN

- Define targets for storage technology performance and work with other research organizations to explore new storage technologies that have the potential to meet those targets
- Facilitate development of workable storage products through definition of common functional requirements, duty cycles, specifications, test plans
- Create validated analytic tools and methodologies, with transparent data sets and models, that calculate the value of storage in specific bulk grid contexts with reasonable accuracy
- Inform utilities and regulators on the magnitudes of indirect and residual benefits of storage that may play a role in the determination of whether storage makes sense in certain places and contexts.

VALUE AND RISK

When the action plans are realized, the following values will result:

- Utilities will have practical options for bulk energy storage that can be used to provide additional flexibility and control for the bulk grid.
- Utilities or other stakeholders will be able to use storage to shift energy from one time to another, allowing more efficient and effective operation of the grid.
- Stakeholders will have access to analytical tools and models that will allow them to accurately model the value for storage, along with the sensitivity to various parameters and an understanding of how the storage can best be operated.

If the research activities are not carried out, the following risks are evident:

- Timely, accurate and verified information on storage

technologies and best practices may not be available, increasing uncertainty and inefficiency in selection and use of storage products

- Utilities may undertake costly deployment of storage infrastructure through promotion of non-standard approaches or through over-building, potentially resulting in 'stranded assets'
- Only a small number of "grid-ready" storage technologies and products may be available, limiting the options utilities have when implementing energy storage and possibly resulting in higher costs and reduced societal benefits
- Tools and information required to adapt to rapid changes in the industry may not be available to those who need it, leaving them unprepared to adapt
- The lack of information and tools will bias most stakeholders to decide towards the status quo, meaning that substantial opportunities may be missed to cost-effectively improve stability, control, and reliability on the grid.

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Storage Technologies	Technology Characterization and Understanding								
			Future Storage Technololgies						
Storage Systems	Storage System Integration								
	Grid Interfaces								
	Communication and Control								
	Siting and Permitting								
	Storage System Testing and Assessment								
Integrating Storage at the Bulk Level		Interfacing with the Bulk Grid							
		Dispatching Storage							
Analytics		Bulk Grid Operating Benefits							
	Storage Used to Enhance Grid Flexibility for Renewables								

Legend

EPRI Work

Other Stakeholders

Key Milestone

END-USE ENERGY EFFICIENCY, DEMAND RESPONSE, AND CUSTOMER BEHAVIOR

VISION

Envision a future in which utilities employ the demand-side resources of energy efficiency and demand response – through enabling technologies in buildings, homes, and industrial facilities – as the first options to help maintain reliable and affordable electric service and reduce emissions. A future in which new homes and buildings are designed with energy-efficient principles, constructed with energy-efficient materials, and equipped with energy-efficient appliances to approach net zero energy consumption (in conjunction with on-site generation). A future in which existing homes and buildings are retrofitted with cost-effective envelope improvements and efficient end-use equipment to significantly reduce energy consumption. A future in which industrial facilities employ energy-efficient machinery, including adjustable-speed motive drives and electrotechnologies to reduce energy-intensity and lower operating costs while enhancing product quality, thereby improving competitiveness. A future in which homes and buildings are equipped with energy management control systems networked to smart end-use appliances to automatically and seamlessly adjust power demand based on utility or ISO price signals or event notifications in accordance with user preferences. A future in which consumers can view real time displays of their energy consumption on dedicated display devices, smart phones or other mobile device, and have the flexibility to adjust settings for comfort or economy or set preferences once and let the home energy management system work automatically, or let systems "learn" your preferences and optimize accordingly.

These constructs of the future are within the grasp of realization, but will not come to fruition on a meaningful scale without the concerted research, development, and demonstration (RD&D) efforts of the utility industry in conjunction with end-use device manufacturers, academia, and government. EPRI's research in end-use energy efficiency and demand response can play a pivotal role in assessing, testing, and demonstrating the technological and behavioral measures that can benefit consumers, businesses, utilities, and society.

DRAFT: HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)

FUTURE STATE COMPONENTS

Space conditioning – inclusive of cooling, heating, and ventilation (collectively labeled by convention as "heating, ventilation, and air conditioning" or HVAC) – represents fully one third of electricity use in homes and commercial buildings. It is also the principal driver of seasonal peak demand. More efficient methods of, and technologies for, space conditioning will vastly reduce energy intensity and peak demand in homes and buildings, particularly when coupled with more precise control technologies.

GAPS

Virtually all space cooling systems, and some space heating equipment, operate using a vapor compression process by which a circulating refrigerant fluid absorbs and rejects heat to provide cooling or heating. While ubiquitous, most vapor compression equipment operates at efficiency levels significantly below the governing thermodynamic limits of the Carnot cycle and also do not employ control technology that regulates operation without energy waste.

Success will be realized by R&D innovation in four key areas to *improve the efficiency of vapor compression equipment* for both central air and room device applications: 1) improved heat exchanger coil design and topology to provide more efficient heat transfer; 2) improved design of compressor systems to more efficiently pressurize and superheat the refrigerant fluid for the subsequent condenser and evaporator stages of the vapor compression cycle; 3) use of alternative, thermodynamically-favorable refrigerants to provide better media for heat absorption and transfer that are at the same time non-corrosive, chemically unreactive, and safe; and 4) application of superior controls technology for more precise equipment operation.

Additional technological gaps for which innovation can potentially yield considerable gains in energy efficiency include:

- Innovations in *integrated design of space conditioning and water heating systems* in buildings
- Innovations in *dehumidification technologies* have the potential to yield fundamental gains in energy efficiency through decoupling transfer of latent heat (humidity control) from sensible heat (temperature control) in buildings for specific regional climate zones, including dedicated air treatment systems.
- Disruptive space conditioning innovations, e.g., *thermoelectric cooling, vortex cooling, magnetic cooling, acoustic cooling*
- Integration of refrigeration with HVAC systems
- Innovations in integration and improvements of ancillary systems that will enable techno-economic viability of *ground-source (coupled) heat pumps*.
- Innovations in *heat-activated cooling* in buildings (such as absorption cooling using waste heat)

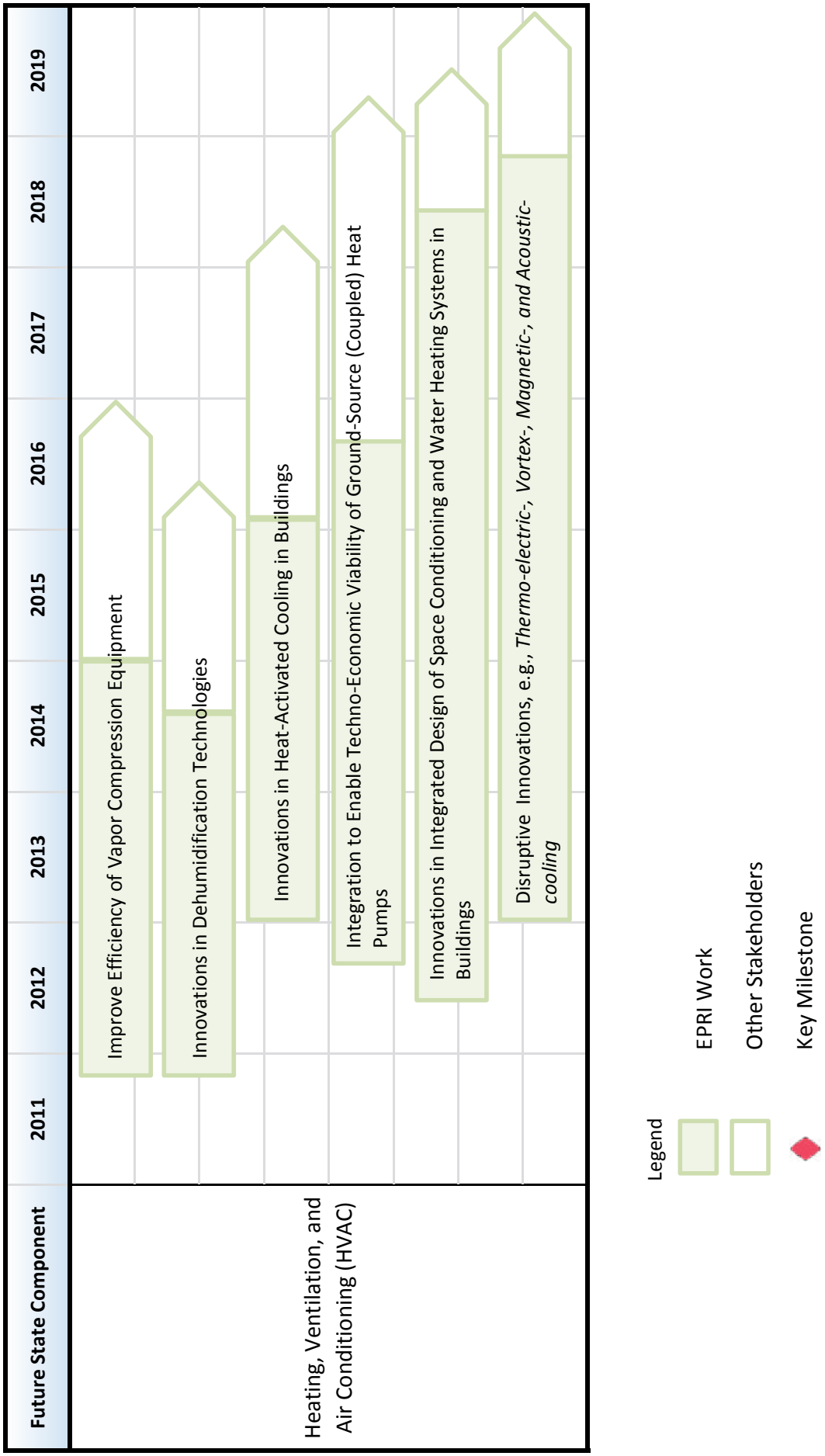
ACTION PLAN

The following activities can help close these gaps:

- Collaborate with technology developers, national labs, universities, etc.
- Conduct lab and/or field testing of HVAC applications employing micro-channel heat exchangers
- Determine relevant technology extensions into small and medium compressors
- Field evaluation of promising technologies
- Collaborate with technology developers to identify best technologies/applications for testing
- Conduct lab and/or field testing of systems incorporating magnetic compressors
- Identify existing and potential regulatory drivers affecting restriction of existing refrigerants and adoption of new/alternative refrigerants
- Lab/field tests of HVAC systems using alternative refrigerants
- Lab/field tests of systems incorporating advanced variable speed compressors

VALUE AND RISK

The value of these activities is the ability to capture significant energy savings and peak demand reduction, as HVAC is the single largest energy end-use category that also drives seasonal peak demand. If research is not conducted to address these gaps then significant potential energy savings risk being lost. Given that the 20+ year operational life of new HVAC equipment, delayed efficiency gains will take a generation to realize as the installed base of equipment turns over.


Future State Component
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Heating, Ventilation, and Air Conditioning (HVAC)
Improve Efficiency of Vapor Compression Equipment
Innovations in Dehumidification Technologies
Innovations in Heat-Activated Cooling in Buildings
Integration to Enable Techno-Economic Viability of Ground-Source (Coupled) Heat Pumps
Innovations in Integrated Design of Space Conditioning and Water Heating Systems in Buildings
Disruptive Innovations, e.g., Thermo-electric-, Vortex-, Magnetic-, and Acoustic-cooling
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

Water heating represents about 9% of energy consumed in U.S. buildings. The traditional method of heating water in a storage tank through an electric resistance element has reached its efficiency limits. The future of domestic- and commercial building- water heating lies in heat pump water heaters (HPWHs), that draw heat from the air or ground to attain efficiencies exceeding 200%, and potentially much higher. In this regard, heat pump water heaters represent a far more energy-efficient option that either electric resistance or gas tank or tankless water heating systems. Moreover, systems that integrate solar thermal design with heat pump water heaters can potentially yield even greater levels of energy savings for homes and buildings.

Additionally, in the future, efficient electric water heaters, including HPWHs, will have a communications link to the electric grid and will be used as "storage batteries" to shift peak load and provide ancillary services and help integrate intermittent renewable resources onto the grid.

GAPS

- Market supply gaps: lack of familiarity among plumbers and mechanical contractors on how to properly install, commission, and service HPWHs creates a disincentive for these point-of-sale market actors to carry HPWHs.
- Insufficient pace of technological innovation in the following areas impedes potential energy efficiency gains for HPWHs:
  - Compression design (such as oil-less compressors like magnetic bearing compressors)
  - Integrating HPWHs with solar thermal systems
  - Application of alternative refrigerants in U.S. market, including CO_2
- HPWHs that mitigate load peaking. The EPRI Energy Efficiency Demonstration has revealed that while HPWHs can yield significant energy savings, their peak reduction benefits are marginal at best due to operation of resistive backup. Overcoming this gap would vastly improve the value proposition of HPWHs
- Performance of systems that integrate space conditioning with domestic water heating
- Unknown how HPWHs will perform in grid-connected mode to provide demand response, including peak reduction, peak shifting, ancillary services, and renewable resource integration.

ACTION PLAN

Near term action plans include:

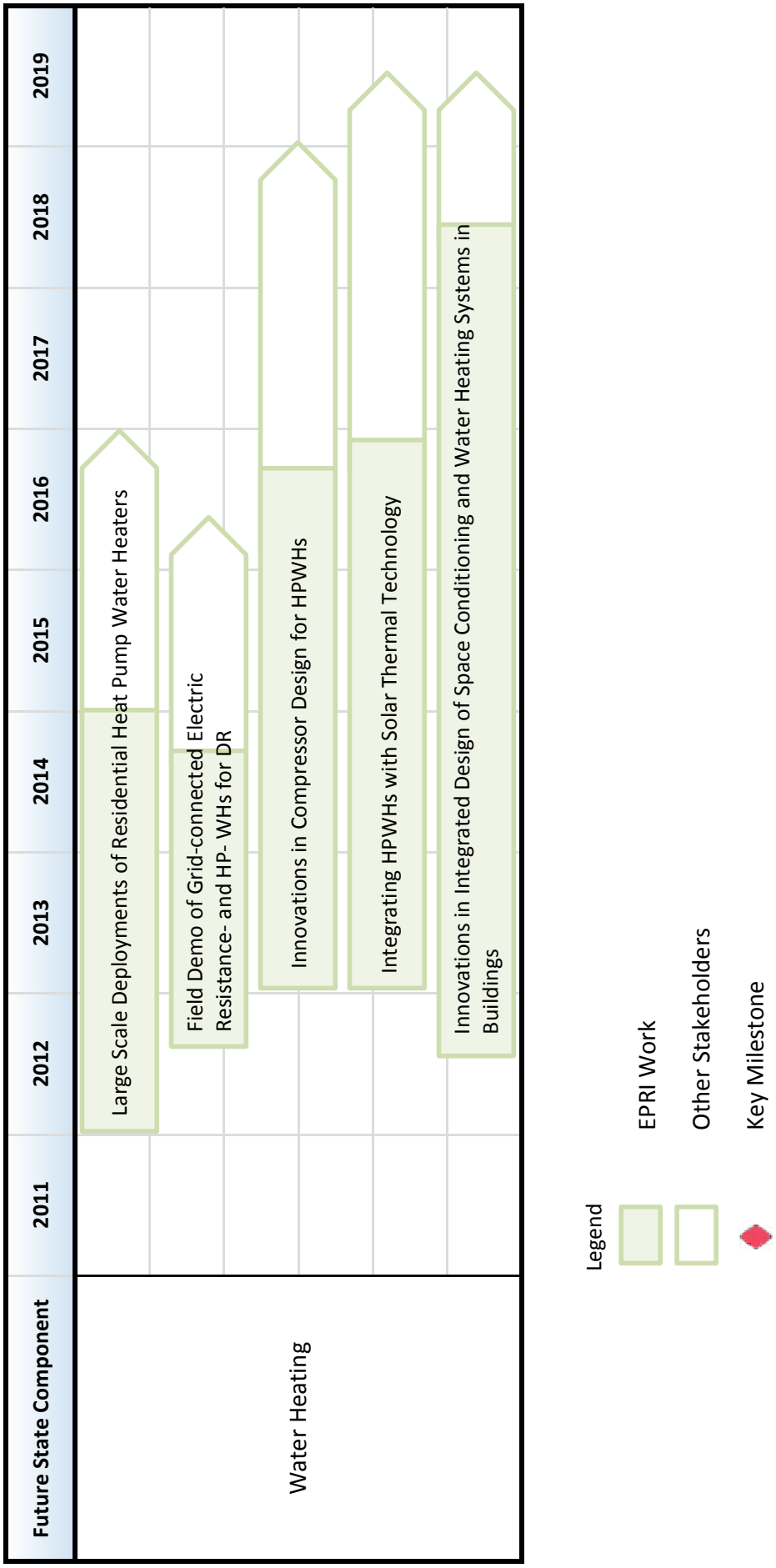
- Continued testing of state-of-the-art HPWHs
- Large scale deployments of heat pump water heaters to help mobilize the local supply chains of contractors and plumbers, and stimulate interaction with utilities to educate them on HPWHs
- Develop, test and deploy the next generation of higher efficiency HPWHs that also reduce peak demands
- Field demonstration of grid-connected smart water heaters and HPWHs for demand response, energy storage/renewable integration and ancillary services
- Further test and deploy commercial heat pump water heaters
- Investigation of CO_2 and other refrigerants for U.S. market

Key activities for the industry to conduct include:

- Determine relevant technology extensions into small and medium compressors for water heating applications
- Conduct lab and/or field testing of systems incorporating advanced variable speed compressors
- Identify potential of cutting edge solar thermal water heating technologies

VALUE AND RISK

Advancing heat pump water heater technology can yield significant energy savings. Following the action plan will improve the efficiency and lower the cost of heat pump water heaters, which will accelerate their market adoption. This action plan will validate the performance of HPWH equipment to reduce the uncertainty of the net benefits to hasten their inclusion into utility energy efficiency programs.


Future State Component
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Water Heating
Large Scale Deployments of Residential Heat Pump Water Heaters
Field Demo of Grid-connected Electric Resistance- and HP- WHs for DR
Innovations in Compressor Design for HPWHs
Integrating HPWHs with Solar Thermal Technology
Innovations in Integrated Design of Space Conditioning and Water Heating Systems in Buildings
Legend
EPRI Work
Other Stakeholders
Key Milestone

DRAFT: CONTROL TECHNOLOGY FOR DYNAMIC ENERGY MANAGEMENT

FUTURE STATE COMPONENTS

Advances in energy control technology in homes and buildings can enable *dynamic energy management* – automated adjustments in energy consumption based on dynamic factors such as occupancy, weather, ambient lighting, and, utility price signals and event notifications.

Energy management systems that integrate control technologies – such as advanced occupancy-, temperature-, humidity-, and daylight- sensors – along with utility pricing gateways can optimize operations to yield energy savings and more effective demand response. In this way, home- and building- owners can lower energy bills and reap economic incentives from demand response with minimal inconvenience to occupants.

The proliferation of such advanced control systems can make demand response a more ubiquitous and reliable resource for utilities to dispatch in lieu of supply-side resources to curb peak demand and even provide grid stability through ancillary services and renewable integration.

GAPS

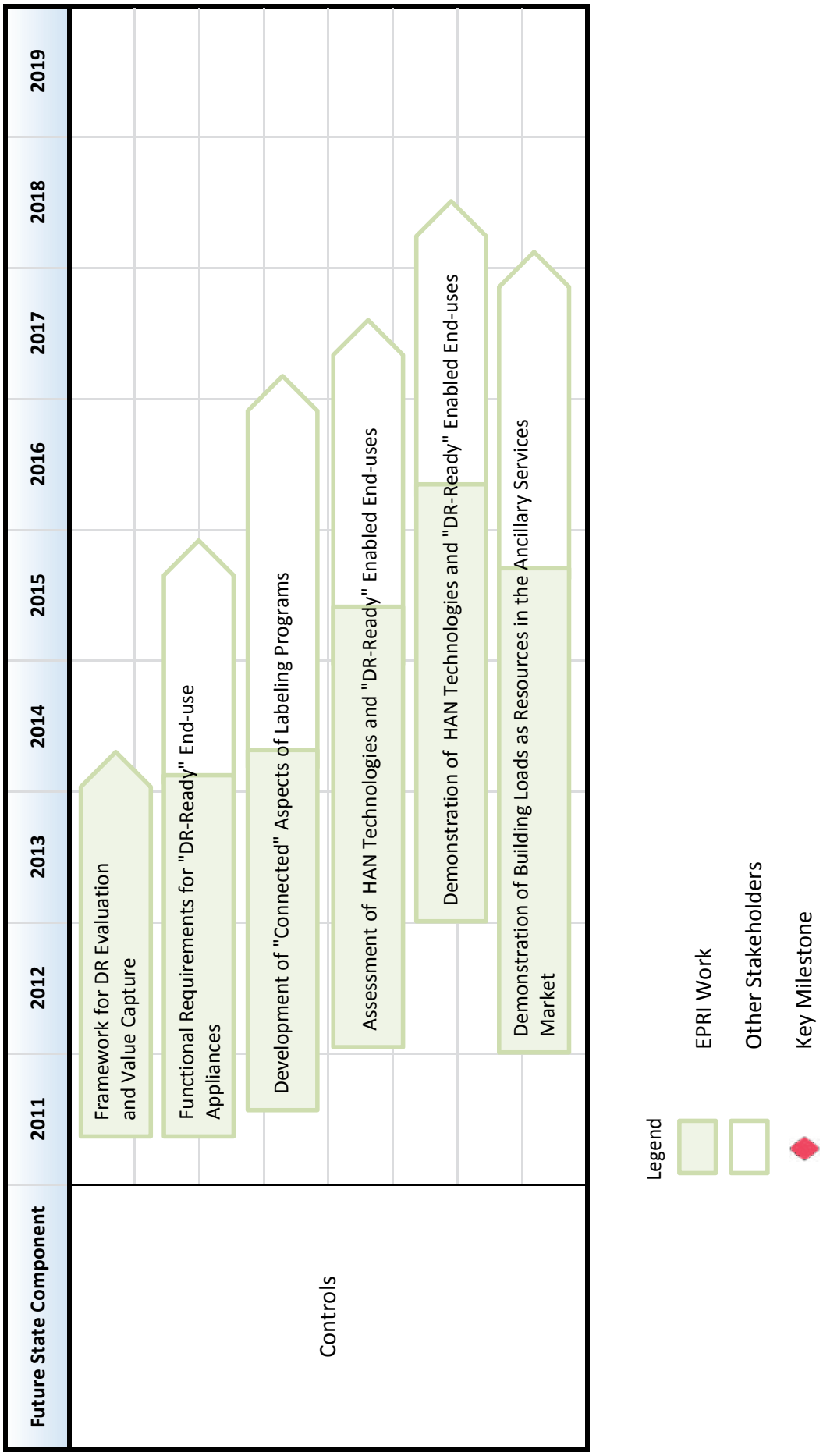
- Development of standardized communications protocols to convey grid system information, such as pricing signals or wholesale market conditions, to the customer premises. Despite significant progress, for example in the evolution of the OpenADR 2.0 protocol, no compliant devices are presently available.
- Development of standardized communications protocols for Home Area Networking (HAN), such as Smart Energy Profile 2.0. Without the acceptance and maturation of such communications standards building owners and home owners will continue to struggle with proprietary system choices that impede interoperability or scalability.
- In comparison to standard communications interfaces or communications gateways, the technical viability of a standard physical interface that decouples communications from end-use needs to be understood for different end-use categories, along with the implications of interface choice on demand response.
- Development of "DR-Ready" definitions, capabilities, and functional requirements by end-use category. These should reflect the perspectives of utilities and manufacturers, serving as precursor to DR-Ready product designation in the market. That, in turn, would make demand response a more automated and ubiquitous resource.
- Capability of building loads to be utilized as resources in the ancillary services market for frequency control or to balance the intermittency of renewable resources on the grid.

ACTION PLAN

- Develop assessment framework connecting DR provisions in retail contracts to factors of sustainability (e.g., DR drivers and grid needs). Apply framework to reveal signaling and other requirements supportive of specific grid needs, and to scope sustainable DR implementations for demonstration and deployment.
- Gather and prioritize utility requirements for DR applications to meet grid needs. Clarify level of automation and reliability required in various applications that may leverage HAN and DR resources, with respect to grid needs including grid security. Extend DR Ready focus to HAN devices.
- Test and demonstrate viability of standard physical interface, standard communications interface, and communications gateway to enable DR capability by end-use category.
- Assess DR actuation and control methods against collected requirements. Identify suitability of methods and areas of critical gaps. Devise recommendations for filling critical gaps, especially in areas where the manufacturers may be slow to act on own.
- Conduct industry workshops to identify issues and build collaborative bridges to support crossing the chasm in the market development cycles for HAN and DR-Ready technologies.
- Demonstrate select HAN technologies in the lab and field settings in operation with DR-Ready technologies for demand responsiveness and enhanced customer choice

VALUE AND RISK

Concerted industry research and development in control technology can enable more automated, cost-justifiable demand response and dynamic energy management, which can enhance customer choice and support grid needs, thereby improving the viability of demand-side resources and sustainability of DR implementations.


Future State Component
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Controls
Framework for DR Evaluation and Value Capture
Functional Requirements for "DR-Ready" End-use Appliances
Development of "Connected" Aspects of Labeling Programs
Assessment of HAN Technologies and "DR-Ready" Enabled End-uses
Demonstration of HAN Technologies and "DR-Ready" Enabled End-uses
Demonstration of Building Loads as Resources in the Ancillary Services Market
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

A new wave of advanced lighting technologies – such as solid-state (e.g., LED), electronic high-intensity discharge (HID), and micro-HID plasma – are on the path to widespread market entry in part because of federal standards embedded in the Energy Independence and Security Act of 2007. These advanced sources hold the promise of high efficacy, in terms light output (as measured by lumens) per unit of input power. With dedicated industry R&D, the *total performance* of these lighting sources – including photometric/optical, electrical, thermal, and mechanical properties – will be fully vetted prior to widespread market adoption, such that these lighting sources will perform reliably and up to customer expectations while delivering expected energy savings.

Advanced energy-saving lighting technologies—improved efficacy incandescent lamps, CFLs, LEDs, OLEDs, electron-stimulated luminescence (ESL), induction, electronic HID, micro-HID plasma, DC lighting, etc. – will also feature integrated intelligence that enables dynamic, seamless dimming control of light output in response to a variety of stimuli, including ambient light levels and utility/ISO price or grid event signals, in conformance with user preferences. Moreover, advanced lighting technologies will demonstrate the smooth dimming profile to which consumers have become accustom with incandescent lamps, and will provide energy savings and stable illumination over the dimming range.

Finally, buildings will be designed and constructed to make optimal use of available daylight, through daylight harvesting technologies and passive solar design to reduce the need for electric lighting technologies – which themselves will have higher efficiencies.

GAPS

Improve *photometric and optical properties* of advanced lighting technologies, including:

- Lamp and system efficacy
- Luminous flux (lumens)
- Illuminance (lux, foot-candles)
- Lumen depreciation
- Flicker
- Color performance: color rendering index (CRI), correlated color temperature (CCT)
- Color shift
- Glare

Improve *electrical properties* of advanced lighting technologies, including:

- Electronic efficiency
- Energy performance
- Immunity to electrical and electromagnetic disturbances
- Power quality grid impact
- Reliability and product life
- Interference control
- Power on/off cycling

Improve *thermal properties* of advanced lighting technologies, including:

- Operating temperature range (high- and low- temperatures)
- Thermal cycling
- Component thermal performance
- Heat transfer
- Ambient rating of: (a) fixture; (b) electronics package (e.g., ballast, driver, generator); (c) lamps (fluorescent, HID, and solid-state)
- Heat sinking of light sources and electronics
- Thermal hot spot analysis on product cases (metal and plastic)

Improve *mechanical properties* of advanced lighting technologies, including:

- Mounting of optics lens and diffusers
- Vibration rating
- Mounting of electronics package
- Weight
- Size
- Corrosion resistance

Identify *daylight harvesting* technologies and applications that can yield significant energy savings, including:

- Light pipes
- Mirrored ductwork
- Skylights

Identify techniques and applications for integrated passive solar design that can optimize use of daylighting and yield significant energy savings for new building construction.

ACTION PLAN

The activities that would be required to bridge these gaps include:

- Independent lab and field testing for photometric/optical, electrical, thermal, and mechanical performance
- Information-sharing between independent test facilities, lighting manufacturers, and utilities on product performance
- Develop high-efficiency power factor correction for all electronic lighting
- Disseminate results to inform standards bodies for lighting efficiency and performance, including: American National Standards Institute (ANSI) US Environmental Protection Agency (EPA), Institute of Electronics and Electrical Engineers IEEE), Illumination Engineering Society (IES), International Electrotechnical Commission (IEC), International Commission on Illumination (CIE), and Emerge Alliance
- Development of improved heat-sinking techniques
- Testing and development of mounting and subsystem packaging techniques
- Develop measurement instruments and techniques

Lighting Controls

- Independent lab testing of dimming performance
- Development of improved efficiency across dimming range
- Assessment of compatibility between lighting controls and communications protocols for home or building area networks, such as Smart Energy Profile 2.0
- Field testing of lighting control systems for demand response (DR) applications

Daylight Harvesting

- Independent lab and field testing of daylighting technologies and techniques
- Development of lighting controls and daylighting as an integrated package

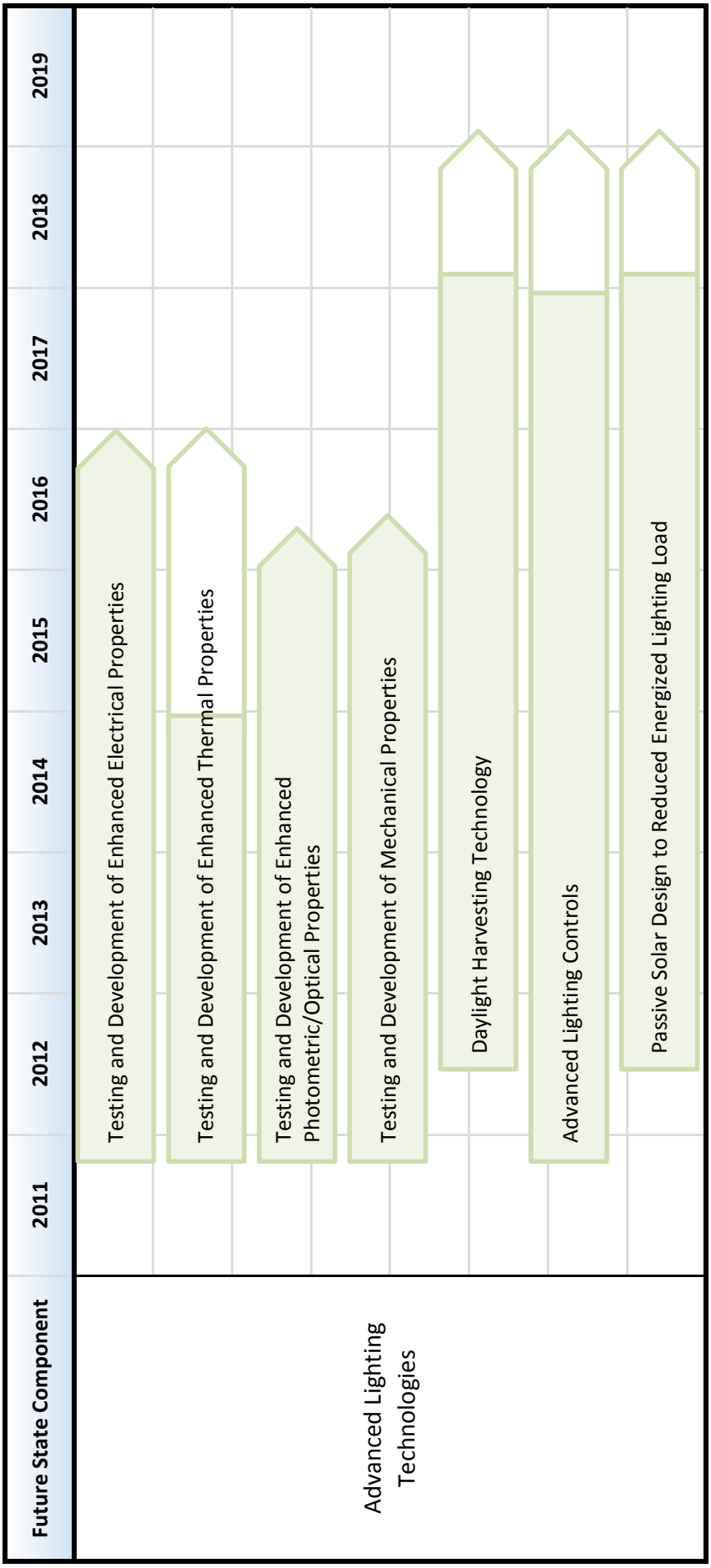
Integrated Passive Solar Design

- Coordination with industry and government experts, domestic and international, including US Department of Energy (DOE) Building America program and its Consortium for Commercial Buildings, manufacturers, designers, and building construction specialists

VALUE AND RISK

If lighting performance is too narrowly defined by efficiency and efficacy alone, then total lighting product performance may be overlooked, leading to sub-optimal performance in the field and disappointed customers.

For example, some advanced lighting technologies cannot be used in facilities exhibiting a wide variation in ambient temperature that can lead to premature failure and customer frustration causing customers to return to the lower-efficiency and non-controllable lighting technologies. Other advanced lighting products do not exhibit the smooth dimming profile that customers expect. Significantly, some advanced lighting products are more susceptible to electrical and electromagnetic disturbances, which can adversely affect product life, or even propagate such disturbances to affect other devices. Accelerating the availability and performance of advanced lighting technologies through testing, demonstrations, and coordinated deployments that qualify the technologies' photometric, electrical, thermal and mechanical, and properties will advance customer acceptance and deployment of these energy saving devices.


Future State Component
2011
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Advanced Lighting Technologies
Testing and Development of Enhanced Electrical Properties
Testing and Development of Enhanced Thermal Properties
Testing and Development of Enhanced Photometric/Optical Properties
Testing and Development of Mechanical Properties
Daylight Harvesting Technology
Advanced Lighting Controls
Passive Solar Design to Reduced Energized Lighting Load
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

Building owners and occupants can realize benefits from automated and ubiquitous building energy management control systems, including savings from integrated occupancy-, temperature-, and daylight sensors that optimize energy usage, and the ability to more effectively participate in utility demand response events, capturing economic incentives while minimizing occupant inconvenience. Control systems can also provide continuous commissioning – the practice of keeping equipment and systems at their design status—as well as optimized operations – the practice of operating the building optimally for energy savings and comfort/productivity, considering weather, season, time of day, occupancy, and other variables.

The availability and application of such control systems requires improved sensors and standard (open) communications protocols to convey both utility signals (such as pricing or grid conditions) to the building premises and to instructions between control devices within a building.

The integrity of a building's thermal envelope is the foundation of its overall energy efficiency. While a building's design, stock of energy-consuming equipment, and presence of control devices affect its energy intensity, the primary determinant of building efficiency is performance of building materials and shell measures to provide a thermal buffer – such as walls, doors, windows, ceilings, roofs, attics, associated insulation, and weather-sealing. A tighter thermal envelope minimizes HVAC loads and helps "right-size" equipment for HVAC as well as on-site generation such as photovoltaics.

Innovations in building shell measure materials, including thermally-resistive insulation and embedded phase-change materials in wallboards to better absorb heat transfer, hold the promise of significant energy savings.

Compounding the issue, the path to market for fundamental advances in more thermally efficient building shell measures lacks a natural pull from end-users. The willingness of building materials fabricators to invest the R&D in more efficient materials depends on the willingness of architects, engineers and contractors to specify, design and build with these new materials. Demonstration of inherent lifecycle economic benefits can increase that willingness.

GAPS

Advances in construction materials for more thermally resistive insulation, wall-boards, windows, etc. can yield significant energy savings in new building construction, while retrofit improvements to the thermal envelope can also yield energy savings in existing buildings.

Innovations in integration of energy efficiency with other disciplines can help attain the goal of (near) zero energy buildings espoused for federal buildings and by several states. Areas for integration may include, but not be limited to:

- Energy-efficient equipment, building design, and building materials
- Energy management controls (i.e., enabling DR, continuous commissioning, optimized operations, and equipment fault diagnostics)
- On-site renewable resources
- Energy storage
- DC power distribution
- Innovations in energy management control technologies and can yield energy efficiency improvements through building automation, e.g.:
  - Sensors
  - Software (control algorithms)
  - Communications protocols (standardization)

Just as significant, the industry lacks software tools sophisticated enough to simulate the performance of innovative building shell measures in occupied buildings while accounting for the interactive effects of building design, local climate, and stock of end-use equipment.

ACTION PLAN

Field Evaluation of Advanced Building Materials – Thermal Envelope

- Phase-change wall-board materials for efficiency and peak shifting.
- Thin, R-value insulation materials that eliminate thermal bridges in wall framing and fastening systems (aerogel materials, etc.).
- Fast perimeter air sealing techniques for new and retrofit applications; recyclable, easy to use foam packs, etc.
- Very high R-40+ sealed attic insulation/roof replacement retrofit strategies for existing homes for hot/dry climates with A/C and ducts in attic.
- Durable, R-30+ wall systems (framing, vapor retarder, insulation, drainage plane) rated as a complete system, rather than a series of components. Needs to address thermal, moisture, air, structural, and bugs. Insulating

wall sheathing that eliminates the need to use oriented strand board for structural purposes (structural external insulating sheathing). Efficient siding attachment systems for use with thick insulating sheathing. Lower-cost structural insulating panels

Zero-Net Energy Building Design and Development

- Coordination with industry and government experts domestic and international, including DOE Building America program and its Consortium for Commercial Buildings, manufacturers, designers, and building scientists and construction specialists
- Conduct gap analysis with particular emphasis on integration of a high penetration of near zero net energy buildings with the distribution system, and opportunities for demand response to help utilities fully realize system benefits from net zero energy buildings
- Field testing and demonstration of efficient, smart grid-(demand response-) capable HVAC equipment and appliances with integrated diagnostics
- Capability of smart meter interval data to reveal the extent (on average) to which the customer is participating in load management programs.
- Field testing and demonstration of whole-house, occupancy-based energy control systems with integrated thermostat, ventilation, lighting, home office, peak electricity demand, home entertainment control, whole-house sleep mode, and low standby power requirements (self-powered wireless) with standardized dashboard allowing for centralized viewing and control of all electricity and with the ability to program appliance use
- Improved occupancy sensors (reducing false positives and negatives) for plug, HVAC zoning, and lighting control. Technical and economic performance of community scale vs. building scale energy storage systems
- Field trials and evaluation performance of DC power distribution in residential and commercial buildings (EPRI, Emerge, LBNL)
- Develop DC power distribution standards (EPRI, Emerge Alliance, LBNL)
- Develop new power electronics (GaN) devices for DC - DC breakers, GFCI, rectifiers and power supplies (EPRI, Fairchild Semiconductor)
- Demonstrate real-time monitoring and control hardware and software to manage the building cooling resources to ensure the temperatures remain within preset limits throughout the building, while simultaneously reducing cooling energy requirements.

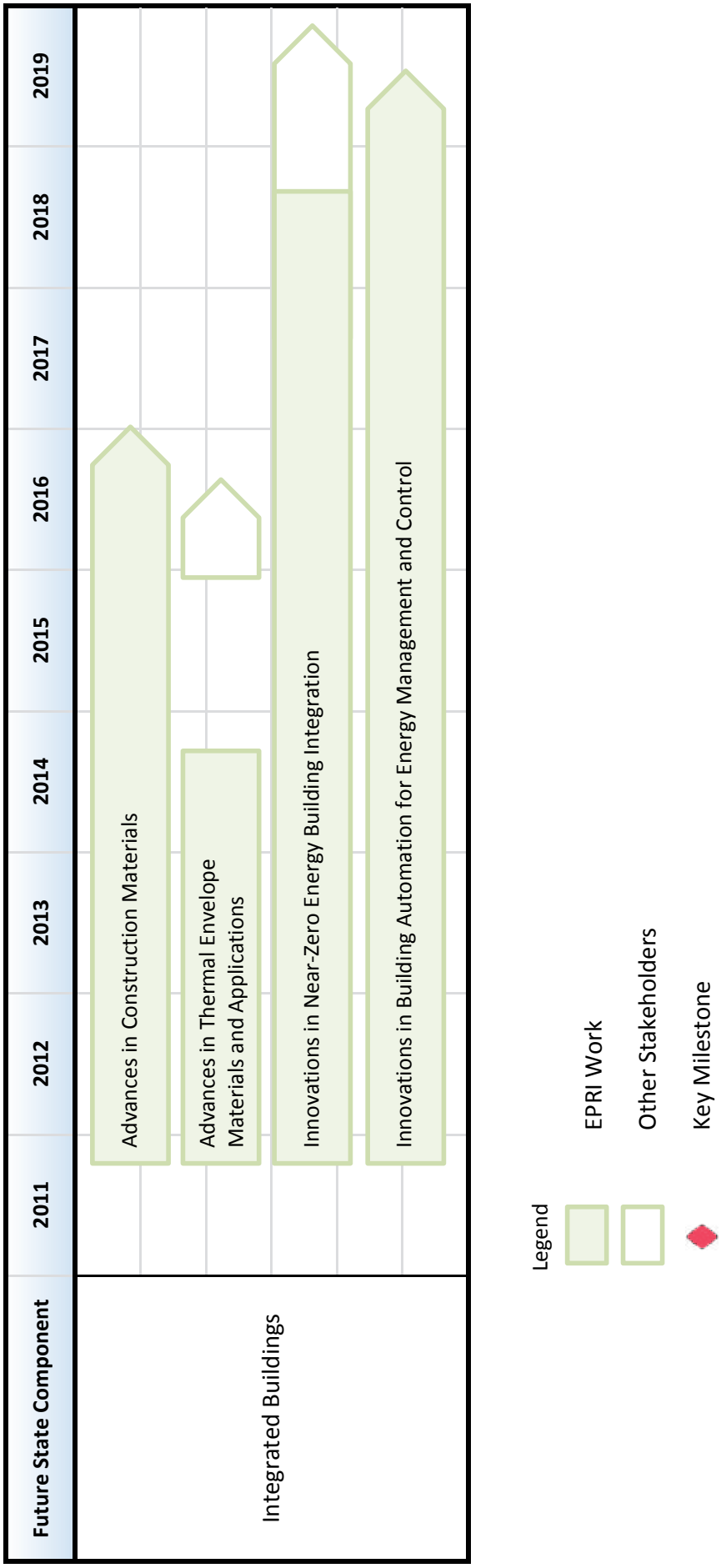
VALUE AND RISK

Integration

The value of integration is that it brings the technology developments, such as controls, sensors, and efficient equipment, together to optimize energy use and reduce consumer bills while meeting consumer productivity and comfort needs. However, to achieve ubiquity, a standard approach needs to be proven and accepted by the industry. Consumers needs to accept the integrated technology or service in order to achieve significant energy savings.

Building Controls

Without open communications standards, building owners will continue to struggle with proprietary system choices that impede interoperability.


Future State Component
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Integrated Buildings
Advances in Construction Materials
Advances in Thermal Envelope Materials and Applications
Innovations in Near-Zero Energy Building Integration
Innovations in Building Automation for Energy Management and Control
Legend
EPRI Work
Other Stakeholders
Key Milestone

DRAFT: CONSUMER ELECTRONICS AND POWER ELECTRONICS IN END-USE DEVICES

FUTURE STATE COMPONENTS

Consumer electronics represents the fastest growing segment of electricity consumption in the residential sector. The past decade has seen a proliferation in the number and variety of electronic devices that are plugged in to charge and operate in the home. Many of these devices are very energy-intensive, such as gaming consoles, large screen high-definition televisions, set-top boxes, and home theater audio systems. Two set-top boxes consume as much electricity in a year as a typical refrigerator.

Moreover, the explosion in number of smaller electronic devices that are charged in the home, including smart phones, tablets, and mobile gaming devices, when aggregated represents significant energy consumption.

With regard to energy, consumer electronics have the following generally in common. First, their energy-efficiency is driven by the efficiency of their internal power supplies, and since most devices are geared for high performance and user experience efficiency is typically not a primary design priority. Second, compared to more established end-use categories such as refrigerators or air conditioners, efficiency standards are not mature and even ENERGY STAR labeling is at the early or emerging stages. As a result, there is high upside for energy efficiency gains in the consumer electronics category.

With the benefit of concerted industry R&D, the next generation of consumer electronics will have improvements in energy efficiency to match the innovations in product features and functionality, which will not compromise the user experience.

GAPS

Technological advances that can improve the active-mode energy efficiency of consumer electronics. Examples include, but may not be limited to:

- Power supply efficiency
- Displays
- Component materials and design
- Motherboard materials and design
- Microprocessor materials and design
- Advanced semiconductors, e.g., silicon carbide (SiC) and gallium nitride (GaN)

Technological advances that can improve the passive-mode energy efficiency of consumer electronics. Examples include, but may not be limited to:

- Integrated sleep-mode applications with standby configurations
- Charging modes (wireless charging, etc.)

Technological advances that can improve process efficiencies through the use of electronics. Examples include, but may not be limited to:

- Adjustable Speed Drives for motor driven processes
  - Washers
  - Dryers
  - Refrigerators
  - Furnace fans
  - Pool pumps
  - HVAC fans, compressors
  - Various industrial motor loads
- Process controllers
  - Gravity feeders
  - Weight measurement

ACTION PLAN

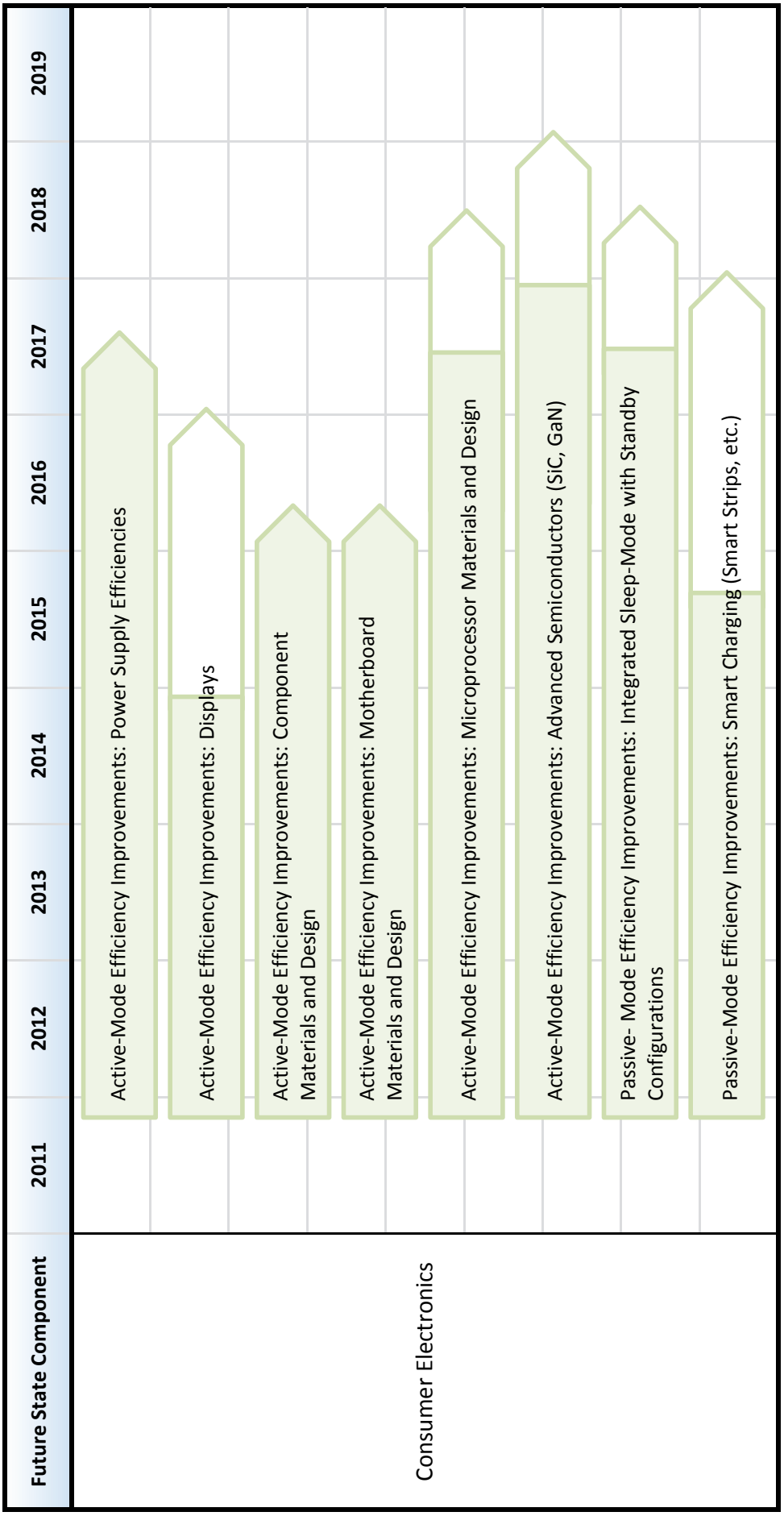
A progressive RD&D agenda can improve the energy efficiency of end-use electronics without diminishing the consumer experience. Steps of overcome the gaps include:

- Enable the development and assessment of novel power supply applications using advanced materials for switches. (EPRI, Fairchild)
- Work with ITIC and CEA on expanding the product list for the 80PLUS program.
- Develop applications that control switching frequency with load (EPRI, Fairchild)
- Develop GaN based motor drives for appliances (International Rectifier, EPRI)
- Independent lab and field testing of above developments
- Develop baseline efficiency database for networking equipment power supplies to inform utility incentive programs

- Develop high efficiency gaming systems (EPRI, ECOS)
- Develop high efficiency kiosk and low end computing devices (EPRI, ECOS)
- Develop right-sized synchronous rectifiers for power supplies (EPRI, Georgia Tech)
- Develop charging techniques to minimize standby losses
- Develop wireless charging techniques to minimize standby losses
- Field trials of memristors

VALUE AND RISK

If the energy efficiency of consumer electronics does not keep pace with innovations in product features then utilities risk forgoing significant energy savings opportunities.


Future State Component
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Consumer Electronics
Active-Mode Efficiency Improvements: Power Supply Efficiencies
Active-Mode Efficiency Improvements: Displays
Active-Mode Efficiency Improvements: Component Materials and Design
Active-Mode Efficiency Improvements: Motherboard Materials and Design
Active-Mode Efficiency Improvements: Microprocessor Materials and Design
Active-Mode Efficiency Improvements: Advanced Semiconductors (SiC, GaN)
Passive- Mode Efficiency Improvements: Integrated Sleep-Mode with Standby Configurations
Passive-Mode Efficiency Improvements: Smart Charging (Smart Strips, etc.)
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

IT/Internet data centers are the most energy-intensive subset of buildings on a kWh per square foot basis – 20 to 30 times more energy-intensive than a typical office building and 100 times more energy-intensive than a typical residence. Today, data centers are estimated to consume approximately 100 billion kilowatt hours (terawatt hours) of electricity per year globally. Experts project that electricity consumption in data centers could double every five years, at which rate data centers would represent 20% of total U.S. electricity use by 2030.

Large, new stand-alone data centers (for example Apple, eBay, Facebook and Google) are usually extremely efficient but account for less than 1% of all data centers. The other 99% of data centers are buried within commercial office buildings and are not operating as efficiently.

Based on current technology, only 40 watts of every 100 watts of electricity delivered to the data center is actually utilized for computation – the rest is used to cool equipment or lost in multiple conversions between alternating-current and direct- current across equipment power supplies.

Data centers of the future, though concerted industry partnership in R&D, will feature improved thermal performance through systems that optimize airflow management, high-efficiency computer room air conditioners (CRACs), and techniques to capture waste heat from devices and components, to yield considerable energy savings.

In addition, data centers of the future will feature highly efficient power supplies. Moreover, data centers of the future will operate on a standard direct current (DC) bus that provides DC power from the point of service entry through the server without the following conversions, thereby reducing the energy losses associated with each conversion:

- Uninterruptable Power Supplies 88–92% Efficient
- Power Distribution 98–99% Efficient
- Power Supplies 68–75% Efficient
- DC to DC Conversion 78–85% Efficient

In addition, all the lost energy has to be cooled. This is typically done with air conditioning requiring 1,000 watts for each ton of cooling, typically at an efficiency of 76%.

GAPS

Technologies and techniques that can significantly improve the energy efficiency of data centers, reduce their heat load, and increase their productivity, include:

- Air-flow management improvements
- DC power distribution to reduce AC/DC conversion losses
- "Heat pipes" to capture and utilize waste heat from electronic devices and components
- Better uninterruptable power supply efficiency/design
- Application of virtualization software
- Establishment of standard metric for data center efficiency
- Establishment of standard metric for data center efficiency
- Integration of facility and computer equipment infrastructure management
- Improved server and storage array power consumption
- Improved cooling for servers

ACTION PLAN

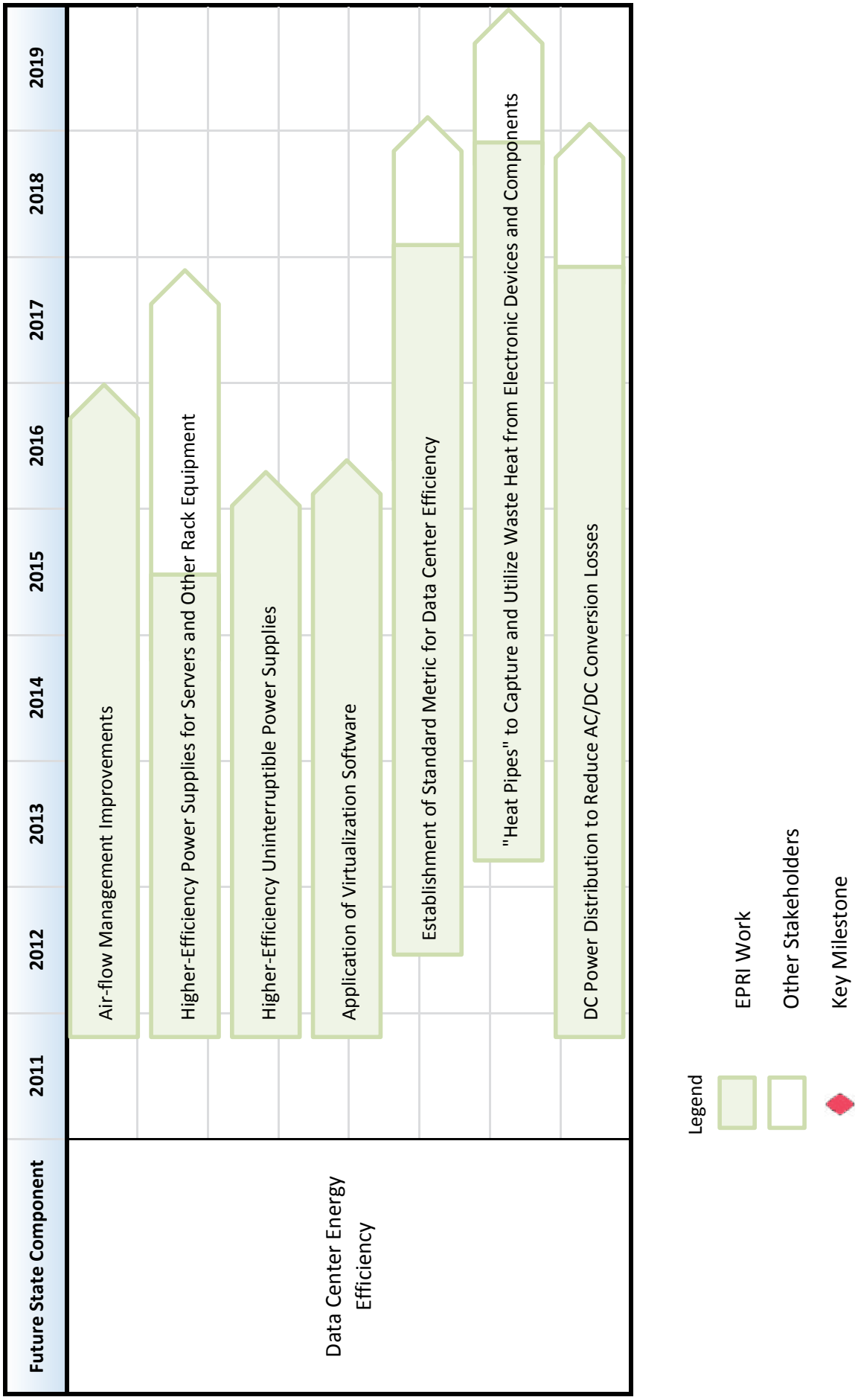
The following progressive agenda of industry R&D can bridge the identified gaps:

- Continue field trials of automated air flow management techniques (EPRI, LBNL)
- Use results to inform utility incentive programs (EPRI)
- Develop DC power distribution standards (EPRI, Emerge Alliance)
- Develop baseline efficiency database for UPS (EPRI)
- Test and verify adequacy of ECO mode UPS
- Provide estimate of energy savings potential from ECO mode UPS (EPRI, vendors)
- Develop standard metric for data center efficiency that reflects improvements in server efficiency (EPRI, Green Grid)

- Lab and field testing for liquid cooling techniques (heat pipes, immersion) (EPRI)
- Establish viability of vibration suppression as efficiency measure for HDD (EPRI)
- Lab testing to compare best HDD with Solid state drives (EPRI)
- Lab and field testing of improved conversion devices (server power supplies, rectifiers) using GaN FETs (EPRI, Fairchild)
- Develop new power electronics (GaN) devices for DC power distribution - DC breakers, GFCI, rectifiers and power supplies (EPRI, Fairchild Semiconductor)
- Coordination of energy efficiency research effort from individual and consortia of IT companies (EPRI, Green Grid, Intel, AMD, HP, Oracle, IBM, EMC)
- Server-on-a-chip prototype performance testing (EPRI, HP)
- Migration of "mobile" product technologies into data center environments to utilize the energy efficiency benefits designed to extend battery life
- Field trials of new building controls methodologies within data centers (EPRI, Johnson Controls)
- Lab testing of the highest efficient power supplies to determine what features could be used to spread this benefit to other applications and products (EPRI, Delta, Emerson)
- Field trials of memristors (EPRI, HP)

VALUE AND RISK

If this agenda of industry R&D is not undertaken, the electricity consumption of data centers may grow unabated to very high levels, increasing exponentially in relationship to the projected geometric growth in Internet bandwidth consumption, that is being fueled by greater numbers of people going online and ever more data-intensive online activities, such as movie streaming, video conferencing, and social networking.


Future State Component
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Data Center Energy Efficiency
Air-flow Management Improvements
Higher-Efficiency Power Supplies for Servers and Other Rack Equipment
Higher-Efficiency Uninterruptible Power Supplies
Application of Virtualization Software
Establishment of Standard Metric for Data Center Efficiency
"Heat Pipes" to Capture and Utilize Waste Heat from Electronic Devices and Components
DC Power Distribution to Reduce AC/DC Conversion Losses
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

The use of electric motors is ubiquitous across the residential, commercial, and industrials sectors. The overall installed base of electric motors in the U.S. is 90 million, of which the manufacturing sector employs 40 million. A vast majority of these motors are old motors with poor efficiency. According to the DOE, the energy savings from replacing existing electric motors with more efficient motors and motor-drive systems ranges from 11% to 18%. This would yield a potential annual energy savings of 62 to 104 billion kWh per year for the manufacturing sector alone.

Significant additional energy savings can be had with the addition of an adjustable speed drive (ASD). The use of drive also improves productivity through increased automation and also contributes to increased sustainability and reduced emissions. Despite these well-documented advantages, ASDs contribute only to a small percentage of industrial systems. As an example, only 3.2% of pump systems in the US use ASDs.

Increased adoption of high efficiency motors and adjustable speed drives can contribute significant energy savings, increased productivity, and high sustainability. Recently developed motor technologies offer the additional advantage of being able to directly drive loads without an intermediate mechanical coupling. This further increases overall system efficiency and reliability.

Several applications could benefit from the use of advanced motor technologies and ASDs. One such area is water management, which uses large number of motors and pump systems. Use of ASD-driven pumps can contribute to decreased water wastage besides energy savings. Optimization of water resource management also forms one of the six Strategic Issues identified by EPRI in its overall R&D roadmap.

Other applications, include for example, in the commercial and industrial sector - thermal management (heating and cooling), process-based industries (such as petrochemicals, cement, automotive, aerospace), and constructions (cranes, lifts, conveyors). In the residential sector, applications of ASDs to pumps and elevators can result in further energy savings.

Electric motors of the future may utilize superior materials, such as rare earth elements, to achieve levels of "ultra-" and "super-" premium efficiency. In addition, variable-speed drive may be retrofitted for motive applications in which partial output is sufficient for the majority of the duty cycle. In addition, where applicable, new motors may couple directly to loads in lieu of traditional mechanical coupling or gearing arrangements, yielding additional energy savings and improved system reliability.

GAPS

Many industrial applications use line-start induction motors. Replacement of these motors with "ultra" or "super-premium" line-start high efficiency motor technologies can yield significant energy savings benefits. Motor manufacturers have recently unveiled a slew of new technologies, - direct-line-start permanent magnet machines, copper rotor induction motors, and synchronous reluctance motors. Additional R&D and field trials will accelerate adoption of such motor technologies. These new motor technologies can also increase energy savings in ASD-driven applications such as elevators, pumps, and compressors.

Rising material cost, namely that of rare-earth permanent magnets, has been a significant hurdle in increased deployment of high efficiency motor technologies. R&D in the following three areas can significantly address this issue:

- Development of new motor technologies that can provide increased torque and power thereby decreasing the amount of magnetic material needed (several new axial and transverse flux motors are being researched),
- Development of motors that permanent magnets such as reluctance motors, and
- Development of permanent magnet motors that use alternatives to high cost rare-earth permanent magnets materials (for example, ferrites).

One of the key reasons for low ASD adoption rate is the "perceived" low reliability and high cost. These can be addressed through R&D through new technologies and user application aides. From a technology perspective, several options exist - embedded motor systems that integrated the ASD into the motor can significantly reduce issues with long cable and decrease overall cost, the use of ASDs that minimize low life components such as electrolytic capacitors, and so on.

From an application perspective, perhaps the most important need of the hour is the development of new software tools (such as ASD Master) and guides that can enable and educate the user on appropriate drive selection, installation, and economic value. The lack of an application guide or software tool to estimate the net energy savings of adjustable speed drives, when coupled with electric motors, results in customers making sub-optimal decisions.

Finally, several new applications have emerged recently that call for complete rethink on motor and drive requirements. Perhaps, the most important example of such an application is the plug-in electric vehicle (PEV). Increased R&D will be needed in development of new high-efficiency, high-power/torque density motors for transport applications.

ACTION PLAN

Success will be realized through: 1) accelerating the adoption of high-efficiency motors and drive technologies through testing, demonstrations, and coordinated deployments to qualify technical performance and energy savings; and 2) the availability of application guides and software tools to help customers and utilities make informed decisions on the use of adjustable speed motor drives to yield energy savings.

A progressive R&D agenda will be needed to bridge the identified gaps to develop high-efficiency motors, including;

Near Term

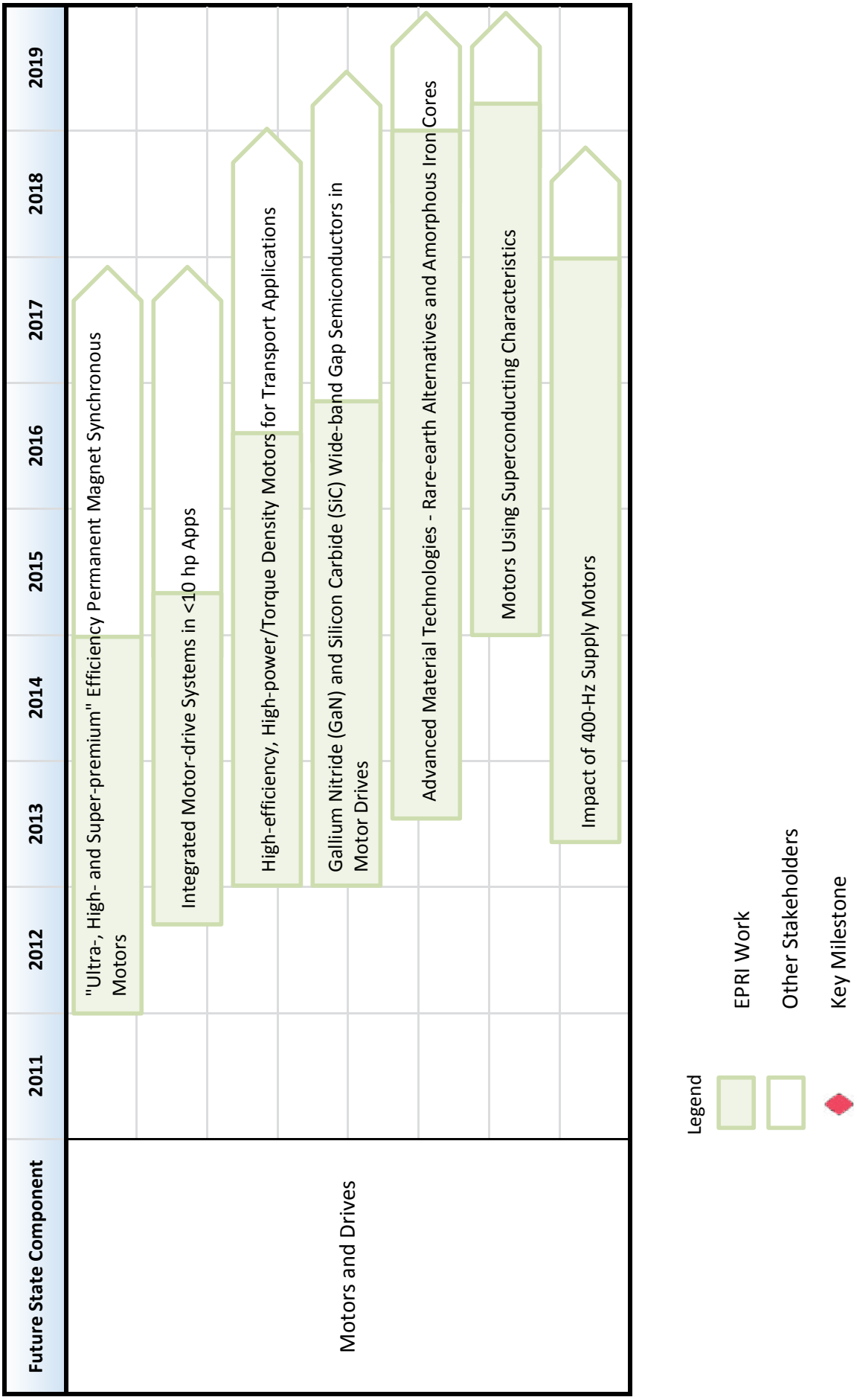
- Conduct lab tests of new motor technologies; identify the most effective applications for those motors; conduct the test of new application and perform preliminary market assessment.
- Identify manufacturers/university partners of high efficiency drives based wide-band gap devices. Conduct laboratory demonstrations of this concept.
- Participate and monitor worldwide developments in the standards and regulation arena. Develop new software tools and application guides for enabling increased ASD adoption
- Initiate cooperation with DOE and manufacturers with aim to join on-going research to develop new motor and drive technologies. EPRI cooperation could include identification of new applications, cost-benefit analysis, identification of barriers to success, and laboratory demonstration of new technologies.
- Identify the new applications needed for productivity improvement where integrated motor/drive systems can be major and new contributing factor for gaining competitive position by utility customers; assess if that approach can be extended to 50hp range while maintaining the same benefits like for lower horsepower range.
- Enable improved rewinding and repair processes to ensure that loss of efficiency and reliability is minimal.

Long Term

- Look at next generation motor technologies such as superconducting motors.
- Work with component and system OEMS to incorporate new component technologies that can provide significantly high energy savings – high band-gap power devices, novel alternatives to passive components such as capacitors.

VALUE AND RISK

Without concerted industry research into more energy-efficient motors and better-configured motor-drive systems, vast potential energy savings may be foregone.


Future State Component
2011
2012
2013
2014
2015
2016
2017
2018
2019
Motors and Drives
"Ultra-, High- and Super-premium" Efficiency Permanent Magnet Synchronous Motors
Integrated Motor-drive Systems in <10 hp Apps
High-efficiency, High-power/Torque Density Motors for Transport Applications
Gallium Nitride (GaN) and Silicon Carbide (SiC) Wide-band Gap Semiconductors in Motor Drives
Advanced Material Technologies - Rare-earth Alternatives and Amorphous Iron Cores
Motors Using Superconducting Characteristics
Impact of 400-Hz Supply Motors
Legend
EPRI Work
Other Stakeholders
Key Milestone

DRAFT: INDUSTRIAL PROCESS HEATING & WASTE HEAT RECOVERY

FUTURE STATE COMPONENTS

Industrial process heating and waste heat recovery accounts for the largest use of energy in US manufacturing, and therefore any improvement in these two areas can offer significant energy savings benefits to industrial customers. In U.S. manufacturing, process heating accounts for over one-fifth of total energy use, making it the largest energy end use. Process heating also accounts for 12% of net electricity consumption in manufacturing, and also represents up to 15% of total industrial production cost. As such, improvements in process heating present opportunities to significantly benefit industrial customers through cost reduction, improved productivity and reducing energy intensity, while reducing their greenhouse gas emissions.

GAPS

- Lack of useful, easy to use tools for utility representative and industry customers
- Lack of centralized knowledge base – lot of information related to process heating and waste heat recovery are available, but need to have all the latest information from trustworthy sources in one location.
- Identification of innovative technologies to improve energy efficiency and lower volatile organic compounds (VOC), e.g., low-temperature plasma technologies, acoustic process heating etc.
- Innovations that can enable economically viable hybrid process heating systems that use multiple heating technologies simultaneously (e.g., infrared (IR) pre-heating, ultra-low-emission (ULE) burner, enhanced fired heater, and high efficiency heat recovery system).
- Demonstration of the new as well as existing technology for proper application
- Lack of technology transfer to account executives at utilities – create awareness about the existing energy efficient process heating technologies
- Retrofit and re-commissioning – these are low hanging fruit to achieve high energy efficiency with existing technologies.
- Innovations that can lead to waste heat recovery systems that can feasibly reduce plant energy intensity.
- Advanced materials (composites, etc.) of the future to enable more precise temperature sensors, and estimate the associated energy-efficiency benefits.

ACTION PLAN

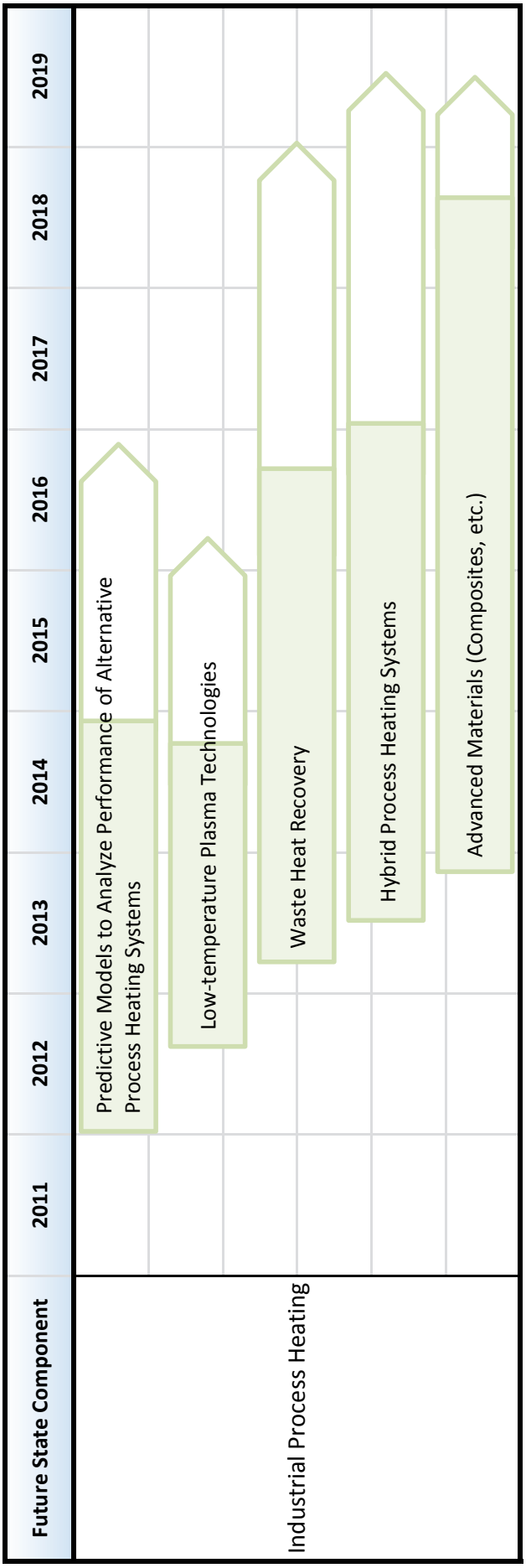
- Create easy to use tools for utility representatives and their industrial customers (tools such as PQ investigator used by power quality group)
- Create a central repository of all available information relevant to process heating and waste heat recovery, sorted according to the source, such as DOE, CEE, EPA, CEC etc on existing technologies.
- Scout for innovative, state of the art technologies (in the area of process heating ad waste heat recovery) with the help and assistance from utilities, manufacturers, trade magazines, conferences etc.
- Conduct lab testing of the identified technologies or perform on-site demonstration of the technology with a utility champion and industry champion
- Create case studies out of the successful demonstrations and create awareness among utilities and industrial clients
- Conduct workshops on efficient process heating electro-technologies to utility representatives and educate them about the losses in the system and how the system efficiency is improved
- Develop retrofit and re-commissioning methodologies with existing technologies that provides energy efficiency improvement
- Create guidelines for proper waste heat recovery in various industrial processes and applications.

VALUE AND RISK

Without concerted industry research into advanced electric process heating and waste heat recovery applications, vast potential energy savings may be foregone. In addition, novel electric process heating technologies have the potential to enhance productivity, reduce operating costs, and eliminate on-site emissions in many industrial applications.

In addition, rejuvenated industry R&D can yield valuable technology transfer tools that can help:

- Extend process heating knowledge to utility representatives
- Position electro-technologies at the forefront of measures to improve industrial productivity and reduce energy intensity
- Provide system level improvement through recovery of wasted process heat


Future State Component
2011
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2016
2017
2018
2019
Industrial Process Heating
Predictive Models to Analyze Performance of Alternative Process Heating Systems
Low-temperature Plasma Technologies
Waste Heat Recovery
Hybrid Process Heating Systems
Advanced Materials (Composites, etc.)
Legend
EPRI Work
Other Stakeholders
Key Milestone

FUTURE STATE COMPONENTS

While consumers are changing the ways they use electricity though the advent of new types of technologies, utilities are still relying on outdated and sparse load profile data, to understand customer behavior.

Utilities in the future need to be able to characterize loads and their constituent elements to a higher level of detail to design pricing plans. Then utilities need to offer incentives to modify the level and profile of usage to better match underlying supply costs and reflect external costs. Moreover, realizing the benefits that appear to be associated with offering consumers timely and actionable feedback on usage requires establishing a robust characterization of all customer load profiles.

The universal deployment of smart meters provides the utility with the means to more accurately profile household load profiles and to track changes in those profiles over time. New load research methods are needed to be able to mine these data to provide insight and structure for pricing and feedback initiatives. Additionally, robust load research methods that can support other uses of smart meter data, such as supporting distribution system operations and enabling the adoption of distributed generation technologies, are needed.

GAPS

There is a lack of established alternatives to sub-metering to reliably and cost-effectively disaggregate whole premise electricity consumption by end use. It would be beneficial to identify and test innovative technologies and techniques with potential to be scaled on a regional or national level to acquire more accurate and up-to-date end-use load shape data to benefit the industry. Such techniques may include:

- Waveform signature detection
- Smart power distribution panels (i.e., circuit breaker panels)
- Conditional demand analysis (or other analytical techniques)
- Statistical techniques to assimilate, synthesize, and draw meaningful insights on customer behavior and load patterns from fine-interval smart meter data.

ACTION PLAN

Disaggregating load shapes into the various end -use components may be accomplished in one of several ways - each with its own level of accuracy and cost.

- Survey existing methods currently being employed
- Test waveform and voltage methods in the field for accuracy
- Refine CDA methods to estimate load shape and use sample design of CDA participants to confirm accuracy
- Build industry load shape library

The availability of low cost interval load data provides new opportunities for utilities to understand their customers purchasing and energy attitudes.

- Collect survey information of customer demographic and attitudinal data
- Cross correlate for commercial building types
- Incorporate into industry load shape library

VALUE AND RISK

There is a growing and troublesome disparity between how utilities plan to serve electricity loads, which involves large—and in many cases indivisible—investments in generation, transmission, and distribution plants and the loads they will actually serve. The lack of reliable, up-to-date load research data lies at the heart of this disparity, which will only become exacerbated over time without a concerted industry effort to revitalize load research. Specifically, insight into end-use load shape characterization is critical to more accurately conducting baseline forecasting and estimating the energy and demand impacts of energy efficiency and demand response activities. Without such research, variances between estimated and realized loads may lead to less optimal and more costly provisions of resources.

Future State Component	2011	2012	2013	2014	2015	2016	2017	2018	2019
Load Research		Develop End-use Load Shape Library and Software							
		Tech Assessment of Non-Intrusive Load Monitoring Techniques							
			Assessment and Scaled Field Demonstration of Statistical Techniques						

Legend

EPRI Work

Other Stakeholders

Key Milestone

FUTURE STATE COMPONENTS

A new paradigm of consumerism is coming to electricity markets quickly, permanently, and radiating to all sectors and segments. The character of this movement is distinguished from how customers traditionally have influenced utility operations. It is succinctly summarized as: customer choice and control.

Acknowledging consumer wants and needs begins with development of an in-depth characterization and understanding how electricity delivers value to consumers of diverse situations and circumstances, which evolve over time. Success in meeting those needs will be defined by how well the industry anticipates and meets diverse consumer demands while fulfilling its fiscal and social responsibilities.

New technologies are being added to the grid to enable greater consumer participation in how they manage their electricity usage. This provides an opportunity for the electric utility industry to get consumers actively and sustainably involved in electricity usage decisions. However, fundamental research is first required to get to the root of various aspects of utility customer behavior, such as the effects of rate structure and information provision (or feedback) on customer response, response variation by customer segment, and how initially established behaviors change over time.

Applying insights from the behavioral disciplines such as economics, psychology, and sociology, among others, will help us understand the motivational factors that determine consumers' electricity usage. This serves as a starting point for developing practical methods for ascertaining consumer preferences for new product and services and developing consumer associations to effectively engage consumers and convey the benefits.

GAPS

Achieving the transformation to customer choice and control requires taking the goal literally: consumers must be provided with choices in how they purchase electricity. And, they must have an understanding of how to use available technologies and tools required to realizing the full benefits of managing electricity consumption. The gaps are obvious and compelling:

Choices in how consumers pay for electricity. New rate structures may provide better ways to match customer wants and needs with supply capabilities. But, research results inconsistent and incomplete, and therefore not actionable.

The energy savings and/or load-shifting impact of alternate retail pricing structures, which must be confidently predicted, include:

- Real time pricing
- Time of Use pricing
- Critical Peak Pricing
- Peak Time Rebates Demand Subscription Service
- Inclining Block Rates
- New, consumer inspired, structures

Realizing the power of personalized information. The old adage, *You can't manage what you can't measure*, is apropos to customer choice and control. Consumers need information, or feedback, on when they use electricity in order to formulate ways to use it more effectively and productively. However, questions remain as how much and what type of information. Specifically, what are the energy/ demand and customer satisfaction impacts of feedback, such as the level and persistence of these impacts depending on the type of feedback (e.g., IHDs, day-lagged or real-time web portals with smart phone apps) and the information presented (e.g., normative/peer comparisons, appliance-level consumption information). Also, how do potential impacts vary with different customer types? Feedback mechanism that require characterization include

The role of control. New technologies provide customers with opportunities to take control of their electricity usage. Do these technologies conform with household or business organization and operation? What types of customers want them and what level of benefit can they expect?

Menu of offerings. What different combinations of the pricing, feedback, and control technologies will appeal to a wide range of customers as well as achieve utility goals?

Wild cards. What will be the customer-oriented (and perhaps customer-designed) technology or service offerings that will be transformational in nature, but are as of yet undefined? What role, if any, will the utility play in the delivery of these new products to their customers?

Consumer demand for and expectation of choice and control represents both an opportunity and a daunting challenge for utilities. How well the industry meets this challenge depends on how well they anticipate those expectations and make preparations to meet them.

ACTION PLAN

Achieving the vision of customer choice and control requires undertaking multiple research streams.

1. **Develop actionable models of behavior.** Develop and verify behavior models to provide a foundation for understanding and measuring how customers value and use electricity. Behavioral disciples such as psychology, decision analysis, economics, and sociology offer alternative, but not necessarily contradictory, conceptual and operational characterizations of customer decision processes. Useful models describe how customers process information and prices and how behavior changes and evolves with experience and time. A key criterion is that the models selected lead to a corresponding empirical specification to direct field trials to quantify key cause and effect relationships.

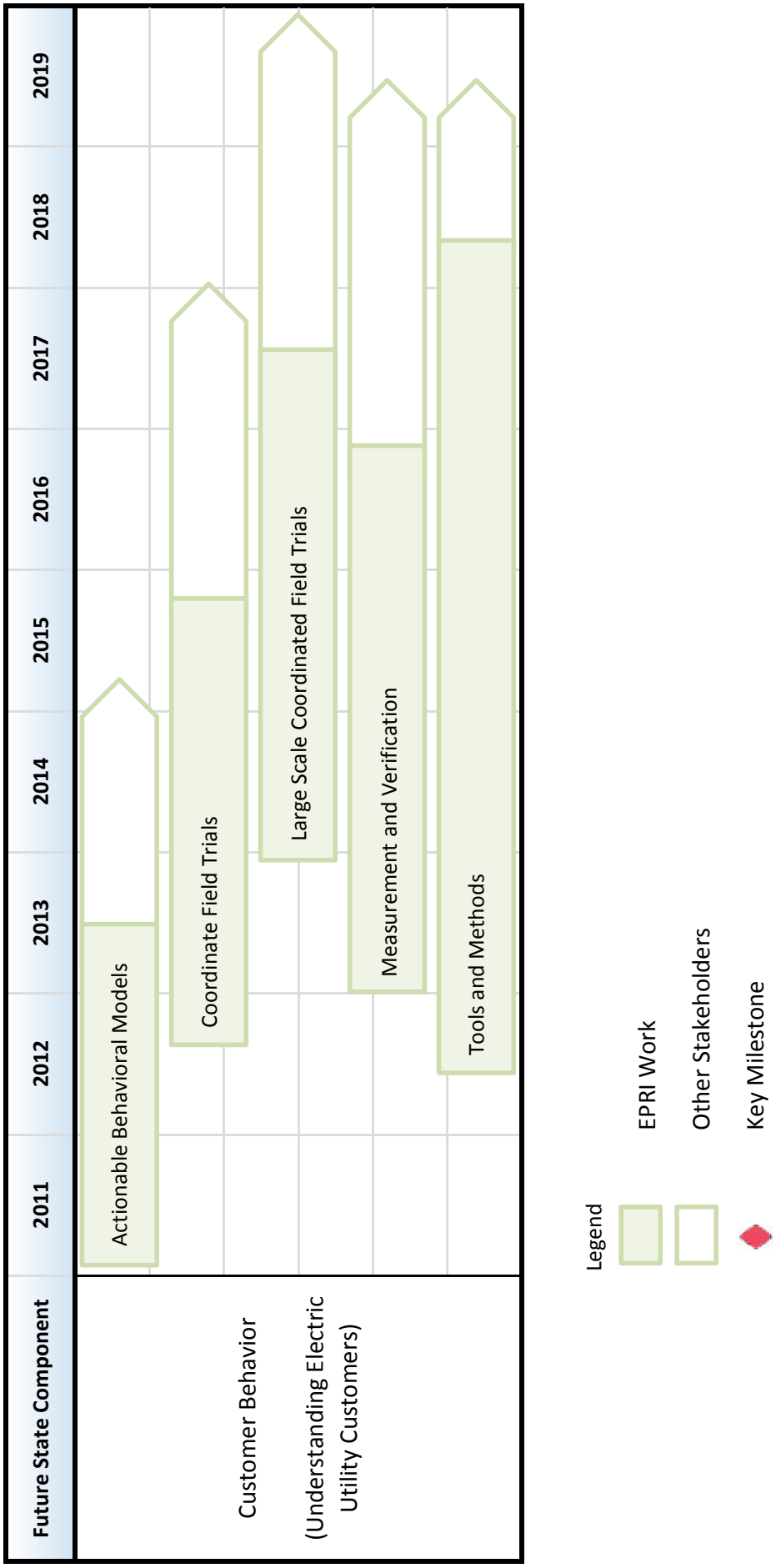
2. **Coordinate field trials.** Verifying how behavioral programs affect customers requires extensive and rigorously constructed field trial: demonstrations, pilots, and experiments. Adoption of accepted research protocols ensures that the findings are widely acknowledged, and avoids duplicative but informative replication. Coordinating individual utility initiatives accelerates and reduces the cost of reducing the many uncertainties needed to produce credible and extensible results.

3. **Measurement and verification.** Develop credible and widely accepted impacts attributable to behavioral programs. Utilize field trial and program data to characterize and quantify all impacts attributable to rate structures, feedback, and control technology. Analyses will establish the extent to which key impacts can be used to estimate deemed savings for various behavioral interventions.

4. **Develop implementation tools and methods.** Behavioral programs involve developing new ways to communicate, interact, and engage customers using behavioral mechanisms whose impacts have been verified and applicable over a wide range of consumer and market circumstances.

VALUE AND RISK

Utilities are aware that consumer acceptance and use is key to realize the potential benefits attributed to, but not yet realized from, new investments in generation, delivery, and utilization technologies. The transformation to a smarter and more productive electricity sector cannot be accomplished without involving consumers early and continuously. Understanding how consumer use and value electricity therefore must commence now, to guide utility investments decisions so that customer choice and control defines how the electricity sector.


Future State Component
2011
2012
2013
2014
2015
2016
2017
2018
2019
Customer Behavior
(Understanding Electric Utility Customers)
Actionable Behavioral Models
Coordinate Field Trials
Large Scale Coordinated Field Trials
Measurement and Verification
Tools and Methods
Legend
EPRI Work
Other Stakeholders
Key Milestone

February 2012

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ENVIRONMENT SECTOR ROADMAPS

September 2011

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ELECTRIC POWER
RESEARCH INSTITUTE

BRYAN HANNEGAN, Ph.D.
Vice President
Environment and Renewables

September 1, 2011

Dear EPRI Environment Advisor:

Each year at our Fall advisory meetings, we review our Environment R&D strategic plans to ensure that our EPRI activities are synchronized with your environmental needs. In the past, these have taken the form of one large Strategic Plan per EPRI Program Area, with a broad discussion of future projects and priorities at our advisory meetings.

This year, we have instead chosen to develop focused R&D "Roadmaps" for key Research Issues that we believe will be the key environmental drivers for our industry in the future. In the pages that follow, you will find a Roadmap for each of these key Research Issues, including a brief description of the R&D gaps we see relative to each Issue, and our preliminary R&D plans for addressing these gaps.

We encourage you to read these Roadmaps prior to your arrival in New Mexico, so you can provide us with your thoughts and feedback at our upcoming meetings. We intend these to be "living documents" that will evolve over time with your continuous feedback, and we invite you to hold us accountable at each advisory meeting to make sure our Environment R&D is meeting your needs and delivering what we have promised.

Following our meetings in New Mexico, we will incorporate your feedback into our Roadmaps, and present them in consolidated form to our Research Advisory Council (RAC) and Board of Directors at a joint meeting this November. Each Roadmap will also be reviewed by a body of outside experts to ensure we are meeting EPRI's public interest mission, as well.

We will also create – as needed – key supplemental projects to address high-priority R&D gaps, and we will use these R&D Roadmaps to guide the evolution of our future year Annual Research Portfolio. In this manner together we can ensure that your scarce R&D investments are made available for the highest-priority and highest-value collaborative research projects.

Thus, your careful review and feedback on these Roadmaps is vitally important to helping us serve you better, and we are looking forward to engaging you on the details in New Mexico.

Sincerely,

Bryan Hannegan, Ph.D.
Vice President, Environment & Renewables

Together . . . Shaping the Future of Electricity

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DRAFT: AIR QUALITY

ISSUE STATEMENT

Emissions of nitrogen oxides (NOx), sulfur dioxide (SO_2), primary particulate matter (PM), mercury and a host of other air toxics (i.e., hazardous air pollutants) from fossil-fired power plants may contribute to several environmental concerns including adverse human health effects, deposition of pollutants to land and water, and visibility impairment. These concerns have led to a myriad of regulations to reduce emissions and to help meet increasingly stringent air quality standards. Air emissions regulatory compliance is among the highest cost items facing the electric industry.

Over the next decade, air pollutant emissions from the electric sector will be controlled to increasingly lower levels to meet planned and anticipated regulatory measures. At the same time, new technologies and new fuels (e.g., biomass) will be deployed, resulting in changes to the character of power plant emissions and raising a host of new issues. As air emissions are controlled to satisfy more stringent requirements, discharges to other media (e.g., to wastewater and solid waste streams) become more important. Management of these releases requires development of tools (such as emissions characterization and measurement techniques, human health effects studies, multi-media emissions modeling) that can perform assessments of pollution management strategies integrated across media.

DRIVERS

There are many specific regulatory and legislative drivers at the state and federal levels affecting air emissions and their eventual management in water and solid waste streams.

National Ambient Air Quality Standards (NAAQS) – The Environmental Protection Agency (EPA) will continue to review the NAAQS for ozone, PM, SO_2 and NOx. Standard revisions could lead to continuing pressure on the electric sector to reduce emissions if the standards are lowered further. These standards include both the primary (health-based) and the secondary (welfare-based) NAAQS.

Regional Haze Rule – This is a 60-year long rule that aims to return the visibility in Class I areas to "natural conditions" by 2064. This rule will continue to place pressure on reducing emissions of SO_2, PM, and NOx in its progress towards that goal.

Transport Rules –The Cross-State Air Pollution Rule will require significant reductions in SO_2 and NOx emissions to limit upwind state contributions to downwind state non-attainment of ambient standards for criteria pollutants. The Rule could be revisited when NAAQS levels are lowered or as evidence indicates that interstate transport continues to hinder the ability of downwind areas to reach attainment.

Maximum Achievable Control Technology (MACT) Rule – The U.S. Environmental Protection Agency (EPA) is developing a MACT rule applicable to all utility trace pollutants, but mercury is the primary driver. Trace and transition metals remain a major component of all HAPs released and act as the major elements driving site and industry risk assessments. After implementation of the MACT rule, EPA's residual risk analyses will likely focus on metals to determine the efficacy of HAPs controls to meet regulatory health thresholds.

State Rules –State Implementation Plans are typically issued to meet EPA mandates. States need the best modeling tools and scientific information to make technically sound decisions. States are also promulgating various Renewable Portfolio Standards (RPS) that may result in increased use of biomass among other bioenergy sources.

Clean Water Act – EPA is revisiting its effluent guidelines for the steam electric sector and one of the primary concerns is discharge of mercury and selenium from FGD wastewater. Other water pollutants from air emissions controls systems may also become issues as technologies are deployed to comply with the HAPs MACT rules.

Safe Drinking Water Act (SDWA) – The SDWA establishes Maximum Contaminant Levels (MCLs) for compounds such as arsenic that may cause adverse health effects. Low

MCLs for arsenic mean potential concerns for storage or use of by-products, discharge of waste water and potential contamination of groundwater.

Total Maximum Daily Loads (TMDLs) – Atmospheric deposition is being considered by the states and EPA for satisfying a variety of TMDLs including pH, nitrogen, and mercury.

Pending Legislation – Legislative activity is always possible. The Clean Air Act has been amended on several occasions. Multi-pollutant bills have been considered aimed at reducing emissions of SO_2, NOx, and HAPs beyond the levels being considered by EPA under its current regulatory authority and proposed climate legislation that also includes provisions for air quality pollutants in addition to greenhouse gases.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All EPA rules are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Scientific research results provide critical, objective input to such discussions.

RESULTS IMPLEMENTATION

EPRI air quality research provides a unique multidisciplinary approach to addressing air emissions issues of scientific and technical importance to the electric sector. The research anticipates and addresses critical issues well before they become regulatory concerns and offers financial and scientific collaboration with other research organizations. EPRI regularly briefs state agencies and the EPA on the results of its air research. EPRI air quality experts are frequently asked to participate in joint research programs and regularly invited to sit as members of national and international scientific review panels to assess and guide large-scale research programs. EPA and state agencies often incorporate EPRI research results into decision-making processes. A few examples include:

- EPA revised the visibility algorithm used to assess regional haze due in large part to EPRI research.
- EPA's Clean Air Mercury Rule (which was vacated by the courts on a legal technicality, not on scientific grounds) followed a protocol similar to EPRI's air research and arrived at similar conclusions.
- EPRI research on sulfate aerosols in PM attainment demonstrations was adopted by EPA, thereby providing a more realistic estimate of PM mass.
- EPRI research on the arsenic cancer slope factor has been crucial in clarifying the science and providing comments to EPA to reconsider its proposal.
- EPRI research on PM components resulted in a shift in the EPA's PM health research focus to understand the health effects of various PM components and gaseous co-pollutants and possibly considering supplemental standards in addition to the PM mass standard.
- EPRI's work characterizing HAPs emissions – specifically recent work on the ICR data quality review and preliminary analysis of the ICR data – appears to have been considered by EPA in its proposed MACT rule. Specifically, EPRI's observations regarding the difficulties in making measurements of organics at the extremely low concentrations in utility stack gas, may have resulted, at least in part, to EPA proposing work practice standards for these compounds.

PLAN

Air quality issues must be addressed in a comprehensive manner including characterizing emissions, assessing how emissions partition within the power plant (up the stack, liquid water discharges, or solid waste products), understanding air emissions fate and transport in the environment (transformations from air to deposition on land and water), and quantifying the impacts on human health and the environment. This involves careful measurement and chemical analyses and understanding the overall process chemistry at the power plant and its chemical transformation and transport in the atmosphere. This also includes clarifying the cycling among different environmental media and environmental reservoirs. Sophisticated analytical measurement methods and the development of advanced environmental models, and execution of detailed studies will be required to elucidate the role of power plants versus other sources contributing to potential human health and ecosystem impacts. Specific actions needed to address current and anticipated air quality issues include:

1. *Effectively characterize emissions and discharges from current and emerging technologies:* Characterization of emissions from current and emerging combustion-based generation technologies will continue to be a critical

need for conducting air quality modeling studies, understanding control technology performance, and conducting health risk studies.

2. *Conduct air quality measurements and develop novel measurement techniques:* Improve the detail and resolution of atmospheric air quality measurements is essential for understanding the various transformation processes of emissions in the atmosphere and representing those processes in atmospheric models. It is also crucial for studying human health, welfare, and ecosystem effects of air pollution.

3. *Conduct basic health and welfare effects research as input to regulatory and legislative rulemaking:* The concern for human health and environmental effects is the primary driver for controls of emissions from all anthropogenic sources, including power plants. Thus, it is critical that the role of the electric sector in contributing to any adverse health and welfare outcomes be clearly delineated. Scientifically rigorous, objective and peer-reviewed studies become the foundation for establishing regulations and emissions limits. Health and welfare based reviews are conducted by EPA on an ongoing basis, requiring EPA to revise primary or secondary NAAQS if the science indicates a change in the standards is warranted. Understanding the electric sector's relative contributions to adverse health and welfare effects and an overall acceptable level of risk will continue to be critical needs as new technologies are employed.

4. *Develop, improve and evaluate atmospheric models for regulatory compliance:* As states and EPA implement regulations, sophisticated computer models are needed to determine the impact of various sources on air pollution and the level of controls needed to reach compliance. Thus, it is critical that these models provide a realistic representation of atmospheric physics and chemistry as they relate not only to power plant emissions but all emissions sources to accurately portray their specific contributions. With the short-term NAAQS for SO_2 and NO_2, there is also a need to improve the regulatory models used in application and renewal of air permits.

5. *Conduct multimedia environmental fate and risk studies to understand the potential risk implications of emissions from current and new technologies:* Multimedia environmental fate and risk studies are important for both human health and ecosystem impact assessments. Many air toxics (e.g., mercury, arsenic) require a comprehensive risk assessment across different media (air, land, and water) because of complex cycling of these compounds in the environment and the potential for bioaccumulation. In addition to air toxics, deposition of NOx and SO_2 reaction products are under scrutiny over concerns of acidification and nutrient enrichment in terrestrial and aquatic ecosystems.

As air emissions continue to be reduced in response to more stringent standards, it is critical that the industry understands the ultimate fate and overall risk of pollutants to society. The research will focus on exploring basic science questions and development of risk assessment models to examine future scenarios and run case studies of utility air emissions and toxic releases.

RISK

EPRI air research informs industry, regulators and society alike with high quality, objective and credible scientific information, providing an independent perspective that otherwise would not exist. The following benefits could suffer without EPRI air quality research:

- **Addressing new, emerging issues that could impact the electric utility sector:** EPRI research on characterizing emissions and evaluating health risks associated with those emissions enables possible impacts of advanced energy systems to be proactively addressed during the technology development process. Without this research there is potential danger of discovering environmental risks too late in the process, which could prove extremely costly to address through later changes in technology and equipment retrofit.

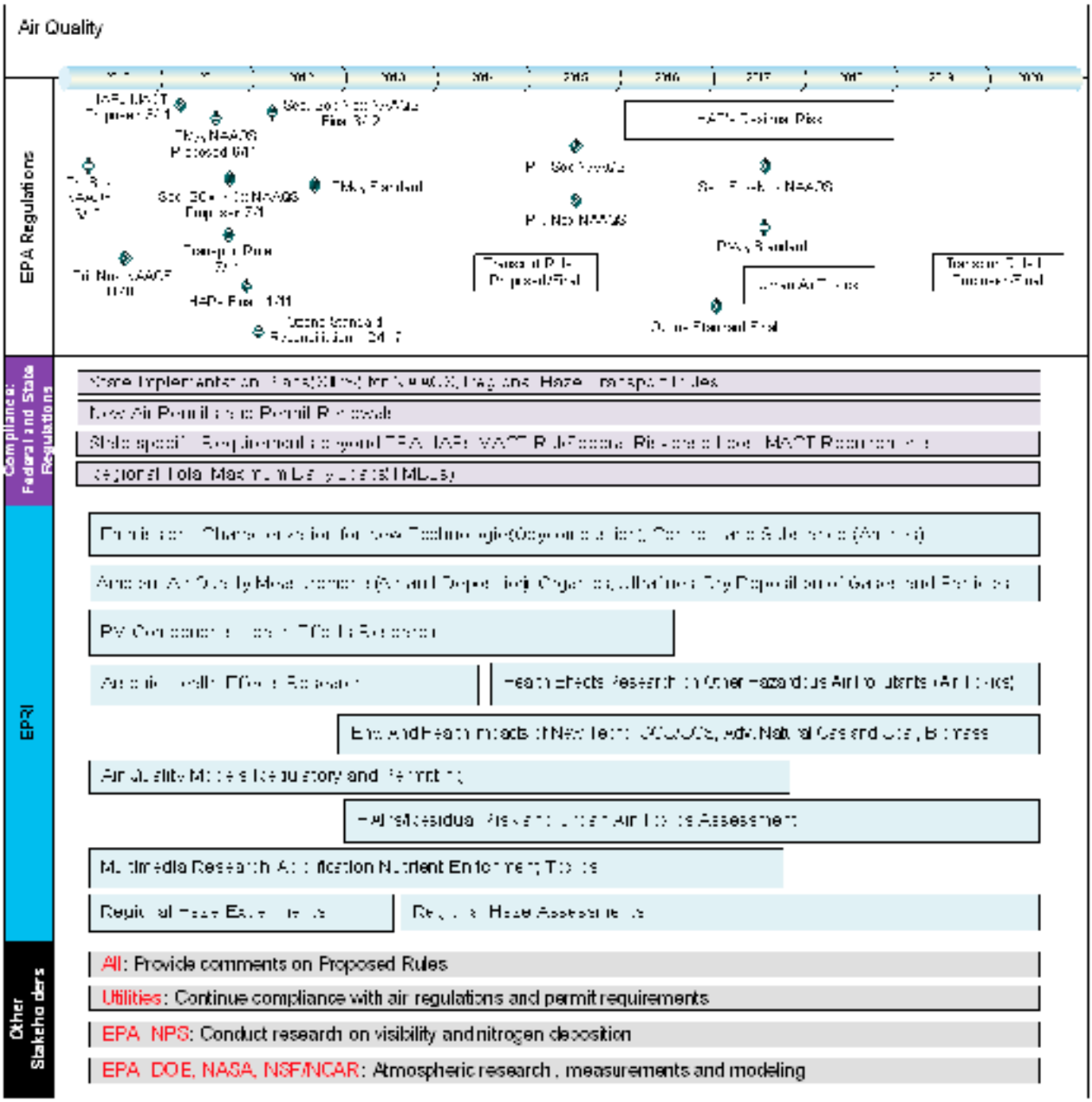
- **Updates to the detailed database of mercury and other HAPs emissions from coal- and oil-fired power plants:** This historical database and its frequent updates will continue to benefit member companies during the Agency's future rulemaking to determine whether health risks remaining after implementation of the MACT standards warrant additional emission controls.

- **Cost-effective management of multimedia discharges:** The advent of new technologies, new fuels, and switches in fuel sources can change emissions, liquid discharges and solid waste streams. As these changes

occur, it is important that EPRI research continue to help power plants manage their risk to understand the implications of such changes.

- **Air quality standards based on sound science:** EPRI research provides comprehensive health impacts information for criteria pollutants to help stakeholders develop scientifically sound policies and standards for achieving acceptable air quality to protect public health. Without that information, there is the potential for regulators to promulgate overly conservative rules resulting in costly emission control requirements.
- **Effective air quality management:** EPRI research ensures that the air quality models used by regulators in the development of air quality implementation plans include the best available science and accurate treatment of power plant emissions. Without EPRI research on improved modeling tools, regulations and policy decisions will rely on inferior methodologies that may result in overly conservative solutions.
- **The ability to construct key collaborations across multiple topics and issues to address air quality and other related environmental concerns:** One of the key advantages of participating in EPRI programs is that technical staff members work cooperatively across EPRI as well as with their colleagues in other research organizations. This allows EPRI to have a much broader and detailed perspective on issues related to power plant emissions and control technology than most other scientific research organizations. The fact that the air quality scientists work cooperatively with the air quality control technology teams allows for issues to be addressed and resolved quickly and cost-effectively. Interfaces between air-water-solids-climate are also addressed on an ongoing basis.

Air Quality


EPA Regulations
Compliance: Federal and State Regulations
EPRI
Other Stakeholders
All: Provide comments on Proposed Rules
Utilities: Continue compliance with air regulations and permit requirements
EPA, NPS: Conduct research on visibility and nitrogen deposition
EPA, DOE, NASA, NSF/NCAR: Atmospheric research, measurements and modeling

ISSUE STATEMENT

Health concerns about air pollution are the basis for most of the air regulations that impact fossil fuel generation. These regulations include the primary National Ambient Air Quality Standards (NAAQS) as well as many other air quality rules, such as the Clean Air Transport rule and the proposed Utility MACT (Maximum Achievable Control Technology) Rule for air toxic emissions from power plants. The bases for these rules are health effects studies of human populations and laboratory animal and human studies which are conducted in controlled environments. Health studies are sponsored by several agencies and groups, most notably the US EPA. Most studies have focused upon the subset of pollutants that are currently regulated rather than on a more comprehensive set of pollutants that could impact health. The result of the current approach could be tighter regulations and limits on pollutants of less concern for public health, resulting in expensive controls that provide limited benefits to the public health. Hence there is a need to consider health effects of a broader set of pollutants, and to utilize several research tools in this consideration.

DRIVERS

Public health concerns underlie or greatly influence most air regulations at the federal and state levels. Specific regulatory drivers include:

National Ambient Air Quality Standards (NAAQS) – The Environmental Protection Agency (EPA) will continue to review the adequacy of the health protection provided by NAAQS for ozone, PM, SO_2, NO_2, CO and lead. NAAQS revisions could lead to continuing pressure on the electric sector to reduce emissions if the standards are lowered further. Reviews of the primary standards include assessments of health studies and public health risk assessments. In addition, health co-benefits are considered in the benefits assessments for these regulations.

Transport Rules –The Cross-State Air Pollution Rule will require significant reductions in SO_2 and NOx emissions to limit upwind state contributions to downwind state non-attainment of ambient standards. This Rule could be revisited whenever NAAQS levels are lowered or when evidence indicates that interstate transport continues to hinder the ability of downwind areas to reach attainment. Associated health benefits have been a primary benefits driver for these rules.

Hazardous Air Pollutants (HAPs) Rules – EPA recently proposed emission limits for HAPs from coal and oil-fired plants. The co-benefits associated with PM reduction have been determined by EPA to far outweigh the direct benefits of mercury or other HAPs reductions.

State Rules –State Implementation Plans are developed to attain and maintain the NAAQS. Since there are alternative ways to meet ozone and PM NAAQS, States need the best scientific information to make technically sound decisions.

Pending Legislation – Legislative activity is always possible. The Clean Air Act has been amended on several occasions. Multi-pollutant bills have been considered aimed at reducing emissions of SO_2, NOx, and HAPs beyond the levels being considered by EPA under its current regulatory authority. Proposed climate legislation has included provisions for air quality pollutants in addition to greenhouse gases.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All new EPA rules are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Scientific research results provide critical, objective input to such deliberations.

RESULTS IMPLEMENTATION

EPRI air quality health research generates information and data that inform our understanding of the basic association between air pollution and health. There are three major types of studies undertaken in this arena: epidemiological studies, which study human populations and their activities with respect to pollution exposure; toxicological studies, which examine the responses of people/animals in a controlled setting in which exposures are well-characterized; and exposure studies, which estimate the quantity and sources of air pollution to which individuals are exposed. The results from all of these studies are published in the peer-reviewed literature.

Health study results to date indicate important associations of pollutant gases and carbon-containing (organic) compounds

in the atmosphere with alternative health measures. Because of the numerous ways in which organic pollutants are measured, it is unclear which subset(s) of these compounds are related to adverse health outcomes. There is also some limited evidence from these studies suggesting that metals also can play a role in affecting health. It is not clear whether these metallic compounds, in the minute concentrations in which they exist in the atmosphere, impact health directly; help facilitate health impacts of other substances; or serve as a marker for other pollutants or pollutant sources. In addition, health study results to date have provided only limited support for the role of particulate sulfates *per se* in influencing adverse health outcomes.

PLAN

It will be important to ascertain which carbon-containing species impact human health as future regulations will likely target these species; this will alter the need to reduce other fractions of particulate matter (PM), such as sulfates, in order to achieve PM standards. Success will be achieved when a framework for component-specific regulations is widely accepted by the community. It will also be important to learn if the gaseous pollutants identified to be of concern are agents responsible for adverse health outcomes or if they are markers for other compounds.

Current research gaps include:

- Completion of the ARIES suite of studies, which relate a multiplicity of health endpoints to detailed air pollution characteristics in several cities. Emphasis will be given to understanding the importance and extent of the carbon fraction impacting health.
- Meta-analyses which combine the results from the several ARIES cities into a combined analysis across all available cities. The resulting analysis will have greater statistical power and may be more representative of a greater cross-section of the US. The US EPA also gives greater weight to multi-city studies in its consideration of scientific results.
- Completion of ongoing toxicological studies to understand the importance of air pollution components, especially carbon-containing compounds, on health and physiological mechanisms.
- Evaluation of the ability of various particulate fractions to deliver organic materials to the lung. Carbon-containing particles have been shown in some studies to effectively adsorb volatile and semi-volatile organic compounds, making them efficient carriers. It will be important to contrast the "carrying" ability of carbon-containing compounds with inorganic particles, such as sulfates and nitrates.
- Additional epidemiological analyses to examine the relationship between new definitions/categories of organic compounds and health endpoints, as well as determining whether there is any epidemiological evidence to support hypotheses about the "carrying" ability of particles.
- Identification of ways in which sulfates could possibly influence health and investigating these mechanisms thoroughly.

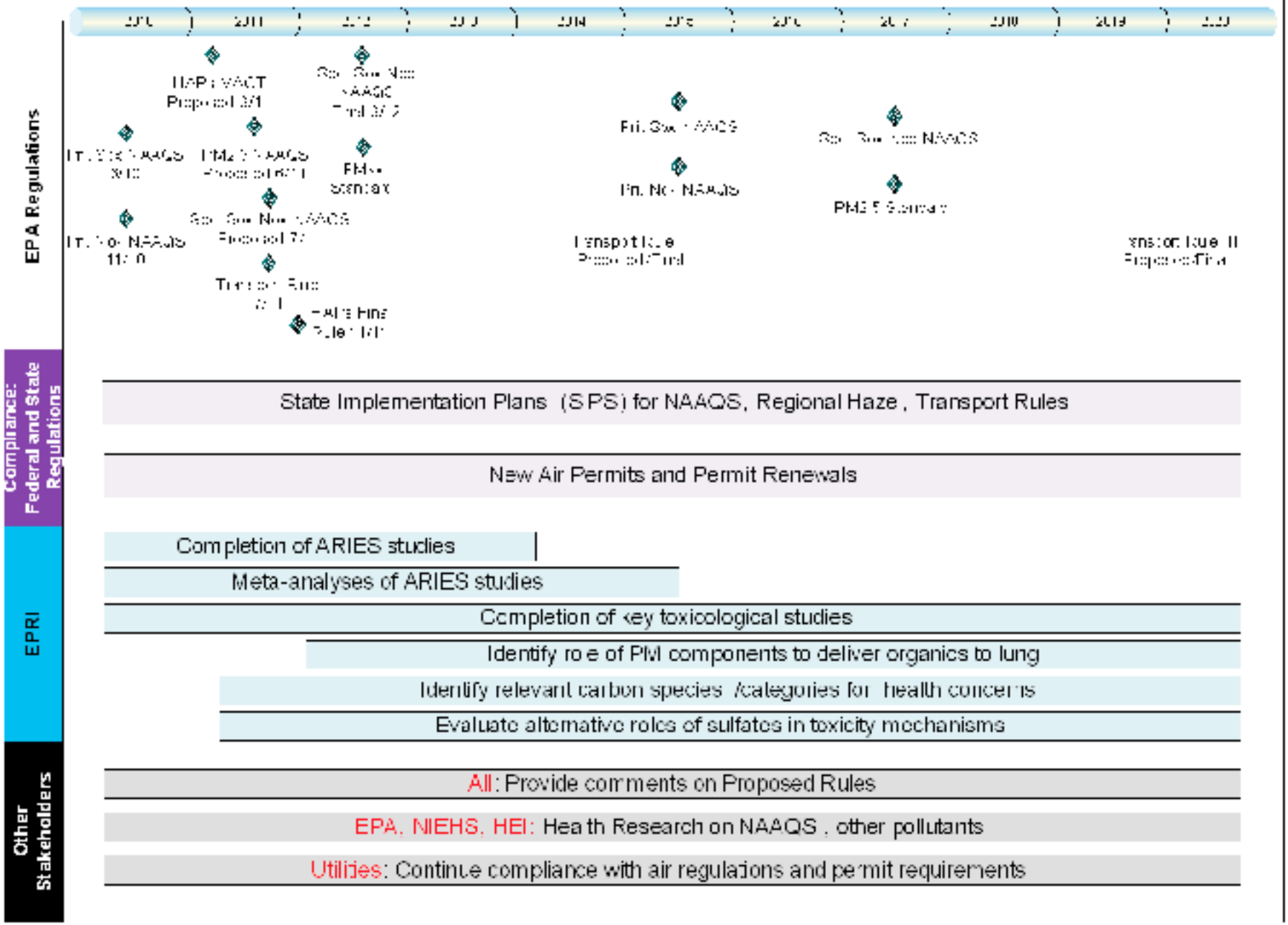
RISK

EPRI has been a leader in identifying the role of carbonaceous compounds as pollutants that impact the public health. Research outside of EPRI has been limited and has focused upon a few general categories of carbon-containing compounds. Without EPRI research, consideration of carbon-containing compounds would be limited and could likely focus only on a small subset of the compounds that are easily measured.

There are two significant risks of not undertaking this research:

- The incorrect species of concern would be addressed in future regulations, and human health would suffer accordingly;
- A limited regulation of carbon-containing compounds would place greater pressure on the non-carbon-containing compounds to attain PM standards, even if the reduction of these compounds would yield little health benefit.

Air Quality Health Effects



ISSUE STATEMENT

Air quality measurements are used to identify the chemicals that are present in the atmosphere, understand their transformation to other chemicals and losses to processes such as deposition, provide some information as to their sources, to serve as inputs to air quality models, and to provide data with which to evaluate model performance. Ancillary parameters (such as other chemicals, meteorological information, or properties of the Earth's surface) that influence air quality are measured in addition to pollutants. Air quality measurements play a crucial role in compliance determinations, development of state implementation plans, and permitting processes related to all air quality regulations. One particular issue that is critical to robust air quality management is the need to improve the detail and resolution of atmospheric measurements. Highly time resolved measurements on hourly or sub-hourly time scales are required to properly parameterize many atmospheric processes for inclusion into three-dimensional air quality models and to provide adequate information for understanding issues related to recently promulgated 1-hour standards. Continuous records of detailed air quality measurements are crucial inputs to long-term epidemiological analyses of human health impacts. The quality of these measurements is a direct contributor to the ability of health researchers to determine how the various components of air pollution contribute to observed health effects.

DRIVERS

There are many specific regulatory and legislative drivers at the state and federal levels requiring measurements of pollutants and ancillary data in ambient air. Continued monitoring of all air pollutants will remain crucial to proper evaluation and application of the models used in rule development. Additional specific drivers are listed below.

National Ambient Air Quality Standards (NAAQS) – The Environmental Protection Agency (EPA) will continue to review the NAAQS for ozone, PM, SO_2, lead, CO, and NOx. Standard revisions for both the primary (health-based) and the secondary (welfare-based) NAAQS may require modified measurement requirements. In particular, the new short-term 1 hour forms of the SO_2 and NOx standards call for additional monitoring (e.g. roadside monitoring of NOx, and re-siting as well as new monitoring sites for SO_2). New ozone measurements in micropolitan (smaller urban) areas have also been recommended. Measurements in rural areas are becoming a requirement to support various secondary NAAQS.

Regional Haze Rule –This rule will continue to place pressure on reducing emissions of SO_2 and NOx in its goal to achieve "natural conditions" for visibility at National Parks and other Class I areas. Measurements of gases and PM components are central to understanding impacts and compliance.

Transport Rules –Future revisions to the he Cross-State Air Pollution Rule will likely require significant reductions in SO_2 and NOx emissions to limit upwind state contributions to downwind state non-attainment of ambient standards for ozone and PM.

Hazardous Air Pollutants (HAPs) Rules – EPA recently proposed emission limits for HAPs from coal and oil-fired plants, will soon conduct a residual risk analysis to determine if the HAPs controls have been sufficient to fully address health risks, and must also address urban air toxics which could affect electric utility emissions. The two monitoring networks that support research and decision-making on these issues (the National Air Toxics Trends Stations (NATTS) and Urban Air Toxics Monitoring Program (UATMP)) have only been started recently, use methods that are subject to high uncertainty, and have poor geographical coverage. These issues must be addressed.

State Rules –State Implementation Plans are typically issued to meet EPA mandates. States need the best air quality monitoring data, modeling tools and scientific information to make technically sound decisions and to understand the impacts of decisions on air quality.

Total Maximum Daily Loads (TMDLs) – Atmospheric deposition is being considered by the states and EPA as requiring a TMDL for such aquatic parameters as pH, nitrogen, and mercury. A strong need exists for method development for direct measurement of wet and dry deposition of various chemicals.

RESULTS IMPLEMENTATION

EPRI has continually been working for many years to provide improved measurement tools to the research and regulatory community. This work has ranged from initial development of new measurement approaches at bench-scale, to modification of research-grade instruments for operation in a commercial-grade format (closer to 'plug and play' format). Research has also included deployment of novel instrumentation for various chemicals to existing air quality measurement networks, during special intensive campaigns sponsored by EPRI and through collaborations with other research entities. In addition, EPRI and collaborators sponsor a long-term (>10 yr.) independent measurement network that deploys high time resolution/high quality monitors to track detailed air quality trends. EPRI's research approach has been to begin methodological development as early as potential pollutants or impacts are identified. This is done in order to anticipate needs before potential regulatory concerns arrive and to have the measurement technologies ready for deployment when the air quality management process requires deployment of the measurement technology and use of the resulting data. EPRI research on air quality measurements has resulted in a crucial "seat at the table" for discussions with federal, regional, state, and local air quality managers and scientific researchers. EPRI measurement data have been used by a wide variety of regulators, scientists, other industries, and EPRI in various analyses related to air quality assessments as well as regulatory rule-makings.

PLAN

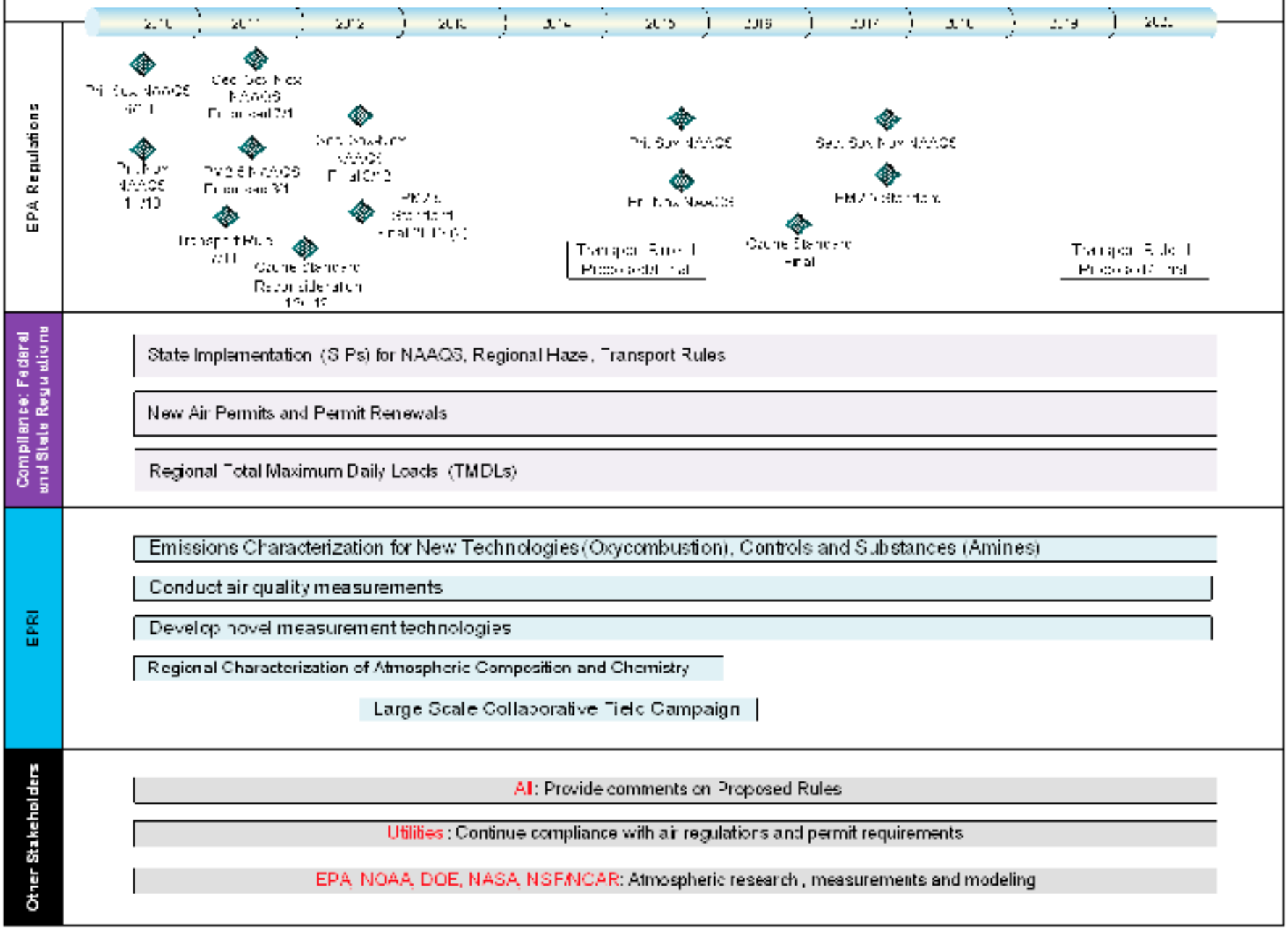
EPRI air quality measurement and analysis research will improve the detail, spatial resolution, and temporal resolution of atmospheric measurements and related analyses through instrumentation development and deployment in small-scale field sampling campaigns or as part of larger collaborative field studies. Both planned projects and projects of opportunity will be pursued. Research plans include the following elements:

1. *Characterize emissions and discharges from current and emerging energy generation technologies:* Emissions measurement at the stack will continue to be a critical need for conducting air quality modeling studies, understanding control technology performance, and conducting health risk studies.
2. *Conduct and analyze air quality measurements:* Measurement data is necessary in order to understand the various atmospheric transformation processes and properly represent those processes in atmospheric models. This area includes deployment of an aerosol chemical speciation monitor and sampling activities conditional on atmospheric composition to segregate source impacts.
3. *Develop novel measurement techniques:* Development of new sampling techniques for power plant, industrial, and natural emissions sources and ambient air is an ongoing fundamental need. This area includes characterization of new tracer chemicals for various sources and improvement in the detail and resolution of atmospheric air quality measurements.
4. *Conduct analyses of atmospheric composition and chemistry in specific regions:* Air quality issues can be weighted differently depending on the regional mix of sources and geographical and meteorological characteristics, thus requiring specific analyses. Examples include continued and upgraded operations of the SEARCH network and analyses of natural sources of emissions and industrial sources other than power plants.
5. *Participation in a large-scale collaborative field study:* Participation in a large (~20) research group collaborative field campaign, including government agencies, universities, and research institutions. This work would complement and extend the existing suite of atmospheric measurements, allow for critical evaluation of measurement techniques and data analysis/ interpretation, allow flexibility to address unanticipated questions by nature of the collaborative efforts, and take advantage of large multi-researcher datasets. This work would leverage the long-term historical record of air quality measurements and associated analyses created through the SEARCH network that can provide a wealth of context for a campaign undertaken in a single year at a single site. Most importantly, participation in this type of campaign provides a seat at the table in multi-stakeholder discussions on ambient measurements, instrumentation needs, and interpretations/implications as to atmospheric chemistry and physics.

RISK

EPRI research on air quality measurements has played a key role over the years in informing industry, regulators and society with the best possible datasets on atmospheric composition and chemistry. The research provides comprehensive data from state-of-the-art high resolution measurement techniques to complement or improve upon those that are available in current national monitoring networks and databases and that are used for determining air quality and management strategies. Finally, EPRI air quality measurement research enhances knowledge about the various sources contributing to air pollution, enabling electric utilities, industry, regulators, policymakers, and other stakeholders to determine the most efficient, cost-effective measures to address local and regional air quality concerns. These benefits would be lost if EPRI air quality measurement research did not occur. In many cases this information would not be available from other sources, and thus an independent, and often only, source of data critical to air quality management analyses would be lost.

Air Quality Measurements and Analysis



ISSUE STATEMENT

Implementation of regulatory programs under the Clean Air Act requires the development and application of rigorous air quality models. Improved techniques are needed for estimating emissions from various sources, for estimating the air quality consequences of those emissions and their changes, and for determining the impact of cross-state pollution. Previously these tools and techniques have been used to enable informed rulemaking processes for establishing National Ambient Air Quality Standards (NAAQS), to develop state implementation plans (SIPs) to attain those standards, and to make determinations of Prevention of Significant Deterioration during permitting of power plants. However, over the past few years the use of these models has been extended to essentially every part of the air quality regulatory process. In addition to their use in the implementation of standards, air quality models will be applied in following ways: setting the level of ambient standards; determining attainment designations; and determining the levels of significant contributions to interstate transport of air pollution. It is clear that improving different air quality models (through better representation of chemistry and transport) is essential to informing decisions at different steps of the regulatory process. These models include comprehensive three-dimensional models as well as single source models used in permitting process and attainment compliance for short-term sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) standards. For the models to provide accurate results, the emissions and meteorology used as the input to the models need to be developed with the best-available science and methods.

DRIVERS

National Ambient Air Quality Standards (NAAQS) – The Environmental Protection Agency (EPA) will continue to revise the NAAQS for ozone, PM, SO_2 , Lead, CO, and NOx. Standard revisions could lead to continuing pressure on the electric sector to reduce emissions if the standards are lowered further. These standards include both the primary (health-based) and the secondary (welfare-based) NAAQS.

Regional Haze Rule –This rule will continue to place pressure on reducing emissions of SO_2, PM, and NOx in its goal to achieve "natural conditions" for visibility at National Parks and other Class I areas.

Transport Rules –The Cross-State Air Pollution Rule will require significant reductions in SO_2 and NOx emissions to limit upwind state contributions to downwind state non-attainment of ambient standards for criteria pollutants. The Rule could be revisited when NAAQS levels are lowered or as evidence indicates that interstate transport continues to hinder the ability of downwind areas to reach attainment.

State Rules – State Implementation Plans are typically developed to attain and maintain the NAAQS. Since there are alternative ways to meets ozone and PM NAAQS, States need the best modeling tools and scientific information to make technically sound decisions.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All EPA rules are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Scientific research results provide critical, objective input to such discussions.

RESULTS IMPLEMENTATION

EPRI has a long record of advancing the science supporting air quality models used for policy development, regulatory decision making, and implementation planning. The EPRI research approach is designed to anticipate and address critical needs related to air quality modeling systems used in the regulatory process. EPA and state agencies often incorporate EPRI model development research results into EPA recommended models and release them for use by agencies and the public. Additionally, the research community frequently uses EPRI models and results for basic research, which in turn supports air quality management decision-making process. EPRI research allows:

- Policymakers, regulators and the public to use EPRI's scientific data, modeling tools, and analytical resources to fully evaluate air quality impacts from all emissions and sources, thereby enabling informed, science-based decision making;

- For analysis of additional regulatory options and evaluations of the effectiveness of proposed policies; and
- Development of detailed scientific perspectives on environmental policy and regulatory deliberations of power plant emissions.

PLAN

Air quality models and analyses are critical in addressing air quality issues in a comprehensive manner. These analyses include characterizing emissions and understanding air emissions fate and transport in the environment (transport and transformations in the atmosphere; from air to deposition on land and water). This involves careful measurement of emissions and ambient chemicals, as well as a detailed understanding of the overall process chemistry at the power plant and its chemical transformation and transport in the atmosphere. Development of advanced air quality models and execution of detailed studies is required to elucidate the role of power plants versus other sources contributing to ambient levels of air pollutants. This work will continue to stay important as long as there are air quality regulations and power plant emissions contribute to ambient air pollution. Specific actions needed in this research area include:

1. *Effectively characterize emissions from current and emerging technologies:* Characterization of emissions from current and emerging combustion-based generation technologies will continue to be a critical need for conducting air quality modeling studies, understanding control technology performance, and providing input to health risk studies. With the advent of short-term air quality standards, estimating power plant stack emissions during plant start-up/shut-down periods may also become critical. In addition, accurate emissions from non-power plant sources are needed to fully investigate the role of different sources in contributing to air pollution and to design effective air pollution mitigation strategies.
2. *Develop, improve and evaluate eulerian atmospheric models:* As states and EPA implement regulations, sophisticated computer models are needed to determine the impact of various sources on air pollution and the level of controls needed to reach compliance. Thus, it is critical that these models provide a realistic representation of atmospheric physics and chemistry as they relate not only to power plant emissions but all emissions sources to accurately portray their specific contributions. Some of the key atmospheric processes whose representation in air quality models needs further development include cloud chemistry and simulation of organic compounds and nitrate aerosol.
3. *Conduct eulerian air quality model application studies:* As advanced air quality models are developed, there is a need to apply those models to regulatory case studies to better understand contribution of different sources to ozone, particulate matter, and regional haze. One important application of the models is to examine the transboundary contributions to ozone, particulate matter, regional haze, and atmospheric deposition in the United States that define "policy-relevant background" levels, as that determines the extent of controls needed on domestic sources to reach attainment.
4. *Develop, improve and evaluate single source (lagrangian) models:* With the short-term NAAQS for SO_2 and NO_2, there is a need to improve the regulatory models used in application and renewal of air permits. Improvements in existing models are needed to remove or minimize potential biases that exist; however there is also a need to explore whether better alternatives to existing models can be supported. Recent advances in computational speed suggest there may no longer be a need to keep using simple representations of atmospheric processes in single source models. Advances are also needed in interfacing lagrangian models within the eulerian models to better simulate local sub-grid scales in a single regional simulation, e.g., the plume dynamics or the urban-scale gradients.

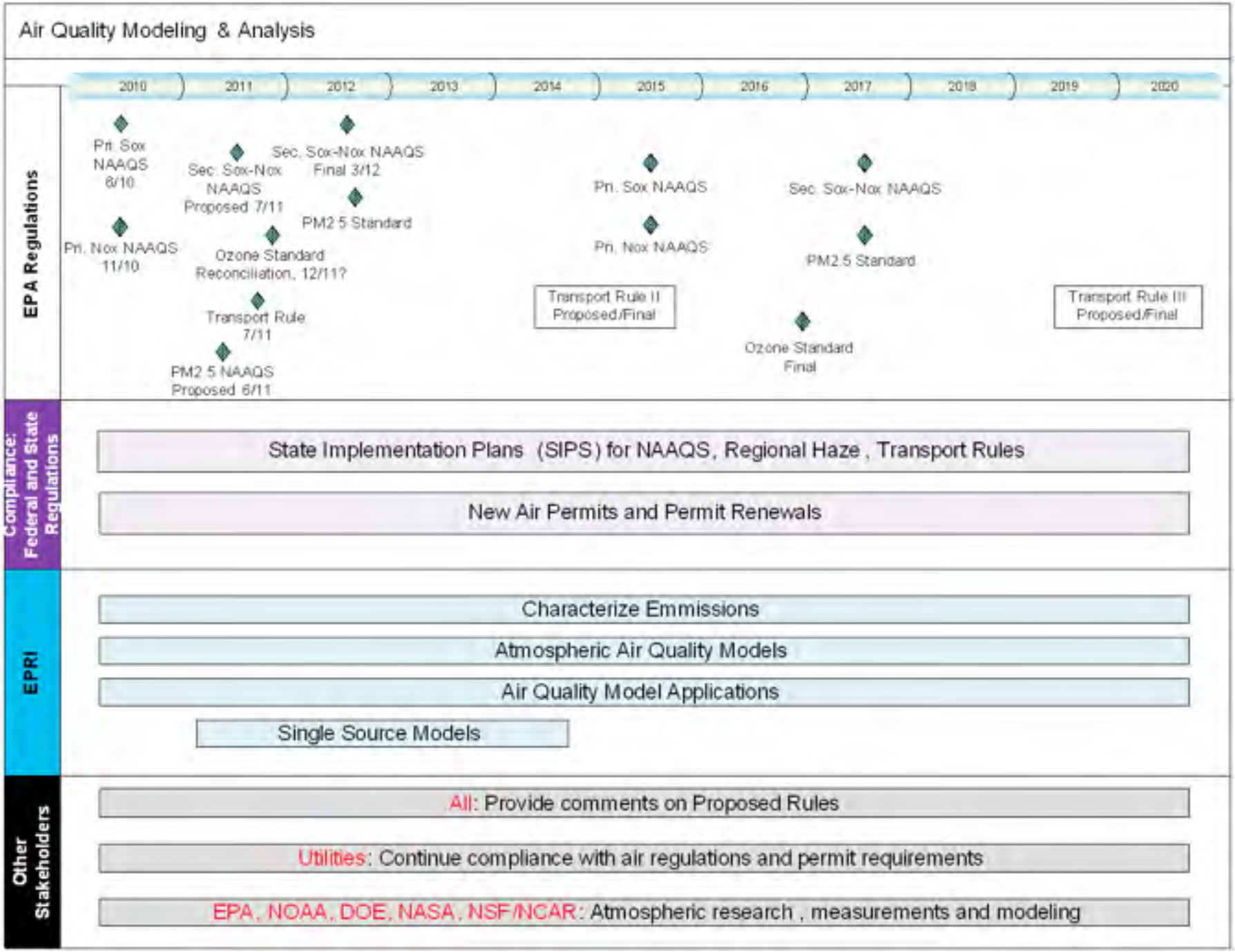
RISK

EPRI research on air quality modeling and characterization of emissions informs industry, regulators and society alike with high quality, objective and credible scientific information, providing an independent perspective that otherwise would not exist. The following benefits could suffer without EPRI research in this area:

- **Ability to address new and emerging issues that could impact the electric utility sector:** EPRI research on characterizing emissions enables evaluation of possible health impacts of advanced energy systems to be proactively addressed during the technology develop-

ment process. Without this research there is potential danger of discovering environmental risks too late in the process, which could prove extremely costly to address through later changes in technology and equipment retrofit.

- **Effective air quality management:** EPRI research ensures that the air quality models used by regulators in the development of air quality implementation plans include the best available science and accurate treatment of power plant emissions. Without EPRI research on improved modeling tools, regulations and policy decisions may rely on inferior methodologies that often result in overly conservative and costly solutions.


Air Quality Modeling & Analysis
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EPA Regulations
Pri. Sox NAAQS 8/10
Pri. Nox NAAQS 11/10
Sec. Sox-Nox NAAQS Proposed 7/11
Ozone Standard Reconciliation, 12/11?
Transport Rule 7/11
PM2.5 NAAQS Proposed 6/11
Sec. Sox-Nox NAAQS Final 3/12
PM2.5 Standard
Pri. Sox NAAQS
Pri. Nox NAAQS
Transport Rule II Proposed/Final
Ozone Standard Final
Sec. Sox-Nox NAAQS
PM2.5 Standard
Transport Rule III Proposed/Final
Compliance: Federal and State Regulations
State Implementation Plans (SIPS) for NAAQS, Regional Haze, Transport Rules
New Air Permits and Permit Renewals
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Characterize Emmissions
Atmospheric Air Quality Models
Air Quality Model Applications
Single Source Models
Other Stakeholders
All: Provide comments on Proposed Rules
Utilities: Continue compliance with air regulations and permit requirements
EPA, NOAA, DOE, NASA, NSF/NCAR: Atmospheric research, measurements and modeling

ISSUE STATEMENT

Emerging fuel sources, plant designs, and control technologies—including carbon capture and storage (CCS) systems and biomass combustion—may result in new types of emissions with possible adverse impacts on the environment and human health. It is important to understand these potential effects in order to both protect human and environmental health and to provide an opportunity for developers and engineers to address issues prior to widespread technology deployment. Power producers annually incur hundreds of billions of dollars in costs to reduce releases associated with existing generation technologies, mainly through the use of back-end controls—many installed on a retrofit basis to meet regulations developed based on incomplete knowledge of environmental and health impacts. Improved understanding of the potential effects of future generation options will inform technology development and deployment as well as regulatory decision-making, helping optimize economic, environmental, and social performance within the electricity sector.

DRIVERS

Air quality and other regulations directly apply to some of the emissions generated by emerging technologies; however, not all pollutants are currently targeted by regulatory frameworks. For example, amines and their degradation products are as of yet not regulated in the ambient environment, although they do have occupational health and safety standards. Specific regulatory drivers include:

National Ambient Air Quality Standards (NAAQS) – The Environmental Protection Agency (EPA) will continue to review the NAAQS for ozone, PM, SO_2, lead, CO, and NOx. Standard revisions could lead to continuing pressure on the electric sector to reduce emissions if the standards are lowered further. These standards include both the primary (health-based) and the secondary (welfare-based) NAAQS.

Greenhouse Gas Regulations – EPA's GHG permitting program, which applies to new and substantially upgraded sources that emit GHG above certain thresholds will begin in 2012. This covers pre-construction permits under the Prevention of Significant Deterioration (PSD) portion of New Source Review as well as operating permits under Title V. EPA is poised to roll out GHG New Source Performance Standards (NSPS) for power plants and refineries in 2011.

Pending Greenhouse Gas Legislation – While Congressional action on climate is unlikely to occur in the next several years, at some point Congress is expected to act to reduce GHG emissions from the electric sector, including consideration of a Clean Energy Standard. Some states, such as California, have passed legislation and will soon be regulating GHG emissions.

Renewable Portfolio Standards – Currently, 30 states have renewable energy mandates, which include biomass.

Emissions Standards – For some chemicals emitted as a result of, for example, an amine-based post combustion capture system, emission limits may apply. Formaldehyde, an oxidative degradation product of many amines, is included in the list of 189 air toxics regulated under the National Emissions Standards for Hazardous Air Pollutants (NESHAP).

Hazardous Air Pollutants (HAPs) Rules – EPA recently proposed emission limits for HAPs from coal and oil-fired plants. Following implementation of the rule, EPA must conduct a residual risk analysis to determine if the HAPs controls have been sufficient to fully address health risks. If not, more controls could be forthcoming.

Occupational Health and Safety Administration Permissible Exposure Limits (PELs) – PELs apply to some particular amines.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All EPA rules are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Scientific research results provide critical, objective input to such discussions.

RESULTS IMPLEMENTATION

EPRI is actively evaluating the potential health and environmental impacts of emerging technologies. The near-term intent of the work is to identify any potential issues in advance of widespread deployment such that mitigative approaches can be developed if warranted. The results of the work will be

shared with technology researchers and developers, particularly if indications exist of potential health or environmental risks. The information will also benefit regulators and the public regarding the potential impacts, if any, of new generation and control technologies likely to be employed in the future.

PLAN

EPRI is taking a multidisciplinary approach to evaluate air quality impacts of emerging technologies, involving risk assessment, toxicology, emissions measurements, air quality modeling, chemistry and thermodynamics studies, and occupational health and safety. Focus has centered on two specific generation configurations. The first is carbon capture: the use of amines as CO_2 absorbents in post-combustion capture, for example, may be associated with emissions of potentially hazardous materials. It will be critical to better understand the formation and emissions of these materials. Other CCS technologies, such as oxyfuel combustion, also need to be examined for any potential health or environmental impacts. The second area of focus is the increasing use of biomass as a generation option. While there is much information on residential wood smoke and its health effects, little is known about the detailed composition and potential toxicity of emissions from bioenergy applications. The portfolio of research activities described below will comprehensively address these issues and others to generate data critical for informing current and future technology development. Specific activities include:

1. *Conduct comprehensive risk assessment of emerging technologies:* Incorporating inhalation, multimedia, and ecosystem risk analyses, the overall relative risk of different "future" plant configurations is being determined. We have determined 20 configurations using expert judgment as well as modeling that are projected to be the most prevalent in approximately 2030.

2. *Characterize biomass emissions and evaluate toxicity:* Because of the lack of detailed information on utility-scale biomass operations and in light of the increasing interest in biomass both in the US and overseas, activities in this area focus on generation of fundamental chemical and health-related data. Specific research activities include field sampling of emissions with comprehensive chemical characterization as well as toxicological experiments in animals and cell cultures to evaluate the potential toxicity of PM (and possibly gases) collected from stack gas.

3. *Characterize emissions from CCS technologies and evaluate toxicity:* The issue of potential health and safety concerns related to the use of amines for post-combustion capture has been actively under investigation recently, especially in Europe. EPRI's role includes field sampling of emissions from chilled ammonia and amine-based pilot and demonstration projects, chemical characterization, and toxicological experiments. A recent workshop on "Health and Environmental Toxicity of Amines for Post-Combustion Capture: Launching a Dialogue on Research Needs" explored various options for a holistic and standardized solvent toxicity testing framework.

4. *Conduct chemistry and thermodynamics studies:* In order to fully understand the atmospheric behavior of amines once emitted, studies are needed to better understand the thermodynamic, partitioning, and chemical conversion properties of these compounds. In addition, modeling work is needed to understand the formation of ultrafine particles in power plant plumes and to include treatment of new emissions constituents.

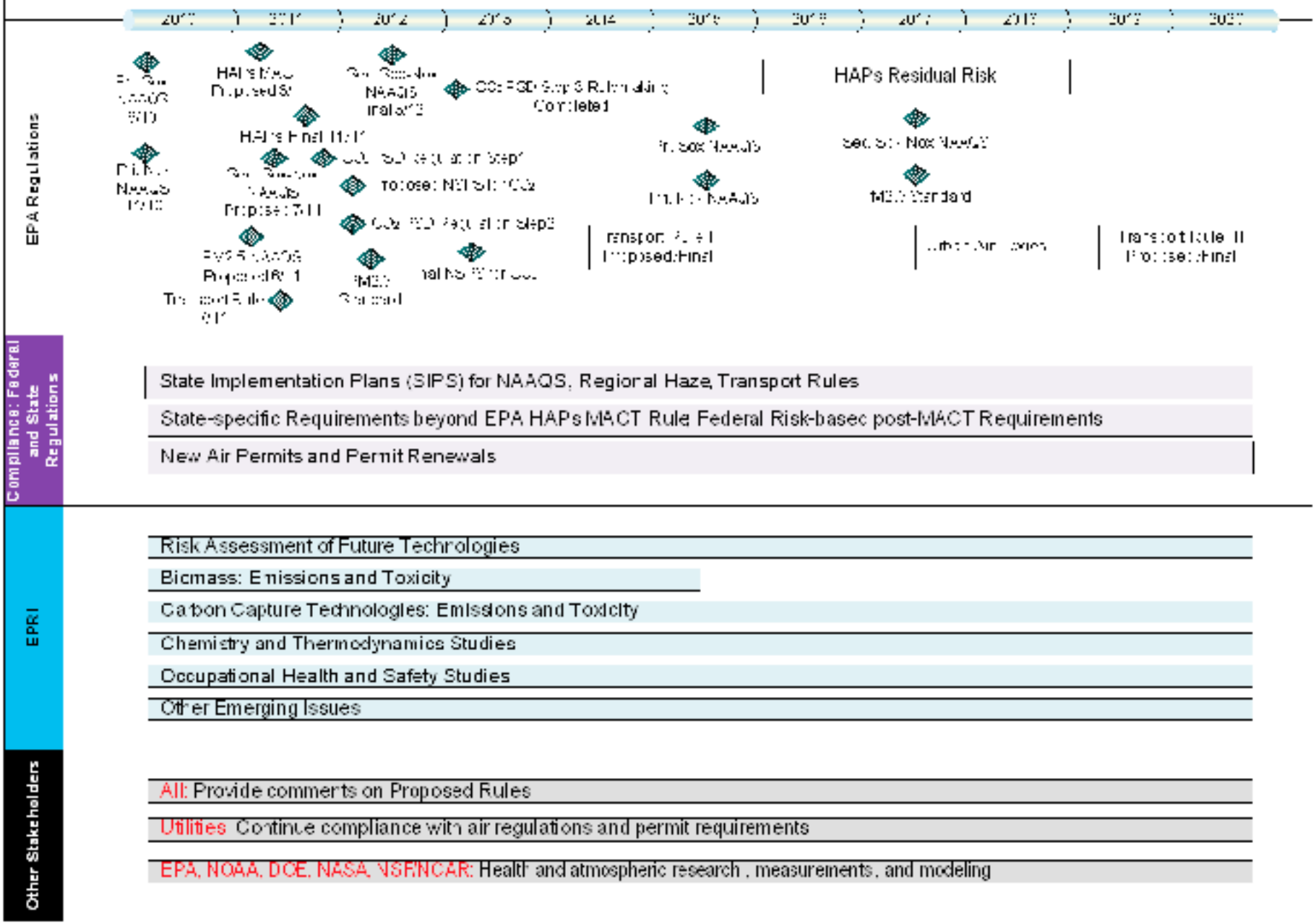
5. *Evaluate occupational health and safety issues associated with emerging technologies:* Because occupational hazards may exist with emerging technologies, OH&S monitoring will be conducted in conjunction with the field activities at biomass and CCS facilities to better understand potential risks to workers.

6. *Continually scan the landscape for emerging issues:* A white paper will be prepared on the downstream issues related to natural gas. In addition, a critical review on the potential health and environmental issues associated with oxyfuel combustion will be prepared. Other issues that arise related to advanced fossil-based generation will be scoped out as they are identified.

RISK

The risks of not conducting this basic research on emerging technologies are significant indeed. If technologies are placed into widespread use and risks are only later identified, not only is public health at risk in the interim but the retrofit costs are also likely to be very high. Although there is some research occurring on this topic, primarily in Europe, there remain many important knowledge gaps that EPRI can take a leadership role in addressing on behalf of both society and industry.

Air Quality Impacts of Emerging Technologies



DRAFT: ARSENIC, CHROMIUM AND OTHER TRACE METALS

ISSUE STATEMENT

Exposure to trace and transition metals such as arsenic, chromium, manganese, selenium and cobalt may lead to an array of adverse health outcomes, including cancer, as well as respiratory and neurological health effects. Therefore, assessing the potential for community exposure to such metals, as well as quantifying any associated exposure-to-health relationships, continues to be of critical importance to the industry and the public due to the presence of multiple metals in both pre-combustion (coal, oil stocks, intake water) and post-combustion waste streams (air, water, and solids). Establishing the potential risk associated with the metal component of any waste stream requires quantifying the relationship among levels of exposure, intake, and negative health effects. Limited integration exists between mechanistic toxicology and human epidemiological data to inform risk assessment evaluations. If chemical-specific data are not available to support derivation of the IRIS (Integrated Risk Information System) value, then EPA will default to conservative modeling assumptions. For example, in order to address uncertainties in health outcomes, default assumptions presume equal effects at low versus high dose exposures resulting in linear modeling and thus more conservative, stringent assessments.

EPRI research is needed on the biological processes underlying exposures to trace metals to better inform development of dose-response values used in human health risk assessments for determination of both national and site-specific criteria for waste streams (air emissions, wastewater discharges and handling of solids). Additionally, future compliance under the HAPs MACT (Hazardous Air Pollutants Maximum Achievable Control Technology) rules will lead to additional focus on pollutants from air emissions controls systems as additional technologies are deployed. Major data concerns also exist related to understanding the actual industry-related exposures; one major R&D gap is the limited information regarding the extent and range of chromium exposure (and risk) associated with contaminated infrastructure (e.g., anti-corrosives in soil and water). Finally, there is limited and unclear methodology available for quantifying cumulative risk for trace metals with similar, or dissimilar, health outcomes for use in regulation and health effects research.

DRIVERS

Integrated Risk Information System (IRIS) – The EPA IRIS program develops dose-response values for cancer and non-cancer health effects related to metals exposure for use in risk assessments under a range of federal and state regulatory programs. These assessments are designed to evaluate risk and establish environmental media guidelines, regulatory standards, permit levels and public health goals. Human health risk assessments, for both inhalation and multimedia effects, require the use of these IRIS dose-response values. Currently, the agency has multiple IRIS values under review.

Hazardous Air Pollutants (HAPs) Rules – EPA recently proposed emission limits for HAPs from coal and oil-fired plants. Trace and transition metals remain a major component of all HAPs released and act as the major elements driving site and industry risk assessments. After implementation of the MACT rule, EPA's residual risk analyses will likely focus on metals to determine the efficacy of HAPs controls to meet regulatory health thresholds. EPA derived IRIS dose-response values will continue to be used in these health risk assessments, both inhalation and multimedia effects.

Clean Water Act (CWA) – EPA develops national ambient water quality criteria (AWQC) to be implemented by the states. Utilities are subject to limits on metals and other substances in their discharge permits based on existing and any new developed criteria. As part of the EPA review of all AWQC for possible revision, supporting data on exposure and underlying dose-response are required.

Safe Drinking Water Act (SDWA) – The SDWA establishes Maximum Contaminant Levels (MCLs) for compounds, including trace metals, with the potential to cause adverse health effects. As with AWQC, EPA derived dose-response values are used in development of MCLs. Trace metals, particularly those found in coal (including arsenic, chromium, cobalt, selenium) and removed by emission controls, become part of the solid or liquid by-products (waste effluent streams). MCL levels have implications for storage or use of by-products, discharge of waste water and groundwater contamination.

State Regulation & Compliance – States require a range of health risk assessments to derive state-specific environmental levels (such as public health goals, TMDLs, hazardous waste cleanup levels) and to demonstrate compliance with both state and federal regulation (such as air and water discharge permitting). States need the best supporting science, health and exposure modeling tools to make technically sound decisions.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All EPA rules are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Scientific research results provide critical, objective input to such discussions.

RESULTS IMPLEMENTATION

EPRI has focused on research surrounding exposure and cancer risk related to inorganic arsenic, including on the IRIS arsenic cancer slope factor that has been crucial in clarifying the science and providing comments to EPA to reconsider its current proposal. This work will continue to inform the regulatory process across environmental media, as well as serving as a model of integration of multi disciplinary science and interpretation for risk assessment for other important trace metals. The EPRI research approach is designed to identify data gaps, to evaluate potential data requirements, and to address critical issues related to assessment of health risks from trace metals. EPRI regularly briefs state agencies and the EPA on the results of its air toxics research.

PLAN

The research needed to better understand the role of trace and transition metals released from power generation emissions sources on human health requires improvements in the integration and interpretation of both the underlying biological data (experimental and observational research), and, evaluation of the potential levels of population exposure across the multiple environmental media. Specific gaps needed to address current and anticipated issues surrounding trace and transition metals include:

1. *Integrated analysis of toxicological and epidemiological data available for targeted trace metals:* For each metal of concern, a study to identify current available data and data gaps required for initiating additional primary studies, both experimental and alternative dose-response modeling, needs to be conducted. Initial trace elements to focus on include arsenic (non-cancer effects), chromium, manganese, selenium and cobalt. The major issues to be studied include identifying how well experimental biological data does or does not support (or exists for) dose-response modeling of human observational data, thereby determining if the EPA must rely on default assumptions, or if scientifically supported inputs may be applied to dose-response analyses.
2. *Additional dose-response toxicological studies on targeted trace metals at environmentally relevant low doses:* In order to fully describe dose-response relationships at low levels relevant to environmental population exposures, targeted studies utilizing genomic and cellular test systems can help establish appropriate assessment and modeling methods in the IRIS process.
3. *Analysis of actual exposure levels associated with individual metals released from power plants:* Initial focus will be on hexavalent chromium, a human carcinogen and major health risk driver for power plants, specifically to determine the extent and range of chromium exposure associated with contaminated infrastructure (e.g., anti-corrosives), soil, and water, and the potential for environmental multimedia releases. Additional metals of concern with limited data on exposure, but with potential carcinogenic or neurological properties at relatively low exposure levels, include manganese and cobalt. These studies are required to establish the extent and range of exposure levels for applying to risk assessments and regulatory processes.
4. *Studies to develop cumulative risk modeling methodology for trace and transition metals:* This work is aimed at identifying modeling methods to quantitatively combine "background" toxic levels with major source emission data to determine the relative influence on estimating marginal health risks due to power generation, particularly for urban air toxics. Also, models for cumulative risk assessment at an urban airshed level capable of accounting for non-chemical stressors are of growing regulatory focus for identifying and protecting susceptible populations.

RISK

EPRI research on the underlying toxicological, exposure and health effects outcomes associated with trace and transition metals informs industry, regulators and society alike with high quality, objective and credible scientific information, providing an independent perspective that otherwise would not exist. By engaging with a range of academic, consulting and other scientists, EPRI serves as a credible source for informing regulatory based assessments and policies, and serving to elucidate alternative modeling strategies for public and governmental review. If EPRI does not conduct this work, then regulatory risk assessors will be more likely to follow non-specific modeling defaults resulting in stringent, overly conservative regulatory values.

ARSENIC, CHROMIUM AND OTHER TRACE METALS

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020

EPA Regulations and Assessments

- HAPs MACT 3/11
- HAPs Rule Final 11/11
- Development IRIS Cancer Arsenic
- Development IRIS Cancer/NonCancer Cadmium
- Development IRIS Non-Cancer Arsenic
- HAPs Residual Risk
- Development IRIS Cancer Beryllium
- Development IRIS Cancer Hexavalent Chromium(Oral)
- Development IRIS Non-Cancer Manganese
- Development IRIS Cancer Hexavalent Chromium(Inhalation)
- Development IRIS Cobalt
- Development IRIS Cancer Nickel, Soluble Salts
- Urban Air Toxics
- Development , Review and Finalization of Maximum Contaminant Levels (MCLs) & Amber Water Quality Criteria (AWQC)

State Regulations & Programs

- Risk Assessment Related to Air Permit Renewals and New Source Air Permits
- Development/Update of Water and/or Soil-Based Public Health Goals , and Total Maximum Daily Loads (TMDLs)
- State-specific requirements beyond EPA HAPs MACT Rule; Federal risk-based post-MACT Requirements
- Risk Assessment Related to Water/Effluent Discharge and Solid Waste Handling Permits

EPRI Role

- HAPs/Residual Risk and Urban Air Toxics Assessment
- Integrated Analysis of Toxicological and Epidemiological Data
- Targeted Low Dose-Response Studies
- Analysis Exposure Levels Associated with Individual Metals
- Development of Cumulative Risk Modeling Methodology

Other Stakeholders

- ALL: Provide comments on Draft/Final IRIS Values, Proposed Rules, Guidelines and Standards
- UTILITIES: Continue compliance with air, water and waste handling regulations and permit requirements
- EPA, CalEPA, NAS, DOE: EPRI leverage for research, exposure assessment and cumulative modeling development.

ISSUE STATEMENT

Emissions of mercury from coal-fired power plants have the potential to remain a regulatory and scientific issue for many years. As a chemical element, mercury may remain environmentally active for years after its release into the human environment. Associated with both oil and coal deposits, mercury can be mobilized into the global atmosphere via combustion of these fuels and may then impact human health at distances of thousands of miles. Improved research methodologies combined with more extensive surveys and modeling of human populations may result in ever more subtle toxic effects being discerned and quantified. Current steps to cut U.S. utility emissions are going forward in parallel with basic health effects research on mercury. The threshold dose based on subtle mercury health effects is defined in national regulation by what is "observable" in laboratory or epidemiological studies; as methods and data improve, these levels of observable adverse effect are likely to drop so that health standards would tend to become more stringent.

The most recent focus on mercury impacts to subsistence anglers and their families has the added potential to involve the issue of "environmental justice": high-exposure or high-sensitivity individuals that are part of minority or ethnic subpopulations exposed via consumption of locally-caught fish. This trade-off, between relatively small populations of potentially highly impacted individuals, will continue to shine the spotlight on mercury into the foreseeable future. In addition to the U.S. focus on domestic subpopulations, the Federal government is an active participant in ongoing United Nations negotiations towards a 2013 treaty limiting international transport of mercury. This process has been informed by the research work done by EPRI, via data briefings to U.S. negotiators.

DRIVERS

Mercury's unique position as a trace pollutant with exposure pathways involving multiple environmental compartments brings it under the purview of several federal and state requirements

Maximum Achievable Control Technology (MACT) Rule – The U.S. Environmental Protection Agency (EPA) is developing a MACT rule applicable to all utility trace pollutants, but mercury is the primary driver. The key findings of "harm" in the draft MACT rule are based on mercury's putative impact on intelligence quotient (IQ) among high-end consumers of fish, and the economic consequences of IQ lowered due to prenatal mercury exposure. At several places in the rule, EPA refers to the MACT rulemaking as necessary, but not sufficient, to address current U.S. human health risk.

Residual Risk Rule – After the promulgation of the MACT standard, the EPA has to evaluate remaining (i.e. residual) risks from HAP emissions for public health and the environment within 3 years. If EPA deems the remaining risks "unacceptable," more stringent emissions standards have to be established within 8 years after the MACT standard was released. Arguments made in the MACT rule and in supporting documents appear to show that even after full MACT implementation, high-end fish consumers will still suffer from IQ loss due to mercury exposure. Additional unquantified effects such as adult-onset cardiovascular disease also will require investigation.

Urban Air Toxics Rule –The Urban Air Toxics provisions of the Clean Air Act Amendments of 1990 require EPA to reduce the inhalation cancer risk from exposure to all sources in U.S. urban areas to below 1 in 1 million. "Urban" areas are broadly defined at the county level, so that even entire states in the western U.S. (where counties tend to be larger) may be classified as predominantly urban. Most recently, EPA has broadened the consideration of Urban Air Toxics to include multimedia toxics from any source within or introduced into an urban area.

Clean Water Act – EPA is revisiting its effluent guidelines for the steam electric sector and one of the primary concerns is discharge of mercury and selenium from FGD wastewater. Other water pollutants from air emissions controls systems may also become issues as technologies are deployed to comply with the HAPs MACT rules.

Safe Drinking Water Act (SDWA) – The SDWA establishes Maximum Contaminant Levels (MCLs) for discharges such as mercury that have established regulatory fish tissue criteria.

Total Maximum Daily Loads (TMDLs) – A number of states and regions have formulated TMDL studies or action plans to assess how much of their local fish levels of mercury need to be reduced to attain lower-threshold limits for safe consumption. Studies to date have indicated that only inclusion of long-range mercury transport from other states will provide enough input to make a significant difference in receiving waters. This indirect approach to regulating air sources via their potential impact on water quality requires improved tools for simulating atmospheric long-range transport, transformation, and deposition, as well as models of the dynamics of mercury, arsenic, and other substances in receiving waters and ecosystems.

RESULTS IMPLEMENTATION

EPRI has attained recognition as a center for high caliber mercury research. Our mercury research has been designed and operated as a cross-discipline, cross-organizational integration of specialties brought to bear on all aspects of the mercury issue. EPRI expertise in mercury science has brought our staff before Senate and House committee hearings, White House meetings, and state legislative and regulatory bodies. In addition, EPRI staff has briefed State Department negotiators on mercury long-range transport as part of the preparation for United Nations mercury treaty negotiations. EPA and other federal agencies, as well as state agencies, have often incorporated EPRI research results into their decision-making processes. A few examples include:

- EPA engaged EPRI scientific staff to review its mercury MACT Technical Support Document.
- EPA's analyses for its Clean Air Mercury Rule (later vacated on legal, not scientific, grounds) were informed by EPRI's preceding research protocol.
- The Texas State Commission on Environmental Quality, following a technical briefing by EPRI staff, requested use and incorporation of EPRI technical reports on mercury exposure and risk into its own report to the Texas legislature.

PLAN

The mercury issue requires a comprehensive understanding of its biogeochemical cycling through air, water, ecosystems, and terrestrial environments. Each stage of this cycling may alter the ultimate human exposure to trace amounts of mercury. To comprehend mercury's complex pathway from emission to human exposure and risk involves an integrated program of field measurement, laboratory analyses, computer simulations, and data integration. The mercury research for the utility industry will continue to be important until all the risks (residual risk and the urban areas risk) due to utility emissions have been adequately assessed. Specific actions needed to address current and anticipated mercury issues include:

1. *Characterizing Present and Future Mercury Emissions:* A hallmark of the EPRI mercury strategy is close coordination across programs and sectors. Essential work on utility mercury emissions by fuel, power plant configuration, and operations in other programs is brought together with work on mercury emissions from other sources to fully characterize emissions to the atmosphere. This work provides a basic understanding of mercury emissions from non-utility sources in the U.S. and from all source categories in other countries. The global characteristic of mercury requires this comprehensive approach.

2. *Assessing the Toxicity of Emissions and Discharges from Advanced Technologies, Controls and Substances:* Characterization of emissions from current and emerging combustion-based generation technologies is a requirement for quantifying the origin of the substance in the complex exposure of humans. These future emissions may include reactants such as amines that can alter what is known about mercury reactions near source points.

3. *Air, Deposition, Environmental Compartments:* A critical issue as U.S. utility mercury is controlled by the EPA MACT rule is the remaining mercury entering U.S. ecosystems from non-U.S. sources. How total mercury partitions into consumable fish will change with time. EPRI will continue its support of monitoring of mercury import by atmospheric transport while participating in emerging national programs to evaluate ecosystem trends in mercury and its burden in environmental compartments.

4. *Evolving Mercury Health Effects Research:* Mercury health effects range from well to poorly understood, from infantile neurological development impacts to possible effects on IQ attainment. Research is needed on critical mercury health effects, especially those that have the potential to lower the threshold mercury dose for adverse effects. That level is currently set by the observed impacts on fetal neurodevelopment; if this Reference Dose is lowered further;

current emission reduction targets may be determined to be insufficient.

5. *Air Quality Models for Research and Regulatory Application:* The global reach of mercury requires a suite of atmospheric and ecosystem models to account for its chemistry, bioavailability, and mobilization through the aquatic food chain. Improved modeling is used to provide research guidance into field and laboratory studies as well as investigate regulatory scenarios for their impact on future mercury deposition.

6. *HAPs/Residual Risk and Urban Air Toxics Assessment:* Federal regulation is certain to continue following the MACT rule with statutory investigations of Residual Risk (unacceptable risk levels remaining after full MACT rule implementation) and Urban Air Toxics (risks to residents in "urban" areas from all sources via all routes of exposure). EPRI research will address these issues as they continue to evolve.

7. *Multimedia Research: Source apportionment of toxics, Inter-media transfer, redox chemistry between media:* The EPRI mercury research program is planned around a comprehensive investigation of the substance and its complex environmental behavior. Key aspects of this are clarification of source contributions to human exposure, mechanisms involved in, and limiting, the transfer of mercury among air, water, and terrestrial systems; and chemical changes that directly determine mercury movement between media.

RISK

EPRI serves as a primary source of mercury research information for industry and the public. Without a continuing, focused mercury research program, there would be a lessening of societal and sector benefits from the EPRI effort:

- **Air quality standards based on sound science:** EPRI research has repeatedly informed EPA and other agencies when technical shortcomings in their data evaluations may compromise mercury standard-setting. Most recently, the risk basis for the EPA utility HAPs MACT rule has been examined and reviewed to ensure that sound science is applied to these critical issues.

- **Collaborative research across sectors and disciplines:** One of the hallmarks of EPRI mercury research has been the continuing consultation among programs across multiple EPRI sectors. That recognized collaboration has allowed the issuance of periodic mercury science updates summarizing developments across many areas of EPRI.

Mercury

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020

EPA Regulations

- HAPs MACT Proposed 3/11
- HAPs Residual Risk: Scoping Studies
- HAPs Residual Risk: Regulatory Steps
- HAPs Final Rule 11/11
- Urban Air Toxics

Compliance: Federal and State Regulators

- Permits Renewals and New Source Air Permits
- State-specific Requirements beyond EPA HAPs MACT Rule; Federal risk-based post-MACT Requirements
- Regional Total Maximum Daily Loads (TMDLs)

EPRI Role

- Characterizing Present and Future Mercury Emmissions
- Assessing the Toxicity of Emissions and Discharges from Advanced Technologies, Controls and Substances
- Ambient Toxics Measurements and Trends: Air, Deposition, Environmental Reservoirs
- Evolving Mercury Health Effects Research (late-in-life effects; indirect impacts)
- Air Quality Models for Research and Regulatory Application
- HAPs/Residual Risk and Urban Air Toxics Assessment
- Multimedia Research: Source apportionment of toxics, Inter-media transfer, redox chemistry between media

Other Stakeholders

- All: Provide comments on Proposed Rules
- UTILITIES: Continue with air regulations and permit requirements
- NOAA, DOE, NASA, EPA, NSF/NCAR: EPRI leverage for atmospheric/multimedia research, measurements and modeling

DRAFT: ORGANICS AND ACID GASES

ISSUE STATEMENT

Utility emissions of organic and inorganic Hazardous Air Pollutants (HAPs) occur primarily in the vapor phase. Organic HAPs are typically a result of incomplete combustion, although their formation mechanisms are poorly understood, and can range from simple structures such as formaldehyde through complex families of compounds such as dioxins and furans. The higher molecular weight forms ("congeners") of these substances generally result in human exposure via non-air pathways, as they deposit to the surface more readily and can bioaccumulate in foods. Inorganic acid gas HAPs are formed during combustion from fuel-bound chlorine and fluorine and result in significant emissions of hydrogen chloride (HCl) and hydrogen fluoride (HF). Acid gas emission rates are orders of magnitude greater than those of other trace substances (e.g., mercury and arsenic). However, acid gas toxicity levels, expressed for instance as PELs (Personal Exposure Levels) or air concentrations that may pose significant health consequences, are significantly lower than those of most other non-carcinogenic HAPs emitted from electric generating units. The fact that Organics and Acid Gases (OAGs) are both emitted in the vapor-phase and that both are bioavailable requires approaching their particular chemistry, environmental dynamics, and human exposure routes in an integrated manner. Among organics, formation during startup, shutdown, and upset conditions are key considerations; short-term emissions combined with potentially higher health potency can combine for scenario-specific concerns. For acid gases, short-term environmental conditions may lead to high human exposures even during routine source operations, while these same conditions have resulted in documented impacts on nearby structures and vehicles. The focus of this work will be on these combinations of short-term source or environmental conditions with potential primary health or secondary environmental consequences.

DRIVERS

Maximum Achievable Control Technology (MACT) Standard – The Environmental Protection Agency (EPA) has issued a proposed rule, scheduled to be finalized by November 2011 that covers both organic compounds and acid gases.

Residual Risk Rule – After the promulgation of the MACT standard, the EPA has to evaluate remaining (i.e. residual) risks from HAP emissions for public health and the environment. If EPA deems the remaining risks "unacceptable," more stringent emissions standards have to be established within 8 years after the MACT standard was released.

Urban Air Toxics Rule – The Clean Air Act Amendments of 1990 require EPA to reduce the lifetime inhalation cancer risk from exposure to all sources in US urban areas to below 1 in 1 million. "Urban" areas are broadly defined at the county level, so that even western states (where counties tend to be larger) may be classified as predominantly urban. EPA has announced that it considers Urban Air Toxics to include multimedia toxics from any source in or into an urban area.

Clean Water Act and Total Maximum Daily Load – Under section 303(d) of the Clean Water Act, a Total Maximum Daily Load (TMDL) may be developed by individual states to calculate the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality criteria regarding, for example, pH and organics. Given the perceived acidifying potential of utility acid gases, TMDLs could be initiated by individual states or groups of states to address dry deposition of acid gases directly into water bodies or via lower-pH rainfall.

RESULTS IMPLEMENTATION

The applicability of these regulations to an individual facility or group of facilities will be determined by their emissions following full implementation of the utility HAPs MACT rule. Therefore, having accurate emission rates, and emissions patterns during normal and upset conditions, is critical in determining the impact of each regulation on an individual facility. To tackle the issues of vapor-phase OAGs requires a detailed look at concentration patterns associated with short-term peak (acute) and longer-term average (chronic) exposure. The biggest challenge is to develop and apply specialized tools to quantify both types of exposures on a community-population level. First, EPRI researchers will need to develop these specialized tools for application under a variety of environmental conditions. Second, the tools need to be applied properly as to accurately measure and represent exposures at the com-

munity level, especially peak-value exposures. Finally, the tools need to be evaluated, which will require complex models and simulations that consider all types of exposure under a variety of variables, e.g., traditional vs. advanced power plants; plant operation temperatures during startup, shutdown, maintenance and plant cycling, particular meteorological conditions, etc.

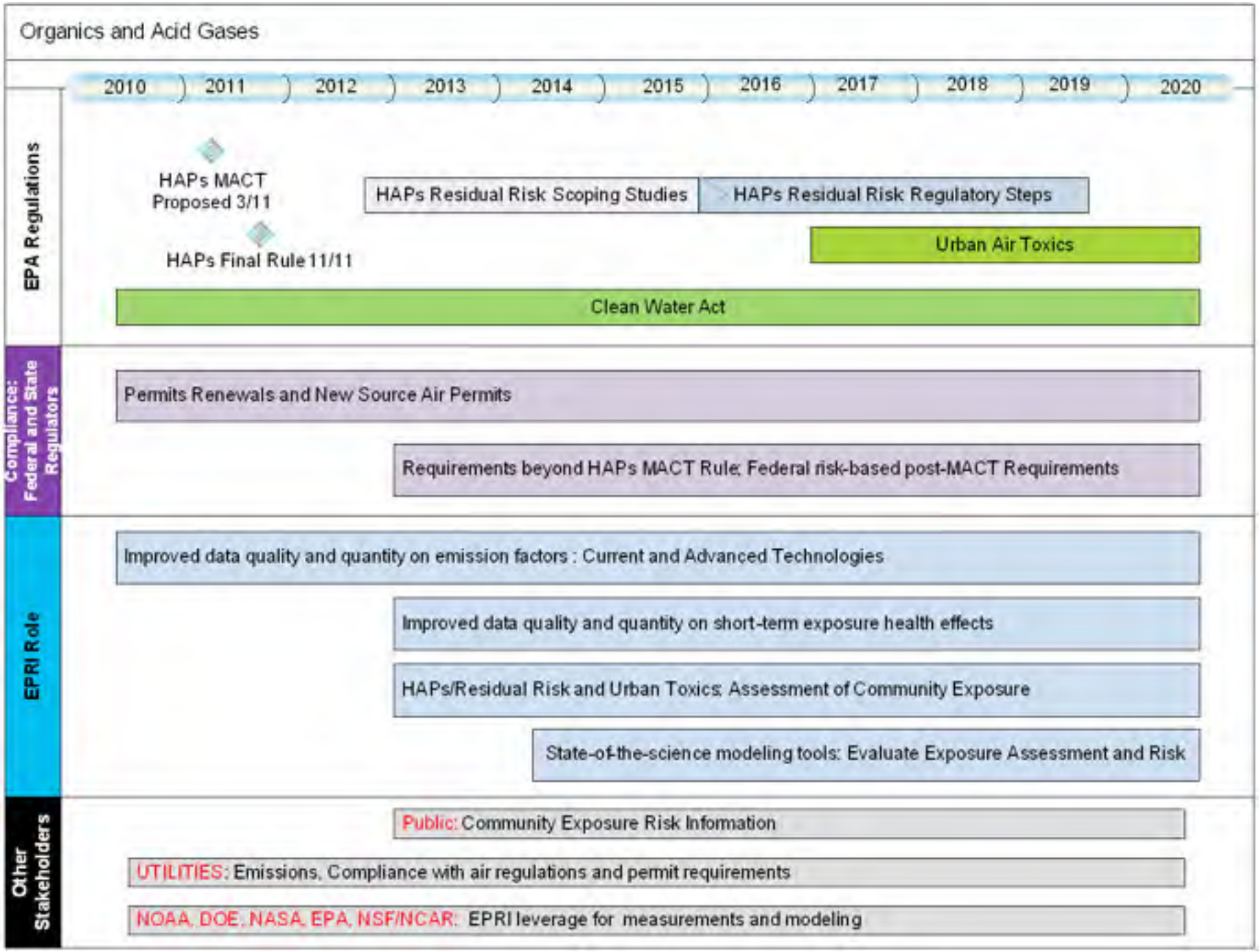
PLAN

The long-term plan is to provide the industry, regulators and the public with both basic research findings and practical tools that can be used to foretell the likelihood of conditions leading to health consequences or environmental impacts of concern. To do this requires an understanding of the linkages between different emissions and environmental scenarios and both high concentrations and health exposures at a community level. In addition, utility workplace exposures may be informed by this work. This research will be closely tied to the roadmap on Multimedia Toxics Characterization to provide accurate source information with which to understand exposures and risks. In addition to developing and applying specialized tools needed to understand community-level exposures, there is also a need to evaluate these tools. The focus on understanding and managing risks under both current and future operations requires development of:

1. *Improved data quality on emission factors:* There has been a very limited amount of information available on emissions of OAGs in general (for example, fluoride levels in biomass fuels). Studies are needed to more rigorously and realistically calculate appropriate emission rates from fuel analyses and emission data under varying conditions, requiring development and testing of methods for characterizing both mean and short-term emissions. The major issues will be obtaining data that represent real-world conditions and different plant-operating scenarios and their concurrence in time with short-term meteorological conditions with the potential for resulting high concentrations.
2. *Improved data quality and quantity on short-term exposure health effects:* Studies for repeated short-term exposures need to be conducted after appropriate exposure-assessment tools have been developed. This is critical to accurately determine the role of the electric sector emissions (as well as other sources' emissions) in contributing to any community level exposures.
3. *State-of-the-science modeling tools:* To be able to evaluate human exposure and environmental upset conditions accurately, modeling tools need to be developed to accurately represent ground-level concentrations during short-term meteorological conditions of concern (such as highly stable conditions, or light wind conditions). Since new and more stringent standards, after the promulgation of the MACT standard, related to community exposure to OAGs are likely, there is an urgent need to develop, apply and evaluate new studies applicable to environmental conditions nationally with rigorous methodology so that better data are available for determining facilities' risk profiles.

RISK

This research will inform all stakeholders involved – industry, regulators, public, and non-governmental organizations (NGOs) – with high quality, objective and credible scientific information. EPRI is the only private-sector organization directly conducting research on organic and inorganic HAPs. EPRI's collaborative multi-disciplinary research across programs allows for critical and objective studies ensuring that sound science is applied to these critical issues.


Organics and Acid Gases
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EPA Regulations
HAPs MACT Proposed 3/11
HAPs Final Rule 11/11
HAPs Residual Risk Scoping Studies
HAPs Residual Risk Regulatory Steps
Urban Air Toxics
Clean Water Act
Compliance: Federal and State Regulators
Permits Renewals and New Source Air Permits
Requirements beyond HAPs MACT Rule: Federal risk-based post-MACT Requirements
EPRI Role
Improved data quality and quantity on emission factors : Current and Advanced Technologies
Improved data quality and quantity on short-term exposure health effects
HAPs/Residual Risk and Urban Toxics: Assessment of Community Exposure
State-of-the-science modeling tools: Evaluate Exposure Assessment and Risk
Other Stakeholders
Public: Community Exposure Risk Information
UTILITIES: Emissions, Compliance with air regulations and permit requirements
NOAA, DOE, NASA, EPA, NSF/NCAR: EPRI leverage for measurements and modeling

DRAFT: PARTICULATE MATTER RISK ASSESSMENT

ISSUE STATEMENT

Particulate Matter (PM) is becoming a significant driver in many regulatory initiatives, both those that target PM directly as well as those that include co-benefits of PM or PM precursor reductions (e.g., the PM and SO_2 reductions from the EGU Maximum Achievable Control Technology (MACT) rule for air toxics). The Regulatory Impact Analyses (RIA) for these regulations) must consider both costs (i.e., control costs to meet a particular regulation) and benefits (i.e., monetization of health benefits purported to occur as a result of mitigation of air pollution). The benefit calculations depend on concentration response functions (i.e., relationships between a particular health endpoint and concentration of a pollutant) that are developed using primary health data from observational studies of human populations. Once the data are generated from these long-term studies, analyses can be conducted to assess the tools used in PM risk assessment. The main activities could include evaluation of and improvements in tools employed to calculate the monetized benefits associated with PM reductions or evaluation of specific default values or assumptions employed by such tools (e.g., value associated with a loss of life). There is a need to ensure that the tools employed to calculate the monetized benefits are designed in a scientifically rigorous manner utilizing and considering the full spectrum of published literature.

DRIVERS

Every new EPA regulation must be accompanied by a Regulatory Impact Assessment in which EPA provides the costs and benefits associated with the new rule. The benefits derived from reductions in PM mortality play a pivotal role in the overall benefits from virtually every air quality regulation issued by EPA, even those that do not target PM specifically. For example, EPA assessed that health improvements from reductions in PM due to the Hazardous Air Pollutant MACT Rule far outweighed (by approximately 99 to 1) the direct benefits of hazardous air pollutant reductions. Specific regulatory drivers include:

National Ambient Air Quality Standards (NAAQS) – The Environmental Protection Agency (EPA) will continue to review the NAAQS for PM, ozone, SO_2, lead, CO, and NO_2. Standard revisions could lead to continuing pressure on the electric sector to reduce emissions if the standards are lowered further. These standards include both the primary (health-based) and the secondary (welfare-based) NAAQS. Inaccurate assessment of the health benefits associated with these standards could lead to overly stringent NAAQS

Transport Rules –The EPA Cross-State Air Pollution Rule will require significant reductions in SO_2 and NOx emissions to limit upwind state contributions to downwind state non-attainment of ambient standards for all criteria pollutants. Transport rules must be revisited whenever NAAQS levels are lowered or when evidence indicates that interstate transport continues to hinder the ability of downwind areas to reach attainment. Although the rules are designed to regulate interstate transport, improper benefits assessment could lead to unnecessary stringency.

Hazardous Air Pollutants (HAPs) Rules – EPA recently proposed emission limits for HAPs from coal and oil-fired plants. The co-benefits associated with PM reduction have been determined by EPA to far outweigh the direct benefits of mercury and other HAPs reductions.

Pending Legislation – Legislative activity is always possible. The Clean Air Act has been amended on several occasions. Multi-pollutant bills have been considered aimed at reducing emissions of SO_2, NOx, and HAPs beyond the levels being considered by EPA under its current regulatory authority. Proposed climate legislation has included provisions for air quality pollutants in addition to greenhouse gases.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All new EPA rules are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Scientific research results provide critical, objective input to such deliberations.

RESULTS IMPLEMENTATION

EPRI air quality health research generates data instrumental in addressing key issues of importance to the electric sector. These data in turn inform key regulatory activities. Research

activities to inform PM risk assessment are generally lower in cost and shorter in duration than the health studies that generate primary health data, but risk assessment research can provide targeted results that are critical in understanding the risk from PM exposure and can provide timely input into regulatory processes.

Specifically, risk assessment activities are expected to:

- Generate improved tools for Regulatory Impact Analyses, including estimation of health improvements and monetized benefits.
- Critically evaluate existing regulatory paradigms used to estimate health risks and propose viable alternatives that cost-effectively protect public health.
- Inform the evaluation of the relative benefits of component-specific and mass-based PM regulation. EPRI research on PM components has been instrumental in shifting the scientific research focus to understand the health effects of various PM components and gaseous co-pollutants. Risk assessment activities will provide important supplemental tools with which to highlight specific issues related to differential toxicity of PM components and related air quality management strategies.

PLAN

The overall approach for the PM risk assessment issue focuses on conducting quantitative and computational analyses to develop new tools for Regulatory Impact Analyses and/or to refine/improve existing tools. This research will be completed in the next 4-5 years. Specific R&D gaps in accomplishing this goal include:

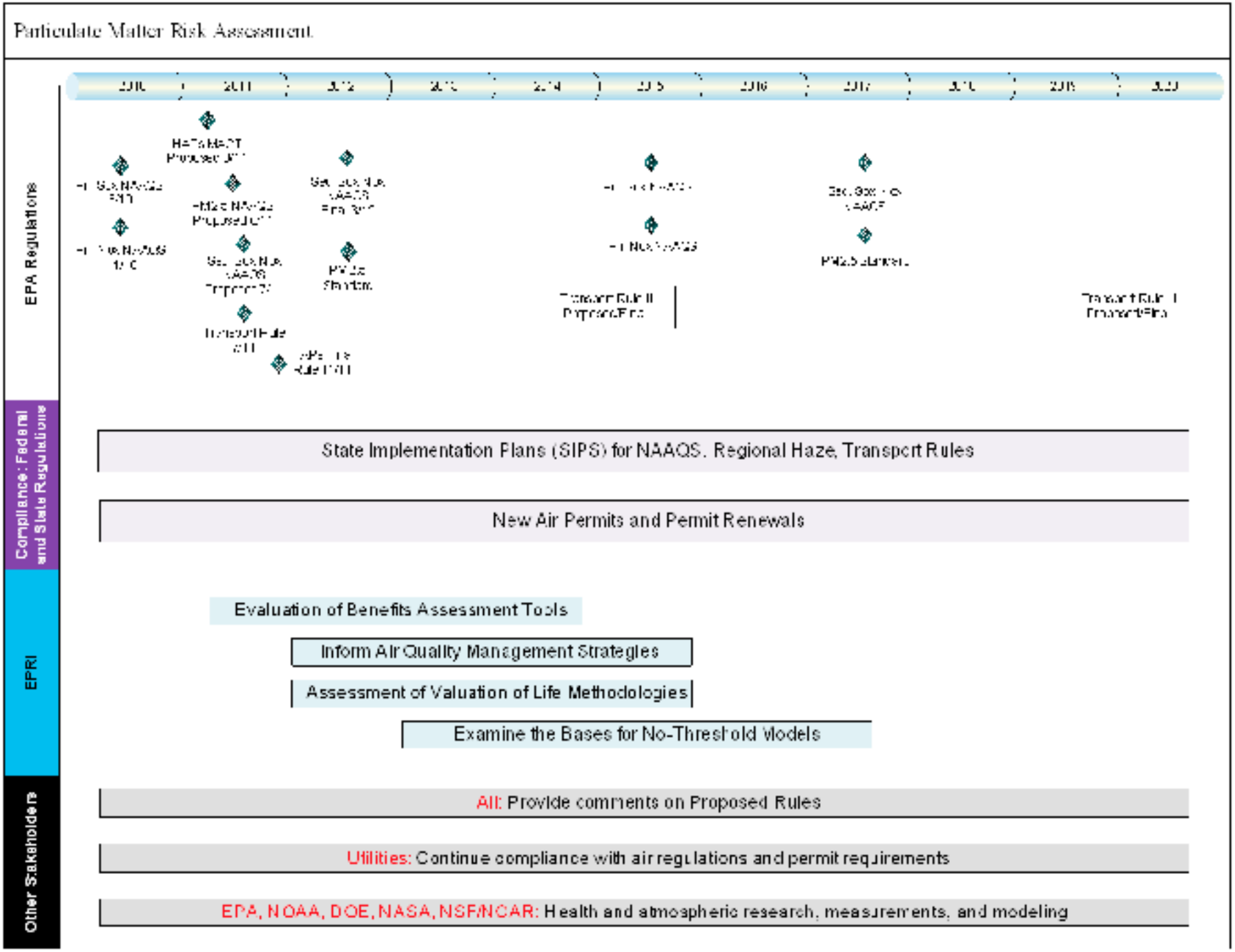
1. *Critical evaluation of the benefits assessment tools used in Regulatory Impact Analyses:* The primary tool for estimating the benefits associated with proposed rules for air quality improvement is EPA's Benefits Mapping and Analysis Program (BenMAP). As part of the benefits estimation, concentration-response (C-R) functions from chronic PM epidemiology studies are used together with air quality data and value of life estimates. This program or tool has a number of limitations and problems, including the reliance on only a subset of studies and a subset of C-R functions within these studies, and the lack of consideration of the differential toxicity of PM components. There is a need to improve BenMAP so that it is a more realistic tool that incorporates the latest scientific knowledge related to PM health risks.
2. *Informing air quality management strategies:* There are conceptually simple—but as of yet not demonstrated in the peer-reviewed literature—analyses regarding the most efficient approaches to improve public health though air quality improvements. For example, it can easily be shown that targeting a potent PM constituent alters the risk associated with the current NAAQS and is thus a more protective and efficient approach than targeting all PM mass equally. Similarly, if an inert component "potentiates" the effect of another component, i.e., increases its toxicity, controlling the potent constituent is much more efficient that targeting the inert component.
3. *Valuation of human life methodologies:* The Value of Statistical Life (VSL) used by EPA in regulatory impact analyses is higher than that used by any other federal agency. The Agency has also assumed that the VSL – which is based on studies from the 1970s and 1980s - has increased over time in conjunction with standard of living. There is a need to understand the origin of the current VSL and assess whether the value accurately reflects the most recent literature on this topic. Since more than 90% of the benefits in PM RIAs are attributed to saving of lives due to reductions in PM, it is critical to understand the basis of such estimates.
4. *Bases for no-threshold models for health impacts:* The Clean Air Act calls for standards to protect the most sensitive individual with a margin of safety. Moreover, epidemiological studies employ linear models with no effects thresholds. A "no-threshold model" assumes that there is no exposure below which there is no effect; every exposure has some impact. It will be important to evaluate alternatives to the no-threshold model and to subsequently define a "safe level" of exposure. Other regulatory frameworks, both within the US and elsewhere, have different underlying assumptions and objectives. Ultimately, the goal is to evaluate the feasibility and appropriateness of a fundamental paradigm shift with respect to the way we think about air pollution exposure and health.

RISK

EPRI's PM risk assessment research can inform industry, regulators and society alike with high quality, objective and credible

scientific information, providing an independent perspective that otherwise would not exist. For example, development and optimization of tools used in Regulatory Impact Analyses would likely not occur if EPRI did not undertake these activities. Because RIAs conducted as part of proposed rules are not subject to extensive peer review, the current set of tools may be outdated and/or inadequate. Moreover, little relevant information is published in the open scientific literature on this topic. Similarly, objective, rigorous examination of the risk bases for existing air pollution regulations is needed. Again, publications on this topic are few and far between, and without EPRI's initiative these important questions and issues will likely not be addressed.

Particulate Matter Risk Assessment



DRAFT: REGIONAL HAZE AND URBAN VISIBILITY

ISSUE STATEMENT

Visibility impairment in the atmosphere is mainly caused by presence of particles in the air that scatter and absorb light, thus leading to light attenuation. The major particles of concern that lead to visibility impairment are sulfate, nitrate, organic carbon, elemental carbon, and dust. In urban areas the particle pollution can lead to visibility degradation that may limit people's ability to enjoy the urban landmarks as well as distant vistas. Particles in the atmosphere can also be transported long distances leading to visibility impairment in Class I areas (national parks and wilderness areas) – a phenomenon that is termed regional haze. Emissions of nitrogen oxides (NOx) and sulfur dioxide (SO_2) from fossil-fired power plants can lead to formation of nitrate and sulfate particles, thus contributing to regional haze and urban visibility problems. One of the major issues is to understand the relative contribution of power plant emissions and emissions from other sources to visibility impairment in the atmosphere. The air quality models used for estimating effects of single sources also require evaluation.

DRIVERS

National Ambient Air Quality Standards (NAAQS) for PM – The Environmental Protection Agency (EPA) will continue to review the NAAQS for PM, and may establish an urban visibility standard as part of the secondary (welfare-based) standard for PM. Standard revisions could lead to continuing pressure on the electric sector to reduce emissions of SO_2, PM, and NOx if the standards are lowered further.

Regional Haze Rule –This is a 60-year long rule that aims to return the visibility in Class I areas to "natural conditions" by 2064. This rule will continue to place pressure on reducing emissions of SO_2, PM, and NOx in its progress towards that goal.

State Rules – State Implementation Plans will be required to show progress towards attainment of the secondary PM NAAQS and the regional haze rule. States will need the best modeling tools and scientific information to make technically sound decisions.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All EPA rules are subject to litigation by third parties. While many times these challenges involve legal issues, some are technically based and thus relevant research results are often used as part of the litigation process. Scientific research results provide critical, objective input to such discussions.

RESULTS IMPLEMENTATION

EPRI has been at the forefront of visibility research over the last 30 years and conducted major field studies in urban areas as well as national parks as early as the 1980s. With the promulgation of the regional haze rule in 1999, a major focus of the research moved towards evaluating the methodology for implementation of the rule, and EPRI research played a key role in developing and implementing revisions in that methodology. The EPRI research approach is designed to anticipate and address critical issues related to regional haze and visibility well before they become regulatory concerns. Currently, EPRI is conducting a series of experimental studies in national parks to better understand the processes leading to visibility impairment by different kinds of particles so as to make further improvements in the science of visibility.

PLAN

The research needed in understanding the role of different emissions sources to visibility impairment is closely tied in with the research under the Roadmaps on "Air Quality Modeling" and "Measurements". In addition to developing state-of-the-science models to understand the fate and transport of different emissions in the environment, one also needs to conduct measurement and analysis of pollutants causing visibility impairment to understand the mechanisms by which the various constituents affect visibility. The proposed research will be conducted until 2018 when the next implementation plans are due; the research needs will be reviewed at that point of time to devise future plans. Specific R&D gaps needed to address current and anticipated regional haze and urban visibility issues include:

1. *Visibility measurements at national park sites:* Measurement studies are needed to collect new particle and visibility data at Class I areas followed by focused laboratory experiments. This research will provide a rigorous and realistic assessment of the contributions of different

types of particles to visibility degradation in Class I areas. The major issues that need to be studied include water absorption by organic and inorganic aerosols, as that is the key in understanding the impact of these particles on visibility degradation.

2. *Analysis of data at national park sites to provide input to implementation of a regional haze rule:* The data collected from EPRI experiments will be used in conjunction with routine data collected by EPA at Class I areas to develop improved methodologies for regional haze rule implementation. This process is critical to accurately determine the role of the electric sector emissions (as well as other sources' emissions) in contributing to any visibility degradation. The knowledge gained from this work on regional haze can also be transferred to urban visibility issues.

3. *Visibility perception studies in urban areas:* Visibility perception studies are one way to determine the level of visibility impairment considered to be "unacceptable" and these studies play an important role in setting the secondary standard for $PM_{2.5}$ based on urban visibility. There are very few studies done in the U.S. – they are all local studies conducted for a particular city and lack the rigor needed for being considered in setting national regulations. There is a need to evaluate the current studies and to conduct a new national scale study with rigorous methodology so that better data are available for consideration in developing nationwide standards.

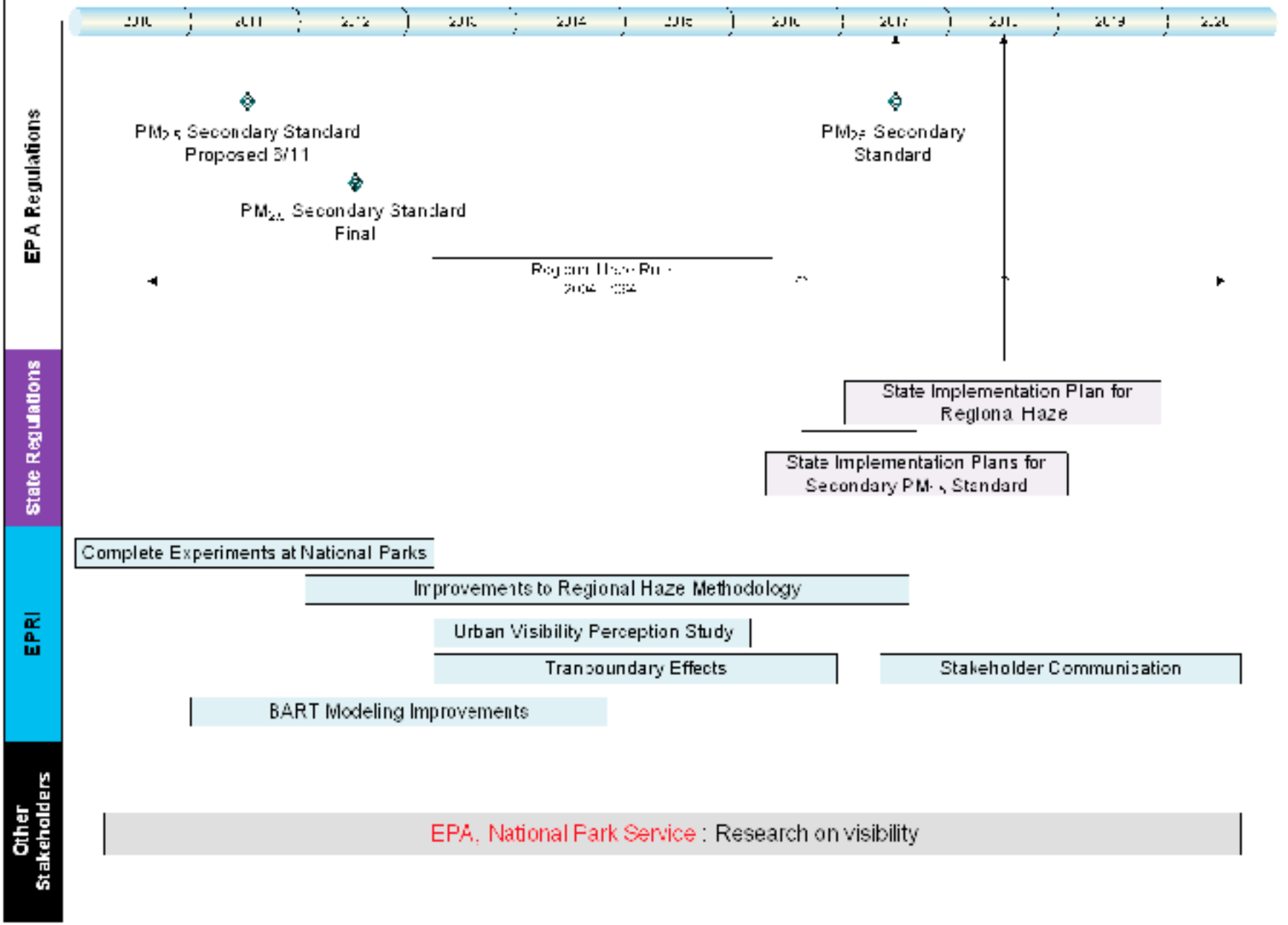
4. *Studies to understand the implications of emissions from other countries:* A key challenge with the regional haze rule is how to define or determine the levels of natural visibility that each Class I area must achieve by 2064. EPA's definition of this endpoint does not include transboundary anthropogenic pollutants, nor the new science pertinent to understanding naturally occurring levels of particles contributing to haze. Although EPRI research has demonstrated that states need to recognize the importance of transboundary pollution when developing plans for meeting regional haze progress goals, significant uncertainty remains in estimating the transboundary contribution of organic aerosol concentrations, and thus additional studies are needed to understand the impact of emissions from other countries.

5. *Improved single source models for long-range transport:* Current single source models used in PSD (Prevention of Significant Deterioration) analysis and for BART (Best Available Retrofit Technology) determinations are considered too conservative in their estimates of particulate matter (PM) formation from SO_2 and NO_2. There is a critical need to improve these models so that the best-available science is brought to understand the contribution of single sources to visibility impairment at Class I areas, and the best tools are used in permitting applications as well as BART determinations.

RISK

EPRI research on visibility issues informs industry, regulators and society alike with high quality, objective and credible scientific information, and provides an independent perspective that otherwise would not exist. Other than EPA and National Park Service, there is no other entity directly conducting research on visibility issues. Thus, if EPRI visibility research didn't occur, society would lose an independent source of credible science that is critical in developing scientific sound policies and standards in achieving acceptable level of visibility in urban and Class I areas.

Regional Haze and Urban Visibility



DRAFT: ENERGY SUSTAINABILITY

ISSUE STATEMENT

Growing attention on corporate transparency, disclosure, and "triple bottom-line" performance are driving investment and interest in sustainability research. Financial and credit markets are increasingly using environmental and social measures alongside economic metrics as a factor in valuing and determining investment risk for a company. For over 10 years, international reporting efforts like the Global Reporting Initiative, Dow Jones Sustainability Indexes, and Carbon Disclosure Project have been encouraging transparency on sustainability-based issues. Yet, power companies continue to face unique challenges in identifying and achieving sustainability targets, while still providing safe, clean, and affordable power.

Improved understanding of the industry best practices to improve sustainability and the indicators to measure progress will inform management decisions as well as international reporting standards to help optimize economic, environmental, and social performance within the electric power sector.

DRIVERS

Worldwide, electric companies are increasingly being driven by investors to disclose environmental, social, and economic data, and show efforts to improve performance. However, there has not been an organized effort for electric companies to identify a sustainability performance framework and specific best practices for management. The breadth of the issues encompassed in sustainability for the electric power industry are substantial, and industry interest in developing a common measurement framework is driving a collaborative effort to clearly define performance indicators.

In addition, public relations, environmental stewardship, and shareholder activism introduce both opportunities and threats for electric companies related to sustainability. Collaborative, scientific research provides objective analysis that can inform public discussions, improve management decision making, and structure a strategic and industry-appropriate approach to sustainability.

RESULTS IMPLEMENTATION

Since 2008, EPRI has engaged the industry in discussions and information sharing about what it can do to accelerate the path towards sustainability and develop common strategies to shape such a future. The intent of the work has been to identify and share sustainability management strategies and best practices throughout the industry. This has been conducted by engaging a broad group of electric companies as well as representatives from academia and outside industries in an on-going series of webcast discussions and workshops. As sustainability management practices are still evolving in the industry, electric companies have been individually developing economic, environmental, and social performance indicators to gauge progress. In 2011, EPRI began to identify common key sustainability performance indicators for electric companies, and benchmark the industry's current performance. This research will enable the identification of industry best practices that positively affect sustainability performance. The results of the work will be shared throughout the electric power industry and with international sustainability reporting organizations, as applicable.

PLAN

EPRI will continue to collaboratively engage the industry and evaluate its needs to improve sustainability performance. At the core of its Energy Sustainability area, EPRI will conduct a portfolio of research activities to address specific sustainability needs in the electric power industry and to generate data to inform current and future management and reporting practices. Activities identified include:

1. *Assess and benchmark sustainability performance indicators:* Currently there is not a specific set of sustainability performance indicators that have been identified for the electric power industry. However, many companies are reporting sustainability performance data according to broad international reporting frameworks such as the Global Reporting Initiative. The development of a com-

mon set of sustainability performance indicators for the industry will enable performance to be benchmarked and best practices affecting key performance areas to be identified. Findings from these efforts will also be used to inform international reporting frameworks.

2. *Develop decision-support tools for improving company process:* While there are many changes that the industry as a whole can make to achieve sustainability targets, not all of the options will be appropriate to individual companies. EPRI will develop decision-support tools for companies to use in real time that will assess tradeoffs and benefits for specific company decisions related to achieving sustainability goals.

3. *Scan the landscape for emerging issues:* With an ongoing objective to identify and connect members to the wide variety of technologies and research areas that impact economic, environmental, and social performance in the industry, many sustainability-related research needs may be identified and subsequently developed in a different technical research area. In this fashion, the sustainability issue area may serve as a feeder for the identification of new topics of significance for the industry. Similarly, existing EPRI research areas that are relevant to industry sustainability performance will be highlighted to participants of the Energy Sustainability research area.

RISK

The risk of not conducting research on these issues is continued industry misalignment on sustainability, which could lead to inappropriate regulation or goal setting by external organizations A scientifically-informed approach to defining the sustainability challenge, identifying industry-appropriate performance metrics, and creating models that will improve internal company processes will reduce stakeholder scrutiny, provide direction to environmental groups and agencies, and potentially increase business performance. EPRI's collaborative model provides a unique opportunity to take a leadership role in addressing sustainability that will appropriately consider economic, environmental, and social performance issues, on behalf of the industry and society.

DRAFT: EVALUATION OF ALGAE BIOENERGY TECHNOLOGIES

ISSUE STATEMENT

Algae, which are microscopic plants and seaweeds that grow in aquatic environments, are a potential source of a variety of biofuels (biodiesel, gasoline, and jet fuel) and other metabolites that can be used as ingredients for food products, pharmaceuticals, chemical manufacture, animal feeds and other purposes. Efficient algal growth requires concentrated CO_2 sources such as that in power plant flue gas, and thus electricity generation providers are being targeted as potential host sites for large scale algae growth systems. Potential benefits to the power plants could include mitigation of CO_2 emissions, production of liquid or solid biofuels for combustion, concurrent treatment of wastewaters, and novel algae product revenue streams. However, there is considerable uncertainty as to whether algae technologies are affordable, scalable, and operationally robust approaches for displacing significant amounts of conventional fuels or other products. Very limited data exists for pilot-scale or larger operations of algae systems. Despite the nascent stage of the algae industry, it is well funded and has multiple market drivers including the federal government driving its growth. This, coupled with the algae's dependence on concentrated CO_2, suggest that the algae industry will continue to seek opportunities to co-locate with fossil plants. Thus there is a need on the part of power plants for engineering-based evaluations, unbiased data analyses, and technology comparisons to support their decision-making processes regarding engagement with algae bioenergy technologies.

DRIVERS

Multiple drivers are motivating the development of large-scale algae systems, the largest being the need to increase the production of domestic biofuels (particularly biodiesel) in order to meet the federal Renewable Fuel Standards 2 (RFS2) production target of 36 billion gallons by 2022. Traditional biodiesel crops (e.g., soy and canola) have significantly lower oil yields compared to high-rate algae systems, only if, however, the algae are cultivated with an abundance of CO_2. This requirement for CO_2 from a large point source combined with the utility sector's desire to mitigate CO_2 emissions has created a nexus between fossil plants and large-scale algae cultivation systems.

From the utility perspective, the primary driver is CO_2 emissions reduction. In order to quantify the carbon mitigating potential of utility connected algae systems (UCAS), it is necessary to consider the net carbon emissions using a lifecycle analysis which accounts for the energy of operations of the algae plant as well as the GHGe values for process inputs and outputs. This is the focus of EPRI's current work.

Another utility driver is to understand which co-benefits algae systems could provide at the plant site. Algae have inherent abilities to extract nutrients and some metals from impaired water and wastewater and are used in this capacity at several California wastewater treatment plants. EPA is revisiting its effluent guidelines for the steam electric sector and one of the primary concerns is discharge of mercury and selenium from FGD wastewater. Other water pollutants from air emissions controls systems may also change in the future. EPRI is testing the performance of algae to treat FGD wastes. Other co-benefits include firing or digesting waste biomass or biomass solids, or firing the liquid biodiesel product.

RESULTS IMPLEMENTATION

EPRI algae bioenergy research provides an independent, engineering-based perspective to the evaluation of various algal bioenergy processes of interest to the electric sector. This research has been providing education to both utilities and algae technology developers as to the potential benefits and challenges of linking the fields, as well as qualitative and quantitative evaluation of proposed algae systems. This research also anticipates and investigates issues related to the integration of algae growth systems into power plant equipment and operations.

EPRI results can be applied in the following ways:

- Provide clear and rigorous analysis regarding the potential and challenges of the operation of large utility-connected algae systems,
- Provide input to utility decision-making as to whether to, or how to, participate in pilot, demonstration, or full-scale utility-connected algae system projects, and
- Confirm a 'seat at the table' in collaborative projects, governmental studies or regulatory actions related to algal bioenergy as the expectation is a continuing strong interest in developing capabilities for production and use of advanced biofuels.

PLAN

EPRI algae bioenergy research has been ongoing for several years. The work was designed to proceed in a comprehensive manner to understand the state-of-the-science, to quantitatively and qualitatively evaluate prior research by various entities, and to create a robust yet flexible model for energy and carbon balances in algae systems, with the overall goal of effectively characterizing current and future technologies.

EPRI results thus far have included case studies and "lessons learned" from prior algae operations, and the creation of decision-analysis tools that can independently assess feasibility of utility-connected algae systems. These tools can now be leveraged to answer questions about theoretically designed algae systems or to evaluate actual real-world pilot or larger scale implementations of algae systems. Initial analyses will include:

- Comparative energy requirements and net CO_2 equivalents resulting from various choices of process steps, geographical/meteorological conditions, water sources, flue gas pumping designs, cell characteristics, and other options,
- Relative benefits/drawbacks to certain feedstock growth and processing choices, and
- Determination of technological lever points for net carbon and energy results.

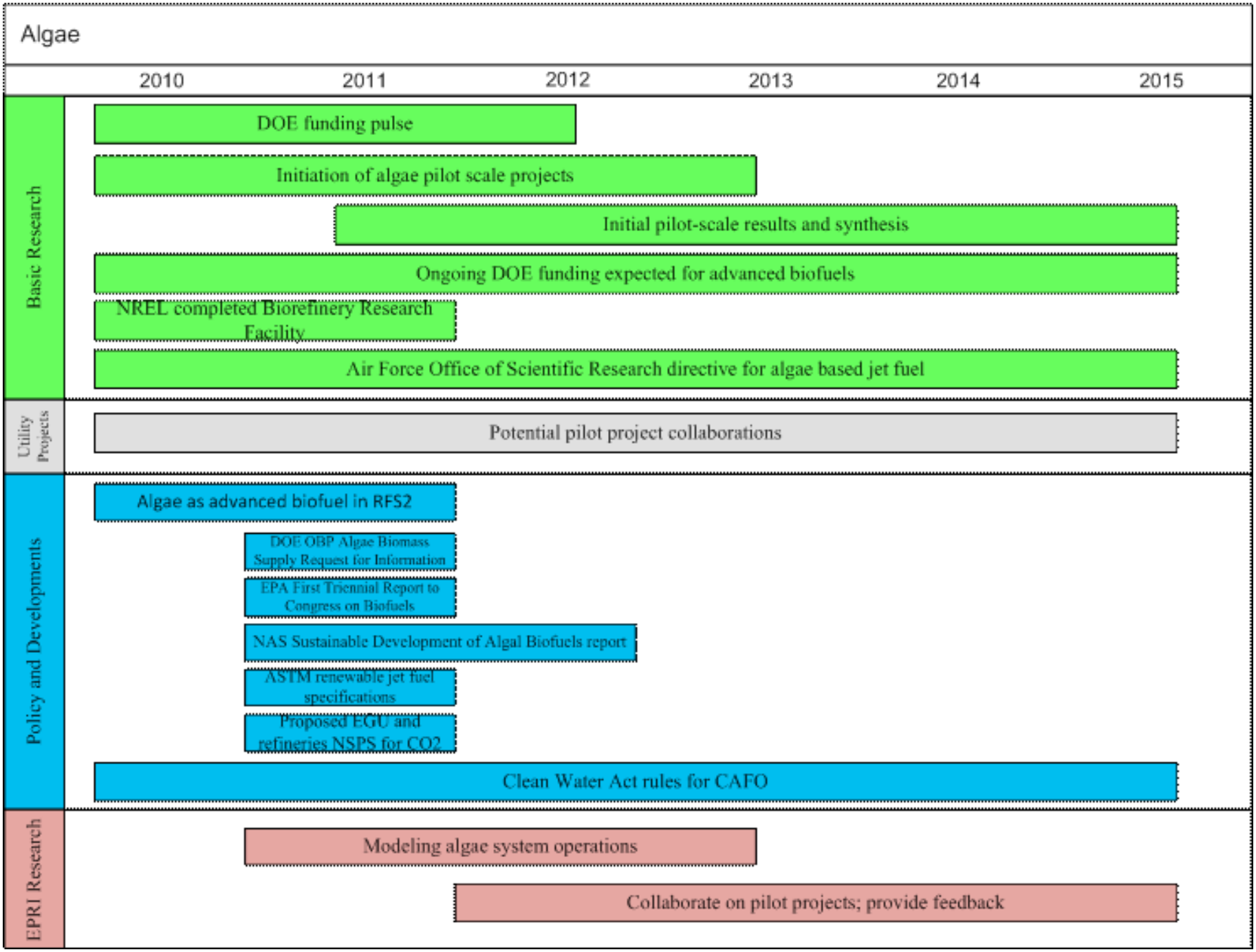
These analyses will inform evaluations of potential real-world project collaborations between EPRI and algae system developers. Looking ahead several years to a time when the algae industry has matured, EPRI envisions an expansion of work to participation in pilot testing of utility-connected algae systems. Due to a large influx of Department of Energy and venture capital funding into the industry since approximately 2008, a number of large scale algae projects are expected to provide substantial new learning on the topics of laboratory and field testing of novel algal species, growth chambers/harvesting/biomass extraction and preparation, fuel synthesis, and algae biofuel use over the next few years.

RISK

There are numerous technical and market risks from the algae developers perspective; most focused on reducing production costs. From the utility perspective there are technical risks associated with identifying proper site selection criteria and issues associated with interconnection. There are also business risks associated with how algae developers and utilities will share in savings provided by future carbon markets or regulations.

EPRI's activities on algae to date have focused on educating member companies about the fundamentals of algae science and the types and limits of their growth systems. More sophisticated analysis of utility connected algae systems is limited due to the lack of quality empirical data available to EPRI on the actual operations of these systems. Recent awards from DOE and DOA support the development of larger scale operations and these projects will report some data publicly but likely not before 2013. The need for a fully transparent data from a utility connected plant operating over at least one year will provide critical information on the benefits of today's technology, and better insights as to possible industry improvements.

Another risk is that algae developers will not be able to reduce the capital cost of their systems and lower the cost of operations sufficiently to produce biomass at a cost that is competitive with other biofuel feedstocks. Further, the RFS2 standard requires algae biodiesel to have a GHG footprint 50% lower than that of standard diesel. It is not clear how this requirement affects different algae growth systems or limits the quantity, type and source of key inputs, namely macro-nutrients.


Algae
2010
2011
2012
2013
2014
2015
Basic Research
DOE funding pulse
Initiation of algae pilot scale projects
Initial pilot-scale results and synthesis
Ongoing DOE funding expected for advanced biofuels
NREL completed Biorefinery Research Facility
Air Force Office of Scientific Research directive for algae based jet fuel
Utility Projects
Potential pilot project collaborations
Policy and Developments
Algae as advanced biofuel in RFS2
DOE OBP Algae Biomass Supply Request for Information
EPA First Triennial Report to Congress on Biofuels
NAS Sustainable Development of Algal Biofuels report
ASTM renewable jet fuel specifications
Proposed EGU and refineries NSPS for CO2
Clean Water Act rules for CAFO
EPRI Research
Modeling algae system operations
Collaborate on pilot projects; provide feedback

DRAFT: FISH PASSAGE AND PROTECTION

ISSUE STATEMENT

Conventional hydropower and pumped-storage currently provide a substantial portion of the renewable energy generation, and these technologies are poised to increase their contribution through the addition of generating capacity and the facilitation of grid integration of other renewable energy generation technologies. While conventional hydropower generation and pumped-storage are important contributors to renewable energy portfolios, a legacy of fish passage and protection issues at existing hydropower facilities constrains this contribution. Many states and federal programs explicitly exclude hydropower – especially arbitrarily-defined "large" hydropower – from their definitions of renewable energy because of hydropower effects on fish and other aquatic life. Fish passage and protection issues add cost and uncertainty to licensing of hydropower facilities, and measures adopted to address these issues also add to capital, operational, and maintenance costs. EPRI's research program directly addresses these issues by making relevant information accessible to industry, and by developing technologies and operational measures to mitigate potential impacts to fish from hydropower facilities.

DRIVERS

Fish passage and protection is regulated through the Federal Energy Regulatory Commission (FERC) licensing process and consultation with federal fisheries management agencies, which have the power to prescribe fish passage measures at FERC-licensed hydropower facilities. The Environmental Protection Agency and its counterparts at the state level exert influence on the licensing process (including fish protection) through water quality certification. Other stakeholders with an interest in fish passage and protection, such as Native American tribes and anglers, also engage in the FERC licensing process.

A number of fish species that potentially encounter hydropower projects are either listed as threatened or endangered under the Endangered Species Act (ESA), are candidates for listing, or are otherwise under review. Thus, provisions of the Endangered Species Act currently affect some hydropower facilities and their operations, and may affect additional facilities in the future.

Apart from the challenges an individual facility may encounter with regard to FERC licensing and ESA compliance, public perceptions of hydropower affect the contribution of hydropower to meeting renewable energy mandates.

RESULTS IMPLEMENTATION

EPRI research on fish passage and protection at hydropower facilities is expected to inform state, and federal officials, hydropower plant operators, and the public, and develop technologies and operational measures to mitigate hydropower impacts on fish. Specifically, this work will:

- Compile and review widely scattered technical information on fish passage and protection
- Evaluate the environmental performance of pumped-storage facilities
- Continue development and demonstration of the Alden (fish-friendly) hydro turbine as a means of safely passing fish at operating hydropower facilities.

PLAN

EPRI's planned research consists of an evaluation of effects of hydropower facilities and operations on fish and development of structural and operational measures that can be employed to prevent or otherwise mitigate impacts to fish populations. Specific activities include:

1. *EPRI Hydropower Web Site:* EPRI's web site will be updated with the latest hydropower resource, licensing, environmental, and fish passage and protection technologies information.
2. *Review of New Developments in Fish Passage and Protection:* Annual reviews of the technical literature on developments in fish passage and protection will be prepared and distributed to programs funders. EPRI's Fish Passage and Protection manual, a resource on www.epri.com for state-of-the-art knowledge on fish passage and protection at hydropower projects, will be updated with new information
3. *Advanced (Fish-Friendly) Hydropower Turbine Design Development:* EPRI will complete the engineering design

of the Alden fish-friendly hydropower turbine for installation and testing at a hydropower project. Work in 2012 and beyond will be directed toward deployment and field evaluation of the turbine. Annual workshops for the industry, government, and the public will keep stakeholders informed on research progress and future deployment and field testing developments.

4. *Evaluation of Fish Survival Through an Advanced Hydropower Turbine System (Fish-Friendly Turbine):* EPRI will monitor survival of fish passing through the fish-friendly hydropower turbine at a deployment site and summarize the results in a report.

RISK

Fish passage and protection issues add cost and uncertainty to licensing of hydropower facilities, and measures adopted to address these issues add to capital, operational, and maintenance costs. Public perceptions of hydropower impacts on fish also constrain opportunities for hydropower expansion and inclusion in renewable energy mandates. Where endangered species concerns exist, existing generation may be constrained. EPRI's research provides information and technologies to address these issues.

SCHEDULE

Fish passage and protection issues are driven by relicensing schedules of individual hydropower facilities as well as mid-license environmental compliance. No new regulatory requirements are contemplated. Thus, the program is not correlated with a regulatory development and compliance schedule. Development of the advanced (fish friendly) hydropower turbine design will be completed in 2011. Design of the installation and supporting civil works and turbine manufacture are expected to commence in 2012. Turbine installation is anticipated during the period 2013-1014, and testing of the biological, mechanical, and economic performance of the turbine is expected to take place during 2014-1015.

DRAFT: HYDRO ASSET MANAGEMENT

ISSUE STATEMENT

An international focus on renewable and non-carbon-emitting energy sources increases the value of existing hydropower assets, and increases the demand placed on those assets to support integration of other renewable generation. Many conventional hydropower plants are aging and require enhanced maintenance, refurbishment, and in some cases redevelopment in order continue meeting these demands into the future. Timely information and research are needed to optimize the management of these assets. EPRI is developing a suite of research activities to support effective management of existing hydropower assets.

DRIVERS

A significant and growing portion of the U.S. hydropower fleet is aging and in need of improved maintenance and refurbishment. Overall demand for renewable energy combined with the intermittency of other renewable energy technologies increases the potential value of existing hydropower assets and the grid services they provide. Societal constraints on new dam construction severely limit opportunities for de novo development of hydropower projects in the U.S. There is also an accumulation of aging hydropower assets in other parts of the world. Plant life extension, improved performance, redevelopment, and operational changes present opportunities to exploit and enhance the potential value of existing hydropower assets.

RESULTS IMPLEMENTATION

EPRI research on hydropower asset management is expected to:

- Identify and communicate best practices for maintenance of hydropower assets.
- Evaluate technology options for hydro plant refurbishment and redevelopment.
- Inform optimization of plant operations with respect to long-term profitability.

PLAN

EPRI's Hydro Asset Management research plan is under development in consultation with EPRI members. The research program will address issues such as degradation of concrete and reinforcements, upgrades to controls and instrumentation systems, automated operations with grid integration, incorporation of fish passage and protection options, aerating turbines, and other available additions and betterments that should be considered in a life extension analysis. Additional research would address the economics of such retrofits against the remaining life of the project and value of the enhanced generation that would be derived.

RISK

In the absence of information on the state of the art in asset management, hydro assets will likely be managed sub-optimally. If investments in facility refurbishment and upgrade are sub-optimal, the opportunity cost accumulates over the lifespan of the investment. Poor decisions on asset management could result in under utilized potential, early retirement, lost capacity, and difficulty in integrating other renewable sources to the grid. EPRI research will inform hydro asset management to enhance their long-term value.

SCHEDULE

The program schedule is driven by growing member interest. Work in 2011 and perhaps 2012 will be undertaken as supplemental projects. Thereafter, the combination of supplemental and base program-funded projects will be determined by member interest.

DRAFT: INTERACTIONS OF BIRDS AND BATS WITH WIND TURBINES

ISSUE STATEMENT

Deployment of utility-scale wind farms is expanding as both independent power producers and traditional utilities build wind farms to meet state renewable requirements and capture federal subsidies. As this renewable electricity generation expands, it is imperative to understand and mitigate fatal interactions of birds and bats with wind turbines. Already, concerns for the safeguard of bird and bat populations has caused delay or reconsideration of wind projects due to unknown short- and long-term effects. The impacts of utility-scale wind farms are not fully understood, and almost all proposed projects are facing some type of opposition related to actual or assumed fatal impacts on birds and bats or to impacts on habitat. With respect to bats, the issue is becoming more acute, as white-nose syndrome is causing the collapse of many cave dwelling species.

This area of research seeks to minimize impacts of wind turbines on birds and bats to assist owners and operators in expanding placement of utility-scale wind farms. Through this research, EPRI intends to address public and regulatory concerns and inform stakeholders of new information and technologies to minimize impacts.

DRIVERS

Information gaps exist between the scientific knowledge acquired to date and the data needed to address bird and bat fatalities, and the impact of habitat alteration at utility-scale wind farms. Research results are needed to allow project developers, owner-operators, regulators and stakeholders to mitigate interactions so that deployment can move forward to capture the benefits of wind generated electricity.

Project Development Requirements – The requirements to permit a wind farm project can vary depending where the project is being built. Although some regions of the country have no local land use or siting processes, other areas have rigorous requirements, many of which require environmental review by state environmental protection agencies and public service commissions.

Federal Requirements – A project on public land or utilizing government funding, a National Environmental Policy Act (NEPA) review must be completed. The Bureau of Land Management (BLM) manages vast stretches of public lands, much of which is suitable for wind energy development. BLM reviews and approves permits and licenses to explore, develop, and produce renewable energy on federal lands. If endangered species are present, a take permit in accordance with the Endangered Species Act may be required. Further, the US Fish and Wildlife Service has recently proposed new requirements to protect the Golden Eagle and proposed new guidelines for wind farms to protect habitat, migratory birds and bats.

State Requirements – The requirements for permitting projects are often controlled at the state level. There are a variety of environmental requirements depending on the technology and the state. For example the California Environmental Quality Act (CEQA) requires state and local agencies to assess environmental impacts of projects they undertake or permit. In Hawaii, a review by the State Department of Forestry and Wildlife is required to obtain a permit from Hawaii Department of Land and Natural Resources. In many cases pre- and post-construction monitoring are required. For wind projects in Maine, the Department of Inland Fisheries and Wildlife typically requires studies of bird migration, including radar studies of night migrants, daytime counts of raptors and radar and acoustic surveys for migrating bats. Mitigation is often required, particularly when Threatened or Endangered species may be affected. Many states also require consultation with the U.S. Fish and Wildlife service, which may impose restrictions, require monitoring, or disallow the project altogether.

Public Perception Drivers – Public opposition to a project can result in project delays or even cancellation. Whether concerns are raised during formal commenting or simply expressed in protest of a project, developers must be able to address the issues to complete a project as planned.

RESULTS IMPLEMENTATION

An understanding of impacts and advancement of solutions to those impacts will accelerate deployment of renewables in an

environmentally responsible manner. Research in the following areas will significantly improve the information base required for sound decision making:

- Development of direct interaction protection technologies for a variety of bird and bat species
- Advanced siting analysis to reduce impacts
- Population analysis to determine long-term impacts on survivability
- Migratory and habitat analysis to reduce impacts

PLAN

The questions being asked are varied and depend on federal, state and county environmental priorities and regulations where the project is proposed to be built. Specific actions to be undertaken include the following:

Assemble and maintain a knowledge base on environmental aspects of wind generation

This will include information about specific interactions of the technology with the environment as well as data on long-term impacts. Significant research gaps will be identified and responsive research projects will be proposed. Research results will provide the power industry with the understanding needed to improve planning, siting and operation of utility-scale wind farms and will be used to significantly enhance communications on potential impacts.

Development and demonstration of improved technologies

Critical research includes identification of technologies that can mitigate bird and bat interactions with wind turbines. EPRI has done much work on avian interactions with traditional utility infrastructure in the past and this learning will help drive new understanding and solutions. A project currently in its initial stages is developing a bat detection and shutdown system for wind turbines, which will be turbine specific to reduce lost generation.

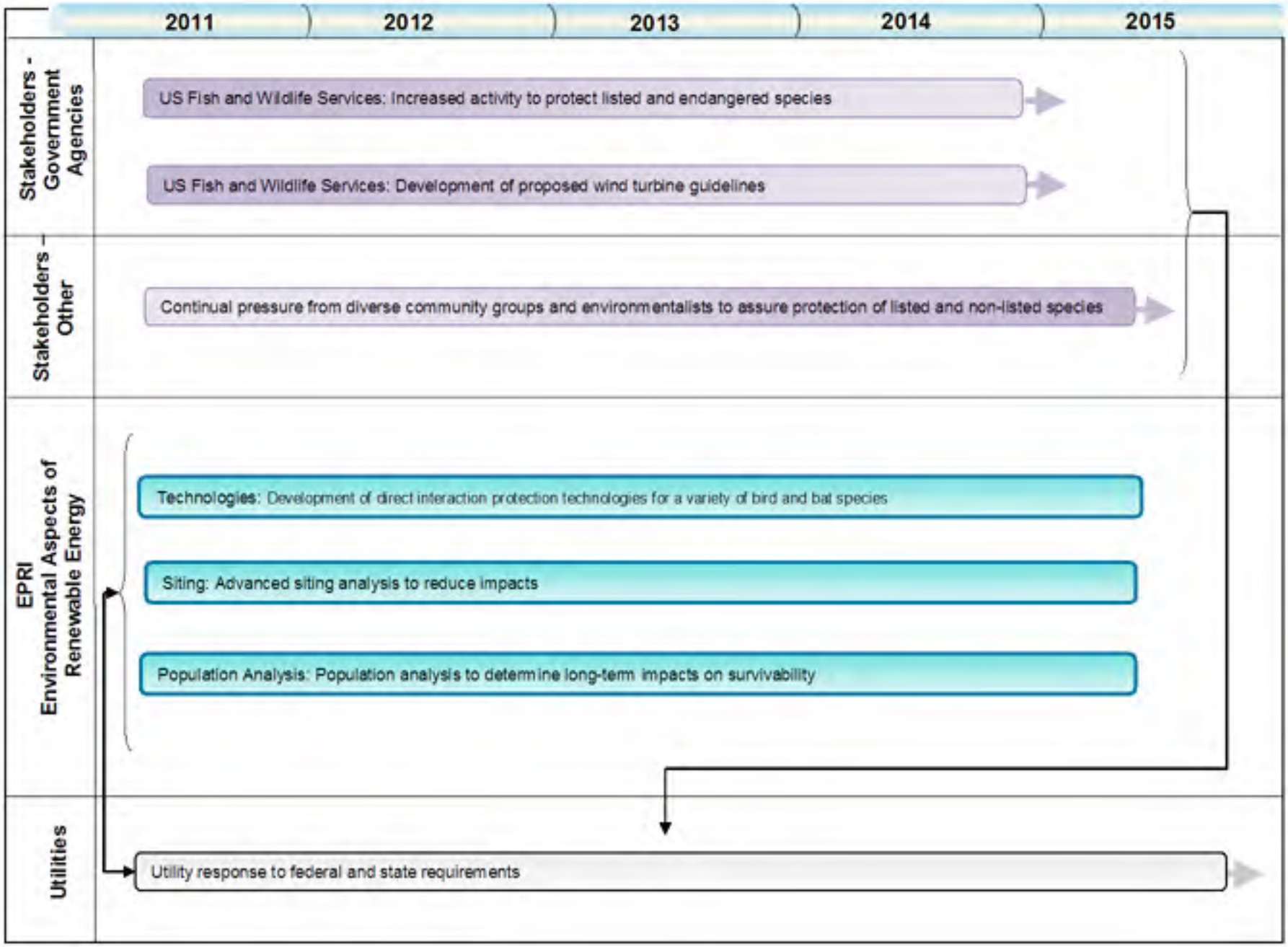
Develop data on and improved approaches to habitat impacts caused by renewable generation

Utility-scale wind farms may involve the use of large amounts of land. When land is used for wind farms there are concerns raised over impacts of the technology or operations on the habitat and the animals that inhabit that space. In cases where threatened or endangered species are present, additional permitting and concerns are raised. EPRI's research will put the impact from these wind farms in context with the threat to these species.

RISK

There has been a severe underinvestment in research on environmental aspects of renewable energy, resulting in a paucity of information relative to the questions that must be addressed to move projects forward rapidly and with a high degree of certainty. The same collaborative benefit that other issues have realized through a comprehensive research plan funded by many companies has not yet been realized in this area. In part this is due to the early stage of renewable project development. The timing is good for collating existing, but dispersed information, from initial project specific studies and early regional work. This can form the basis for more comprehensive studies and data to support future decision making.

In the absence of this collaborative work, each individual project will spend more resources to develop information as questions are raised. Without robust and factual dialog, there remains high risk of delayed projects, stranded investments and unresolved public concerns. Without a look forward to potential cumulative impacts, industry faces a substantial risk of unintended consequences that would only become apparent after significant resources were expended to affect a rapid, large scale build out and harvesting of renewable energy.


2011
2012
2013
2014
2015
Stakeholders - Government Agencies
US Fish and Wildlife Services: Increased activity to protect listed and endangered species
US Fish and Wildlife Services: Development of proposed wind turbine guidelines
Stakeholders – Other
Continual pressure from diverse community groups and environmentalists to assure protection of listed and non-listed species
EPRI Environmental Aspects of Renewable Energy
Technologies: Development of direct interaction protection technologies for a variety of bird and bat species
Siting: Advanced siting analysis to reduce impacts
Population Analysis: Population analysis to determine long-term impacts on survivability
Utilities
Utility response to federal and state requirements

DRAFT: MARINE AND HYDROKINETIC TECHNOLOGIES

ISSUE STATEMENT

Marine and hydrokinetic (MHK) generating technologies are poised for commercial deployment. However, the novelty of these technologies presents unique challenges for their permitting and licensing. Deployment of hydrokinetic devices raises questions about the ability of aquatic organisms to avoid the devices as well as the fate of those organisms that do not. Potential deployment also raises questions related to sediment fate and transport, altered hydrology, and disruption of biotic community structure, among others. These rather open-ended issues inject additional costs, delay, and uncertainty into the permitting and licensing process. Adaptive management, a term of art in natural resource management, has been invoked as a means of deploying projects in the presence of significant uncertainty regarding project impacts and minimizing the potential for adverse consequences. This is accomplished through monitoring and post-deployment modification of the project or its operation. Adaptive management adds additional cost and uncertainty to MHK projects. EPRI's research program reduces the cost and uncertainty associated with permitting, licensing, and post-deployment monitoring of MHK projects by developing information that supports permitting and licensing, and by enhancing the soundness of adaptive management plans.

DRIVERS

Inland and coastal (within three nautical miles of the coastline) MHK projects are licensed by the Federal Energy Regulatory Commission (FERC) in consultation with federal natural resources management agencies. Additionally, various state agencies and other stakeholders whose activities may be displaced or otherwise affected by a project engage in the permitting and licensing process. The number and diversity of stakeholders and interests and the novelty of MHK technology-environment interactions drive environmental review and adaptive management toward large, ill-defined assessments and monitoring plans. Commercially-driven projects will benefit from environmental review and adaptive management planning that are technically sound and procedurally efficient.

RESULTS IMPLEMENTATION

EPRI research on MHK technologies provides information that will inform state and federal officials and the public about MHK system-environment interactions and identify best practices for addressing uncertainties. Specifically, this work:

- Compiles and reviews widely scattered technical information on that can be used to evaluate the potential for adverse fish-hydrokinetic turbine interactions
- Experimentally tests fish-hydrokinetic turbine interactions in laboratory flumes, with quantification of the interactions and affects on aquatic species
- Identifies and demonstrates best practices for evaluating environmental effects of MHK projects and for designing adaptive management plans
- Continues to refine adaptive management plans as more projects provide a better understanding of the true potential for environmental impacts.

PLAN

EPRI's ongoing and planned research evaluates the potential for MHK devices to harm environmental resources, and identifies and demonstrates methods for effectively applying existing information and addressing uncertainties. Specific activities include:

1. *Fish Passage Through Turbines: Applicability of Conventional Hydropower Data to Hydrokinetic Technologies:* EPRI reviewed impacts of conventional hydropower turbines that can be used to evaluate potential impacts of hydrokinetic turbines on fish.
2. *Evaluation of Fish Injury and Mortality Associated with Hydrokinetic Turbines:* EPRI conducted tests of injury and survival of four species of fish exposed to three different types of hydrokinetic turbine in laboratory flumes. The studies also evaluated behavioral response (e.g., avoidance) of fish to the presence of operating turbines. Additional studies will be conducted as funding allows.

3. *Marine and Hydrokinetic Energy Interest Group:* EPRI manages a MHK interest group that serves as a forum for members with an interest in MHK technologies to exchange information with peers and learn about developments related to the MHK industry.

4. *Demonstration of Best Practices for Environmental Assessment and Adaptive Management Planning for MHK projects:* When a suitable project is identified, EPRI will work with the project developer to demonstrate best practices for designing an environmental assessment and adaptive management plan in support of project licensing. Results will be shared with project funders, FERC, resource management agencies, and the public through a combination of reports, workshops, and conference presentations or webcasts.

RISK

Marine and hydrokinetic energy projects face significant challenges in their permitting and licensing. Uncertainty regarding environmental effects of the emerging technologies drives the permitting and licensing process toward large, ill-defined environmental reviews and adaptive management plans. Growth of this sector of the renewable energy market will depend upon improvements to the process through effective development and application of relevant technical information, which EPRI's Marine and Hydrokinetic Technology research program provides. Failure to address these issues could result in underdeployment of MHK technologies. These technologies can provide a larger, more consistent and predictable power source than other renewable options for many power companies and communities.

SCHEDULE

Reports on the first round of evaluation of fish injury and mortality associated with hydrokinetic turbines will be completed in 2011. Follow-up studies will be conducted in 2012 and beyond as funding allows. The Marine and Hydrokinetic Interest Group will continue as long as there is sufficient interest among utility members. Demonstration of best practices for environmental assessment and adaptive management planning for MHK projects will begin in 2012, or as soon thereafter as funding can be obtained and continue for a period of three years.

DRAFT: RENEWABLE IMPACTS ON SPECIES AND HABITAT

ISSUE STATEMENT

The need to reduce dependence on fossil fuels has motivated recent and planned increases in wind and solar production. The production of biomass resources and the construction and operation of wind and central solar installations pose potential risks to plant communities, and wildlife habitat and populations. These risks can influence siting, construction, operation and mitigation practices. There are significant gaps in the scientific and technical knowledge bases that hinder the assessment of potential ecological effects and the evaluation of alternative siting, management and mitigation practices to minimize associated risk.

- There exists a lack of documentation of the life histories of key species vulnerable to impact by wind and central solar installations. These include raptor species, bat species, and desert reptiles.
- Effects of solar and wind installations are usually quantified with respect to individual mortalities. From an ecological perspective, it is the population level that is significant. Studies are needed which demonstrate how population level effects can be calculated.
- Reductions in numbers of individuals are usually predicted based on habitat disturbance; however, there is a lack of data substantiating these impacts. Field experiments are needed to directly measure the impacts of habitat disturbance.
- There often exist ambiguity regarding the range and size of potentially impacted populations. Field studies are needed to better understand size and extent of potentially impacted populations.
- With respect to biomass energy, research is needed to better understand the impact of tree plantations on species habitat, community composition, soils, and corridors for animal movement.

DRIVERS

The U.S. Department of Energy (USDOE) and state government are encouraging development of renewable energy through direct funding, tax incentives and renewable standards. As a result of this support, the technologies are rapidly evolving. Concerns with ecological impacts have led to lawsuits and expensive delays for planned projects. Various avian protection acts create potential liabilities for wind farm operators. The Endangered Species Act can have expensive repercussions for siting, construction and operation of renewable energy installations. Research is required to minimize ecological, economic and reputational risks. Even if electric companies are not developing and operating renewable operations but only buying power form them, the electric companies will need to assess and manage the risks regarding the reliability of the planned or operating operations to deliver the contracted renewable energy at the promised cost.

RESULTS

Power company environment, generation, and planning staff will extract information from EPRI technical reports, peer reviewed open literature scientific journal papers, EPRI issue briefs, and EPRI presentation material. Electric power companies will use results to address the siting, construction and operation of their own renewable energy operations or the purchase of renewable energy from other parties. In addition, EPRI will facilitate broader use and awareness of the results by presenting webcasts; briefing key stakeholders, including the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (USDOE), the U.S. Fish and Wildlife Service (USFWS) and state agencies; developing materials for the trade press/media; and continuing service on various government, academic, and professional organization advisory panels.

PLAN

- Develop life history data base for key species vulnerable to impact by wind, solar and biomass operations.
- Develop integrated field study/modeling methodology to evaluate population level effects of key species.
- Test methodology above using a network of experimental sites. These sites will either already have sited renewable operations or have the potential to support such operations.

- Conduct field studies to develop methodology to determine range and population size of key potentially threatened species.
- Conduct integrated field/modeling study to determine impacts of biomass fuel plantations on habitat and endangered species.

RISK

Without scientifically sound knowledge and data on potential renewable energy ecological effects and mitigation strategies, electric power companies are vulnerable.

- Overly conservative and expensive environmental regulations.
- Reliability problems resulting from inadequately vetted contracts for renewable energy
- Inability to meet state renewable standards
- Risks to reputation

DRAFT: WIND TURBINE NOISE AND HEALTH IMPACTS

ISSUE STATEMENT

As wind generation rapidly expands worldwide, some concerns about wind turbine-associated noise are being raised both in the United States and overseas. In particular, some environmental and health risks—such as ultra-low frequency sound causing annoyance and possible adverse health effects—are perceived by the public to be associated with wind development. While there is still little independent backing of some noise claims, complaints and allegations could limit (and have, in some cases, limited) a company's ability to permit or operate a wind power facility. Several white papers have been prepared by various jurisdictions, including the Government of Australia, the British National Health Service, and the Chief Medical Officer of Ontario (Canada); these have all concluded that wind turbine sound does not constitute a health hazard. However, other work suggests that health issues may be associated with sound from wind projects. More data are needed to evaluate whether audible or subaudible sounds emitted by wind turbines have any direct adverse physiological effects on people living or working near wind farms. EPRI has developed an umbrella of research activities to inform policymakers and other stakeholders on the impacts of wind turbine–related noise.

DRIVERS

This issue is one of international scope. The World Health Organization (WHO) has issued Guidelines for Community Noise (1999); these recommend a maximum sound level of 30 dB in bedrooms at night, and 35 dB elsewhere in residences during the daytime and evening. No specific wind turbine-related noise guidance has been proposed by WHO. Some countries, including New Zealand, Denmark, the Netherlands, and Germany, have established regulatory limits. In some cases, these have included low-frequency sound.

In the United States, no federal noise regulations currently exist, although the US Environmental Protection Agency (EPA) has established noise guidelines. Similarly, most states do not have noise regulations, but many local governments have enacted noise ordinances to manage community noise levels in general, and wind turbine-related noise specifically. Despite the lack of established national noise-related regulatory drivers, there are several regulatory frameworks that influence wind development and are therefore relevant here. In addition, there are important non-regulatory drivers.

Renewable Portfolio Standards (RPSs) – Currently, 30 states have renewable energy mandates. Some of the more aggressive states include California, with 33% of energy to come from renewables by 2020, and Maine, with a target of 40% by 2017.

Extension of Production Tax Credit (PTC) – Companies that generate wind energy (and other renewable sources of energy) are eligible for this credit, which provides a 2.1-cent per kilowatt-hour (kWh) benefit for the first ten years of a facility's operation. In 2009, the PTC for wind was extended until the end of 2012.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship – Wind turbine-related sound can be a sensitive and even divisive issue for communities. Sound scientific research can provide critical, objective input to inform local discussions about wind project siting.

RESULTS IMPLEMENTATION

EPRI research on wind turbine-related noise is expected to generate data critical to informing international, national, regional, state, and local officials about how wind development may affect existing communities. Specifically, this work will:

- Improve understanding of public perception near wind projects, which is the first step in developing strategies to mitigate risk for utilities and the public.
- Generate data that will allow officials to better understand the nature and origin of noise complaints.
- Involve laboratory-based research which will serve a critical role in examining in a scientifically rigorous manner the potential biological impacts of infrasound and low-frequency sound.
- Help wind operators communicate more effectively any potential risks, as well as develop siting criteria to minimize risks.

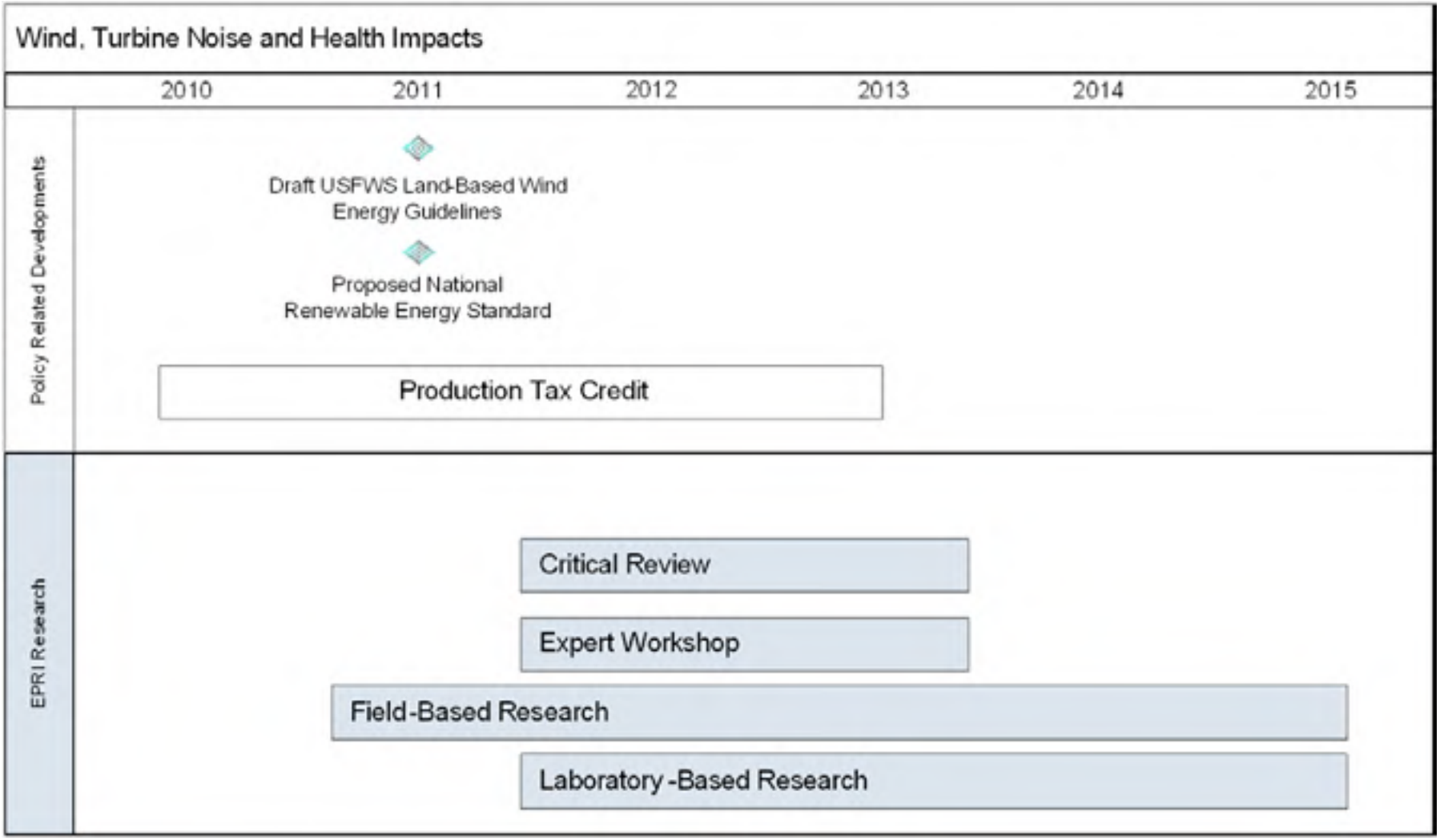
PLAN

EPRI's planned research consists of a comprehensive evaluation of wind turbine–related noise and potential community impacts. The umbrella of research is multidisciplinary, bringing together certified industrial hygienists, acoustical professionals, experts in public policy and public health, and industry representatives to address critical issues related to wind generation and noise impacts. These activities are generalizable and highly relevant to the global community. Specific activities include:

1. *Development of a critical review on wind turbine noise:* Although there are a number of reviews in the "grey literature", there are currently no published papers in the peer-reviewed literature that comprehensively and critically evaluate all the evidence and data related to wind turbine noise and health/annoyance.
2. *Expert workshop:* This will bring together international researchers to discuss the state of the science and identify key knowledge gaps and research needs.
3. *Field-based research:* This will include detailed sound monitoring from the low-frequency through audible range as well as specific monitoring of infrasound in the vicinity of operating wind projects. Importantly, community surveys will be conducted to evaluate the influence of both sound- and nonsound-related factors on complaints and potential health impacts. The research is unique in that residential sound exposures will be measured and therefore correlations with complaints can be evaluated.
4. *Laboratory-based research:* Using animals and/or humans, the biological effects of infrasound and other-low frequency sound will be examined.

RISK

EPRI research on wind turbine-related sound informs industry, regulators and society alike with high quality, objective and credible scientific information, providing an independent perspective that otherwise would not exist. In particular, there are few rigorously conducted studies on the impacts of win turbine-related noise; EPRI will be filling critical knowledge gaps by conducting its research in this area. If such research does not move forward, regulators and other stakeholders will be forced to rely on the available data, some of which is being generated by non-objective parties.


Wind, Turbine Noise and Health Impacts
2010
2011
2012
2013
2014
2015
Policy Related Developments
Draft USFWS Land-Based Wind Energy Guidelines
Proposed National Renewable Energy Standard
Production Tax Credit
EPRI Research
Critical Review
Expert Workshop
Field-Based Research
Laboratory-Based Research

DRAFT: ENERGY AND CLIMATE CHANGE ANALYSIS

ISSUE STATEMENT

What are the impacts of proposed energy and environmental policies on the electric sector's operations? Are there alternative measures that could attain the same energy and environmental goals but at lower costs to the electric sector and to the U.S. economy? Are federal policies effectively aligned with regional and state energy and environmental policies? What information is needed to help make new policy approaches work efficiently and effectively? What are the portfolios of technologies—for energy demand, supply, and transmission—that show promise for providing a robust, risk-management approach to dealing with the uncertainty confronting the sector? Developing and communicating informational insights on these types of questions to utility executives, policymakers, and the public is the purpose of EPRI's Energy & Climate Change Analysis research.

International negotiations on climate change move forward as countries weigh the imperatives of economic growth and environmental improvement against increasing concerns about energy security. Domestically, the U.S. Congress is considering new approaches and policies to deal with energy issues, reassessing policies on climate change, and also reviewing the application of existing regulations to emerging energy and environmental issues. Meanwhile, the U.S. Environmental Protection Agency (EPA) is actively pursuing regulation of greenhouse gases under the Clean Air Act, and certain states and regions are pursuing GHG emission reductions. Moreover, increasingly stringent EPA regulation of criteria air pollutants, hazardous air pollutants, coal combustion products, and cooling water will make the use of coal and other fossil fuels for electricity production increasingly difficult and likely more expensive. Added to these regulatory initiatives is a broader societal imperative which seeks a cleaner energy future. Some form of renewable portfolio standards (RPS) or alternative energy standards or goals are in force in 37 U.S. states, and federal energy policy discussions may result in national renewable energy standards.

These issues are complex individually, closely intertwined, and the stakes for companies and society are high. Development and maintenance of a strong analytical foundation for policy, technology, and corporate strategy decisions is of critical importance. EPRI's Energy & Climate Change Analysis research provides analysis and insights that can illuminate pathways toward an energy future with abundant, affordable, reliable, and clean electricity.

DRIVERS

Energy Policy – There is a greater focus on national energy policies due to expectations of increased domestic energy supplies, renewed attention to international energy issues and their impact on the U.S., and the on-going debate in Congress regarding climate change policies. A key example is the Administration's proposed goal of generating 80 percent of the nation's electricity from clean energy sources by 2035. EPRI can help inform important questions, such as: What are the implications of alternative thresholds for inclusion in the new program? What are the impacts of different definitions of "clean energy"? How will a clean energy standard affect the deployment of specific technologies? How would a clean energy standard interact with other policies? How can standards incorporate market elements that make them more flexible and lower costs?

Environmental Regulations – Over the next decade, new and more stringent regulations will take effect for SO_2, NOx, hazardous air pollutants, coal combustion residuals, and cooling water systems. Understanding the cumulative effect of these regulatory developments at the level of an individual generating unit, and for the industry as a whole, requires sophisticated analytical capability.

Electric Sector Technology Development – Technological advances in the supply, transmission, storage and use of electricity can profoundly affect the cost of complying with energy and environmental policies and regulations. The ability to assess what comprises a prudent investment portfolio in

the face of uncertain technology advances and costs, public acceptance, and future regulations relies on the availability of a rigorous analytical framework.

Climate Policy – International, national, regional, and local climate policies can fundamentally change the economics and makeup of power generation and the energy system. The issue is global, with choices and actions in one part of the world fundamentally affecting choices and actions in others. Understanding the integrated electric system and the overall economy in which it operates are essential to arriving at environmentally effective and economically efficient policies and regulations.

Corporate Strategy – Economically efficient policies, coupled with technology advances and sound implementation, can substantially reduce the cost of meeting energy and environmental goals. Company capital investments will have to be made under great uncertainty—climate policy uncertainty, broad environmental regulatory uncertainty, and electric system uncertainty due to an influx of intermittent generation together with traditional uncertainties related to fuel and electricity markets. These uncertainties create the need for new methods to help companies evaluate the risks and opportunities associated with key generation, transmission and distribution, end-use and market choices.

RESULTS IMPLEMENTATION

EPRI's energy and climate change analysis provides value to the electricity industry and the public in many ways:

- Informs the development and implementation of economically efficient policies, regulations, and mechanisms that can help society meet energy and environmental goals in a cost-effective manner,
- Informs technology development in the electric sector by identifying the need, value, and specifications for developing and improving electricity generation, transmission and distribution, and end-use technologies
- Informs corporate decision-making for optimizing capital investment, operations, market, and brand management decisions

In addition, close integration with the relevant technology development programs at EPRI provides an economic and policy context for driving research by EPRI as well as other public- and private-sector organizations. Conversely, the technical programs and the industry provide the real-world knowledge to gain fundamental insights into the future challenges the industry faces.

PLAN

EPRI's energy and climate change research is long-term by necessity and design. The content must be dynamically adjusted to accommodate changes in policies, technology development, and the ramifications of decisions that are made over time. Thus, this roadmap indicates a general approach to be taken, but cannot prescribe a specific course of action leading to a finished product, nor can the timing or cost be explicitly defined far into the future. The precise needs for policy and technology evaluations and for company decision support will evolve over time as scientific, economic, and technological knowledge advances; as the global economy and societies expand; and as energy and environmental policies are implemented and refined.

The long-term plan for EPRI's Energy & Climate Change Analysis is based on the following key areas:

Develop and enhance analytical capabilities:

- Includes staff, contractor, and modeling resources;
- Will be based on member and stakeholder feedback and R&D program needs;
- Will build upon the intellectual frameworks developed by the Prism 2.0 supplemental project, and
- Will position EPRI analyses for a broader range of analyses beyond traditional climate change issues, e.g., environmental controls, energy security.

Conduct world-class analysis:

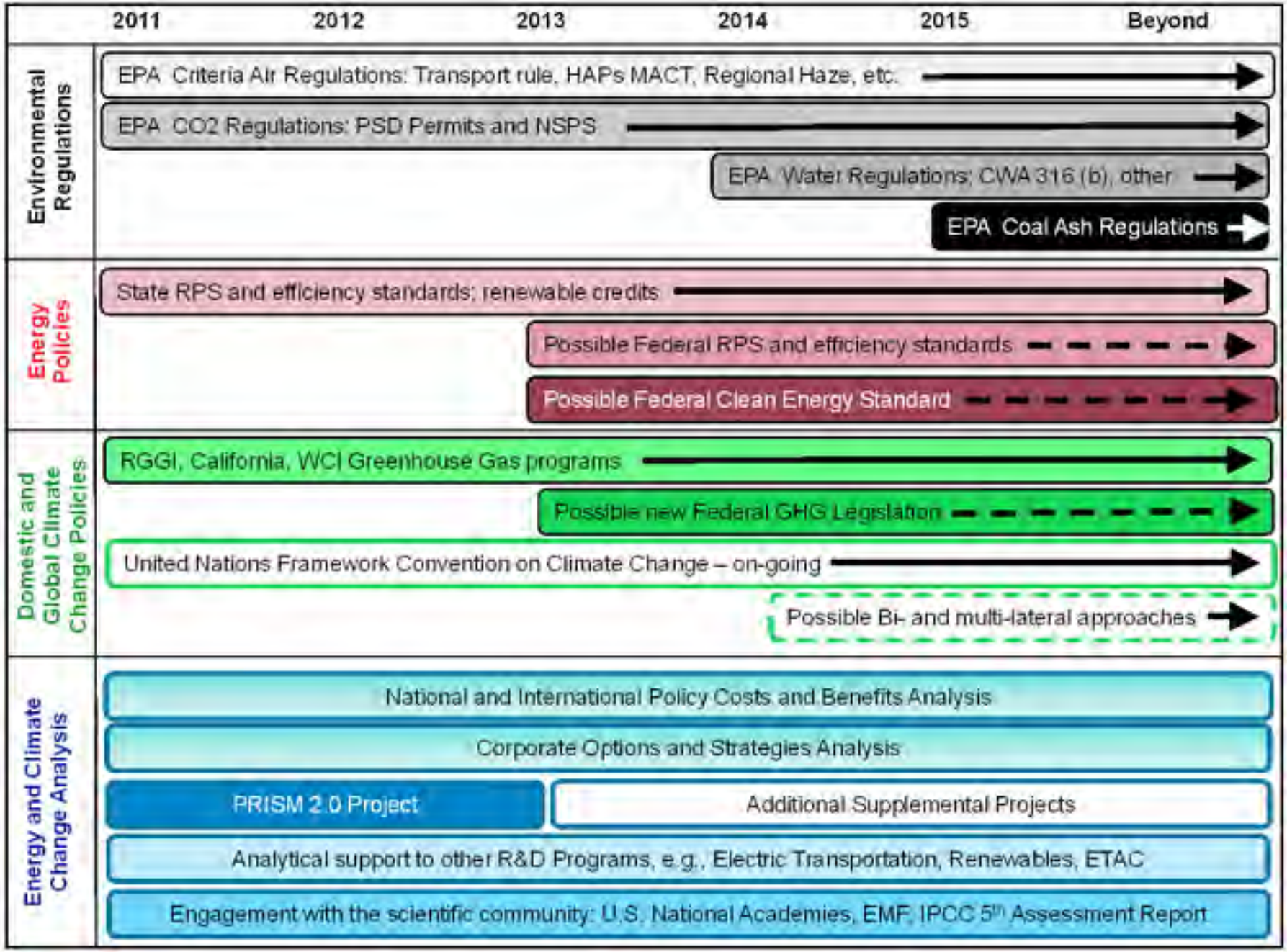
- Focus on critical electric sector, energy, environment, and related economic issues;
- Improve the internal consistency and quality of analyses produced across EPRI's R&D sectors;
- Conduct additional analyses in support of other programs across the R&D sectors, for example renewables, energy efficiency, electric transportation; and
- Provide strategic insights to EPRI's leadership, utility executives, policymakers, and the public.

Engage with the scientific community:

- Share and vet model design, methodologies and results in scientific forums (e.g., Energy Modeling Forum);
- Participate in modeling exercises that provide an opportunity for model comparison and cutting edge model development and application; and
- Publish papers in the peer-reviewed literature.

RISK

EPRI's climate research provides value to companies and society by increasing the likelihood that future energy and climate policies will be efficient as well as effective, and by helping companies make better decisions in a time of unprecedented uncertainty. Electricity sector compliance with evolving policies and regulations will result in expenditures on the order of tens of billions of dollars over the next decade, and missed opportunities to save even a fraction of those costs far outweigh the cost of EPRI's research.


2011
2012
2013
2014
2015
Beyond
Environmental Regulations
EPA Criteria Air Regulations: Transport rule, HAPs MACT, Regional Haze, etc.
EPA CO2 Regulations: PSD Permits and NSPS
EPA Water Regulations: CWA 316 (b), other
EPA Coal Ash Regulations
Energy Policies
State RPS and efficiency standards; renewable credits
Possible Federal RPS and efficiency standards
Possible Federal Clean Energy Standard
Domestic and Global Climate Change Policies
RGGI, California, WCI Greenhouse Gas programs
Possible new Federal GHG Legislation
United Nations Framework Convention on Climate Change – on-going
Possible Bi- and multi-lateral approaches
Energy and Climate Change Analysis
National and International Policy Costs and Benefits Analysis
Corporate Options and Strategies Analysis
PRISM 2.0 Project
Additional Supplemental Projects
Analytical support to other R&D Programs, e.g., Electric Transportation, Renewables, ETAC
Engagement with the scientific community: U.S. National Academies, EMF, IPCC 5th Assessment Report

DRAFT: COMPANY STRATEGIES FOR MEETING ENERGY AND ENVIRONMENTAL INITIATIVES

ISSUE STATEMENT

Electric sector companies face unprecedented uncertainty today. New and emerging energy and environmental policy initiatives have the potential to raise electric rates, stretch financing capabilities, strand some existing electricity company assets, and close a portion of existing generation. The timing and structure of these policies will fundamentally impact today's decisions. Future prospects for nuclear generation have been made more uncertain by recent events at the Fukushima plant in Japan. Domestic and global natural gas supplies appear more plentiful with advances in recovering shale gas resources, but environmental questions linger. Widespread support and incentives for renewable energy affect the value of existing generation as well as the need for future generation, transmission, distribution and end use investments. Large uncertainty about the economy clouds the need for new capacity investments, and troubled financial markets limit capital investment options and make investment decisions more complex.

EPRI data, analytical tools and technical expertise can help electricity companies assess the impacts of national- and regional-scale energy, environmental, and climate policy initiatives on their operations, customers and investors, identify and refine corporate strategies, and communicate implications to policy makers and other stakeholders.

DRIVERS

Making good strategic and investment decisions in a time of unprecedented uncertainty for the electric industry can make or save billions of dollars for companies,,their customers and the public Key uncertainties include:

- **Policy** – The U.S. Congress is considering new approaches and polices to deal with national energy issues, reassessing policies on climate change, and reviewing the application of existing regulations to emerging energy and environmental issues. Over the next decade, new regulations will take effect for SO_2, NOx, hazardous air pollutants, coal combustion residuals, and cooling water intake systems. At the same time, the U.S. EPA is pursuing regulation of greenhouse gases under the Clean Air Act, and certain states and regions are pursuing GHG emission reductions. Understanding the cumulative effect of these regulatory developments at the level of an individual generating unit, a company, a region and for the industry as a whole, requires a sophisticated analytical capability. For example, the pay-offs for compliance expenditures depend not only on a company's own retrofit costs, but also on how an individual unit's production costs compare in the broader regional markets in which the units compete.
- **Technology** – The future of renewable, nuclear, carbon capture and storage, new transmission lines, Smart Grid, end use and other technologies are uncertain. Some of these technologies may or may not be large-scale options in the future. A broad societal imperative toward a cleaner energy future is expanding. Some form of renewable portfolio standards (RPS) or alternative energy standards or goals are in force in 37 U.S. states, and federal energy policy discussions may result in national renewable energy standards, clean energy standards or mandated energy efficiency goals. Clean energy policies are sparking a large influx of intermittent wind and solar generation, with attendant challenges for supplying electricity and operating a stable electrical grid.
- **Traditional Planning Uncertainties** – Economic growth, load growth and fuel prices are three factors that electric planners have always had to deal with – sometimes successfully, others times not. Load projections are quite uncertain as companies look forward and fuel markets, particularly natural gas, may be characterized by abundant low-cost supplies, moderate-cost supplies, or short supplies depending upon the extent to which shale gas delivers on its potential.

The impacts described above may be compounded by policy interactions, e.g., energy efficiency slowing or stopping load growth (and revenue) at the same time that other policies require financing the turnover of existing capital.

The unique nature and massive scales of these initiatives are

unlike anything seen by utilities in last 50 years.

Together, these uncertainties create the need for new methods to help companies evaluate the risks and opportunities associated with key generation, transmission and distribution, end-use and market choices.

RESULTS IMPLEMENTATION

EPRI's research on company strategies provides fundamental insights that can help companies understand how they are potentially affected by policy; make more informed generation investment decisions; and analyze and choose cost-effective emission reduction investments in light of the key uncertainties. These general insights can be extremely valuable in communicating with company senior management, stakeholders and regulators. In addition, EPRI's research provides data and tools which can be applied to help individual companies or groups of companies with similar questions and insights that are tailored to their specific assets, regulations, regional market and choices.

EPRI's past research has provided well-received tutorials on how a carbon price can affect regional electricity markets, explored the limits to potential wind deployment, and examined the role of energy storage as an economic and enabling technology. These results have been widely communicated to company, academic and stakeholder audiences. Tailored studies have helped companies make generation and environmental retrofit investment decisions, given policy, fuel market and economics uncertainties. In these tailored studies, proprietary information is protected, but generic insights are made public.

PLAN

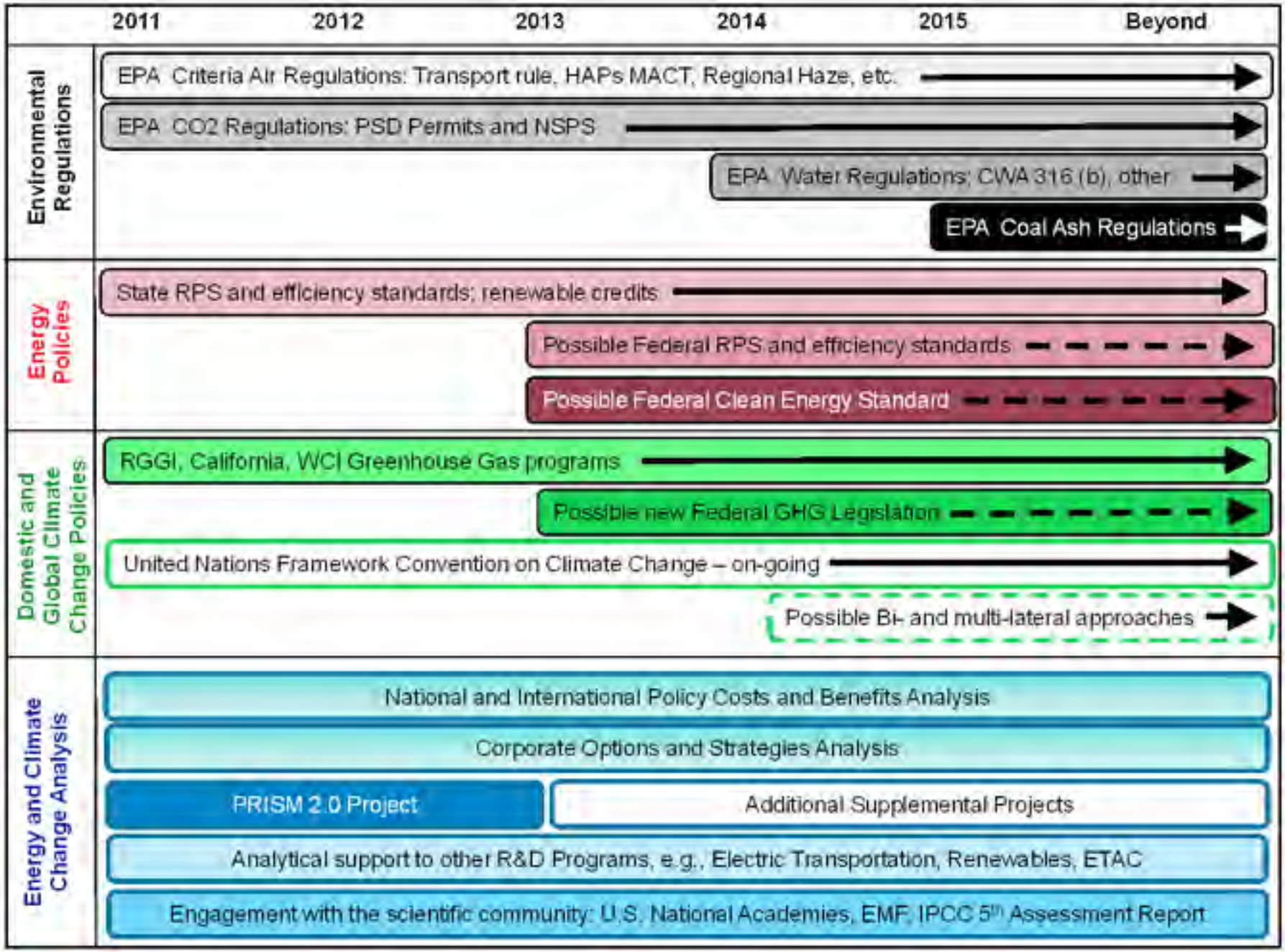
Research will focus on the development of data, methods and tools to support utility decisionmaking under uncertainty. This research area is strengthened greatly by the development of data, methods and tools under the Prism 2 project, which provide the starting point for analyses that will address critical industry issues – including a broad range of energy, environmental and climate polices. Historically this work has advanced by working with individual companies or groups of companies to address real questions and we anticipate such interactions playing a key role going forward.

The questions to be addressed will change over time to correspond to present (and near-future) industry and societal needs

- In the near term (1-3 years), the work will likely be focused on understanding environmental compliance choices under uncertainty, exploring the impacts of renewable deployment, and incorporating a range of approaches for understanding the range and implications of uncertainty.
- In the longer term (3-5 years) the research will support evolving company decision needs and inform further development of the conceptual framework for examining large-scale, economic, environmentally effective reduction options.

RISK

Electricity sector compliance with evolving policies and regulations will likely result in expenditures on the order of tens of billions of dollars over the next decade; missed opportunities to save even a fraction of those costs far outweigh the cost of EPRI's research. In addition, generic insights from company-level analyses of policy impacts are critical inputs to the policy process – for example, a policy that has no net national cost could have very large costs for specific types of companies or regions of the country.


2011
2012
2013
2014
2015
Beyond
Environmental Regulations
EPA Criteria Air Regulations: Transport rule, HAPs MACT, Regional Haze, etc.
EPA CO2 Regulations: PSD Permits and NSPS
EPA Water Regulations: CWA 316 (b), other
EPA Coal Ash Regulations
Energy Policies
State RPS and efficiency standards; renewable credits
Possible Federal RPS and efficiency standards
Possible Federal Clean Energy Standard
Domestic and Global Climate Change Policies
RGGI, California, WCI Greenhouse Gas programs
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Possible Bi- and multi-lateral approaches
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Engagement with the scientific community: U.S. National Academies, EMF, IPCC 5th Assessment Report

DRAFT: GLOBAL ENERGY, ENVIRONMENT, AND CLIMATE CHANGE ANALYSIS

ISSUE STATEMENT

International and domestic climate policies may cost the global economy trillions of dollars. Cost-effective implementation and technology advances can substantially reduce the cost of achieving the environmental objectives of these policies. The unique scientific, economic, and technological concerns of the electricity sector must be addressed in the policy debate. Research results are critical to informing stakeholder discussions over proposed national and international policies. Members and public- and private-sector decision makers can benefit from EPRI's analysis and information on the potential costs and benefits of domestic and international global climate policy proposals.

Managing the risks posed by climate change requires an improved understanding of its global dimensions on both near-term and century-long time scales. The R&D gap addressed by this roadmap is improved frameworks (models) to inform policy choices at global, national and regional levels. These tools need to be more robust in terms of estimating the economic costs of climate policy proposals and identifying policy design principles and accounting for key technology advances. More robust frameworks can help reduce cost of GHG reductions and allow more accurate comparisons of potential costs of policy proposals.

DRIVERS

International, national, regional, state, and local climate policies can fundamentally change the economics and makeup of power generation and the broader energy system. The issue is global, with choices and actions in one part of the world fundamentally affecting choices and actions in others. An understanding of the integrated electric system and the overall economy in which it operates is essential to arriving at environmentally effective and economically efficient policies and regulations.

While international climate policy discussions have been slowed and U.S. federal policy no longer appears imminent, the issue and fundamental challenges to the industry appear largely unchanged, and numerous initiatives can impact short- and long-term electric sector operations, competitiveness, and profitability:

- Ongoing international negotiations under the U.N. Framework Convention on Climate Change
- The regulation of electric generating facilities by the U.S. EPA under provisions of the Clean Air Act
- Possible Federal Renewable Portfolio and/or Clean Energy Standards
- Existing state-level RPS and greenhouse gas regulation, e.g., California's Global Warming Solutions Act (AB32), the Regional Greenhouse Gas Initiative, RPS programs in 29 states
- Interaction of present and future climate initiatives with emerging energy and environmental policy and regulatory requirements

Building the understanding and institutional capacity to implement efficient approaches to reduce greenhouse gas emissions will take substantial investments in money over prolonged periods. The current lull in political activity provides an opportunity to develop the knowledge base and understanding needed to make effective choices when policy makers decide to act.

RESULTS IMPLEMENTATION

This research has informed energy and environmental policy with regard to implementation principles and design details, such as the value of flexibility in meeting greenhouse gas reduction goals. At a high level, the research helps companies understand possible policy directions and how they are potentially affected by policy and therefore, make more informed generation and emission reduction investment decisions. A critical element of this research is to communicate key insights to companies and to the policy process in a timely and effective manner.

PLAN

The primary goal of this research will be focused on informing climate policy at the state, national, and international levels. As the research proceeds, the range of policies considered will broaden significantly to reflect renewed interest in regulatory approaches to complement or replace the market-based policies that have dominated climate policy discussions for the past two decades. Key collaboration with programs in EPRI's Generation Sector (e.g., Coal Fleet) and Power Delivery and Utilization (e.g., energy efficiency and electric transportation) sector will be crucial to providing comprehensive climate policy analysis. EPRI will also reach out to the broader research and scientific/technical community to ensure its research takes advantage of data sources and analyses developed elsewhere.

In the near term, research will inform development of environmentally effective and economically efficient climate policies at international, US, and local levels:

1. Internationally, the focus is to:

    a. Expand assessment of bilateral, multilateral, sectoral, and phased-in agreements. The negotiating focus has evolved from the idea of a common policy for all to one where countries take actions consistent with their individual needs

    b. Examine the stringency and types of international targets, recognizing the implications of scientific uncertainty

    c. Improve assessment of land use change and forestry. Deforestation contributes almost 20% of global GHG emissions annually and has important implications for bioenergy

    d. Improve assessment of technology costs and technology deployment in different regions of the world, recognizing local, non-economic factors

    e. Model additional sectoral detail to provide additional insights regarding possible sectoral policies and to understand the potential supply of international emission offsets (under certain policy proposals)

    f. Understand implications of non-CO_2 policies for electric sector emissions, e.g., aerosols

7. In the US, key research efforts include:

    a. Improve assessments of regulatory and overlapping policies. A wide variety of policy proposals are emerging at the Federal level via USEPA and legislative proposals, and at regional, state and local levels. Examine policy implementation issues such as the relative advantages of market mechanisms (e.g., cap and trade and carbon taxes), command and control, complete vs. partial coverage of sectors of the economy, technology mandates, and point of regulation (upstream vs. further downstream).

    b. Understand better the implications of low-emitting, intermittent resources for the future evolution and operation of the electric system.

    c. Develop better data and approaches for estimating regional impacts of biomass, solar, wind and CCS.

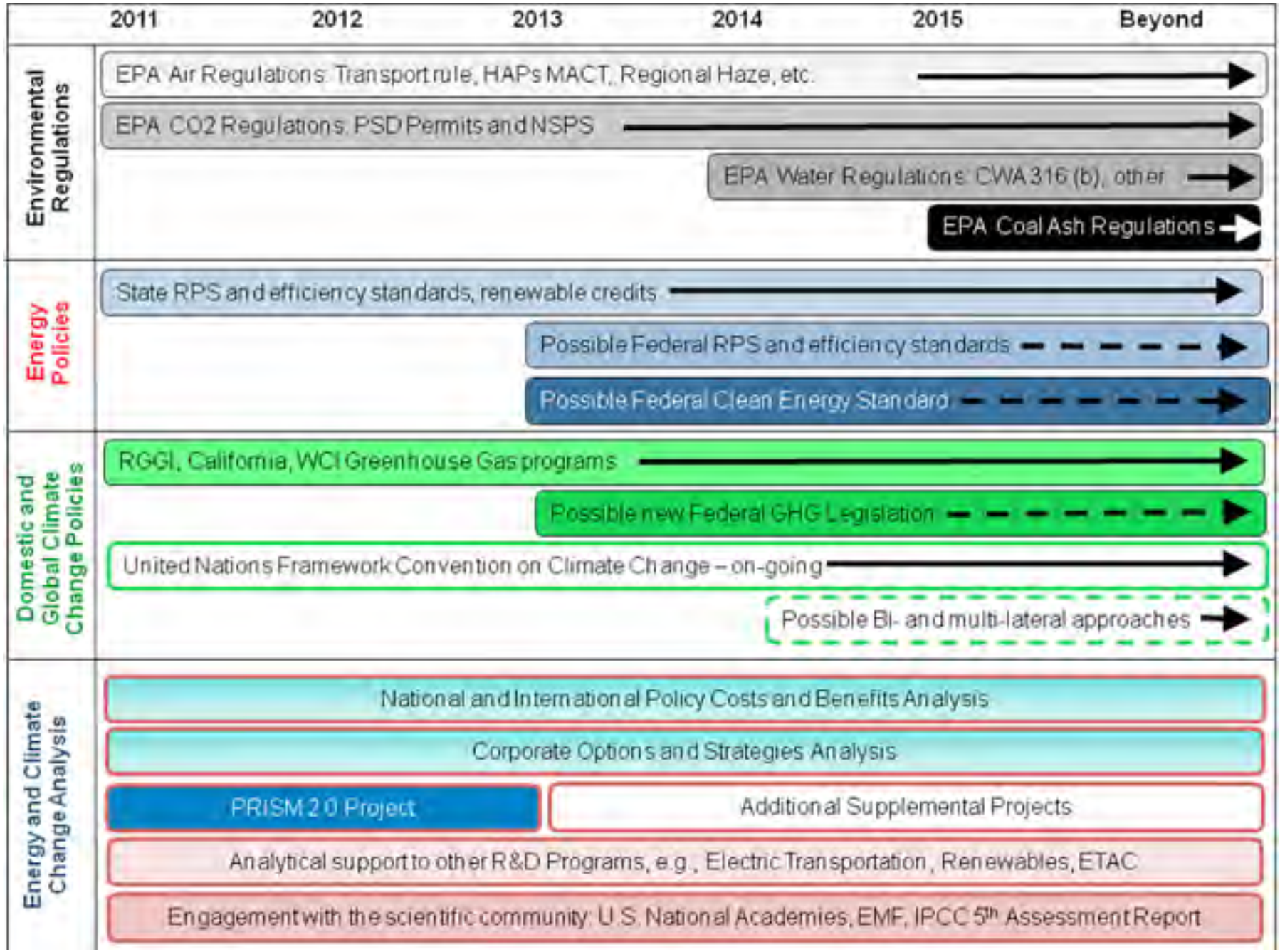
    d. Examine electric sector regulation and how this impacts technology choices, policy impacts and overall investment strategy over time.

    e. Expand understanding of policy implications outside of, but related to, the electric sector – e.g., the expansion of electric transportation and other electro-technologies.

In the longer term, EPRI will enhance its analytical capabilities to conduct studies on a broader range of issues beyond climate, including environmental policy (air, water, solid waste regulations), energy security and regional energy plans. Topically, analyses will focus on critical electric sector, energy, environmental and related economic issues by drawing upon information produced across the EPRI technical sectors. Results will be shared with EPRI's leadership, utility executives, policymakers and the public. It will be important that this research is done in an open and transparent manner; thus, results will be shared and vetted in various scientific fora such as the Energy Modeling Forum. EPRI will participate in other modeling exercises that provide an opportunity for model comparison and cutting edge model development and application. Key results will be published in the peer reviewed literature.

RISK

This research provides value to members, policymakers and society by increasing the likelihood that future energy and environmental policies will be efficient as well as effective, and by helping companies make better decisions in a time of unprecedented uncertainty. Electricity sector compliance with evolving policies and regulations will result in expenditures on the order of tens of billions of dollars over the next decade, and missed opportunities to save even a fraction of those costs far outweigh the cost of EPRI's research.


2011
2012
2013
2014
2015
Beyond
Environmental Regulations
EPA Air Regulations: Transport rule, HAPs MACT, Regional Haze, etc.
EPA CO2 Regulations: PSD Permits and NSPS
EPA Water Regulations: CWA 316 (b), other
EPA Coal Ash Regulations
Energy Policies
State RPS and efficiency standards, renewable credits
Possible Federal RPS and efficiency standards
Possible Federal Clean Energy Standard
Domestic and Global Climate Change Policies
RGGI, California, WCI Greenhouse Gas programs
Possible new Federal GHG Legislation
United Nations Framework Convention on Climate Change – on-going
Possible Bi- and multi-lateral approaches
Energy and Climate Change Analysis
National and International Policy Costs and Benefits Analysis
Corporate Options and Strategies Analysis
PRISM 2.0 Project
Additional Supplemental Projects
Analytical support to other R&D Programs, e.g., Electric Transportation, Renewables, ETAC
Engagement with the scientific community: U.S. National Academies, EMF, IPCC 5th Assessment Report

DRAFT: GREENHOUSE GAS EMISSIONS TRADING AND OFFSETS

ISSUE STATEMENT

While debate continues about how to respond to global climate change, it is becoming increasingly clear electric companies may face future requirements to substantially reduce and/or offset their GHG emissions. Existing and proposed policies to limit GHG emissions in the U.S. and around the world have included market-based approaches like GHG emissions trading that provide companies with flexibility to comply using a variety of activities. Most systems also have included complementary or redundant command-and-control regulations.

While the benefits of market-based approaches are well understood based upon decades of experience in a wide range of contexts, understanding of regulatory approaches that involve both markets and regulation is poor. In addition, the concept of emission offsets – emission reductions, sequestration or avoidance created by projects and activities at emission sources, and in economic sectors, not covered by a GHG emissions trading program's fixed cap – has emerged as a critical factor in controlling the expected costs of climate policies. While many offset projects have been implemented internationally to date along with some in the U.S., there is little experience developing offsets at the massive scale expected to be needed to achieve U.S. and global climate mitigation goals.

Market approaches and emission offsets face a number of challenges if they are to play a key role in future climate and energy policies. In recent years, politicians and the public have grown wary of markets as a result of the Enron and related energy-market scandals a decade ago and the near-global financial crisis that began in late 2007. Although market-based policies appear to be out of favor in the U.S. for now, these approaches remain prominent policy options for the U.S. to pursue in the longer term. A critical step for the future development of carbon markets will be to rebuild trust in their efficacy, and to demonstrate how market approaches can potentially save trillions of dollars compared to more-prescriptive regulatory policies. A closely related goal is to determine how to increase dramatically the scale of offset supplies to match levels of demand that are expected to be 10-100 times greater than can be met with current approaches at current prices.

The design of a large-scale, cost-effective offsets program with a high degree of environmental integrity is a challenging endeavor. There are a myriad of policy-related issues that must be addressed, including the design of basic institutions necessary to administer such a program. Key questions include: What sources of domestic and international offsets may qualify for future compliance with future CO_2 mitigation program, including possibly use of offsets as part of EPA's efforts to regulate electric sector GHG emissions under the Clean Air Act? What specific types of projects and programs may be allowed to generate offsets? How will the "additionality" of project be determined? Will there be limits to the use of offsets for compliance purposes, and if so, how will these limits be designed? How will offset projects be approved, registered, and ultimately issued GHG offset credits? How are offset methodologies established, and who will oversee their development and implementation?

EPRI's research is designed to help address these and other critical questions associated with development and implementation of large-scale GHG emissions trading and offsets programs.

DRIVERS

- Market-based policies can save trillions of dollars compared to more prescriptive regulatory policies. It is critical for policymakers and companies to understand the trade-offs between these approaches.
- Existing and evolving GHG cap-and-trade programs in North America are likely to have a direct impact on electric company operations and financial heath, including those in California, the Regional Greenhouse Gas Initiative (RGGI) in the Northeast U.S., and the Western Climate Initiative (WCI). Future EPA regulatory policies designed to reduce GHG emissions also may include GHG trading and offsets.
- GHG emissions trading programs already have been adopted in other key countries, including the 27 nations of the European Union (EU) and New Zealand, and programs are being actively developed in Australia, Brazil, China, South Korea, Japan and Taiwan. Analysis of these programs can identify key "lessons learned" that can improve development of future policies.

- Many electric companies operating in the U.S. and internationally are required today to comply with market-based and regulatory policies to reduce GHG emissions, and these companies are actively developing and implementing compliance strategies.
- It is critically important to lay the groundwork now to inform potential future climate legislation. It will take many years to develop the policies, institutions, market infrastructure and offset projects that will be needed to generate large-scale offset supplies. Research is needed on institutions, rules, science, and economics associated with achieving GHG reduction levels contemplated in recent U.S. legislation.

RESULTS IMPLEMENTATION

EPRI's research on the design of GHG market mechanisms and offset programs provides value to the electricity industry and the public in a variety of ways, including:

- Informs development and implementation of economically efficient policies, regulations, and mechanisms that can help society meet GHG emissions reduction goals in a cost-effective manner.
- Provides analyses of existing and proposed new market mechanisms for controlling GHG emissions and meeting other clean energy goals.
- Examines and analyzes GHG offset mechanisms, focusing on technical implementation challenges, design issues affecting environmental and political feasibility, and economic value.
- Helps members to communicate program results on climate policy complexities to diverse stakeholders through workshops, issue summary documents, and other communication channels. EPRI's very successful Offset Dialogue series has brought together industry, market makers, academics, environmental NGOs and regulators for open discussions of key issues.
- Catalyzes development of new types of offsets projects by conducting R&D activities to surmount scientific and technological uncertainties, develop methods to measure, monitor and verify emission reductions; and develop necessary offset accounting protocols and methodologies. EPRI's recent research on N_2O reductions illustrates how these efforts can range from fundamental scientific and social science research to practical implementation.
- Develops key Information to help electric companies manage their financial risks by understanding the key role of offsets in policy cost containment and the potential for companies to use offsets for compliance purposes.

PLAN

Successful implementation of EPRI's research plan will help to: increase the economic efficiency of future climate policies, reduce compliance costs for EPRI member companies and society overall, increase future offset supplies, and provide policy makers, EPRI members, and the public with key analysis and information to better understand the critical roles of emissions trading and offsets in achieving large-scale GHG emissions reductions in a cost-effective way.

This work will improve understanding of key issues in the design of GHG emissions trading programs and offset systems, and help electric companies communicate the implications to policy makers and stakeholders. EPRI research activities can provide key insights into experience to date with policies managing GHG emissions from the electric and energy sectors throughout the world. This perspective can help electric companies and others to be better informed participants in GHG policy debates and understand implications for their own business decisions.

EPRI's research to address this strategic issue is based on the following key areas:

Analyze Existing and Evolving GHG Emissions Trading and Offset Programs:

- Examine emerging experience with climate policies and offsets programs evolving in the U.S. and internationally to inform new policy implementation, and identify important lessons learned from experience with early GHG trading and offset programs.
- Conduct analyses of market and non-market mechanisms for controlling GHG emissions and meeting other clean energy goals, and the possible interactions from a combination of the two approaches. Monitor and report on the evolution of GHG emissions trading and offsets programs around the world.

- Examine and analyze key policy choices as they are contemplated in evolving state and regional GHG trading and offset programs in the U.S.
- Conduct quantitative analysis and modeling to estimate the economic potential for domestic and international offsets.

Catalyze Development of New GHG Offsets Approaches:

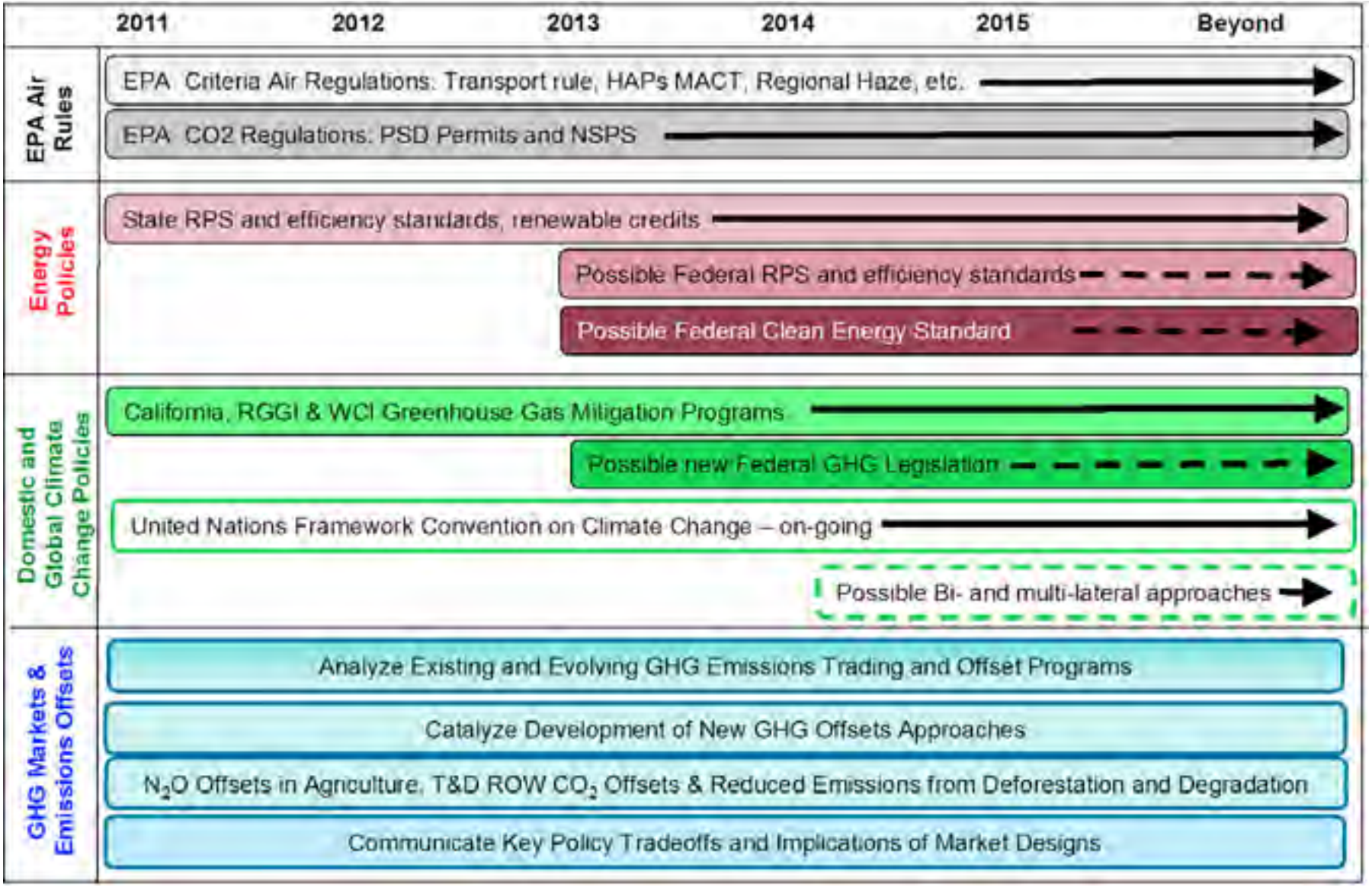
- Facilitate development of innovative new types of GHG emissions offsets that hold promise for achieving large-scale, cost-effective emissions reductions.
- Conduct on-the-ground pilot offset projects to demonstrate the efficacy of new offset approaches, accounting protocols, and methods to measure, monitor and verify emissions reductions.
- Participate in technical working groups established by leading GHG offsets registries and standards programs to address key technical and policy choices associated with creating new types of offsets.
- Analyze potential implementation of new offset market mechanisms such as Sectoral Crediting, NAMA crediting, Reduced Emissions from Deforestation and Degradation (REDD).
- Evaluate and analyze different approaches to creating GHG emissions offsets, and provides insights about the expected cost and potential availability of offsets.
- Conduct basic research into innovative offset ideas and helps to refine methodologies for evaluating offset projects and estimating availability.
- Contribute to development of protocols designed to quantify, measure, monitor, and verify GHG emissions offsets, and examines implications of different rules for crediting offset projects.

Communicate Key Policy Trade-offs and Implications of Market Designs:

- Conduct climate policy design and offsets-related workshops to provide a forum for a facilitated discussion among key constituencies and stakeholders, build a common understanding of market offset system design elements and issues, and explore new ideas and approaches.
- Provide briefings, webcasts, and conference calls for EPRI member companies to highlight results of EPRI analysis and key insights.
- Provide clear communication regarding implications of different rules and restrictions on offsets and emissions trading.

RISK

EPRI's climate research provides value to companies and society by increasing the likelihood that future energy and climate policies will be efficient as well as effective, and by helping companies make better decisions in a time of unprecedented uncertainty. Electricity sector compliance with evolving policies and regulations will result in expenditures on the order of tens of billions of dollars over the next decade, and missed opportunities to save even a fraction of those costs far outweigh the cost of EPRI's research.


2011
2012
2013
2014
2015
Beyond
EPA Air Rules
EPA Criteria Air Regulations: Transport rule, HAPs MACT, Regional Haze, etc.
EPA CO2 Regulations: PSD Permits and NSPS
Energy Policies
State RPS and efficiency standards, renewable credits
Possible Federal RPS and efficiency standards
Possible Federal Clean Energy Standard
Domestic and Global Climate Change Policies
California, RGGI & WCI Greenhouse Gas Mitigation Programs
Possible new Federal GHG Legislation
United Nations Framework Convention on Climate Change – on-going
Possible Bi- and multi-lateral approaches
GHG Markets & Emissions Offsets
Analyze Existing and Evolving GHG Emissions Trading and Offset Programs
Catalyze Development of New GHG Offsets Approaches
N_2O Offsets in Agriculture, T&D ROW CO_2 Offsets & Reduced Emissions from Deforestation and Degradation
Communicate Key Policy Tradeoffs and Implications of Market Designs

DRAFT: LAND AND GROUNDWATER

ISSUE STATEMENT

Electric utility operations generate by-products and solid wastes that require careful examination to mitigate contamination of land and associated groundwater. The Land and Groundwater research focuses on accurate characterization of these wastes and by-products, understanding the fate and transport of contaminants from these wastes to land and groundwater resources and developing cost effective strategies to minimize adverse environmental impacts.

Coal Combustion Products

Annual costs for environmental management of coal combustion products (CCPs) can run into billions of dollars The U.S. electric power industry alone produces an estimated 130 million tons of CCPs . CCP management strategies will have to evolve as tighter air emission controls, new fuel blends, and advanced generation technologies change CCP characteristics and chemistry and increase CCP volumes. This changing landscape highlights the need for new and updated information on the composition and leaching characteristics of CCPs, environmentally protective management methods, groundwater protection and remediation requirements, and risk assessment data for CCP storage, disposal, and beneficial use.

Manufactured Gas Plant Site Management

Most former manufactured gas plants (MGP) ceased operation by the 1960's, but by-products and wastes, typically disposed in the plant's vicinity still remain with the potential to cause adverse environmental effects. More than 1,500 MGP sites in the United States and an equal or greater number in Europe exist. Many still require either investigation or remediation, at estimated cleanup costs typically in the millions of dollars per site. The wastes include tars (containing polycyclic aromatic hydrocarbons or PAHs), tar-contaminated soils, and contaminated sediments in nearby water bodies. Also, there is the potential for degradation of indoor air quality in buildings in the vicinity of these MGP sites from transport of volatile organic compounds. Site managers need credible data and information on alternative investigation and remediation techniques and appropriate site-specific cleanup criteria.

Power Plant Decommissioning

Over the next decade, many older power plants will reach the end of their service lives and will require closure and demolition. As these sites are considered for repowering or other uses, systematic assessment is needed for plant decommissioning and for developing strategies for reuse or redevelopment. Ensuring that plant closure is performed cost effectively and with due concern for addressing environmental impacts from plant operations is a complex undertaking, requiring a thorough knowledge of plant systems and current and past practices.

DRIVERS

There are specific state and federal regulatory drivers affecting the environmental management of CCPs and MGP sites and contaminant releases into air, water and solid waste streams.

Resource Conservation and Recovery Act (RCRA) – RCRA gives EPA the authority to control hazardous waste from "cradle-to-grave" (generation, transportation, treatment, storage, and disposal). RCRA also sets forth a framework for management of non-hazardous solid wastes. EPA recently proposed regulatory options that include management of CCPs as hazardous waste or as non-hazardous waste, with significantly varying implications to the electric utility industry. While RCRA regulations may apply to the disposal of wastes generated at MGPs, federal and state Superfund statutes can impact site management practices.

Hazardous Air Pollutants (HAPs) Rules – EPA is developing maximum achievable control technology (MACT) standards for all HAPs, including mercury, from coal and oil-fired power plants. As newer and better HAPs air emissions control technologies are implemented,, these will have an impact on CCP characteristics and management strategies.

Clean Water Act – EPA is revisiting its effluent guidelines for the steam electric sector and one of the primary concerns is discharge of many trace metals (such as arsenic, mercury and selenium) from power plant streams. The guidelines will significantly impact on-site and off-site CCP management.

Safe Drinking Water Act (SDWA) – The SDWA establishes maximum contaminant levels (MCLs) for trace inorganic elements that may cause adverse health effects. These trace elements are components of coal that are captured by the environmental controls systems and are thus in the solid or liquid by-products, with some remaining in the flue gas particulate matter as it exits the stack. Low MCLs for some of the trace constituents - notably arsenic, hexavalent chromium, and mercury - are potential concerns for storage or use of by-products, discharge of waste water and potential contamination of groundwater.

Natural Resource Damage (NRD) – Natural resource damages may occur at sites as a result of releases of hazardous substances. Natural Resource Damage Assessments (NRDAs) are used to assess injury to natural resources held in the public trust. This is an initial step toward restoring injured resources and services and toward compensating the public for their loss. "Natural resources" include land, fish, wildlife, biota, air, water, ground-water, drinking water supplies, and other such resources. Some MGP sites can be impacted by NRDAs.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All EPA rules are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Many interveners and third parties continue to push EPA and individual states to reduce environmental releases to very low levels. Scientific research results provide critical, objective input to such discussions.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed by EPRI and its members to address the near term and longer-term Land and Groundwater research needs.

- The results developed from this research will be made available to program members to help them meet their site management and remediation needs in a cost effective and environmentally protective manner.
- The results will also be made available to a variety of other stakeholders including federal and state regulatory agencies to inform relevant rulemaking activities.

PLAN

Over the next 5-7 years, Land and Groundwater research will continue to focus on the evolving needs of CCP and MGP site environmental management. All stakeholders – the appropriate regulators (federal and/or state), environmental organizations, industry participants, and the public—must be satisfied that these sites can be managed safely and pose no unacceptable public health or environmental impacts. Specific actions that need to be undertaken to address current and anticipated issues include:

- *Thorough characterization of by-products and wastes from current and emerging combustion-based generation technologies*. The near term focus is on changes to CCP characteristics due to mercury and SO_3 controls, co-burning of biofuels, radionuclides, and by-products resulting from IGCC. Work will also continue in parallel with EPA on development and interpretation of laboratory leaching methods and geochemical models for estimating leachate release. This research will provide core data touching all facets of CCP disposal and beneficial use.
- *Compile risk and health effects information as input to regulatory and legislative decision-making and public communications regarding CCP management:* Research is focused on specific inorganic constituents that are commonly found at power plant facilities and are likely to drive human health and ecological risk.
- *Field validation of data and interpretation methods to support utility use of new leaching procedures:* This research addresses concerns regarding EPA's new LEAF (Leaching Environmental Analysis Framework) protocol in terms of the potential for inappropriate use of the large volume of data generated and the lack of field validation to help guide application of the field data. EPRI is planning to conduct controlled field experiments to understand how the results from the leaching protocol compare to actual field conditions.
- *Development of data and methods to support best practices for CCP handling, disposal and use:* This work uses a mix of laboratory information, field studies, and engineering and economic evaluations to assess and develop

environmentally sound and cost-effective CCP management practices.

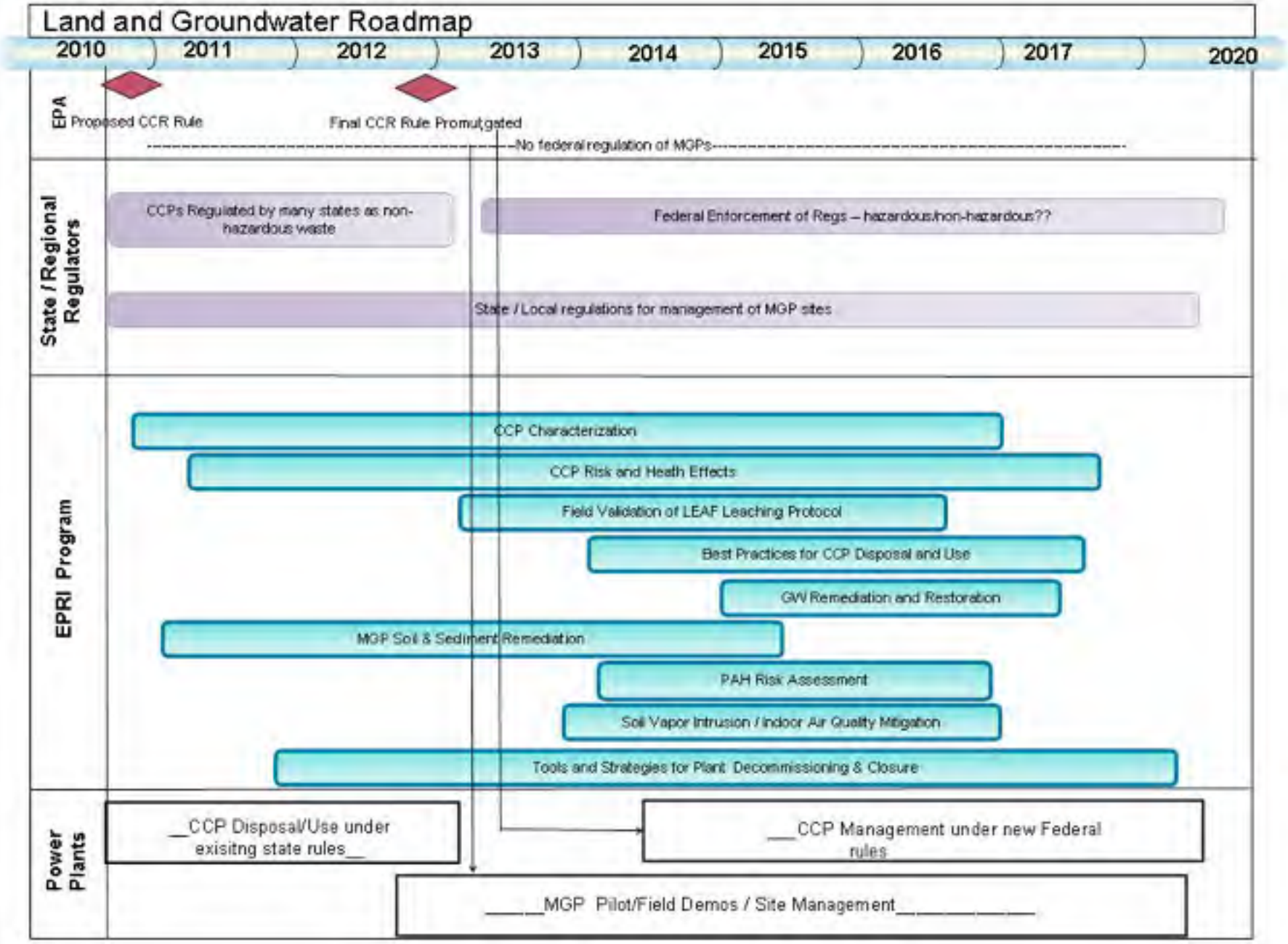
- *Development of groundwater assessment tools and remediation methods for CCP sites:* This research addresses groundwater monitoring, transport, and remediation issues specifically for the suite of inorganic constituents commonly associated with CCP management sites.
- *Development of new and improved methods for MGP sediment and soil remediation for effective and sustainable cleanups:* This work informs decision-making by defining methods to delineate, evaluate, and remediate contaminated sediments and soils. The work seeks to protect human health and restore aquatic and terrestrial environments. The research evaluates alternatives to sediment dredging, documents field performance of a range of remediation technologies, and establishes monitored natural attenuation/recovery using risk-based and environmentally sustainable cleanup strategies.
- *MGP risk assessment for naphthalene and other PAHs:* This work tracks recent developments in the scientific literature and assesses the data to establish scientifically sound risk-based cleanup levels. This research will inform the regulatory process by delivering accurate and credible scientific information regarding the environmental and health risks from MGP site contaminants.
- *Development of tools and mitigation strategies for soil vapor intrusion and indoor air quality near MGP sites:* This research improves decision-making and risk management by providing state-of-the art science and technology information on ambient and indoor air quality. This work will characterize air emissions and odors and investigates subsurface vapor intrusion to indoor air.
- *Development of science, tools, and economic data for plant closure and remediation:* This research provides information on plant closure best practices and pursues projects on plant closure cost estimating tools and development of a database on plant closures to include information on costs, issues of concern/lessons learned, materials recycling, environmental remediation, etc.

RISK

EPRI research on Land and Groundwater is a critical factor in providing, member companies, and other stakeholders such as regulators with high quality, objective, and credible scientific information. Insufficiently funded research will leave critical scientific and technical information gaps detrimental to well-informed decision-making; this will make it very difficult, if not impossible, to achieve cost-effective and environmentally protective management of land and groundwater contamination from CCP and MGP sites that benefit all stakeholders including the general public. The specific risks of not doing the needed research can result in the following:

- **Very high disposal costs (prohibitively high, in some cases) and drastically reduced (or even elimination of) beneficial use of CCPs:** EPRI research on characterization, health and environmental risk assessment, and environmentally sound management of CCPs enables issues to be proactively addressed before wide deployment of the technologies. Without this research, regulatory barriers and public perception may limit the use of sound disposal alternatives, and environmentally acceptable management of CCPs can become prohibitively expensive. Absence of this information can also lead to drastically reduced opportunities for beneficial use of CCPs. This not only leads to increased amounts of CCPs destined for disposal, but also eliminates the benefits of using CCPs in place of other raw materials (reductions in cost, carbon footprint, embodied energy, and extraction of natural resources).
- **Very high costs and increased liability for management of MGP sites:** EPRI's MGP research on rapid and effective MGP site characterization, development and evaluation of technologies for remediation of contaminated soil, sediments and groundwater, and on the realistic assessment of risk from coal tar/PAH toxicity has been invaluable to the MGP community; this has resulted in substantial cost savings to individual member companies and the industry as a whole. Absence of continuing research, especially in remediation of contaminated sediments, demonstrations of alternative remediation technologies and assessment of SVI/indoor air quality issues, will result in significant increase in costs for site management and remediation as well as in a greater potential for increased environmental and economic liability from these legacy sites.
- **Costly and environmentally sub-optimal closure of old plants and other facilities:** Ensuring that plant closure is performed cost effectively and with

due concern for addressing environmental impacts from former plant operations is a complex undertaking and will require a thorough knowledge of plant systems and current and past practices. Absence of this research will likely result in expensive and sub-optimal plant closures, that may limit reuse and redevelopment potential of these sites.


Land and Groundwater Roadmap
2010
2011
2012
2013
2014
2015
2016
2017
2020
EPA
Proposed CCR Rule
Final CCR Rule Promulgated
No federal regulation of MGPs
State / Regional Regulators
CCPs Regulated by many states as non-hazardous waste
Federal Enforcement of Regs – hazardous/non-hazardous??
State / Local regulations for management of MGP sites
EPRI Program
CCP Characterization
CCP Risk and Heath Effects
Field Validation of LEAF Leaching Protocol
Best Practices for CCP Disposal and Use
GW Remediation and Restoration
MGP Soil & Sediment Remediation
PAH Risk Assessment
Soil Vapor Intrusion / Indoor Air Quality Mitigation
Tools and Strategies for Plant Decommissioning & Closure
Power Plants
CCP Disposal/Use under exisitng state rules
CCP Management under new Federal rules
MGP Pilot/Field Demos / Site Management

DRAFT: ADVANCED MGP SOIL REMEDIATION TECHNOLOGIES

ISSUE STATEMENT

Remediation of MGP site soil contamination has historically consisted of excavation and treatment (e.g., thermal desorption) or disposal in landfills. Many MGP sites requiring remediation today are more challenging because of access issues such as coal tar near or under buildings, roadways, utility lines, or at great depth. In some cases, trucking may be restricted due to traffic, roadway, or odor issues. In-situ chemical oxidation has had limited success due factors such as high soil chemical oxidant demand, heterogeneous soil lithology, impermeable silt layers, or coal tar located in discrete stringers in thin sand/gravel lenses. In situ heated soil vapor extraction is costly and impractical if heat sensitive utilities such as gas, electric, or fiber optic lines are present. New technologies are often promoted by developers as highly successful and robust with limited to no information on full scale implementation results.

DRIVERS

MGP sites can consist of soil contamination where conventional dig-and-haul technologies cannot be applied. Research gaps include the need to evaluate emerging in situ treatment technologies such as surfactant enhanced chemical oxidation (S-ISCO), chemical/biological methods using persulfate & peroxide, improved chemical delivery methods using vacuum or pulse wave technologies, alternative product recovery methods, and in situ solidification and stabilization (ISS) methods. The goal is to find lower cost remediation technologies with higher levels of success than traditional methods. Performance data may also be used by regulatory agencies to define remediation endpoints based on cleanup "to the extent practicable".

RESULTS IMPLEMENTATION

Research plans have been developed by EPRI and its members to examine advanced MGP soil remediation technologies. For example, EPRI research on In-Situ Stabilization has been provided to the Interstate Technology and Regulatory Council (ITRC) to help state regulators and others understand the scope of the technology and its application at MGP sites.

- The results developed from this research will be made available to program members to help them meet their site management and remediation needs in a cost effective manner with knowledge about the applicability or limitations of the technology and to other stakeholders including federal and state regulatory agencies.

PLAN

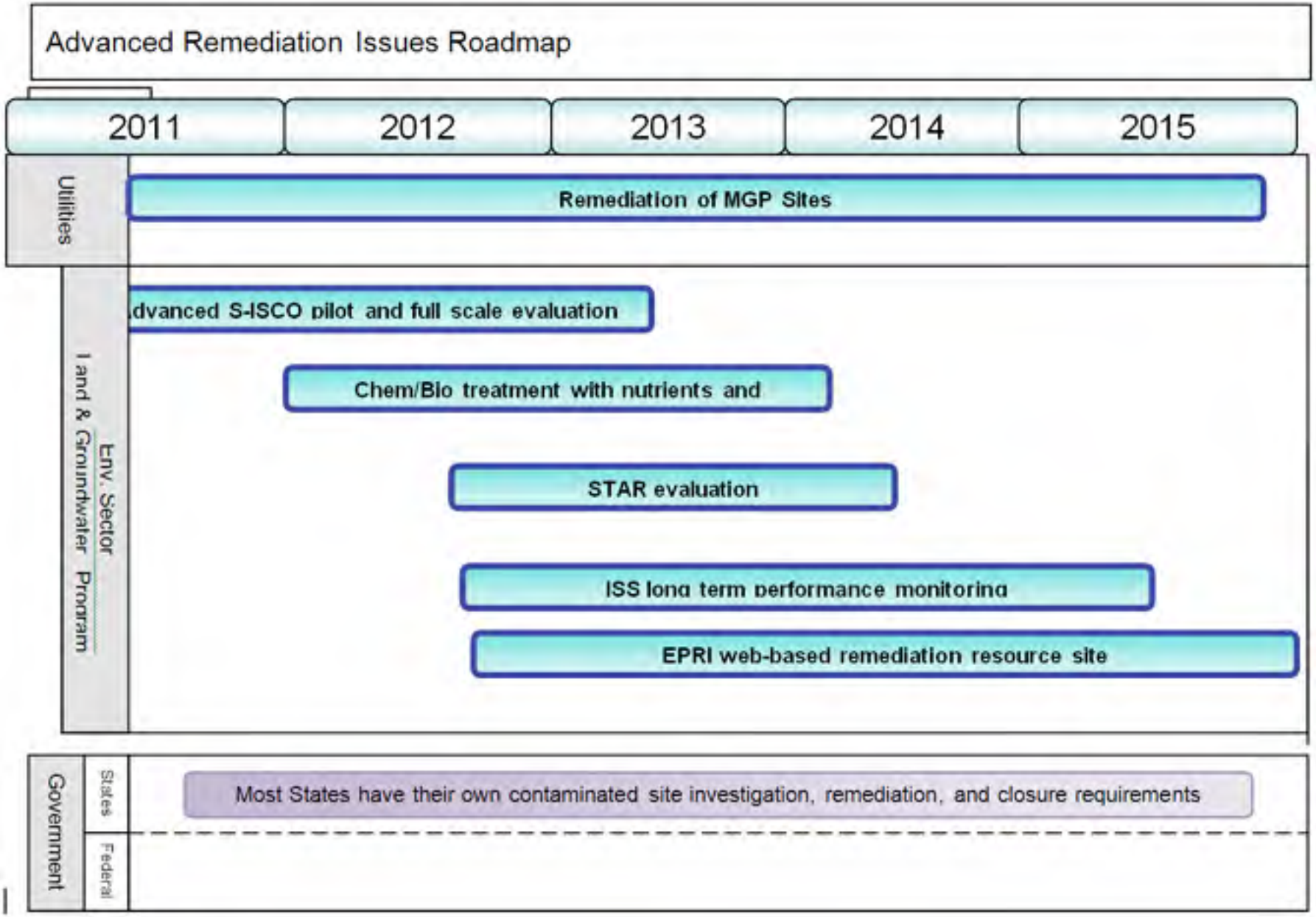
The research needs related to advanced MGP soil remediation include the following:

- Evaluation of Surfactant Enhanced In-Situ Chemical Oxidation (S-ISCO) through laboratory, pilot and possible full scale studies. This technology is designed to treat coal tar in seams by increasing solubility for more effective treatment.
- Evaluation of in-situ chemical/biological methods using partial chemical oxidation followed by oxygen enhancement and nutrient addition to promote co-metabolization. This technology could render MGP soils relatively "inert" from a toxicity and leachability perspective.
- Evaluation of new methods of chemical injection such as vacuum or pulse wave technologies. Better techniques of delivering reagents in the soil will help improve performance of any in-situ technique.
- Evaluation of new thermal processes such as the Self-Sustaining Treatment for Active Remediation (STAR) or in-situ smoldering. Some MGP sites may contain high concentration coal tar zones that would benefit from in-place treatment through smoldering.
- Evaluation of In-Situ Solidification and Stabilization of soils and long term performance based on physical and chemical leaching test methodologies. Additional long term data would help reduce uncertainty about the performance of this technology over time.
- Creation of an EPRI web-based remediation resource for up to date information on emerging and novel remediation technologies. Improved communication about new technologies will benefit utility Project Managers who need to have the latest information on new remediation methods.

RISK

EPRI research is critical in providing member companies and other stakeholders such as regulators with high quality, objective, and credible scientific information. Insufficiently funded research will leave critical scientific and technical information gaps which are detrimental to well-informed decision-making. The specific risks of not doing the needed research can result in the following:

- Regulatory delay, indecision, or rejection due to lack of knowledge of the technology
- Limited success due to improper understanding of chemical or physical limitations or constraints of the technology
- Higher costs/risk to pay for contractor gaining knowledge of the technology at MGP sites
- Higher costs to conduct exceedingly deep excavations to remove "free product" or "source material" when in-situ methods might be more appropriate
- Higher risk long-term liability risk


Advanced Remediation Issues Roadmap
2011
2012
2013
2014
2015
Utilities
Remediation of MGP Sites
Env. Sector
Land & Groundwater Program
dvanced S-ISCO pilot and full scale evaluation
Chem/Bio treatment with nutrients and
STAR evaluation
ISS long term performance monitoring
EPRI web-based remediation resource site
Government
States
Federal
Most States have their own contaminated site investigation, remediation, and closure requirements

DRAFT: COAL COMBUSTION PRODUCT CHARACTERIZATION, MANAGEMENT, AND USE

ISSUE STATEMENT

Electric utility operations generate by-products and solid wastes that require careful examination to mitigate contamination of land and groundwater. The Coal Combustion Product (CCP) Characterization, Management, and Use research focuses on accurate characterization of these by-products, management in landfalls and ponds, and beneficial use applications. Key information includes understanding the fate and transport of contaminants, particularly with respect to groundwater resources, and developing cost effective strategies to minimize adverse environmental impacts.

Annual costs for environmental management of coal combustion products (CCPs) are expected to increase sharply over the next 5 to 10 years as a result of new national regulations for disposal under the Resource Conservation and Recovery Act (RCRA). Depending on the regulatory option that US EPA selects, industry-wide cost are projected to be in the range of $2 billion to $6 billion per year. The U.S. electric power industry currently produces an estimated 135 million tons of CCPs annually; that total will increase with continued reliance on coal-fired power plants and the implementation of new air emissions controls. CCP management strategies will have to evolve due to changes in the characteristics of the CCPs, use of new fuel blends, and advanced generation technologies. This changing landscape highlights the need for new and updated information on the composition and leaching characteristics of CCPs, and environmentally protective management methods.

Continued beneficial use of CCPs is at risk under the new regulations, especially large-scale geotechnical and land use applications (e.g., structural fills, road base, soil stabilization, agricultural use), which account for more than 30% of CCP use. The key concerns with respect to beneficial use are primarily driven by questions about their potential for environmental impacts. Detailed assessment of the environmental risks and benefits will be required if future use is to be maintained.

Finally, monitoring of existing and legacy sites is under intense public scrutiny, and will likely result in the need for more groundwater assessments and corrective actions over the next ten years. This will necessitate the development of assessment tools and remediation methods tailored to the unique suite of inorganic constituents associated with CCP disposal sites.

DRIVERS

There are specific state and federal regulatory drivers affecting the environmental management of CCPs and groundwater protection measures.

Resource Conservation and Recovery Act (RCRA) – RCRA gives EPA the authority to control hazardous waste from "cradle-to-grave" (generation, transportation, treatment, storage, and disposal). RCRA also sets forth a framework for management of non-hazardous solid wastes. EPA recently proposed national disposal regulations for CCPs that included two regulatory options: management of CCPs as hazardous waste or management as non-hazardous waste, with significantly varying implications to the electric utility industry. A final rule is expected in 2013, with a 5-10 year implementation period.

Hazardous Air Pollutants (HAPs) Rules – EPA is developing maximum achievable control technology (MACT) standards for all HAPs—including trace constituents (e.g., mercury, selenium) and acid gases—from coal and oil-fired power plants. The HAPs rule will likely result in extensive retrofit of technologies such as activated carbon injection for mercury and trona/sodium carbonate sorbent injection for HCl. These control technologies may significantly modify the environmental and engineering characteristics of fly ash and FGD solids.

Clean Water Act – EPA is revisiting its effluent guidelines for the steam electric sector and one of the primary concerns is discharge of many trace metals (such as arsenic, mercury and selenium) from power plant streams. The guidelines will significantly impact the continued use of ponds for managing CCPs along with a variety of low-volume wastes.

Safe Drinking Water Act (SDWA) – The SDWA establishes maximum contaminant levels (MCLs) for trace inorganic elements that may cause adverse health effects. MCLs are often the basis for groundwater protection standards at CCP

disposal sites, as well as clean-up goals. Lowering of MCLs for some of the trace constituents - notably arsenic and, hexavalent chromium - are potential concerns from a monitoring and compliance perspective associated with the disposal, storage, or use of CCPs.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All EPA rules are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Even the non-hazardous provisions of the proposed national disposal rule requires that all compliance data be made available on a public website. Many interveners and third parties continue to push EPA and individual states to reduce environmental releases to very low levels. Scientific research results provide critical, objective input to such discussions.

RESULTS IMPLEMENTATION

A wide range of recent EPRI research results were submitted to US EPA in response to their requests for technical information in the proposed national regulations for CCPs. Member companies also drew on the EPRI research for their comments on the proposed rule, and to address disposal and use issues under current state regulations. Current research will provide information and tools to help companies with compliance activities as the new rules are finalized and implemented.

A comprehensive plan has been developed by EPRI and its members to address the near term and longer-term CCP research needs.

- The results developed from this research will be made available to program members to help them meet their site management and remediation needs in a cost effective and environmentally protective manner.
- The results will also be made available to a variety of other stakeholders including federal and state regulatory agencies to inform relevant rulemaking activities.

PLAN

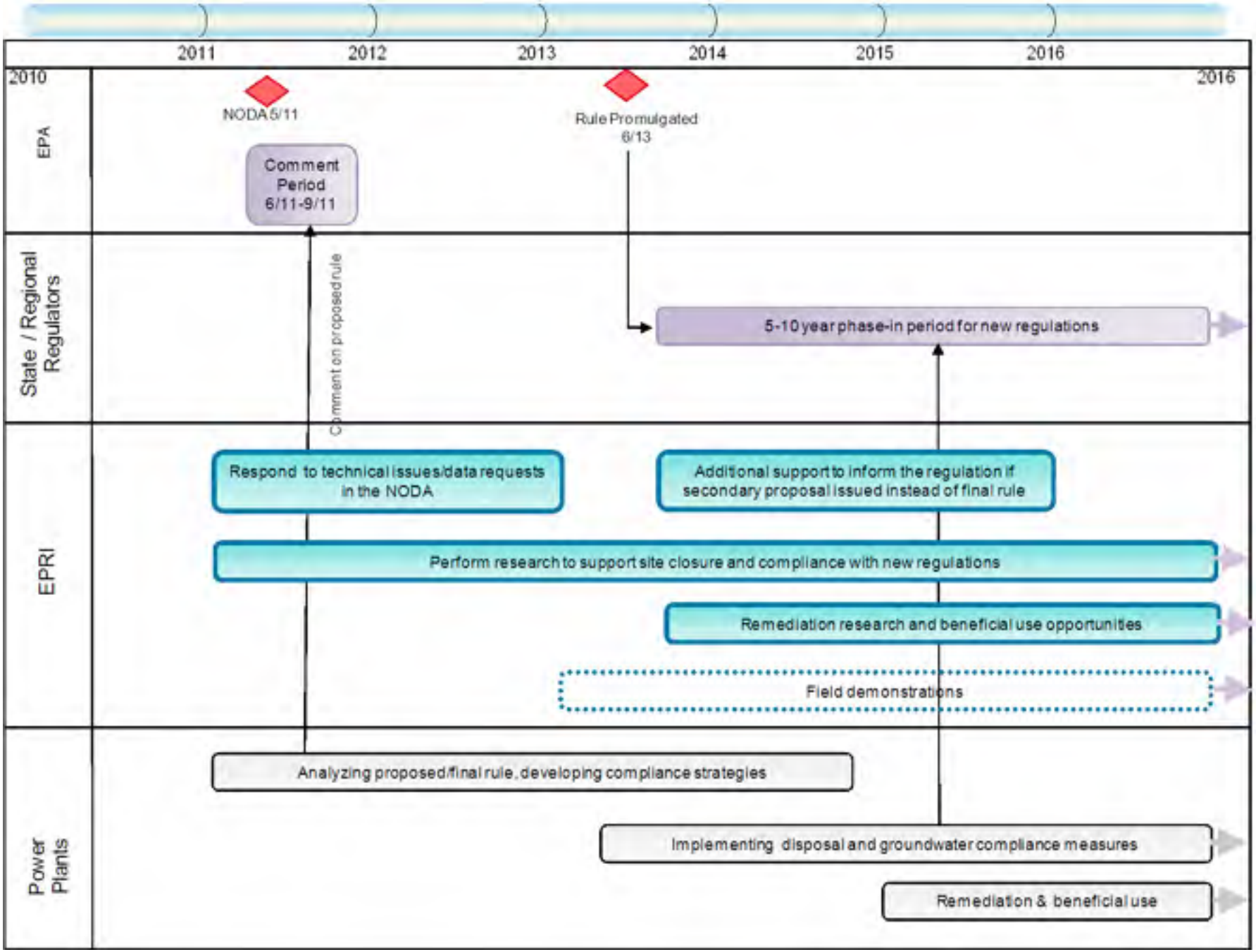
EPRI CCP research will continue to focus on the evolving needs as the regulatory picture clarifies. All stakeholders – the appropriate regulators (federal and/or state), environmental organizations, industry participants, and the public—must be satisfied that these by-products can be managed safely and pose no unacceptable public health or environmental impacts. Specific research to address current and anticipated issues include:

- *Thorough characterization of by-products and wastes from current and emerging coal-based generation technologies.* The near term focus is on changes to CCP characteristics due to mercury and HAPS controls, co-burning of biofuels, and by-products resulting from IGCC. Work will proceed in parallel with EPA on development and interpretation of laboratory leaching methods and geochemical models for estimating leachate release. This research will provide core data touching all facets of CCP disposal and beneficial use.
- *Compilation of risk and health effects information as input to regulatory and legislative decision-making and public communications regarding CCP management:* Research is focused on specific inorganic constituents that are commonly found at power plant facilities and are likely to drive human health and ecological risk.
- *Field validation of data and interpretation methods to support utility use of new leaching procedures:* This research addresses concerns regarding EPA's new LEAF (Leaching Environmental Analysis Framework) protocol in terms of the potential for inappropriate use of the large volume of data generated and the lack of field validation to help guide application of the field data. EPRI is planning to conduct controlled field experiments to understand how the results from the leaching protocol compare to actual field conditions, for evaluating both disposal and use applications.
- *Development of data and methods to support best practices for CCP handling, disposal and use:* This work uses a mix of laboratory information, field studies, and engineering and economic evaluations to assess and develop environmentally sound and cost-effective CCP management practices.
- *Development of groundwater assessment tools and remediation methods for CCP sites:* This research addresses groundwater monitoring, transport, and remediation issues specifically for the suite of inorganic constituents commonly associated with CCP management sites.

RISK

EPRI research on CCPs is a critical factor in providing member companies and other stakeholders, such as regulators, with high quality, objective, and credible scientific information. Insufficiently funded research will leave critical scientific and technical information gaps detrimental to well-informed decision-making; this will make it very difficult to achieve cost-effective and environmentally protective management of land and groundwater contamination from CCP sites that benefit all stakeholders including the general public. The specific risks of not doing the needed research can result in the following:

- **High disposal costs (prohibitively high, in some cases):** EPRI research on characterization and environmentally sound management of CCPs enables issues to be proactively addressed before wide deployment of the technologies. Without this research, regulatory barriers and public perception may limit the use of sound disposal alternatives, and increase disposal cost with little commensurate environmental benefit.
- **Reduced opportunities for beneficial use of CCPs:** Research on the environmental aspects of large scale geotechnical and land applications provides the information necessary to allay regulatory and public concerns with these uses. Absence of this information can lead to drastically reduced opportunities for beneficial use of CCPs. This not only leads to increased amounts of CCPs destined for disposal, but also eliminates the benefits of using CCPs in place of other raw materials (reductions in cost, carbon footprint, embodied energy, and extraction of natural resources).
- **Remediation and long-term liability:** EPRI research provides data on fate and transport of key constituents, human health and ecological risk, tools for assessing risks arising from groundwater releases, and targeted methods for remediation of impacted groundwater. Absence of this research may result in more costly corrective actions, potentially unnecessary remedial measures, and a greater potential for increased long-term environmental and economic liability from these sites.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2016
EPA
NODA 5/11
Rule Promulgated 6/13
Comment Period 6/11-9/11
State / Regional Regulators
Comment on proposed rule
5-10 year phase-in period for new regulations
EPRI
Respond to technical issues/data requests in the NODA
Additional support to inform the regulation if secondary proposal issued instead of final rule
Perform research to support site closure and compliance with new regulations
Remediation research and beneficial use opportunities
Field demonstrations
Power Plants
Analyzing proposed/final rule, developing compliance strategies
Implementing disposal and groundwater compliance measures
Remediation & beneficial use

DRAFT: MGP SEDIMENT REMEDIATION

ISSUE STATEMENT

Most former manufactured gas plants (MGP) ceased operation by the 1960's, but by-products and wastes, typically disposed in the plant's vicinity still remain with the potential to cause adverse environmental effects. More than 1,500 MGP sites in the United States and an equal or greater number in Europe exist. Many still require either investigation or remediation, at estimated cleanup costs typically in the millions of dollars per site. The by-products and wastes include tars and oils (containing polycyclic aromatic hydrocarbons or PAHs, as well as benzene) some of which may have been discharged or migrated into the sediments of adjacent waterbodies. Characterization, assessment, remedial selection, design and implementation are complicated by the complex chemistry and distribution and environmental fate and transport of the contaminants, and by site conditions. Site managers need credible data and information on alternative investigation and remediation techniques and appropriate site-specific cleanup criteria.

DRIVERS

MGP sediment remediation projects are typically conducted under the supervision of state regulators under state superfund or hazardous waste site remediation programs. A few projects are subject to federal programs; however, EPA policy and guidance significantly influences all projects. Additional drivers can include: potential claims arising from Natural Resource Damage Assessments, potential litigation, corporate environmental stewardship programs, public relations activities, and corporate programs to reduce balance sheet liabilities.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed by EPRI and its members to effectively transfer research results.

- The results developed from this research will be made available to program members to help them meet their site management and remediation needs in a cost effective and environmentally protective manner.
- The results will also be made available to a variety of other stakeholders including federal and state regulatory agencies to inform relevant rulemaking activities.

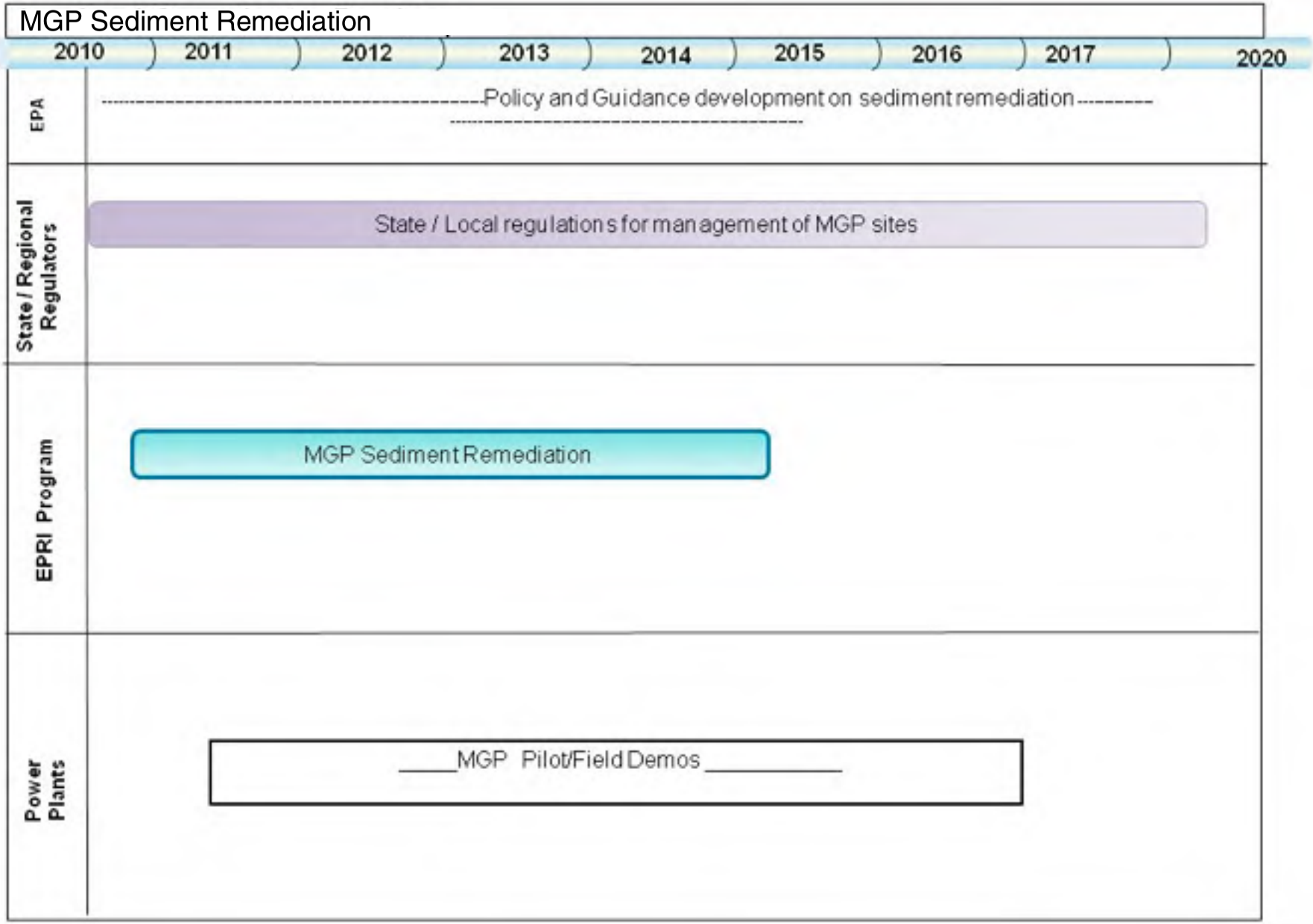
PLAN

The research needs related to remediation of sediments as a result of MGP plant operation will focus on alternatives to dredging and new methods that more appropriately address risk reduction. Regulators and the public must be convinced that these alternatives will be technologically sound, cost-effective and not result in unacceptable public health or environmental impacts. Specific actions that need to be undertaken to address current and anticipated issues include:

- *Sediment contaminant characterization and assessment methods should be improved.* Advances in characterization methods have improved through the application of new technologies such as laser-induced florescence (TarGost®) which has been demonstrated by EPRI research. Likewise, EPRI research in the area of background concentrations has been used to compare site conditions. Further work is needed, however to further clarify background concentrations of MGP contaminants, such as polycyclic aromatic hydrocarbons (PAHs) that are also present in many non-point discharges. Work also is needed to further confirm that screening tests can appropriately characterizes the bioavailability of PAHs and case histories and standard methods are needed.
- *Alternative remediation methods need to be identified and demonstrated.* Dredging is no longer the presumed remedy for sediment remediation, though it still is often favored by regulators and the public. There is a need for guidance that will encourage a more systematic evaluation of alternatives, that begins with less intrusive methods, such as monitored natural recovery, and works through in-situ methods, capping and finally dredging. Further research is needed to identify innovative alternatives, particularly in-situ methods, and to validate these methods with demonstration projects.

RISK

- EPRI research on MGP Sediment remediation is needed to ensure that the appropriate and necessary resources are applied to remediation projects. Concurrently, these projects must satisfy stakeholders that public health and the environment is protected. Absent this research, remediation projects are likely to extremely costly, and may not be as effective.


MGP Sediment Remediation
2010
2011
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2016
2017
2020
EPA
Policy and Guidance development on sediment remediation
State / Regional Regulators
State / Local regulations for management of MGP sites
EPRI Program
MGP Sediment Remediation
Power Plants
MGP Pilot/Field Demos

DRAFT: POWER PLANT MULTIMEDIA MEASUREMENT TECHNOLOGIES

ISSUE STATEMENT

Accurate measurement of potentially toxic chemicals in fuels, reagents, intermediate streams, air emissions, liquid and solid waste streams, and other discharges is essential for understanding risks and meeting discharge limits. Existing sampling and analytical methods do not have the required sensitivity or specificity to meet anticipated stringent regulatory requirements. Better methods, and validation of existing methods, are needed for metals in several discharge streams such as flue gas desulfurization (FGD) wastewaters and stack gases, and fine particulates ($PM_{2.5}$) in flue gas from wet FGD systems. Stringent compliance limits will increase the need for procedures to establish appropriate detection and quantitation limits.

DRIVERS

There are specific federal and state regulatory drivers affecting the issue of power plant multimedia toxics measurement and associated challenges.

Hazardous Air Pollutants (HAPs) Rules – EPA recently released a proposal to set emission limits for HAPs from coal and oil-fired plants. EPA is proposing to set numerical Maximum Achievable Control Technology (MACT) limits for all existing and new units for mercury, total particulate matter (as a surrogate for non-mercury toxic metals) and acid gases (e.g., hydrochloric acid). For all plants, EPA is proposing to limit emission of organic compounds, including dioxins, by work practice standards. Following implementation of the rule, EPA must conduct a residual risk analysis to determine if the HAPs controls have been sufficient to fully address health risks. If not, more controls could be forthcoming.

Resource Conservation and Recovery Act (RCRA) – RCRA gives EPA the authority to control hazardous waste from "cradle-to-grave" (generation, transportation, treatment, storage, and disposal). RCRA also sets forth a framework for management of non-hazardous solid wastes. EPA recently proposed national disposal regulations for coal combustion products (CCPs) that included two regulatory options: management of CCPs as hazardous waste or management as non-hazardous waste, with significantly varying implications to the electric utility industry. A final rule is expected in 2013, with a 5-10 year implementation period.

Clean Water Act – EPA is revisiting its effluent guidelines for the steam electric sector and one of the primary concerns is discharge of many trace metals (such as arsenic, mercury and selenium) from power plant streams. The guidelines will significantly impact the continued use of ponds for managing CCPs along with a variety of low-volume wastes.

Safe Drinking Water Act (SDWA) – The SDWA establishes maximum contaminant levels (MCLs) for trace inorganic elements that may cause adverse health effects. MCLs are often the basis for groundwater protection standards at CCP disposal sites, as well as soil and groundwater clean-up goals. Lowering of MCLs for some of the trace constituents - notably arsenic and, hexavalent chromium - are concerns are potential concerns from a monitoring and compliance perspective associated with the disposal, storage, or use of CCPs.

Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All regulations are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Much of EPRI's research on the capabilities and limitations of sampling and analytical measurement methods for characterizing emissions and discharges from power plants will continue to be made available to the public via a public website. Many interveners and third parties continue to push EPA to reduce environmental releases to very low levels; these in, turn, lead to new challenges in developing measurement technologies for detecting and quantifying lower and lower levels of toxic substances in power plant emissions and discharges.

RESULTS IMPLEMENTATION

Many of our utility members have used EPRI method improvements and guidance to make accurate measurements of their power plant streams to meet compliance needs and make operational process improvements.

A comprehensive plan has been developed by EPRI and its members to address the near term and longer-term research needs with respect to measurement of potentially toxic emissions and discharges from power plant streams.

- The results developed from this research will be made available to program members to help them meet their toxics measurement needs and challenges.
- The results will also be made available to a variety of other stakeholders including federal and state regulatory agencies to inform relevant rulemaking activities and meet other regulatory and compliance needs.

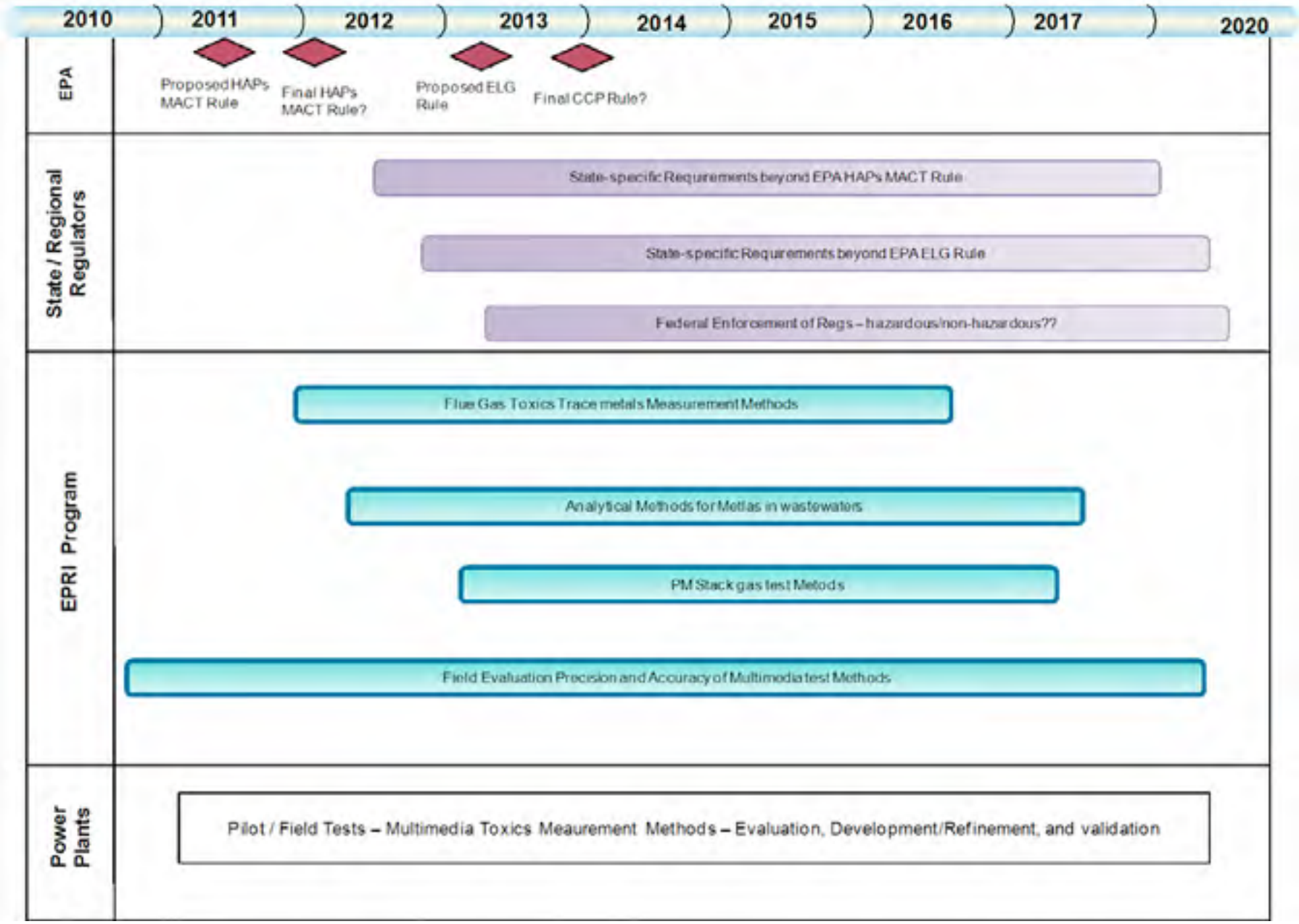
PLAN

This research focuses on the evolving needs for accurate multimedia characterization data regarding emissions and discharges of potentially toxic substance from power plants. All stakeholders – the appropriate regulators (federal and/or state), environmental organizations, industry participants, and the public—must be satisfied that characterization data on power plant emissions and discharges is accurate and can facilitate cost-effective and environmentally protective management of toxic substance releases from power plants, taking into account the distribution/partitioning of substances between gaseous, liquid, and solid streams in power plants. New and innovative methods will be developed for accurate measurement and monitoring of a variety of HAPs in power plant streams and discharges. Specific needs to address current and anticipated issues include:

- *Analytical Methods for Metals in Wastewaters.* This research will develop procedures for analyzing selected trace metals using advanced measurement methods such as Inductively Coupled Plasma - Mass Spectrometry (ICP-MS) equipped with collision reaction cell modifications.
- *Analytical Methods for Trace Metals in Stack Gas.* This research will address accuracy issues of trace metals (e.g., arsenic and selenium) measurement by EPA Method 29 in stack gas.
- *Evaluation and Improvement of Particulate Matter (PM) Test Methods in Stack Gas.* Accurate measurement of particulate matter (PM), including filterable and condensable particulate matter (CPM) is becoming critical in the context of EPA's proposed HAPs MACT rule. This research will target improvement of current methods and development of better methods for CPM measurement in utility stack gas
- *Analytical Methods Index.* The index will be updated periodically to reflect the latest information on analytical methods.
- *Field Estimation of Precision and Accuracy of Stack Gas Measurement Method.* Multiple parallel train stack tests for various analytical methods will be performed at full scale power plants to determine the precision of the measurement methods.
- *Improved Detection/Quantitation Estimation Procedures.* Scientifically sound statistical estimation procedures will be developed to address this challenging issue.

RISK

EPRI's research on evaluation, development, and validation of analytical methods for measurement of trace substances in power plant streams over the past two decades,has played a critical role in assisting member companies and in helping to inform related regulatory discussions regarding the capabilities and limitations of measurement methods. Insufficiently funded research will leave critical scientific and technical information gaps and thus could lead to a dearth of suitable analytical methods for measurement of trace substances in power plant streams and to absence of scientifically sound procedures for estimating the detection and quantitation capabilities of methods, especially when dealing with concentrations at extremely low levels.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EPA
Proposed HAPs MACT Rule
Final HAPs MACT Rule?
Proposed ELG Rule
Final CCP Rule?
State / Regional Regulators
State-specific Requirements beyond EPA HAPs MACT Rule
State-specific Requirements beyond EPA ELG Rule
Federal Enforcement of Regs – hazardous/non-hazardous??
EPRI Program
Flue Gas Toxics Trace metals Measurement Methods
Analytical Methods for Metlas in wastewaters
PM Stack gas test Metods
Field Evaluation Precision and Accuracy of Multimedia test Methods
Power Plants
Pilot / Field Tests – Multimedia Toxics Meaurement Methods – Evaluation, Development/Refinement, and validation

ISSUE STATEMENT

Future air emission, water discharge, and solid waste disposal regulations combined with the introduction of new technologies (generation and emissions control) will result in constantly changing characteristics of discharge streams. Thus there is a need to address such releases in a holistic, multimedia (air, land, water) manner so that a pollutant removed by a control technology from one medium (such as air) does not adversely affect the regulatory situation in other media (such as water or solid waste). The challenge is to understand the discrete multimedia environmental impacts of the discharges and the interplay between the receiving media from changes in fuel composition, implementation of new or enhanced generation and control technologies, or changes in plant operating practices. The ultimate need is to reduce the overall environmental footprint of power plants through further optimization of management practices.

DRIVERS

There are specific federal and state regulatory drivers affecting the issue of power plant multimedia toxics management.

Hazardous Air Pollutants (HAPs) Rules – EPA recently released a proposal to set emission limits for HAPs from coal and oil-fired plants. EPA is proposing to set numerical Maximum Achievable Control Technology (MACT) limits for all existing and new units for mercury, total particulate matter (as a surrogate for non-mercury toxic metals) and acid gases (e.g.,hydrochloric acid). For all plants, EPA is proposing to limit emission of organic compounds, including dioxins, by work practice standards. Following implementation of the rule, EPA must conduct a residual risk analysis to determine if the HAPs controls have been sufficient to fully address health risks. If not, more controls could be forthcoming.

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Non-Regulatory Drivers – Public Relations/ Environmental Stewardship; Potential Litigation – All regulations are subject to litigation by third parties. While many times these challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Much of EPRI's research on characterizing emissions and discharges from power plants will continue to be made available to the public via a public website. Many interveners and third parties continue to push EPA to reduce environmental releases to very low levels. Scientific research results provide critical, objective input to such discussions.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed by EPRI and its members to address the near term and longer-term research needs with respect to characterization of potentially toxic emissions and discharges from power plants.

- The results developed from this research will be made available to program members to help them meet their multimedia toxics characterization and management needs in a cost effective and environmentally protective manner.

- The results will also be made available to a variety of other stakeholders including federal and state regulatory agencies to inform relevant rulemaking activities.

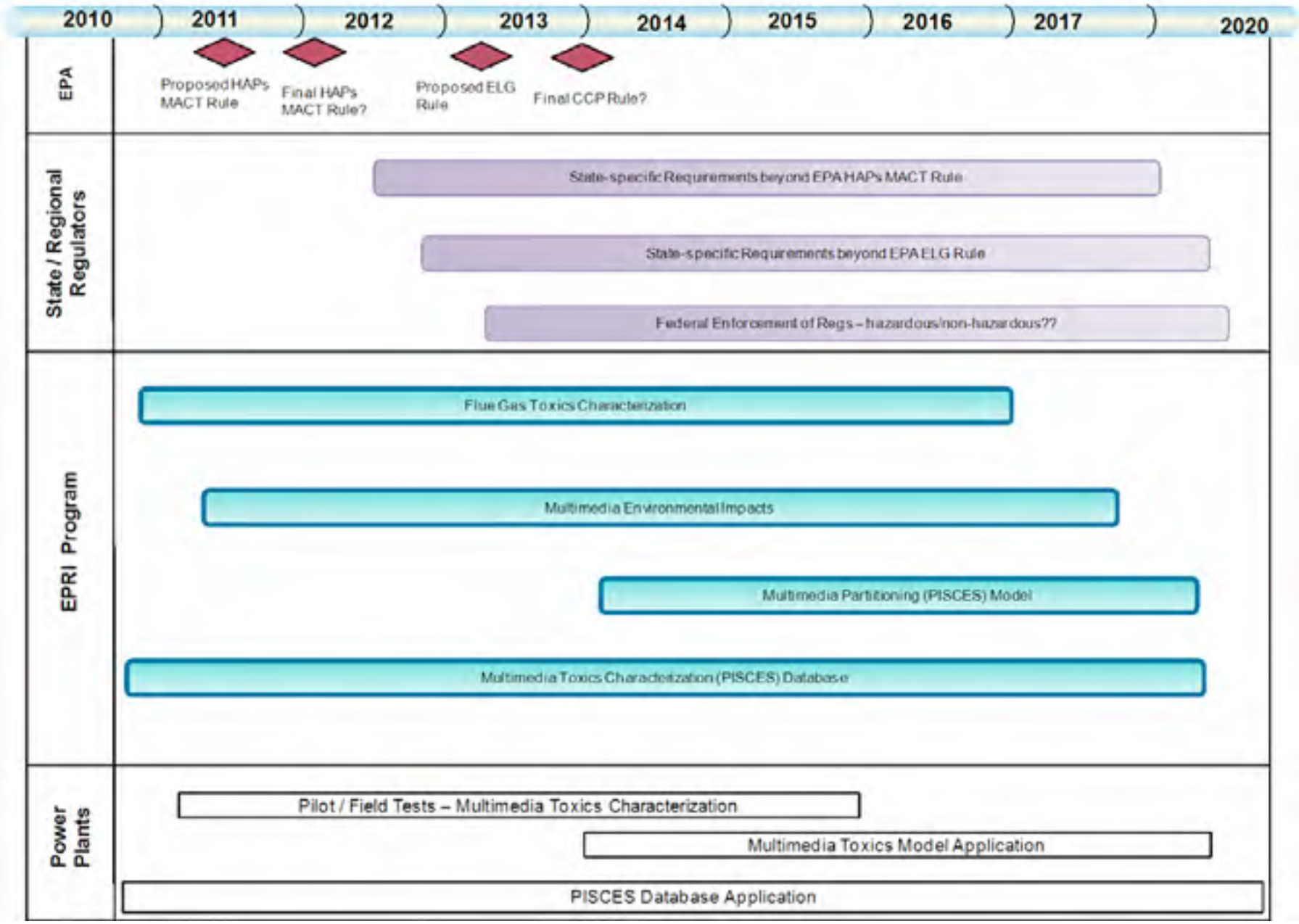
PLAN

This research focuses on the evolving needs for accurate multimedia characterization data regarding emissions and discharges of potentially toxic substance from power plants. All stakeholders – the appropriate regulators (federal and/or state), environmental organizations, industry participants, and the public—must be satisfied that characterization data on power plant emissions and discharges is accurate and can facilitate cost-effective and environmentally protective management of toxic substance releases from power plants, taking into account the distribution/partitioning of substances between gaseous, liquid, and solid streams in power plants. Specific actions that need to be undertaken to address current and anticipated issues include:

- *Flue Gas Toxics Characterization*. Power plants will be evaluating compliance approaches for meeting the air emission limits in the final MACT rule. Depending on the exact details of the MACT final rule, technical analyses and data synthesis will continue to address data gaps.
- *Multimedia Environmental Impacts*. Research will continue to improve understanding of the multimedia partitioning and fate of selenium and other trace elements in power plant streams; research will also continue on understanding the impacts of fuel changes (e.g., fuel switching, use of alternative fuels, such as biomass) and new/emerging control technologies (e.g., activated carbon and other sorbent injection).
- *Multimedia Partitioning (PISCES) Model*. There appears to be an increasing need for a multimedia model that will help predict the partitioning of chemical substances between power plant streams as a function of plant operating conditions. Such a model will not only help control and manage release of the chemicals in the various streams but can also be of great help in implementing process/operating changes that can 'steer' specific chemicals to the desired stream (medium) where they are most cost-effectively captured and managed.
- *PISCES Database*. This multimedia database will continue to be the repository of valuable data on power plant streams including fuel, intermediate process streams, and plant air emissions, water discharges, and solid waste releases. The web-based database will continue to serve the needs of member company personnel, in helping to meet regulatory needs and in enhancing plant operations.

RISK

EPRI's visionary research on power plant multimedia toxics characterization, over the past two decades, has played a critical role in anticipating emerging issues, in helping to inform the related regulatory discussions and in developing practical and effective solutions and approaches to meet the changing regulatory needs. This program's research has helped to reduce future risks by anticipating future emissions control configurations and addressing toxics issues before they become an issue. Thus, if we don't have funding, we will be less anticipatory in terms of effectively characterizing emissions and their cross media impacts.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EPA
Proposed HAPs MACT Rule
Final HAPs MACT Rule?
Proposed ELG Rule
Final CCP Rule?
State / Regional Regulators
State-specific Requirements beyond EPA HAPs MACT Rule
State-specific Requirements beyond EPA ELG Rule
Federal Enforcement of Regs – hazardous/non-hazardous??
EPRI Program
Flue Gas Toxics Characterization
Multimedia Environmental Impacts
Multimedia Partitioning (PISCES) Model
Multimedia Toxics Characterization (PISCES) Database
Power Plants
Pilot / Field Tests – Multimedia Toxics Characterization
Multimedia Toxics Model Application
PISCES Database Application

DRAFT: POWER PLANT DECOMMISSIONING AND SITE REDEVELOPMENT ISSUES

ISSUE STATEMENT

Over the next decade, many older power plants will reach the end of their service lives and will require closure and demolition. As these sites are considered for repowering or other uses, systematic assessment is needed for plant decommissioning and for developing strategies for reuse or redevelopment. Ensuring that plant closure is performed in a cost and environmentally effective manner is a complex undertaking, requiring a thorough knowledge of plant systems, current and past practices and options for the land once closure is complete.

DRIVERS

Power plant closure projects are typically driven by economics and the life cycle status of the plant. For example, the costs associated with increasing levels of environmental control due to compliance with new environmental regulations often preclude further investment—this is especially true for smaller plants that run intermittently. Some elements of closure projects may be subject to federal and state regulation (e.g. asbestos removal and disposal), and state public utility commissions often must approve the projects.

Plant decommissioning is a complex and costly undertaking and requires involvement of a variety of resources to address the demolition engineering, environmental, safety, human resources, public affairs and contracting issues that arise during project planning and implementation.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed by EPRI and its members to address the near term and longer-term plant decommissioning and site redevelopment research needs.

- The results developed from this research will be made available to program members to help them meet their site management and remediation needs in a cost effective and environmentally protective manner.
- The results will also be made available to a variety of other stakeholders including federal and state regulatory agencies to inform relevant rulemaking activities.

Members can use the results of the information provided to better plan and manage their plant decommissioning projects. For example, key tasks and staffing requirements can be more clearly identified in the decommissioning process, including considerations for permitting, public affairs, safety, contracting arrangements, environmental assessments, etc.

PLAN

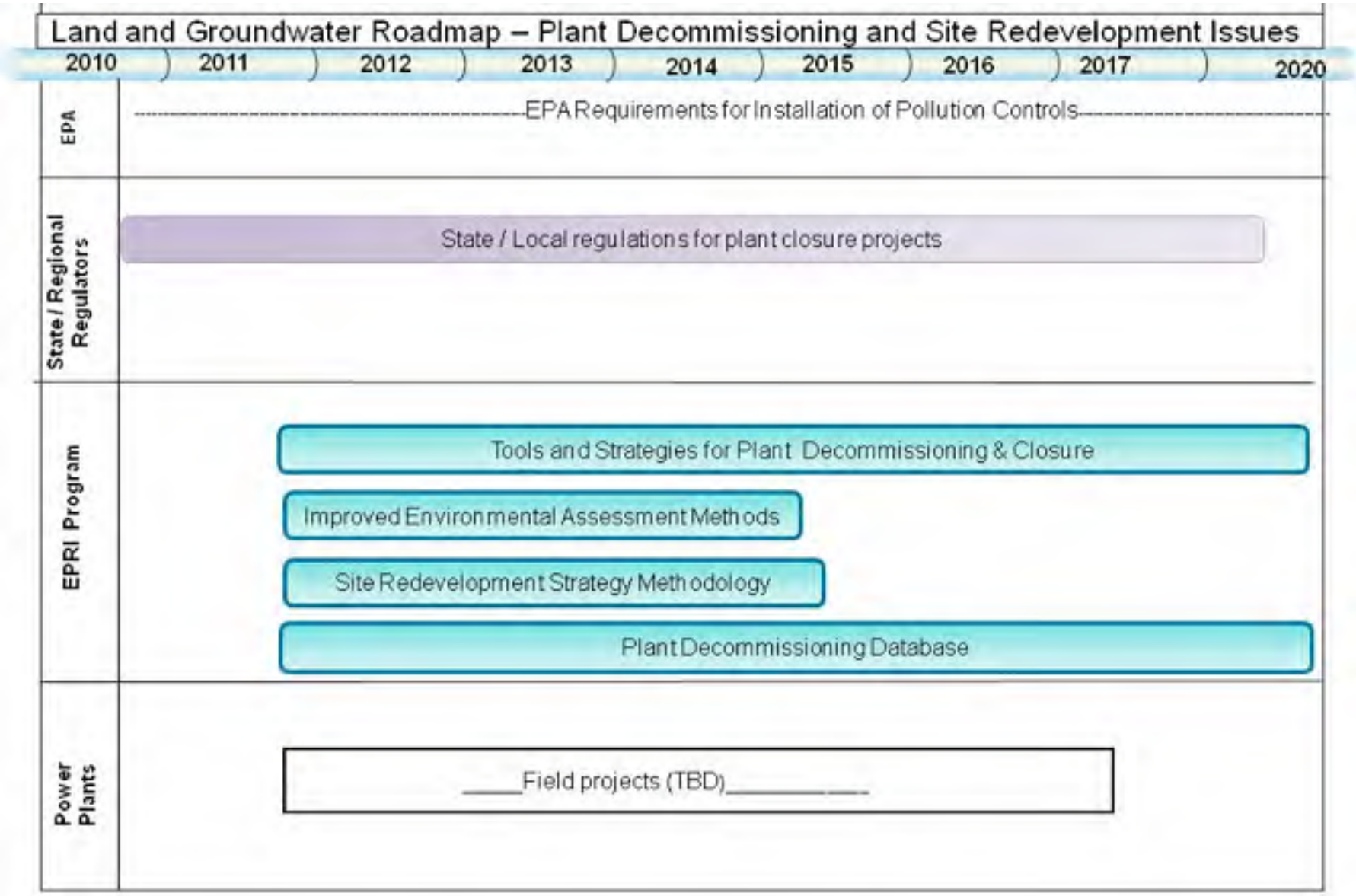
Specific research needs to be undertaken to help utilities with anticipated plant closures include:

- *Identification of best practices.* This involves accessing and transferring the lessons learned from past projects. A number of plants have undergone decommissioning in recent years and the experience gained from these projects is invaluable to those just beginning their projects.
- *Identification of project elements.* Planning and implementation of decommission projects must be thorough and systematic to insure that all elements are done efficiently, cost effectively, safely and with due concern for the environment. An initial product – Plant Closure Guidelines (1022263) provided an annotated checklist of project components. Future efforts will evaluate critical components to determine if more detailed guidance is needed.
- *Identify and enhance methods for environmental assessments.* Most projects require a comprehensive evaluation of site conditions to identify and correct environmental issues associated with plant operation. Many plants used asbestos insulation and mercury filled gauges and meters. Transformers and other electric equipment may also have used PCB insulating fluids. Land impacts may have occurred through disposal practices. Efficient methods are needed to survey and identify these issues, to determine if remediation is necessary and if so, to develop and implement cost effective remediation measures.
- *Assess redevelopment opportunities.* While the future use of a plant site can significantly affect the scope of remediation efforts, often little is known about the planned post closure use of the site. Tools to assess redevelopment options would assist in decision making.

- *Plant Decommissioning Database*. An online database of information on existing plant closure projects will be developed and continually updated.

RISK

Ensuring that plant closure is performed cost effectively and with due concern for addressing environmental impacts from former plant operations is a complex undertaking and will require a thorough knowledge of plant systems and current and past practices. Absence of this research will likely result in expensive and sub-optimal plant closures, that may limit reuse and redevelopment potential of these sites.


Land and Groundwater Roadmap – Plant Decommissioning and Site Redevelopment Issues
2010
2011
2012
2013
2014
2015
2016
2017
2020
EPA
EPA Requirements for Installation of Pollution Controls
State / Regional Regulators
State / Local regulations for plant closure projects
EPRI Program
Tools and Strategies for Plant Decommissioning & Closure
Improved Environmental Assessment Methods
Site Redevelopment Strategy Methodology
Plant Decommissioning Database
Power Plants
Field projects (TBD)

DRAFT: CLOSURE OF COAL COMBUSTION PRODUCT STORAGE AND DISPOSAL PONDS

ISSUE STATEMENT

In June 2010, EPA proposed national regulations for disposal of coal combustion products (CCPs). A final rule is expected by 2013. One alternative included in the proposal was regulation as a special waste under Subtitle C (hazardous waste provisions) of the Resource Conservation and Recovery Act (RCRA). Regulation under Subtitle C would essentially result in complete conversion from wet handling of CCPs to dry handling and in closure of all active CCP ponds. A second alternative in the proposal was regulation as a solid waste under Subtitle D (nonhazardous waste) provisions in RCRA. While Subtitle D regulation would offer more opportunity to continue some wet handling practices, such as for bottom ash, it would still lead to a significant number of wet to dry conversions and closure of many CCP ponds. The EPA proposal includes an aggressive timeline for these closures, which will require special engineering practices in many instances. In addition, the rules may contain provisions for reclosing old ponds that do not currently meet the RCRA closure requirements.

An associated issue is the loss of wastewater treatment capacity when an active pond is closed. While replacement of wastewater treatment capacity is not a focus of this research, the costs and logistics should be considered in planning and implementing pond closures. This research will interface with ongoing EPRI work on wastewater treatment to ensure a continuum in research results that addresses the full picture. In addition, as ponds are closed, long-term monitoring will be established and, in some cases, additional remediation may be required.

Under any regulatory scenario, power plants will likely be closing a large number of ash and flue gas desulfurization (FGD) storage and disposal ponds over the next 10 years. Research in this area will help power companies meet the challenges presented by the evolving regulations with environmentally sound practices while controlling costs. These challenges include premature closures, accelerated closures, long-term stability, liner construction materials, monitoring strategies, final land use, and groundwater remediation.

DRIVERS

Resource Conservation and Recovery Act (RCRA) – EPA is expected to finalize disposal regulations under RCRA by 2013. Under the hazardous waste option, it is likely that all CCP ponds will be phased out. Under the nonhazardous option, there is more flexibility to maintain ponds, but it is expected that most utilities will still begin to phase out fly ash ponds. Some utilities are already beginning to close ponds in advance of the regulation; once promulgated, the rule will allow a 5-10 year implementation period.

Effluent Limitation Guidelines (ELG) Rules – EPA last promulgated ELGs for steam electric power plants in 1982. At that time, they indicated a preference for eventual conversion from wet handling to dry handling of CCPs when new generating units were constructed. EPA is currently revisiting the steam electric ELGs and is expected to propose a revised rule in 2012. While the requirements of the revised rule are not yet known, it is likely that they will at a minimum contain provisions for treatment of several metals contained in CCP wastewater. Combined with the RCRA rule, the ELG rule will drive companies to consider conversions to dry handling and elimination of CCP ponds.

Safe Drinking Water Act (SDWA) – The SDWA establishes maximum contaminant levels (MCLs) for trace inorganic elements that may cause adverse health effects. MCLs are often the basis for groundwater protection standards at CCP disposal sites, as well as clean-up goals. Lowering of MCLs for some of the trace constituents - notably arsenic and hexavalent chromium – is a potential concern from a monitoring and compliance perspective associated with the disposal, storage, or use of CCPs.

Dam Safety – Since the dike failure at the TVA Kingston plant in 2008, the stability of CCP ponds has been under careful scrutiny. EPA began a nationwide program to inspect and rate the safety of these facilities. While most facilities have been found to be well constructed and safe, with exceptions primarily due to paperwork issues rather than construction, the issue of dam safety has been elevated in the eyes of regulators and the public since Kingston, resulting in additional impetus to phase out CCP ponds.

RESULTS IMPLEMENTATION

It is expected that many CCP ponds will be closed over the next 5 to 10 years due to the new national disposal regulations as well as decisions by utilities to convert from wet to dry handling of fly ash. The research results from this project can be used to help companies implement pond closures that optimize use of the disposal area, apply alternative closure methods where applicable, avoid instability issues, and mitigate any groundwater impacts. A comprehensive research plan is being developed by EPRI and its members to address the technical needs with respect to pond closure:

- The results developed from this research will be made available to program members to help them meet their site closure and remediation needs in a cost effective and environmentally protective manner.
- Results may also be made available to a variety of other stakeholders including federal and state regulatory agencies to inform relevant rulemaking activities.

PLAN

Over the next 10 years, research will focus on the evolving needs for pond closures and remediation as the regulatory picture clarifies. Specific research to address current and anticipated issues include:

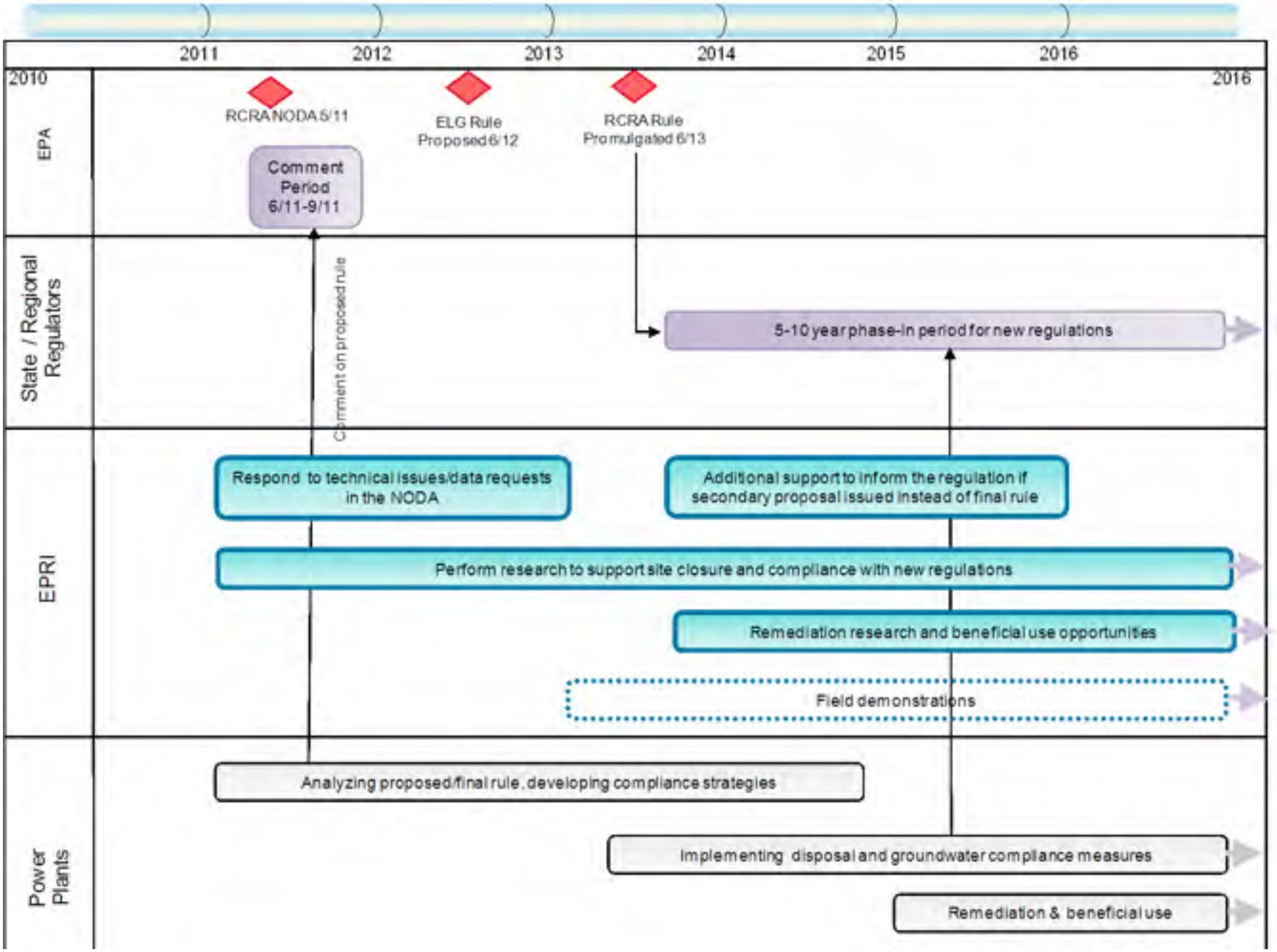
- *Ash liquefaction:* Liquefaction was cited as one of the underlying causes contributing to the Kingston failure. Research will lead to improved understanding of the causes of ash liquefaction, development of monitoring tools to predict the potential for liquefaction in advance of closure, and demonstration of methods to minimize the likelihood of post-closure failure.
- *Alternative covers:* The standard cover prescribed in many regulations may not be the best choice for a given geographic location, or final land use. Research will investigate alternative covers that meet the prescribed performance standards and provide the flexibility for use of available materials.
- *Construction on closed ponds:* Land space at power plants is often constrained. This research will develop guidelines for the construction of new landfills or other facilities over closed ponds.
- *Groundwater monitoring, risk assessment, and remediation:* Closure plans for ponds will likely include a requirement for long-term groundwater monitoring. This research will provide tools and methods for monitoring and assessing risks from recently closed sites, as well as legacy sites. Focused research efforts will develop and demonstrate remediation methods for those cases where monitoring suggests a potentially significant risk to groundwater users or other receptors.
- *Wastewater Treatment:* Wastewater treatment research is performed under other programs at EPRI. However, consideration of replacement wastewater treatment for closed ponds is integral to the planning of conversions from wet to dry handling. We will work with the appropriate EPRI programs to integrate wastewater treatment research results with the pond closure research.

RISK

EPRI research on CCPs is a critical factor in providing member companies and other stakeholders, such as regulators, with high quality, objective, and credible scientific information. Insufficiently funded research will leave critical scientific and technical information gaps detrimental to well-informed decision-making; this will make it very difficult to achieve cost-effective and environmentally protective management of land and groundwater contamination from CCP sites that benefit all stakeholders including the general public. The specific risks of not doing the needed research can result in the following:

- **Post-closure failures:** Inadequate information and tools to assess and minimize the likelihood of significant groundwater releases or engineering failures after closure is completed can be costly and represent a significant liability. Resolution of such issues can cost several times more than the original closure.
- **Reduced opportunities for alternative designs and land use:** The proposed EPA disposal regulations are relatively prescriptive. Without research and demonstration of environmental performance, it can be difficult to obtain approval for alternative designs. This limits the ability of a company to use locally available materials, take advantage of site specific hydrogeology and climate, and employ innovative final use plans.

- **Remediation and long-term liability:** Monitoring at some ponds will likely lead to the need for additional remediation. EPRI research provides data on fate and transport of key constituents, human health and ecological risk, tools for assessing risks arising from groundwater releases, and targeted methods for remediation of impacted groundwater. Absence of this research may result in more costly corrective actions, potentially unnecessary remedial measures, and a greater potential for increased long-term environmental and economic liability from these sites.


2011
2012
2013
2014
2015
2016
2010
2016
EPA
RCRA NODA 5/11
ELG Rule Proposed 6/12
RCRA Rule Promulgated 6/13
Comment Period 6/11-9/11
State / Regional Regulators
Comment on proposed rule
5-10 year phase-in period for new regulations
EPRI
Respond to technical issues/data requests in the NODA
Additional support to inform the regulation if secondary proposal issued instead of final rule
Perform research to support site closure and compliance with new regulations
Remediation research and beneficial use opportunities
Field demonstrations
Power Plants
Analyzing proposed/final rule, developing compliance strategies
Implementing disposal and groundwater compliance measures
Remediation & beneficial use

DRAFT: SOIL VAPOR INTRUSION AND AIR MONITORING AT MGP SITES

ISSUE STATEMENT

Numerous states have published rules or guidance on conducting soil vapor intrusion (SVI) studies at sites with known soil or groundwater contamination in order to identify and prevent indoor air contamination from subsurface soil gas. EPA plans to update their 2002 Guidance in the fall of 2012. The Interstate Regulatory and Technology Council (ITRC) issued SVI guidance and is considering updating that guidance during 2012. SVI studies are often required when site owners or responsible parties conduct site environmental investigations or seek to obtain site closure following remediation. SVI issues can also become important during property transactions such as lease, sale, development, or financing of the property.

Regulatory agencies often require air monitoring and emission control plans during Manufactured Gas Plant (MGP) site remediation activities. Odor complaints or concerns regarding health impacts can result in project delays and costly changes to remediation plans.

DRIVERS

Release of volatile organic compounds (VOCs) from soils or groundwater at MGP sites has the potential to cause soil vapor intrusion (SVI) into buildings. Excavation of MGP impacted soils can cause odor or VOC emissions that are of concern to nearby residents or regulatory agencies. Current management options include costly SVI investigations, installation of subsurface mitigation systems, and perimeter air monitoring during remediation. R&D is needed on methods to interpret the data obtained from SVI investigations, characterization of odor emissions (and the impact on ambient and indoor air quality), subsurface vapor intrusion (to indoor air) mechanisms, and on developing and monitoring the performance of SVI mitigation systems.

RESULTS IMPLEMENTATION

Research plans have been developed by EPRI and its members to address issues involving soil vapor intrusion investigations and volatile hydrocarbon emissions during MGP site remediation. Utilities have used guidance provided by EPRI to help understand the methods available. Several utilities have participated with EPRI on field research involving air monitoring and prediction of downwind hydrocarbon concentrations and odor.

- The results developed from this research have been made available to program members to help them meet their site management and remediation needs in a cost effective and environmentally protective manner.
- The results are also available to a variety of other stakeholders including federal and state regulatory agencies to inform relevant rulemaking activities.

PLAN

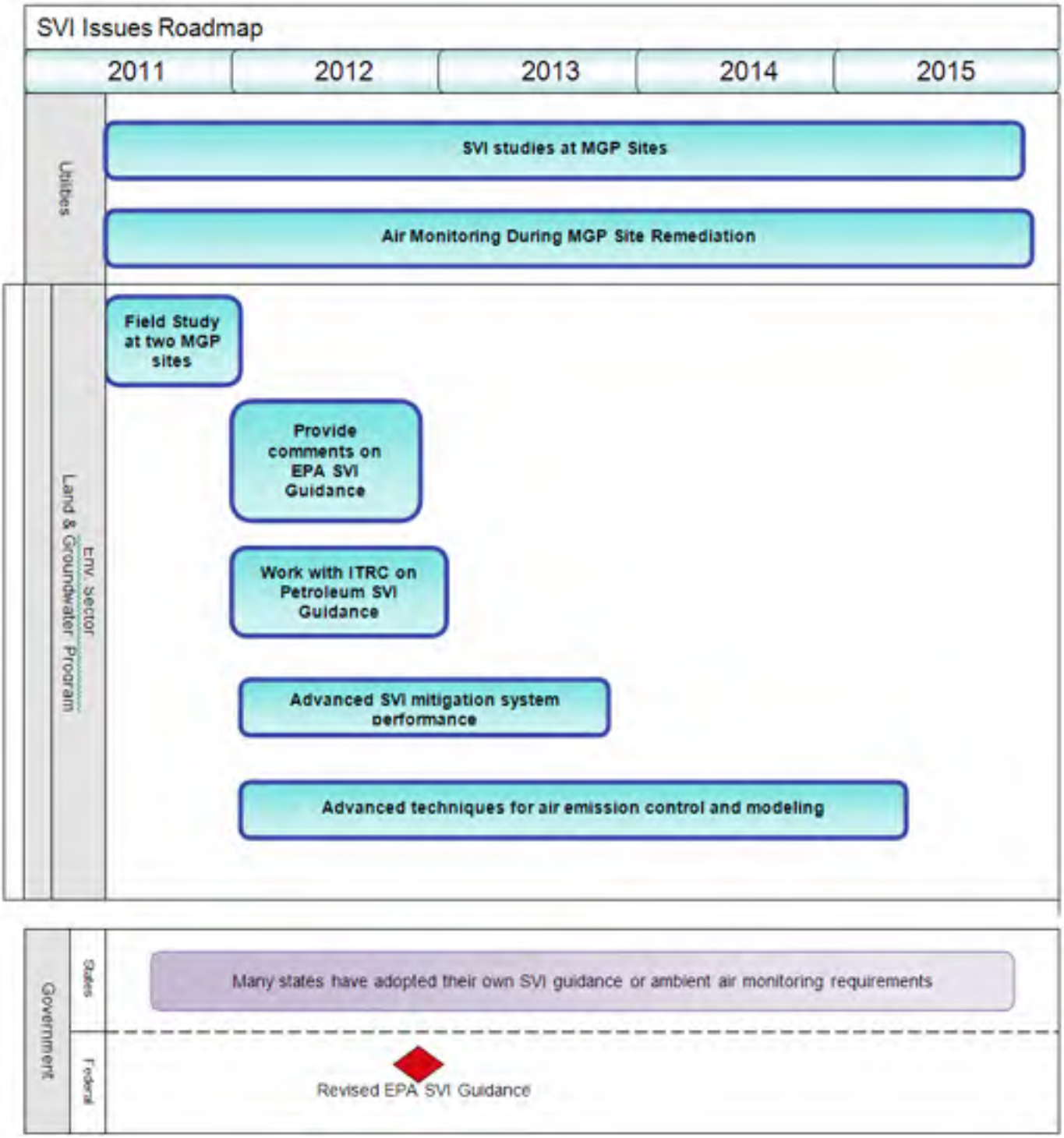
Research needs related to soil vapor intrusion at MGP sites, odor prediction and air monitoring include the following:

- Evaluation and comments on draft EPA SVI Guidance. The utility industry has been vocal on state and federal SVI guidance and will need the support of EPRI research to help make the guidance technically appropriate for MGP sites.
- Participation with the Interstate Technology Regulatory Council (ITRC) on development of guidance for petroleum hydrocarbons. MGP sites have a lot in common with petroleum sites, and ITRC guidance that incorporates, rather than excludes MGP sites will be helpful, especially at the state level.
- Evaluation of advanced mitigation measures for SVI. Mitigation measures should be economical to install and operate, but also prevent future long term liability. EPRI research can examine factors that affect performance and cost.
- Use of modeling to predict downwind odor and airborne hydrocarbon concentrations during MGP site remediation. Perimeter ambient air monitors cannot always be located upwind of sensitive receptors. Modeling can be a tool to interpret air quality data where such limitations exist.

RISK

EPRI research is a critical factor in providing member companies and other stakeholders, such as regulators, with high quality, objective, and credible scientific information. Insufficiently funded research will leave critical scientific and technical information gaps detrimental to well-informed decision-making. The specific risks of not doing the needed research can result in the following:

- Higher costs to conduct "multiple lines of evidence" evaluations to determine if soil vapor intrusion is or could occur at or near MGP sites
- Installation of "preventative subsurface soil gas mitigation systems" which result in long term O & M cost and potential liability
- Increased concern by regulators and neighbors about "What is in that odor?" coming from MGP site remediation
- Inadequate methods to determine downwind hydrocarbon concentrations at receptor sites where fixed ambient air monitor stations were not located


SVI Issues Roadmap
2011
2012
2013
2014
2015
Utilities
SVI studies at MGP Sites
Air Monitoring During MGP Site Remediation
Land & Groundwater Program
Env. Sector
Field Study at two MGP sites
Provide comments on EPA SVI Guidance
Work with ITRC on Petroleum SVI Guidance
Advanced SVI mitigation system performance
Advanced techniques for air emission control and modeling
Government
States
Many states have adopted their own SVI guidance or ambient air monitoring requirements
Federal
Revised EPA SVI Guidance

DRAFT: OCCUPATIONAL HEALTH AND SAFETY

ISSUE STATEMENT

Workplace injuries and illnesses affect employee health, productivity, and job satisfaction and increase the cost of doing business. Efforts to reduce injuries and illnesses, medical costs, and productivity losses and to improve overall morale are high priorities for electric power companies. Within the electric power industry, injuries resulting from poor ergonomic design and procedures and exposure to various physical agents have continued to be a source of lost work time and worker productivity. Companies must also develop strategies for compliance with worker health and safety requirements while providing a reliable, 24/7 source of electricity to customers. Occupational health and safety (OHS) research helps electric power companies maintain safer, healthier work environments and control labor-related costs. The research identifies injury and illness trends, develops cost-effective ergonomic interventions and designs, and addresses critical occupational exposures from workplace activities such as welding or physical stressors such as heat and noise. Scientific research provides the basis for informed health and safety practices for both the current and anticipated future electric utility infrastructure.

DRIVERS

There are a number of factors that drive the need for comprehensive OHS research:

Work-Related Injury and Illness Prevention – Analysis of current exposure, injury, and illness data provides means to intervene and prevent future adverse acute and/or chronic worker health outcomes.

Operational Impacts – A demographic shift is occurring in the workplace as the electric utility workforce is aging. Staff turnover and increased training frequency can severely impact day-to-day and emergency operations. A healthy workforce can lead to fewer illness events and improve company retention, morale and product quality.

Regulatory – Within the next few years, the U.S. Occupational Safety and Health Administration (OSHA) may accelerate its regulatory agenda, which includes injury illness and prevention programs; combustible dust; beryllium; and slips, trips, and falls hazards.

Limitations of Existing Equipment – Protection of worker health may be accomplished through controls including: engineering controls, administrative controls and personal protective equipment. EPRI ergonomic research targets these controls in handbooks such as design of substations and recommendations of tools to minimize the impacts of excessive forces.

Cost – The implementation of OHS programs within individual companies is expensive. An effective OHS program needs to track and analyze injury and illness data, develop and assess ergonomics interventions, characterize exposures and conduct health studies; however, few companies have the resources to support all of these activities. Furthermore, certain injuries may be millions of dollars per injury case for individual electric utilities and billions of dollars annually for the industry from ergonomics-related injuries alone. Effective OHS programs may reduce the cost burden. A comprehensive program centralized at EPRI offsets and complements existing electric utility company operations.

Coordinated Research Approach – Few companies and government organizations conduct fundamental occupational health research. A vital, holistic research approach is sustained through collaborative research funding and coordination of efforts from academic, government agencies and other scientific organizations.

RESULTS IMPLEMENTATION

EPRI has a comprehensive plan to address worker health and safety research gaps. EPRI's OHS research has developed several innovative solutions to improve worker health and safety which have been transferred to and applied by many companies.

Occupational Health and Safety Database (OHSD):

The database contains over one million worker-years of information from eighteen electric power companies and aides in targeting value-added prevention work. For example, musculoskeletal (strain and sprain) injuries currently account for more than 40% of total medical costs for electric power companies. EPRI researchers analyzed data and found that in just four companies, there was a loss of more than 70 full-time-equivalent employees for one full year owing to these injuries. Examples of value include:

- Annual reports which provide comprehensive, standardized surveillance information on injury and illness rates and statistical analyses drawn from a unique, industry-specific database
- Representation on the advisory council for the National Institute for Occupational Safety and Health National Occupational Research Agenda

Ergonomic Handbooks:

EPRI's ergonomic handbooks contain specific recommendations for improved worker safety and have proven valuable in reducing injury rates due to suboptimal ergonomic practices. To anticipate the gaps in exposure research and continue to deliver benefit to the utility workers, EPRI will continue to investigate the causes of occupational illnesses and injuries. Examples of products include:

- The first ergonomic power plant design handbook, a key reference for design engineers.
- Instructional DVDs describing ergonomic interventions and design guidelines.
- Easy-to-read handbooks on ergonomic design for substations and intervention methods for overhead and underground transmission and distribution workers.
- Peer-review literature on fleet ergonomics.
- Presentations on ergonomics to members, the scientific community, and regulatory agency staff.

Occupational Health and Exposure Studies (OEHS):

Adverse health effects can result from occupational exposure to physical and chemical agents (e.g., heat, noise, dust, beryllium, hexavalent chromium). A recently introduced OSHA standard significantly lowered permissible exposure limits for hexavalent chromium and also required implementation of feasible engineering controls to reduce exposure when overexposure may occur. OSHA may increase regulatory scrutiny in certain areas such as: injury and illness reporting, and exposure to beryllium and crystalline silica. Occupational exposure to temperature extremes (e.g., heat stress in power plants and in areas with warm climate) has been shown to result in productivity loss. In spite of hearing protection programs in the electric power industry, hearing loss due to noise exposure still remains a significant item in medical claims and costs. Examples of products delivered include:

- Research reports on welding fume exposures.
- Peer-review research on toxic and potentially toxic workplace exposures that provides data for guideline setting by the Occupational Safety & Health Administration (OSHA) and for compliance with federal and state regulations.

PLAN

EPRI anticipates expansion of short-term and long-term OHS R&D activities. Short-term activities address needs in the next 3-5 years. Long term (5-10 years) research will focus on building infrastructure for exposure characterization and health impacts of temperature extremes, noise and shift work within the electric utility sector. The primary objective of the EPRI OHS research program is to maintain a healthy electric utility workforce, both for the present and future.

Short-term activities:

- Complete fleet vehicle ergonomic studies.
- Conduct an assessment of industrial hygiene databases available within the electric utility industry.
- Initiate pilot exposure characterization studies on heat to quantitatively characterize work demands of specific work tasks for workers in hot outdoor environments.
- Begin pilot exposure characterization on noise in the work environment and hearing loss among workers over selected frequency levels using improved personal dosimetry technology.

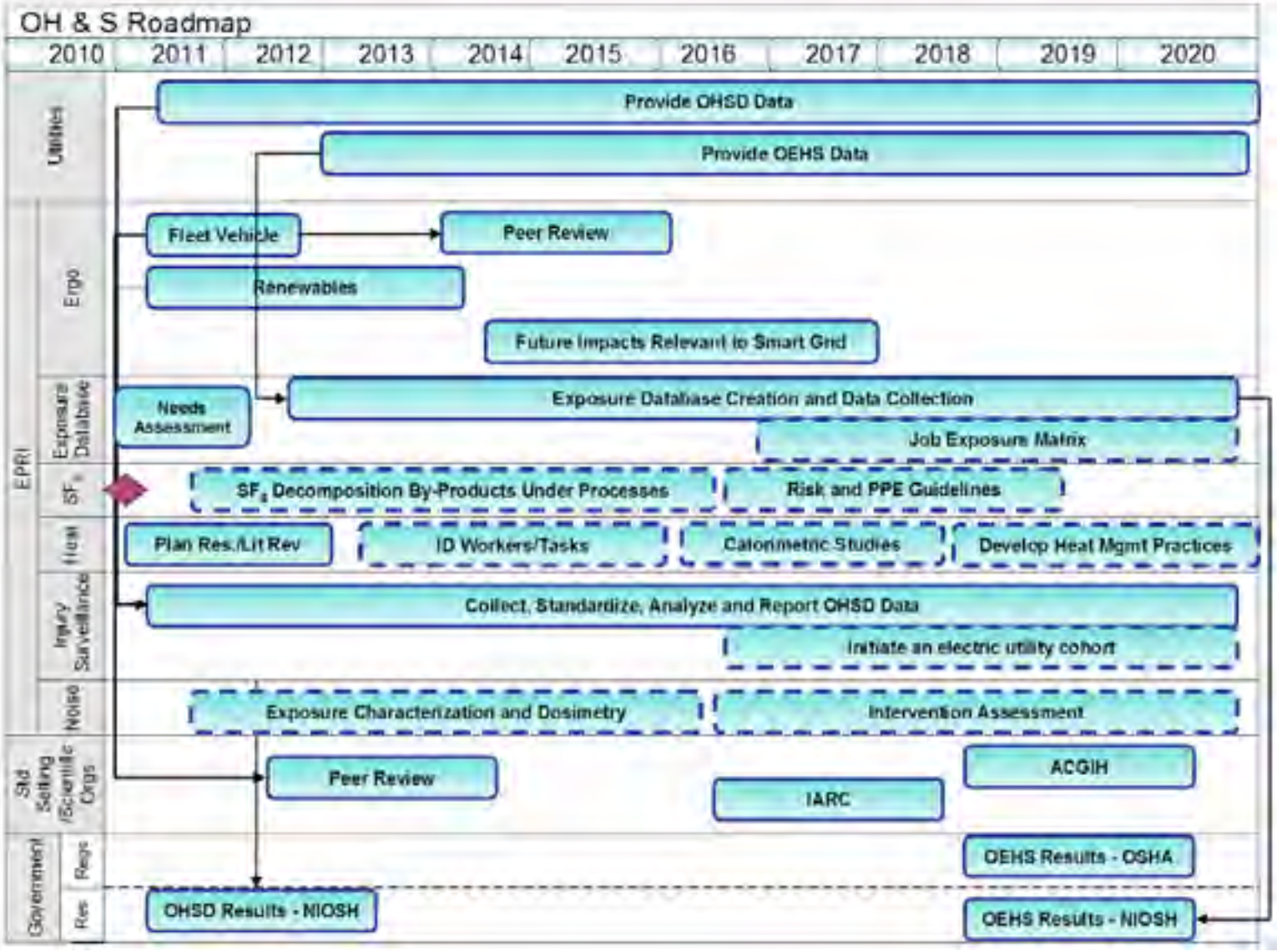
Long-term activities:

- Conduct laboratory calorimetry experiments for assessment of heat stress to provide the scientific basis for guidelines.
- Characterize ergonomic issues associated with the future power grid.
- Compile existing industrial hygiene exposure data the electric industry.
- Expand job exposure matrix to include physical, biological and chemical exposures.
- Characterize and evaluate the health and safety impacts of shift work.
- Establish occupational risk guidelines for sulfur hexafluoride decomposition by-product exposures, which could be integrated into substation safety programs.
- Initiate an electric utility cohort to examine health impacts of select exposures gathered in the planned industry-wide exposure database.
- Address emerging and long-term chronic health effects among electric power industry workers by expanding the OHSD.

RISK

Basic research is the cornerstone of scientifically informed intervention programs. With occupational health and safety research, companies can easily implement prevention strategies and optimize corporate OHS resources. Without the research, benefits may not be realized such as:

- Comprehensive utility-wide data collection strengthens the power of trend analyses. The OHS program provides a means for robust and systematic evaluation of issues potentially affecting the electric utility workforce of tomorrow.
- Compilation of industrial hygiene data for the utility industry provides input for setting more well-informed occupational health and safety standards and allows for efficient use of industrial hygiene resources within companies.
- Well-designed and executed occupational exposure studies provide critical information to inform OHS professionals within companies and close universal gaps in knowledge. Companies participating in this research can immediately access these data and apply lessons learned.



LEGEND

OHSD: Occupational Health and Safety Database
OEHS: Occupational Exposure and Health Studies
ACGIH: American Conference of Governmental Industrial Hygienists
IARC: International Agency for Research on Carcinogens
Issue Brief
Dashed boxes are currently unfunded research

DRAFT: OCCUPATIONAL HEALTH AND SAFETY – ERGONOMICS IN THE WORKPLACE

ISSUE STATEMENT

Workplace injuries affect employee health, productivity, and job satisfaction and increase the cost of doing business. Efforts to reduce injuries and illnesses, medical costs, and productivity losses and to improve overall morale are high priorities for electric power companies. Strains and sprains continue to represent a major fraction of occupational injuries in the electric power industry. Companies must develop strategies to ensure the health and safety of workers while providing a reliable, 24/7 source of electricity to customers. Occupational health and safety (OHS) ergonomics research helps electric power companies build safer, healthier work environments and control labor-related costs. The research identifies injury trends and develops cost-effective ergonomic interventions and/or designs. As the generation and transmission/distribution systems evolve, new occupational risks need to be characterized and potential new ergonomic interventions developed to reduce workplace injury and ensure workers are free from disabilities when they retire. Scientific research provides the basis for informed health and safety practices for both the current and anticipated future electric utility infrastructure. Moreover, translation of these and other improved ergonomic interventions need to be placed into utility work training programs.

DRIVERS

There are a number of factors that drive the need for specific research in the area of ergonomics:

Work-Related Injury and Illness Prevention – Analysis of current exposure, injury, and illness data provides means to intervene and prevent future adverse outcomes from inadequate ergonomic tools and/or designs.

Operational Impacts – A demographic shift is occurring in the workplace as the electric utility workforce is aging. Staff turnover and increased training frequency can severely impact day-to-day and emergency operations. A healthy workforce can lead to fewer injuries and improve company employee retention, morale and product quality.

Grid Modernization and Renewable Integration – New types of occupational environments will be created as a result of the grid modernization. The renewable energy workforce will experience ergonomic hazards not experienced by traditional generation workers. For example, installation, operation and maintenance of wind turbines require performance of tasks in work environments that differ from those in traditional power generating stations, potentially introducing new ergonomic hazards.

Limitations of Existing Equipment – Protection of worker health may be accomplished through engineering controls, administrative controls and personal protective equipment. EPRI ergonomic research targets these controls in handbooks and recommends interventions to minimize injuries.

Cost – The implementation of OHS programs within individual companies is expensive. An effective OHS program needs to track and analyze injury data, and develop and assess ergonomics interventions. However, few companies have the resources to support all of these activities. A specific ergonomic research program developed and conducted at EPRI offsets and complements existing electric utility company operations.

RESULTS IMPLEMENTATION

EPRI's ergonomic research has developed several innovative solutions to improve worker health and safety which have been transferred to and applied by many companies.

Occupational Health and Safety Database (OHSD):

The database contains over one million worker-years of information from eighteen electric power companies and aides in targeting value-added prevention work. For example, musculoskeletal (strain and sprain) injuries currently account for more than 40% of total medical costs for electric power companies. EPRI researchers analyzed data and found that in just four companies, there was a loss of more than 70 full-time-equivalent employees for one full year owing to these injuries. Examples of value include:

- Annual reports which provide comprehensive, standardized surveillance information on injury and illness rates and statistical analyses drawn from a unique, industry-specific database including integration of newer occupations into the database definitions.
- Representation on the services sector advisory council for the National Institute for Occupational Safety and Health National Occupational Research Agenda.

Ergonomic Handbooks:

EPRI's ergonomic handbooks contain specific recommendations for improved worker safety and reducing injury rates due to suboptimal ergonomic conditions or practices. To anticipate the gaps in physical hazards research and continue to deliver benefit to the utility workers, EPRI will continue to investigate the causes of occupational injuries. Examples of products include:

- The first ergonomic power plant design handbook, a key reference for design engineers
- Instructional DVDs describing ergonomic interventions and design guidelines
- Easy-to-read handbooks on ergonomic design for substations and intervention methods for overhead and underground transmission and distribution workers, systematically implemented in two utilities
- Peer-review literature on fleet ergonomics
- Presentations on ergonomics to members, the scientific community, and regulatory agency staff

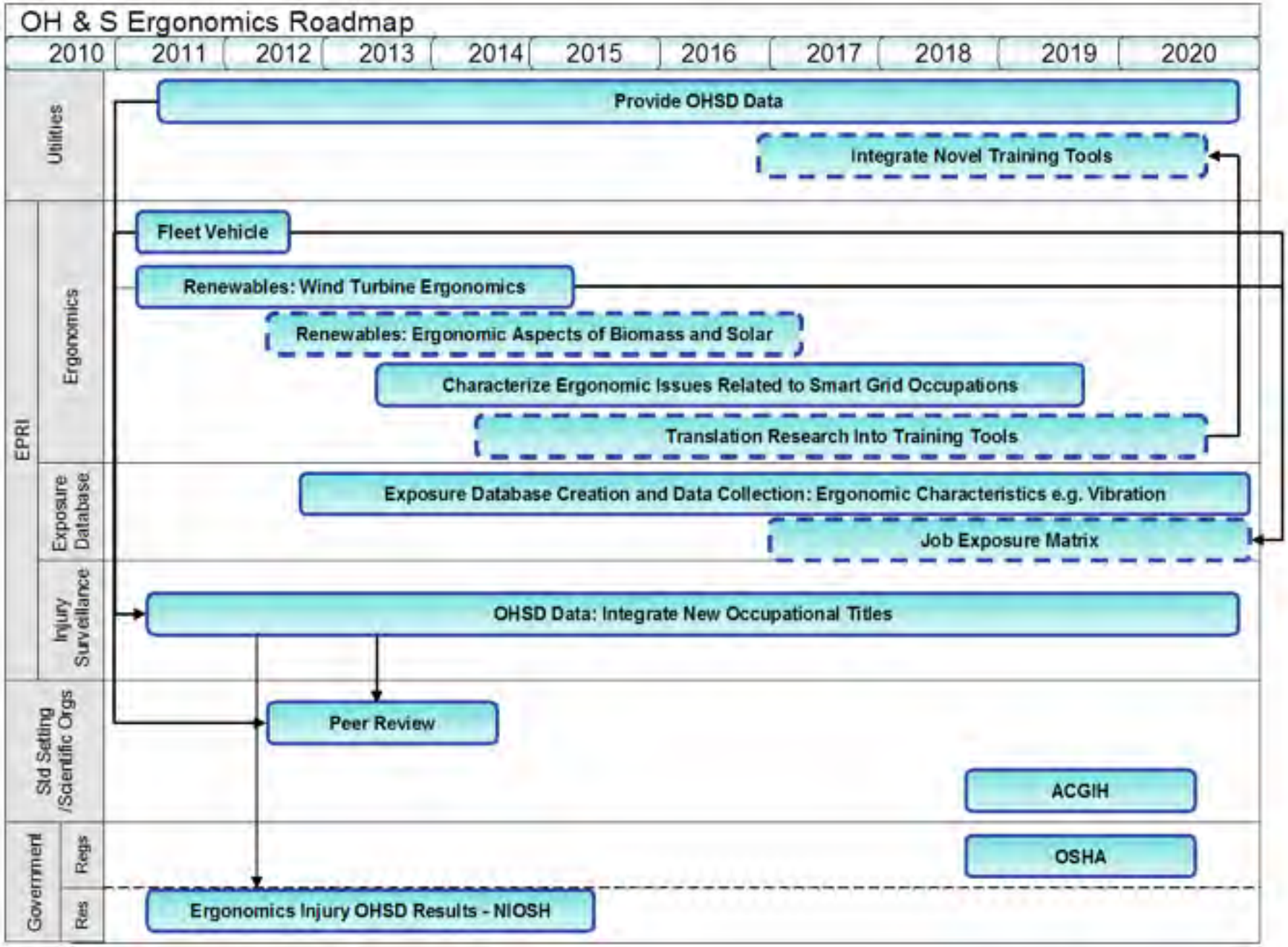
PLAN

Planned research will focus on building infrastructure for the future electric utility sector. The ultimate goal of EPRI ergonomics research is to ensure all electric utility worker ergonomics hazards are well-characterized, have interventions to prevent occurrence of injury and demonstrate value.

- Characterize ergonomic issues associated with the future power grid, e.g., smart meters, wind, solar.
- Assess ergonomics of wind turbine operations and maintenance of select worksites.
- Compile existing industrial hygiene exposure data, including ergonomic-related exposures, for the electric industry.
- Expand job exposure matrix to include ergonomic hazards such as vibration.
- Address emerging and long-term chronic health effects among electric power industry workers.
- Explore ways to adapt research into innovative training tools e.g. smart phone applications.

RISK

Ergonomics research is the science of making the work fit the worker. With ergonomics research tailored specifically for the electric utility industry, companies can easily implement prevention strategies and optimize corporate OHS resources. Without a comprehensive utility-wide program that provides a systematic means for evaluating ergonomic issues and for developing strategies to reduce injury potentially affecting the electric utility workforce of tomorrow, individual utilities may not be able to effectively address ergonomics issues in the workforce resulting in potentially more injuries and added cost.


OH & S Ergonomics Roadmap
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Utilities
Provide OHSD Data
Integrate Novel Training Tools
EPRI
Ergonomics
Fleet Vehicle
Renewables: Wind Turbine Ergonomics
Renewables: Ergonomic Aspects of Biomass and Solar
Characterize Ergonomic Issues Related to Smart Grid Occupations
Translation Research Into Training Tools
Exposure Database
Exposure Database Creation and Data Collection: Ergonomic Characteristics e.g. Vibration
Job Exposure Matrix
Injury Surveillance
OHSD Data: Integrate New Occupational Titles
Std Setting /Scientific Orgs
Peer Review
ACGIH
Government
Regs
OSHA
Res
Ergonomics Injury OHSD Results - NIOSH

DRAFT: OCCUPATIONAL HEALTH AND SAFETY – OCCUPATIONAL EXPOSURE AND HEALTH STUDIES

ISSUE STATEMENT

Occupational health and safety (OHS) is critical to the overall productivity and morale of the workforce. At the individual level, job-related injuries and illnesses affect employee health, productivity, and job satisfaction; while at the company level, injuries restrict workforce management options and increase the cost of doing business. Efforts to reduce worker injuries and illnesses, medical costs, and productivity losses remain on-going priorities for electric power companies. Investigation of workplace exposures to chemical, physical and biological hazards may improve the long-term health of workers, free chronic diseases and disabilities. Additionally, companies must develop strategies for regulatory compliance with worker health and safety requirements while providing a reliable, 24/7 source of electricity to customers. EPRI's OHS research helps electric power companies maintain safer, healthier work environments and control labor-related costs. By building on base projects, such as surveillance of injury trends, and, development of an exposure database, OHS research is able to identify and address critical occupational exposures or practices for targeted intervention. Scientific research provides the basis for informed health and safety practices for both the current and anticipated future electric utility infrastructure.

DRIVERS

There are a number of factors that drive the need for comprehensive OHS research:

Work-Related Injury and Illness Prevention – Analysis of current exposure, injury, and illness data provides means to intervene and prevent future adverse acute and/or chronic worker health outcomes.

Operational Impacts – A demographic shift is occurring in the workplace as the electric utility workforce is aging. Staff turnover and increased training frequency can severely impact day-to-day and emergency operations. A healthy workforce can lead to fewer illness events and improve company employee retention, morale and product quality.

Regulatory – Within the next few years, the U.S. Occupational Safety and Health Administration (OSHA) may accelerate its regulatory agenda, which includes injury illness and prevention programs and regulations on combustible dust and beryllium. Additionally, the development of new generation, storage or transmission technologies, and, the related worker tasks and potential new exposures (chemical or physical), will lead to changing occupational related regulatory considerations (e.g. additional sector requirements for data reporting, exposure monitoring or workplace limits development).

Cost – The implementation of OHS programs within individual companies is expensive. An effective OHS program needs to track and analyze injury and illness data, characterize exposures and conduct health studies; however, few companies have the resources to support all of these activities. A comprehensive program centralized at EPRI offsets and complements existing electric utility company operations.

Other Non-Regulatory Drivers – Few companies and organizations conduct fundamental occupational health research. Therefore, informing policy across the private and public sectors requires a collaborative research approach. By coordinating efforts and sharing results across governmental (such as NIOSH) and non-governmental organizations (such as IARC and ACGIH), scientific research results can provide critical, objective input to public, policy and academic discussions.

RESULTS IMPLEMENTATION

EPRI's OHS research is designed to identify data gaps, to evaluate potential data requirements, and to address critical issues related to the assessment of risks and the design of intervention strategies in the power generation and delivery sector. The Occupational Health and Safety Database (OHSD) contains over one million worker-years of information from eighteen electric power companies and aides in targeting value-added prevention work, identifying specific targets for detailed research and intervention, and provides data to the industry, the National Institute for Occupational Safety and Health, and the National Occupational Research Agenda. Building on this basic injury surveillance, the research results provide an improved understanding of the causes of, and

methods for, preventing adverse health effects resulting from occupational exposure to physical (e.g., noise, heat, cold and vibration) and chemical agents (e.g., beryllium, hexavalent chromium). EPRI research reports and peer-review publications provide data on potentially harmful workplace exposures for guideline setting by the Occupational Safety & Health Administration (OSHA), as well as, for compliance with federal and state regulations. OHSD surveillance data has been used to target additional detailed research into quantifying the burden (magnitude and cost) of motor vehicle injury on the sector workforce; detailing the specific type and parameters related to welding-based metal-exposures; and, identifying specific worker populations for ergonomic interventions across the industry (including substations, generation and distribution). Additionally, EPRI OHS industry-wide exposure assessment data for hexavalent chromium has been used to inform federal agencies in rule-making and occupational reporting requirements for the sector.

PLAN

Short-term (3-5 years) needs include the following:

- Development of an electric power industry specific exposure database – based on an initial assessment of current electric utility industry data and methodology for establishing such a framework.
- Characterization studies on temperature extremes – through a pilot exposure study to quantify task-specific hazards.
- Characterization studies on noise exposure – by initiating a pilot hazard and risk characterization (hearing loss) in the work environment applying improved personal dosimetry technology.
- Identification and characterization of new exposures of concern – including biomass exposures (e.g. biogenic dusts), SF_6 decomposition products, and unique amines related to carbon capture and storage (CCS). The amine related work has been initiated as part of a Technology Innovation project.

In the long term (5-10 years) research will focus on building infrastructure for exposure characterization and health impacts of temperature extremes, noise and shift work within the electric utility sector to inform regulatory policy and health protecting strategies including:

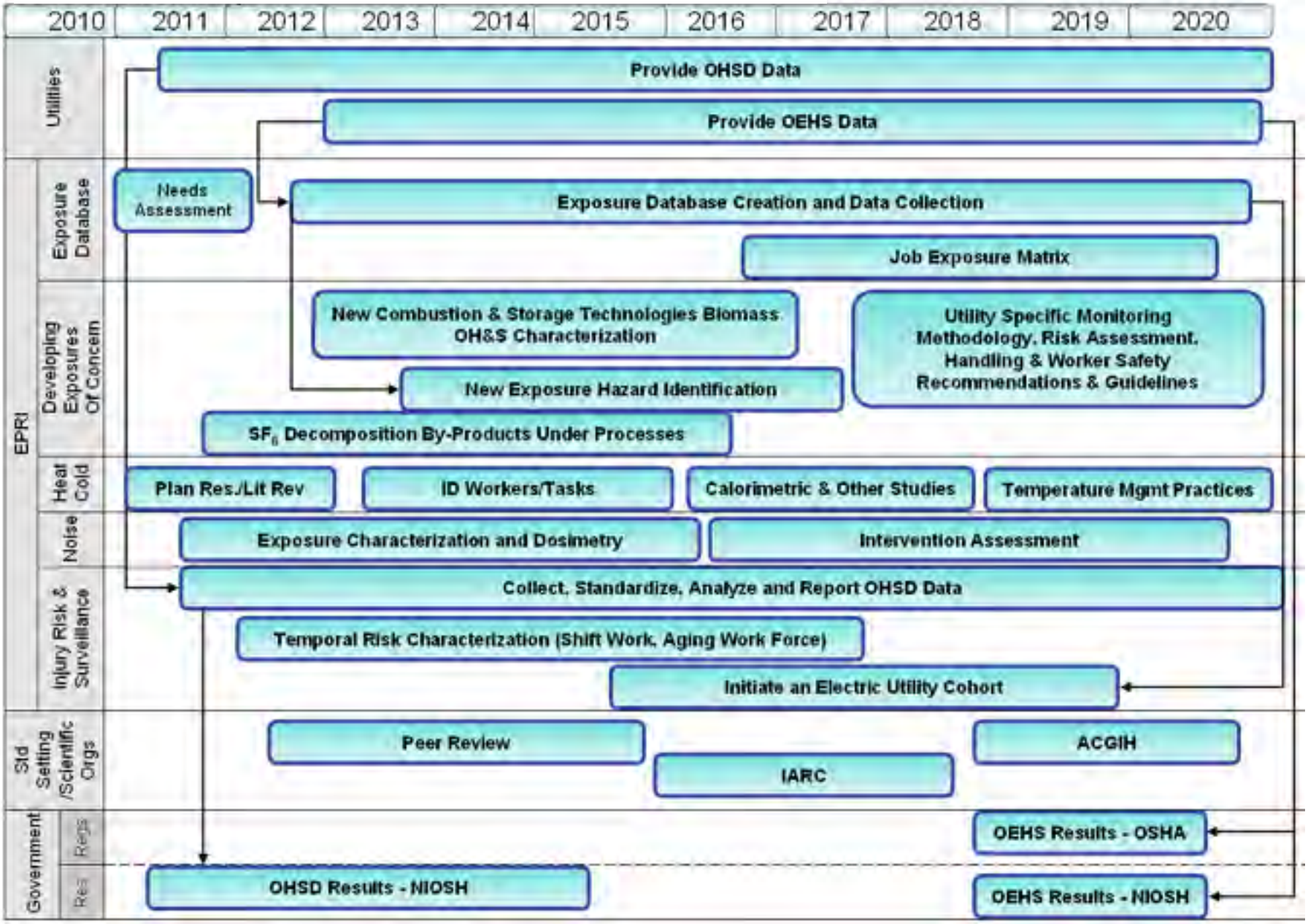
- Expansion of electric power industry exposure database – by continuing to build on the framework and to derive a job exposure matrix to include physical, biological and chemical exposures.
- Quantification of temperature extremes – to conduct laboratory calorimetry and other experiments to assess temperature stress and to provide a scientific basis for industry and regulatory guidelines.
- Evaluate the risk associated with temporal stress – by evaluating the evidence for health and safety impacts related to shift work.
- Establish occupational risk guidelines for emerging technologies – including guidelines for sulfur hexafluoride decomposition by-product exposures with the potential for integrated into substation safety programs.
- Expand primary data collection sector resources – by initiating an electric utility cohort to examine health impacts of select exposures identified in the industry-wide exposure database.

Success of the EPRI OEHS program will be achieved when electric utilities can reliably anticipate potential exposures and prevent adverse health outcomes of their workers.

RISK

EPRI's OHS research on the exposure and health effects outcomes associated with electric sector operations informs industry, regulators and society alike with high quality, objective and credible scientific information. Basic research is the cornerstone of scientifically informed intervention programs – at both the industrial and regulatory level. EPRI serves as a credible source for informing policies under public and governmental review. With OHS research, companies can more easily implement prevention strategies and optimize corporate resources. In the U.S., research into occupational health and safety remains severely restricted, EPRI serves as one of a handful of organizations (private or governmental) working toward protecting worker health and safety through both primary research and informing, science-based regulation. If EPRI does not conduct this work, then both the sector and the regulatory agencies will be limited to retroactive, more poorly informed, responses to addressing health and safety concerns.

OH & S Occupational Exposure and Health Studies Roadmap



DRAFT: TRANSMISSION AND DISTRIBUTION HEALTH AND ENVIRONMENTAL ISSUES

ISSUE STATEMENT

Public confidence in safe and reliable operation of the power delivery system will be crucial as the power grid is expanded, upgraded, and modernized to accommodate emerging transmission and distribution (T&D) technologies. Costs for construction and/or upgrades of T&D facilities and their operation and maintenance are very high. Environmental and health-related concerns are frequently the primary obstacles to expanding, refurbishing and maintaining T&D infrastructure, which can result in significant additional cost and delay. Construction of new or upgraded transmission lines and installation of distributed generation technologies along with deployment of electric transportation infrastructure already is fueling public concern about possible human health risks from exposure to power frequency electromagnetic fields (EMF). This may lead to regulatory decisions that adversely affect project schedules and costs.

New smart grid technologies are also being integrated into the power grid to further increase energy efficiency and reliability. These technologies include two-way, radio-frequency (RF) wireless communications (e.g., smart meters), which along with a growing number of antennas of various types (for cell phones, pagers, etc.) installed on the grid infrastructure, raise concerns of potential RF exposure health effects for workers and the public. Ensuring workers' safety in new exposure environments will be critical to the success of the smarter grid as it is built out, upgraded, and maintained.

As the current T&D infrastructure ages, coupled with anticipated load increases throughout the grid, the potential for leaks, spills and catastrophic events increases, potentially resulting in contaminated soil and groundwater and compromised reliability. Siting challenges for new transmission lines will require identification of measures to address environmental issues and power system reliability. To ensure reliability and minimize maintenance cost, improved vegetation management and prevention of interaction with avian and other species will also be required. Attention to ecological issues, such as creation and maintenance of wildlife habitat, will also be crucial, as will management of environmental liabilities for electrical fluids and chemicals used for wood pole treatment. Identifying where the greatest risks reside and managing the system to prevent potential environmental problems will save money and provide for public safety.

DRIVERS

A number of underlying rules, regulations, and public perception issues are driving the need for research on enhancing and improving the environmental compatibility of the T&D system.

Public Perception Drivers

- **Public opposition to siting of new transmission lines and smart meters:** As new transmission lines are proposed to move power from remote locations to population centers and new grid technologies are implemented (e.g., smart meters), the public is becoming increasingly concerned about potential health effects, causing significant delays. In the absence of federal regulations, the EMF issue is driven heavily by public perception and public health concerns.
- **Stakeholder and ad hoc policy reports:** Organizations, such as the Bioinitiative Working Group, are becoming more forceful in impacting transmission line siting projects and taking a strong stance on the potential health hazards of all EMF exposures, including new smart grid technologies.
- **Public pressure on regulatory agencies:** Public citizen organizations have intervened with regulatory agencies, such as the Federal Communications Commission and the California Public Utilities Commission, calling for EMF limits and other regulations, guidelines, and/or standards.

Regulatory Drivers

- **North American Electric Reliability Corporation (NREC) Standards:** Continuing development of nation-wide enforceable standards for vegetation management on the bulk transmission system.
- **Federal Insecticide, Fungicide and Rodenticide Act (FIFRA):** Establishes the acceptability of chemical treatment options for wood pole preservatives and herbicides for transmission vegetation management. Retaining the use of these chemicals allows for continued use of poles and pole types.
- **Endangered Species Act:** Ecological issues associated with vegetation management, such as the creation and maintenance of wildlife habitat in light of enforceable standards. Increased scrutiny of avian interactions with T&D infrastructure (and wind turbines) by the U.S. Fish & Wildlife Service, with potential for fines.
- **U.S. Occupational Safety and Health Administration (OSHA) requirements:** OSHA establishes and enforces workplace regulatory exposure limits (e.g., RF energy based on tissue heating and for chemicals such as pesticides and metals).
- **Spill Prevention Control and Counter Measures (SPCC) Plans:** Historical and new spills of dielectric fluids require innovative approaches to site investigation and remediation. The potential for explosions and fires demand the ability to simulate and predict these events to address outcomes and response plans.
- **PCB rulemaking under the Toxic Substances Control Act:** PCB issues are of continuing concern and regulatory interest, particularly the various types of PCB compounds.
- **Arsenic Cancer Slope Factor:** Arsenic containing herbicides were used to control vegetation around substations in certain parts of the U.S. and can affect groundwater. EPA's recent proposal to increase the cancer slope factor may result in more stringent cleanup end points.
- **State regulations:** The State of California, Department of Education, has setback rules for transmission lines to protect school children from EMF exposure.
- **FCC Enforcement Bureau (U.S.):** A Notice of Proposed Rulemaking on the use of dose quantities to comply with exposure guidelines is pending; the FCC develops enforceable public and occupational maximum exposure limits for RF.

Non-Regulatory Drivers

- **World Health Organization (WHO):** The WHO, based on scientific evidence from childhood leukemia epidemiologic studies, has classified ELF/EMF as a possible human carcinogen (Group 2B).
- **International Committee on Non-Ionizing Radiation Protection (ICNIRP) and IEEE:** These two organizations establish EMF exposure guidelines that are used world wide to establish safe levels of human exposure.
- **International studies on the health risks of EMF exposure:** Published studies require review for implication and impact to T&D facilities siting and operation.
- **Development of precautionary policies internationally:** The precautionary principle is aimed at avoiding or minimizing harm, if such indications exist and reasonable avoidance can occur. Its application is growing in the U.S. and is strong in Europe.
- **Other:** Need for information and tools to reduce outages on the distribution system whether the outage results from poor vegetation management, or caused by avian or animal interactions with the T&D systems. Large, aging asset base needs proactive management to ensure reliability, control cost, and minimal risk to human health and the environment

RESULTS IMPLEMENTATION

A comprehensive plan has been developed to address the near term and longer-term research needs on T&D health and environmental issues.

- Research results are available to participants to help manage their needs in a cost-effective and environmentally protective manner, and to make objective scientific information available to their customers on a timely basis.
- Results are also available to other stakeholders including federal and state regulatory agencies to inform the appropriate rulemaking activities; the health effects information also is available to non-governmental agencies as well as to the public.

The body of scientific research developed has been transferred to industry and the public in several forms:

- EPRI EMF research peer-review literature has been included in the WHO Environmental Health Criteria. In addition to confirming the epidemiologic relationship with childhood leukemia, the review also concluded that some diseases with great public health impact, such as breast cancer and cardiovascular diseases are likely not related to EMF exposure.
- EPRI manuals have been used to enhance the transmission line siting process by incorporating stakeholders concerns while minimizing environmental impact. Application of integrated vegetation management principles has saved companies up to 50% in transmission rights-of-way maintenance costs once fully implemented while at the same time providing for greater biological diversity and reduced chemical use.
- Utilities have used EPRI's SPCC software (Mineral Oil Spill Evaluation System-MP) to evaluate retrofit options at substations and realized substantial cost savings. One company used EPRI's risk factors on dielectric fluids to convince the state agency that scientifically based clean up standards can simultaneously protect the environment and save significant costs.

PLAN

Over the next 5 years, the T&D Health and Environmental Impacts Issues research will focus on addressing the needs presented by the evolving T&D infrastructure of the future electric grid. Regulators and the public must be satisfied that the grid can be operated safely and pose no unacceptable health or environmental impacts. These are divided into 4 major research activities:

Exposure Characterization

- Characterize complex power-frequency and RF exposure scenarios in emerging environments related to smart grid technologies, electric transportation, and distributed renewable energy resources.

Health and Safety Impacts and Risk Assessment

- Resolve scientific uncertainties concerning the association of power-frequency magnetic fields with childhood leukemia through both epidemiologic and laboratory research.
- Investigate occupational health and safety issues relevant to power-frequency EMF as well as RF environments, including interference with implanted medical devices (such as cardiac pacemakers).
- Address other health priorities, including miscarriage and neurodegenerative diseases related to power-frequency EMF.
- Investigate potential health and safety issues of RF exposure.
- Address emerging concerns about potential EMF effects on animal behavior and health.

Environmental Impacts of T&D Systems Operation and Maintenance

- Develop environmental risk management tools to address aging T&D Infrastructure.
- Assess the environmental impact of current T&D system materials—Institute and develop a life-cycle perspective on materials management.
- Update and enhance SPCC response compliance methods.
- Identify options to manage storm water.
- Identify non-herbicide options for transmission vegetation management to reduce environmental and human health risks.

Planning Tools for Siting and Grid Operations

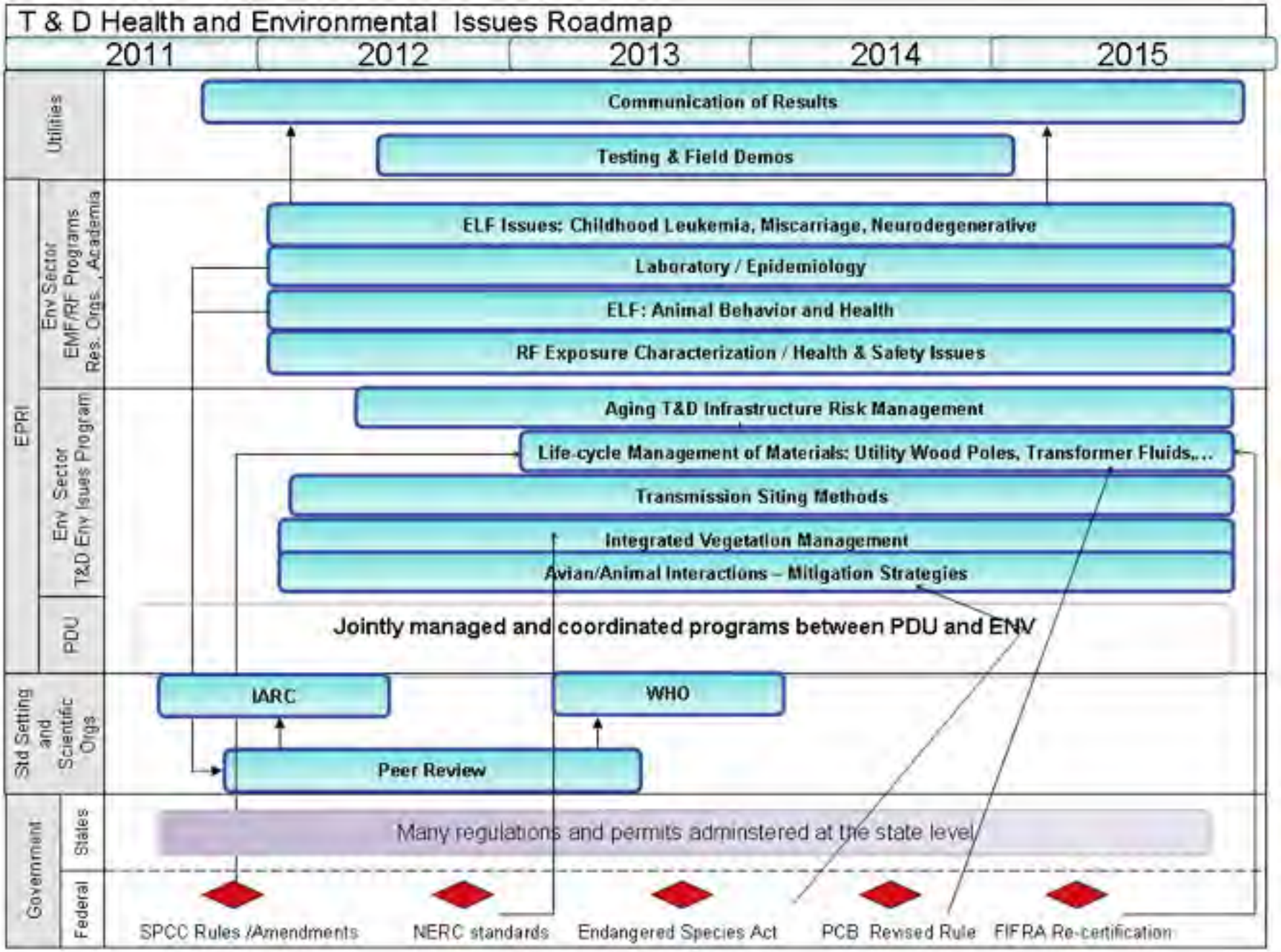
- Evaluate the performance of new fluids and materials
- Implementation of "Green" practices and technologies
- Establish transmission siting methods integrating national corridors and NERC compliance requirements
- Promote integrated vegetation management methods
- Establish reliability analysis tools and mitigation options for animal and avian interaction

RISK

Continued objective and independent research is necessary to resolve outstanding and emerging scientific uncertainties regarding ELF/RF EMF health effects. EMF's continued classification as a possible human carcinogen is likely to continue

to fuel public concern and opposition to transmission line siting, and expansion of the Smarter Grid. This uncertainty has and is likely to continue to slow opportunities for energy efficient technologies, demand response programs and potential expansion of electric transportation. In the absence of reliable and authoritative research, the EMF issue can become clouded by studies and perceptions that are not scientifically rigorous and authoritative. The result may be overly conservative standards not fully supported by scientific evidence or delays in important projects, which can become costly. Lack of credible research may also impact the ability to objectively and successfully deal with potential litigations as credible science is critical to addressing concerns raised by the public. Increased scientific certainty about potential health and environmental risks will be valuable in defining options to mitigate those risks.

Insufficiently funded research would also result in a lack of critical information to make well informed decisions, increase the probability that regulators may take overly conservative positions on clean up levels for soil or groundwater cleanup or even result in an increase in service interruptions or non-compliance with NERC standards by poorly managed rights of way. This research is aimed at helping utilities integrate the T&D system into sustainability programs to reduce a company's environmental footprint. Without this research, such sustainability efforts would be compromised.


T & D Health and Environmental Issues Roadmap
2011
2012
2013
2014
2015
Utilities
Communication of Results
Testing & Field Demos
EPRI
Env Sector EMF/RF Programs Res. Orgs. , Academia
ELF Issues: Childhood Leukemia, Miscarriage, Neurodegenerative
Laboratory / Epidemiology
ELF: Animal Behavior and Health
RF Exposure Characterization / Health & Safety Issues
Env Sector T&D Env Issues Program
Aging T&D Infrastructure Risk Management
Life-cycle Management of Materials: Utility Wood Poles, Transformer Fluids,...
Transmission Siting Methods
Integrated Vegetation Management
Avian/Animal Interactions – Mitigation Strategies
PDU
Jointly managed and coordinated programs between PDU and ENV
Std Setting and Scientific Orgs
IARC
WHO
Peer Review
Government
States
Many regulations and permits adminstered at the state level
Federal
SPCC Rules /Amendments
NERC standards
Endangered Species Act
PCB Revised Rule
FIFRA Re-certification

ISSUE STATEMENT

As the electric transmission and distribution infrastructure grows older, risks of leaks and spills of fuels, dielectric fluids, and other liquids or gases may increase, resulting in increased financial risk to companies as well as increased risk to human health, ecological systems, and the environment. The R&D need is to identify and assess risks and vulnerabilities through development of a proactive approach to improving the understanding of probabilities and ramifications of incidents.

DRIVERS

Rules, regulations, and public perception issues are driving the need for research on risks from aging infrastructure and action plans for repair and replacement of aging equipment.

Public Perception Drivers

- **Public opposition to chemical exposure from spills, explosions, and fires:** The public is becoming increasingly concerned about exposure to chemicals and the potential impacts on human health, ecological systems, and the environment.
- **Public pressure on regulatory agencies:** Public citizen organizations have intervened with regulatory agencies, such as the United States Environmental Protection Agency, calling for prevention and cleanup of spills and other incidents.

Regulatory Drivers

- **Spill Prevention, Control, and Countermeasure Rule:** Evolving USEPA spill prevention rules mandate that substations incidents be prevented where possible, mitigated quickly, and remediated to prevent environmental and human health impacts.

Non-Regulatory Drivers

- **Costs for incident ramifications:** Remediation costs for spills, explosions, and fires can greatly exceed risk-based repair and replacement costs, often by orders of magnitude.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed to address the near term and longer-term research needs on risks from aging T&D infrastructure.

- Research results are available to participants to help prioritize their options in a cost-effective and environmentally protective manner, and to make objective scientific information available to their customers on a timely basis.
- Results are also available to other stakeholders, including federal and state regulatory agencies, to inform the appropriate rulemaking activities; information also is available to non-governmental agencies as well as to the public.

The body of scientific research developed is being transferred to industry and the public in several forms:

- EPRI approaches and models are being used by utility companies to update plans for upgrade and replacement of equipment.
- EPRI research is being used to demonstrate effective proactive spending and to discourage ineffective spending.

PLAN

Over the next 5 years, the aging infrastructure risk assessment research will focus on addressing the needs presented by the evolving rules and continuing operation of aging equipment toward preventing the continuum of incidents, from small spills to catastrophic fires and explosions. Regulators and the public must be satisfied that operations and maintenance plans that minimize incidents that pose unacceptable health or environmental impacts are being implemented at reasonable cost. Research needs include:

Relative Risk Model

- Improve ability to assess and prioritize relative risks of aging infrastructure by comparing across equipment classes, such as large transformers, or across facilities, such as substations
- Streamline development of action plans for repair and replacement of equipment

Communications

- Increase understanding of relative risks of aging infrastructure, including environmental, ecological, human health, and financial risks
- Support communication with stakeholders by training users of the model in its operation and interpretation

Case Studies

- Demonstrate application of the model through actual case studies of relative risks across equipment classes and across facility categories

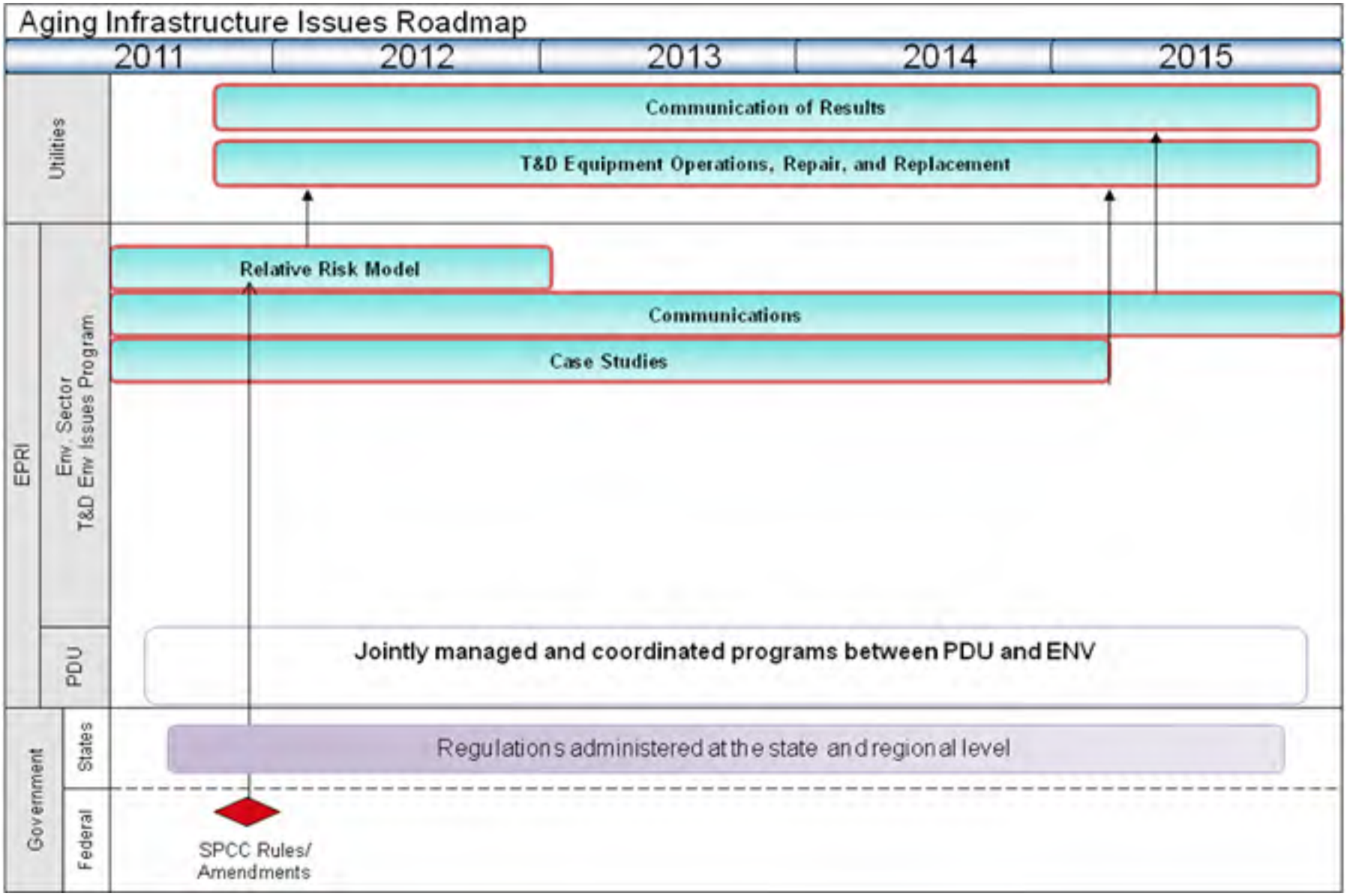
This work will proactively reduce risk, save money and improved reliability by providing industry with tools for identification, assessment, and communication of risks and related options.

RISK

T&D equipment is aging and presents expensive challenges to preventing spills, explosions, and fires while maintaining reliability. Spills and leaks are frequent and result in remedial costs from thousands to hundreds of thousands of dollars, sometimes more; explosions and fires are less frequent but often result in remedial costs exceeding a million dollars. This work should help reduce catastrophic incidents by identifying and focusing preventive action on the highest risk areas and optimizing maintenance. As infrastructure ages without addressing these risks, frequency and impact of these incidents will increase.

The risks that will be mitigated by this work include:

- Reliability – Continued objective and independent research is necessary to facilitate development of reasonable action plans for repair and replacement of aging equipment before failure.
- Costs – Continuing publicity and resulting public pressure following incidents will focus companies toward improved plans. This research is focused on identifying and prioritizing risks of incidents and developing plans to cost-effectively address those risks.


Aging Infrastructure Issues Roadmap
2011
2012
2013
2014
2015
Utilities
Communication of Results
T&D Equipment Operations, Repair, and Replacement
EPRI
Env. Sector
T&D Env Issues Program
Relative Risk Model
Communications
Case Studies
PDU
Jointly managed and coordinated programs between PDU and ENV
Government
States
Regulations administered at the state and regional level
Federal
SPCC Rules/
Amendments

DRAFT: AVIAN AND ANIMAL INTERACTIONS WITH UTILITY FACILITIES

ISSUE STATEMENT

Transmission and distribution (T&D) structures (towers, poles, transformers) and associated ROW habitats can provide favorable sites for bird nesting, roosting, and foraging and for hunting activities for a wide variety of bird and other animal species, without affecting operations. At the same time, birds are at risk from potential interactions with these structures, including collision with wires and towers, and birds and other wildlife can be subject to electrocution (transformers, conductor configurations) and cause negative effects on bird and other wildlife populations. These and other interactions can result in electrical faults and can lead to the disruption of service. Adverse effects on many bird species, such as electrocutions of eagles, may result in fines and penalties. Research is needed to provide information to improve understanding of avian and other wildlife interactions with utility facilities to support the further development of mitigation options.

DRIVERS

Rules, regulations, and public perception issues are driving the need for research to reduce avian and animal interactions at utility facilities. With respect to birds, the need for mitigation is paramount, as most birds are listed species, and failure to take action to mitigate mortality can result in significant fines and imprisonment.

Public Perception Drivers

- **Public pressure:** Public citizen organizations and individuals are watchful to assure that utilities comply with federal and state regulations. For some non-listed species, such as the Monk Parakeet, nest removal to protect the electrical system can become problematic as many members of public are fond of the bird.

Regulatory Drivers

- **Federal and state regulations:** Federal and state regulations list species that must be protected. Proactive planning can foster environmental stewardship and reduce adverse impacts on avian and other wildlife populations, and reduce the potential for fines and imprisonment.

Non-Regulatory Drivers

- **Outages on the transmission and distribution system:** There is a need to reduce outages and associated costs, as a result of interactions. For the distribution system, which has more outages than the transmission system, it is also a significant public relations issue for the industry.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed to address the near- and longer-term research needs to reduce interactions and associated outage risks.

- Research results are available to participants to help prioritize their options in a cost effective and environmentally protective manner, and to make objective scientific information available to their customers on a timely basis.
- Results are available to other stakeholders, including federal and state regulatory agencies to inform the appropriate rulemaking activities; information also is available to non-governmental agencies as well as to the public.

A body of scientific research is being transferred to industry and the public in several forms:

- EPRI information and hardware (Bird Strike Indicator) are being used by utility companies to understand and mitigate avian interactions with the transmission system.
- EPRI coordinates its research with the Avian Power Line Interaction Committee (APLIC); APLIC recently published an update to its *Suggested Practices for Avian Protection on Power Lines*.
- EPRI avian vision perception research is being use to better design flight diverters and other mitigation devices.

PLAN

Over the next 5 years, EPRI's research will focus on innovations to mitigate avian interactions with utility facilities, and will expand to include non-avian species. For non-avian species, the focus will be on understanding and mitigation intru-

sion of land-based animals into facilities, such as substations to reduce outages from animals. Research needs fall into the following major areas:

Avian/ Non-avian Species Interactions

- Expand the avian vision perception research to include additional species to support development of mitigation devices.
- Develop the Bird Activity Monitory (BAM), a high resolution 24/7 digital camera system to better understand and mitigate interactions at all utility facilities to reduce mortality of federal and state listed species. The BAM can also be used to study interactions of non-avian species, such as animal interactions at substations.

Avian/Non-avian Species Protection

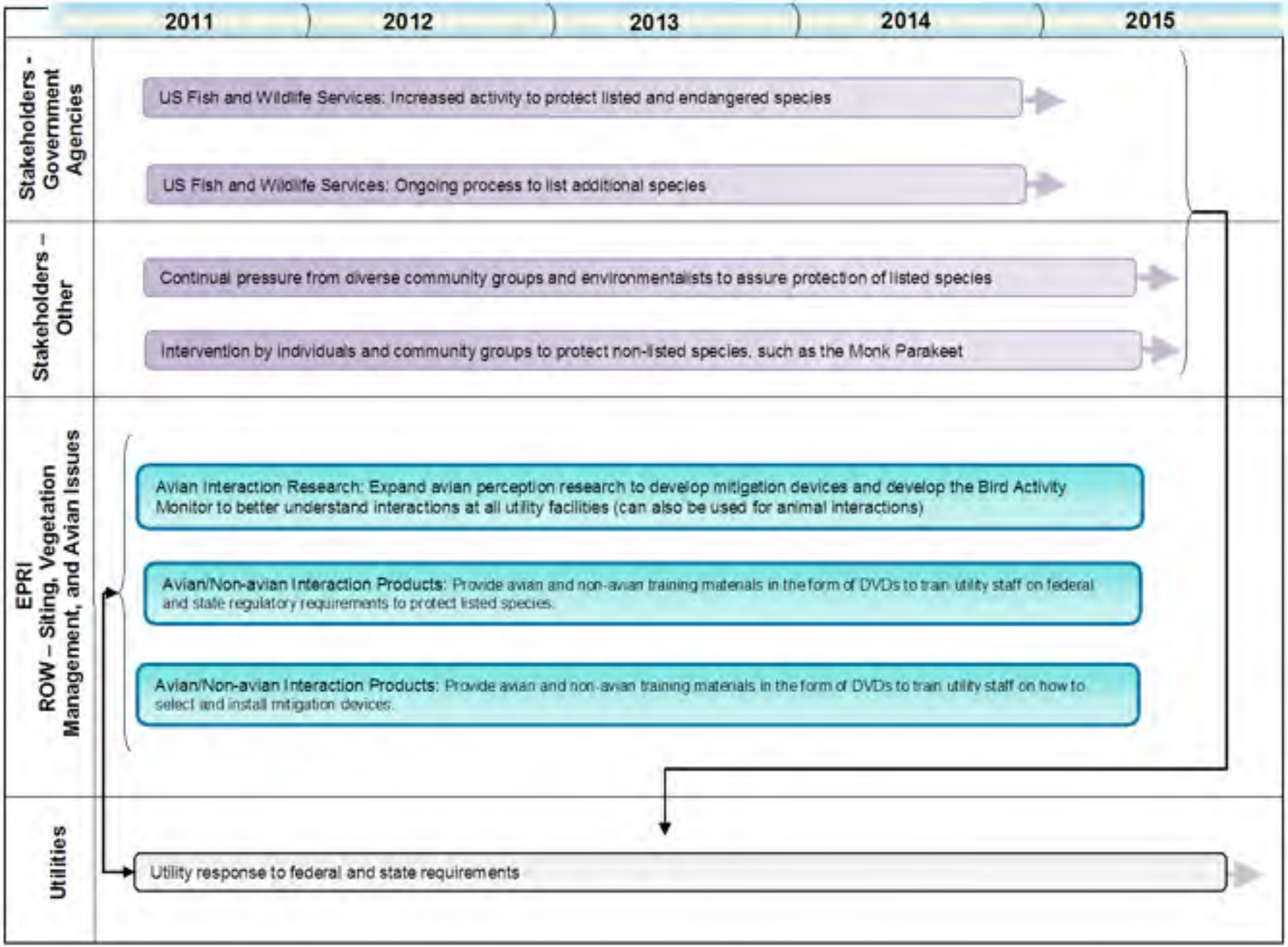
- Provide information on avian and non-avian species interaction products. This will take the form of user-friendly electronic product databases that will allow utilities to be aware of the latest technologies and how they are applied to mitigate interactions
- Provide avian and non-avian training materials in the form of DVDs to train utility staff on federal and state regulatory requirements to protect listed species.
- Provide avian and non-avian training materials in the form of DVDs to train utility staff on how to select and install mitigation devices.

Technology Transfer

- Work with utilities to increase the use of EPRI mitigation technologies and training products.

RISK

Further development of information on avian and animal interactions is necessary to better understand and mitigate the interactions. Reducing fatal interactions is important from several perspectives. Most species of birds are listed species and a number of animals are also listed. Failure to understand and take appropriate steps to mitigate fatal interactions can be a violation of federal and state laws. These interactions can also cause disruption of service with the attendant costs. Research will focus on understanding and mitigating interactions so that utilities can be equipped to take effective action in a timely manner.


2011
2012
2013
2014
2015
Stakeholders - Government Agencies
US Fish and Wildlife Services: Increased activity to protect listed and endangered species
US Fish and Wildlife Services: Ongoing process to list additional species
Stakeholders – Other
Continual pressure from diverse community groups and environmentalists to assure protection of listed species
Intervention by individuals and community groups to protect non-listed species, such as the Monk Parakeet
EPRI ROW – Siting, Vegetation Management, and Avian Issues
Avian Interaction Research: Expand avian perception research to develop mitigation devices and develop the Bird Activity Monitor to better understand interactions at all utility facilities (can also be used for animal interactions)
Avian/Non-avian Interaction Products: Provide avian and non-avian training materials in the form of DVDs to train utility staff on federal and state regulatory requirements to protect listed species.
Avian/Non-avian Interaction Products: Provide avian and non-avian training materials in the form of DVDs to train utility staff on how to select and install mitigation devices.
Utilities
Utility response to federal and state requirements

DRAFT: TRANSMISSION AND DISTRIBUTION – EXTREMELY LOW FREQUENCY MAGNETIC FIELDS HEALTH ISSUES

ISSUE STATEMENT

EMF health issues continue to be raised by the scientific community, the media and the public. New studies and attendant media reports about EMF health impacts, IARC's classification of EMF as a possible human carcinogen (Group 2B), and public concerns frequently raised at open house meetings underscore the importance of addressing this issue with high quality science. Public confidence in safe and reliable operation of the power delivery system is crucial as the power grid is expanded, upgraded, and modernized to accommodate emerging transmission and distribution (T&D) technologies.

Costs for construction and/or upgrades of T&D facilities and their operation and maintenance are very high. Environmental and health-related concerns are frequently raised during the expansion, refurbishment and maintenance of the T&D infrastructure and can result in significant additional cost and delay. These added costs can include: longer permitting process, rerouted lines (adding more miles) including design changes to mitigate purported EMF levels, and high right-of-way payments. Construction of new or upgraded transmission lines and installation of distributed generation technologies along with deployment of electric transportation infrastructure has fueled public concern about possible human health risks from exposure to power frequency electromagnetic fields (EMF).

There are significant remaining scientific uncertainties about potential health effect of EMF exposure. The primary concern focuses around the childhood leukemia issue. However, other outcomes, such as neurodegenerative diseases and adverse pregnancy outcomes also continue to be of interest and concern. Resolution of these scientific uncertainties will be crucial to enable and facilitate the planning and execution of major T&D infrastructure developments and to demonstrate a constructive approach in risk communication.

DRIVERS

A number of underlying rules, regulations, and public perception issues are driving the need for research on enhancing and improving the environmental compatibility of the T&D system.

Public Perception Drivers

- Public opposition to siting new transmission lines and other T&D infrastructure: As new transmission lines and other T&D facilities are proposed to move power from remote locations to population centers, the public is becoming increasingly concerned about potential health effects, in some cases resulting in significant delays. In the absence of federal regulations, the EMF issue is driven heavily by public perception and public health concerns.
- **Stakeholder and ad hoc policy reports:** Organizations, such as the Bioinitiative Working Group, are becoming more forceful in impacting transmission line siting projects and are taking a strong stance on the potential health hazards of EMF exposures.
- **Public pressure on regulatory agencies:** Public citizen organizations have intervened with regulatory agencies, such as the Federal Communications Commission and the California Public Utilities Commission, calling for more stringent EMF limits and other regulations, guidelines, and/or standards.

Regulatory Drivers

- **U.S. Occupational Safety and Health Administration (OSHA) requirements:** OSHA establishes and enforces workplace regulatory exposure limits.
- **State and local regulations:** The State of California, Department of Education, has setback rules for transmission lines to protect school children from EMF exposure.

Non-Regulatory Drivers

- **World Health Organization (WHO):** The WHO, based on scientific evidence from childhood leukemia epidemiologic studies, has classified ELF/EMF as a possible human carcinogen (Group 2B).
- **International Committee on Non-Ionizing Radiation Protection (ICNIRP) and IEEE:** These two organizations establish extremely low frequency field (ELF) exposure guidelines and standards (IEEE) that are used world-wide to establish adequate human exposure levels.

- **Development of precautionary policies internationally:** The precautionary principle is aimed at avoiding or minimizing harm, if such indications exist and reasonable avoidance can occur. Its application is strong in Europe and is growing in the U.S.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed to address the near term and longer-term research needs on ELF EMF health issues. EPRI research results have been used in risk evaluations by national and international expert panels (e.g., NIEHS, IARC, WHO) and contributed to a better understanding of potential health effects of EMF exposure. Research results are also used to inform other regulatory agencies, decision makers, industry and the public.

- Research results are available to members to help manage their needs in a cost-effective manner and to make objective scientific information available to their customers on a timely basis.
- Results are accessible to other scientific organizations to inform the appropriate standard and guideline setting processes; the health effects information also is available to non-governmental agencies as well as to the public.

Results of EPRI ELF health research conducted over the past 35 years have been transferred to industry and the public in several forms:

- EPRI members who interact with constituents on EMF siting issues, draw on information provided by EPRI through advisory council meetings and research reports.
- EPRI EMF peer-reviewed research has been included in the IARC evaluation of EMF carcinogenicity and in the WHO Environmental Health Criteria. In addition to classifying EMF as a possible human carcinogen based on an epidemiologic relationship with childhood leukemia, these reviews also concluded that some diseases with great public health impact, such as breast cancer and cardiovascular diseases are likely not related to EMF exposure.
- EPRI has made its results available to other stakeholders including federal and state regulatory agencies to inform the appropriate rulemaking activities; the exposure assessment and health effects information also is available to non-governmental agencies as well as to the public.

PLAN

EPRI's future ELF EMF health research will focus on addressing the childhood leukemia issue and will work on the resolution of the remaining scientific uncertainties regarding the nature of the association, i.e., whether it is a non-causal or causal relationship. Other issues will be addressed as necessary and as they arise. The ultimate goal is to resolve remaining scientific uncertainties regarding the relationship between power frequency magnetic field exposure and potential health outcomes (e.g., childhood leukemia, neurodegenerative diseases).

Childhood Leukemia Research

- Epidemiology: The EMF childhood leukemia issue is addressed with a threefold approach: supporting high-quality, hypothesis-based health studies; analyzing and integrating available data; and synthesizing and evaluating the state of knowledge. The key elements include: 1) the TransExpo study to examine the role of selection bias in the epidemiologic association between magnetic fields and childhood leukemia in a highly exposed population. TransExpo is an international epidemiologic study of children living in multi-level apartment-buildings with built-in transformer rooms; 2) replication of the 2005 Draper study, which reported a positive association of distance to power lines with childhood leukemia; 3) evaluation of the feasibility of establishing a cohort of children with Down syndrome (a group at extremely high risk of developing childhood leukemia) to asses potential EMF effects. If deemed feasible, a study of this population group may be undertaken.
- Laboratory studies: Development of an in vivo mouse model of childhood leukemia adaptable to studying potential leukemogenic effects of magnetic fields and other suspected exposures, such as contact currents. Full-scale experiments are planned to evaluate the potential carcinogenic effects of magnetic fields in a transgenic mouse model of childhood leukemia with TEL-AML1 translocation

Additional Human Health Research

- In addition to childhood leukemia, there is some epidemiologic evidence linking adverse pregnancy outcomes and neurodegenerative diseases to residential and occupational exposure to ELF EMF. This research will investigate the relationship between magnetic field exposure and mis-

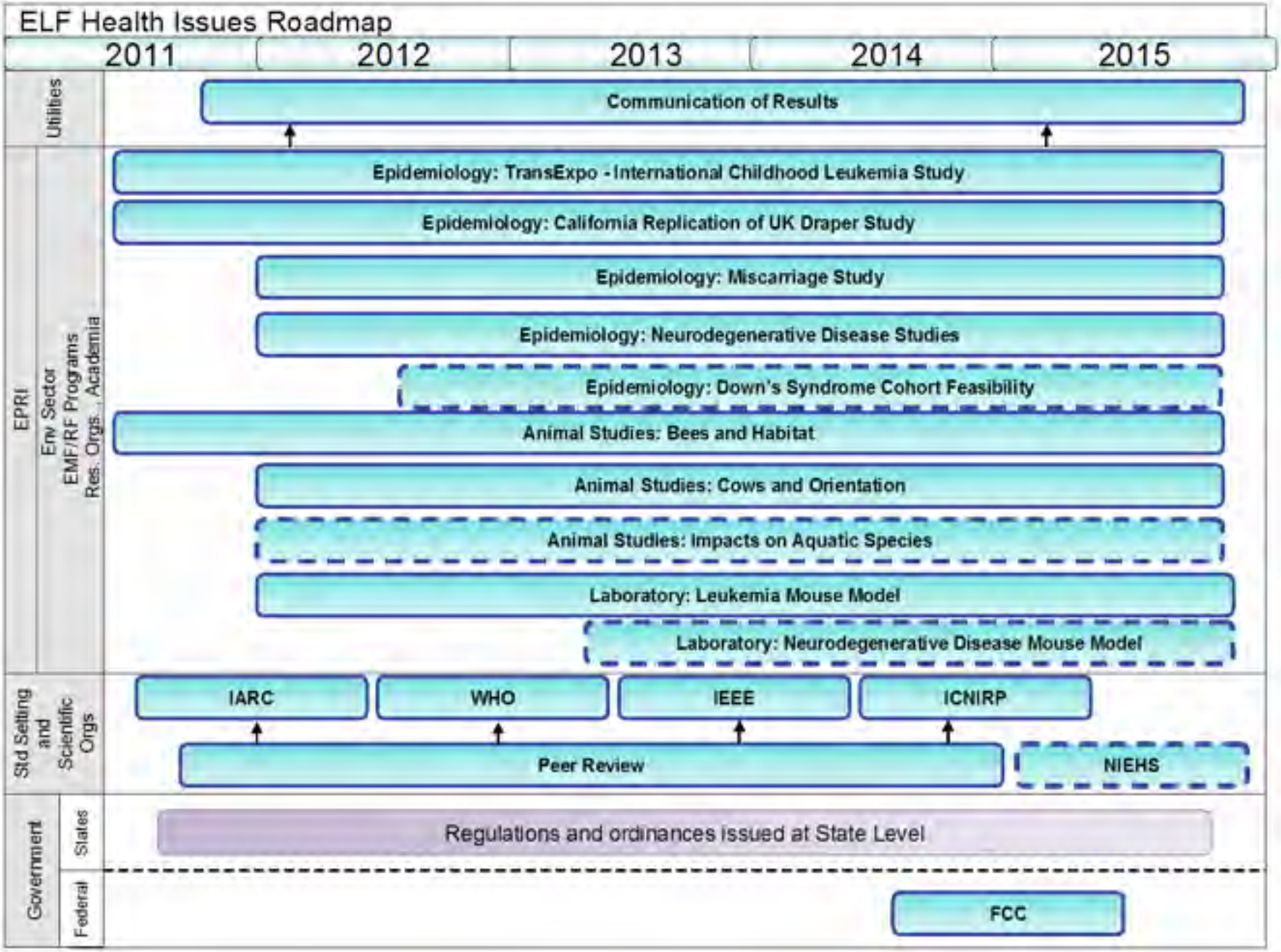
carriage among pregnant women. Evaluation of the potential effects of magnetic fields and electric shocks on development of neurodegenerative diseases are also planned in both epidemiologic and laboratory animal models.

Animal Health Research

- Offshore wind turbine projects are being proposed in many parts of the world. Undersea electric cables are used to connect multiple turbines, transport the electricity and connect it to the onshore grid. Concern has been raised about potential interference with navigation for groups of fish and aquatic mammals, including endangered and threatened species. Electromagnetic fields created by the electric cables running from the turbines and underwater noises and vibrations could affect orientation and navigational ability. This research will summarize the existing literature on the potential effects of EMF due to underwater high voltage cables on marine life, identify research gaps, and if necessary initiate new studies to mitigate impacts. Additional research work will evaluate potential effects magnetic fields on animal behavior and well being (e.g., bees and cattle).

RISK

Continued objective and independent research is necessary to resolve outstanding and emerging scientific uncertainties regarding ELF EMF health effects. EMF's continued classification as a possible human carcinogen is likely to continue to fuel public concern and opposition to transmission line siting and expansion of the Smarter Grid. This uncertainty has and is likely to continue to slow opportunities for energy efficient technologies, demand response programs and potential expansion of electric transportation. In the absence of reliable and authoritative research, the EMF issue can become clouded by studies and perceptions that are not scientifically rigorous and authoritative. The result may be overly conservative standards not fully supported by scientific evidence or delays in important projects, which can become costly. Credible research is necessary to objectively address issues that may become part of hearings or litigation. Increased scientific certainty about potential health and environmental risks will be valuable in defining options to mitigate those risks.


ELF Health Issues Roadmap
2011
2012
2013
2014
2015
Utilities
Communication of Results
EPRI
Env Sector
EMF/RF Programs
Res. Orgs., Academia
Epidemiology: TransExpo - International Childhood Leukemia Study
Epidemiology: California Replication of UK Draper Study
Epidemiology: Miscarriage Study
Epidemiology: Neurodegenerative Disease Studies
Epidemiology: Down's Syndrome Cohort Feasibility
Animal Studies: Bees and Habitat
Animal Studies: Cows and Orientation
Animal Studies: Impacts on Aquatic Species
Laboratory: Leukemia Mouse Model
Laboratory: Neurodegenerative Disease Mouse Model
Std Setting and Scientific Orgs
IARC
WHO
IEEE
ICNIRP
Peer Review
NIEHS
Government
States
Regulations and ordinances issued at State Level
Federal
FCC

DRAFT: TRANSMISSION AND DISTRIBUTION – EMF/RF EXPOSURE ASSESSMENT

ISSUE STATEMENT

The electric power grid and its associated technologies are undergoing fundamental innovation and redesign, frequently referred to as the Smarter Grid. The consequences of this change will serve the goals of both enhanced reliability and efficiency. These goals will become increasingly significant as we move to a progressively more diverse mix of electrical energy sources, with major new contributions from renewable energy (wind and solar) integrating into the current generation mix. A key to the future grid is an electronic communication and control system that can manage loads in real time, pinpoint trouble spots, and accumulate electrical use data critical for near- and long-term planning. One notable example is the EPRI's Green Circuits project, which is literally dissecting every element of the distribution system from substation to customer to provide data on electrical use and flow to enable proper load control, integration of major new demands (PHEV charging on a mass scale), and voltage optimization to drive up efficiency.

Such developments may also be accompanied by human exposures to environments that are novel or are viewed as novel by selected constituencies. EPRI has over 35 years of experience addressing health and safety issues associated with power frequency environments in both residential/community and occupational settings particularly with regard to 60-Hz electric and magnetic fields that accompany transmission lines and substations. EPRI's RF health and safety research was initially aimed at occupational exposure scenarios such as the co-location of cell phone panel antennas on transmission towers. Thus, research included source identification and characterization, evaluation of instrumentation, exposure assessment, near- and far-field dosimetry, exposure software, RF burn analysis, and most recently smart meter assessment and comment.

However, looking forward to the evolution of the electrical grid with its associated technologies, it will be critical to identify and characterize the electromagnetic environments resulting from emerging technologies, and where appropriate, to quantify human exposure and conduct health studies. This is a joint effort between EPRI's Power Deliver & Utilization and Environment Sectors.

DRIVERS

A number of underlying rules, regulations, and public perception issues are driving the need accurately characterize EMF and RF environments associated with emerging technologies.

Public Perception Drivers

- **Public opposition to siting of new transmission lines and smart meters:** As new transmission lines are proposed to move power from remote locations to population centers and new grid technologies are implemented (e.g., smart meters), the public is becoming increasingly concerned about potential health effects, causing project delays and cost increases. In the absence of federal regulations, the EMF issue is driven heavily by public perception and public health concerns.
- **The need to remain proactive:** Though concern from the public is currently focused on EMF from T&D facilities (including substations) and smart meters, such concern is likely to widen with the proliferation of new technology.

Regulatory Drivers

- **U.S. Occupational Safety and Health Administration (OSHA) requirements:** OSHA establishes and enforces workplace regulatory exposure limits (e.g., RF energy based on tissue heating).
- **State regulations:** The State of California, Department of Education, has setback rules for transmission lines to protect school children from EMF exposure.
- **FCC Enforcement Bureau (U.S.):** A Notice of Proposed Rulemaking on the use of dose quantities to comply with exposure guidelines is pending; the FCC develops enforceable public and occupational maximum exposure limits for RF.

Non-Regulatory Drivers

- **World Health Organization (WHO):** The WHO, based on scientific evidence from childhood leukemia epidemiologic studies, has classified ELF/EMF as a possible human carcinogen (Group 2B).

- **International Committee on Non-Ionizing Radiation Protection (ICNIRP) and IEEE:** These two organizations establish EMF exposure guidelines that are used world wide to establish safe levels of human exposure.
- **International studies on the health risks of EMF exposure:** Published studies require review for implication and impact to T&D facilities siting and operation.
- **Development of precautionary policies internationally:** The precautionary principle is aimed at avoiding or minimizing harm, if such indications exist and reasonable avoidance can occur. Its application is growing in the U.S. and is strong in Europe.

RESULTS IMPLEMENTATION

Research results are transferred in a number of ways to benefit EPRI members and other stakeholders including the public, federal and state regulatory agencies and non-governmental organizations. The information is used to inform rulemaking, provide background at public meetings, and provide the scientific community with the latest scientific findings on health and safety issues related to operation of the T&D system.

- Papers in the peer reviewed literature plus technical reports, resource papers and technical briefs and white papers that present research results or provide comment on studies conducted elsewhere.
- Instructional videos on topics that include EMF and RF exposure assessment, proper measurement techniques, and frameworks for in-house safety program.

PLAN

EPRI's EMF/RF exposure assessment research will address uncharacterized technologies and environments that with time are likely to be inhabited by either the general public or occupational populations. Two 2011 workshops were hosted by EPRI's PDU and Environment Sectors on new technologies that will produce potential exposures and health effects associated with such technologies. Based on these two intelligence-gathering activities, foreseen research includes:

Source Identification and Characterization

- With advances and developments in technology it becomes likely that the inventory of exposure sources will continue to expand and that the operating characteristics of existing technologies will evolve. This research will provide up-to-date knowledge of potential sources of human exposures to EMF and RF.

Exposure Assessment Technology

- With sources identified and characterized it becomes important to develop techniques for studying exposure patterns, This will be accomplished through measuring fields in areas occupied by people and when combined with time-location-activity behavioral data, will provide estimates of exposure. Alternatively, people could be instrumented with personal monitors that log exposure in the frequency range of interest. The challenge will be to dissect exposures attributable to one source (such as smart meters) from others (such as cell phone base stations) to attribute source contribution.

Human Exposure Assessment

- Health studies in humans cannot be conducted in the absence of valid exposure assessment. Even in the absence of an ongoing health study, exposure assessment research provides the data that allow health and safety concerns to be benchmarked against standards, such as the FCC's RF exposure limits or the EMF/RF exposure limits published by IEEE and ICNIRP.

Publication and Communication

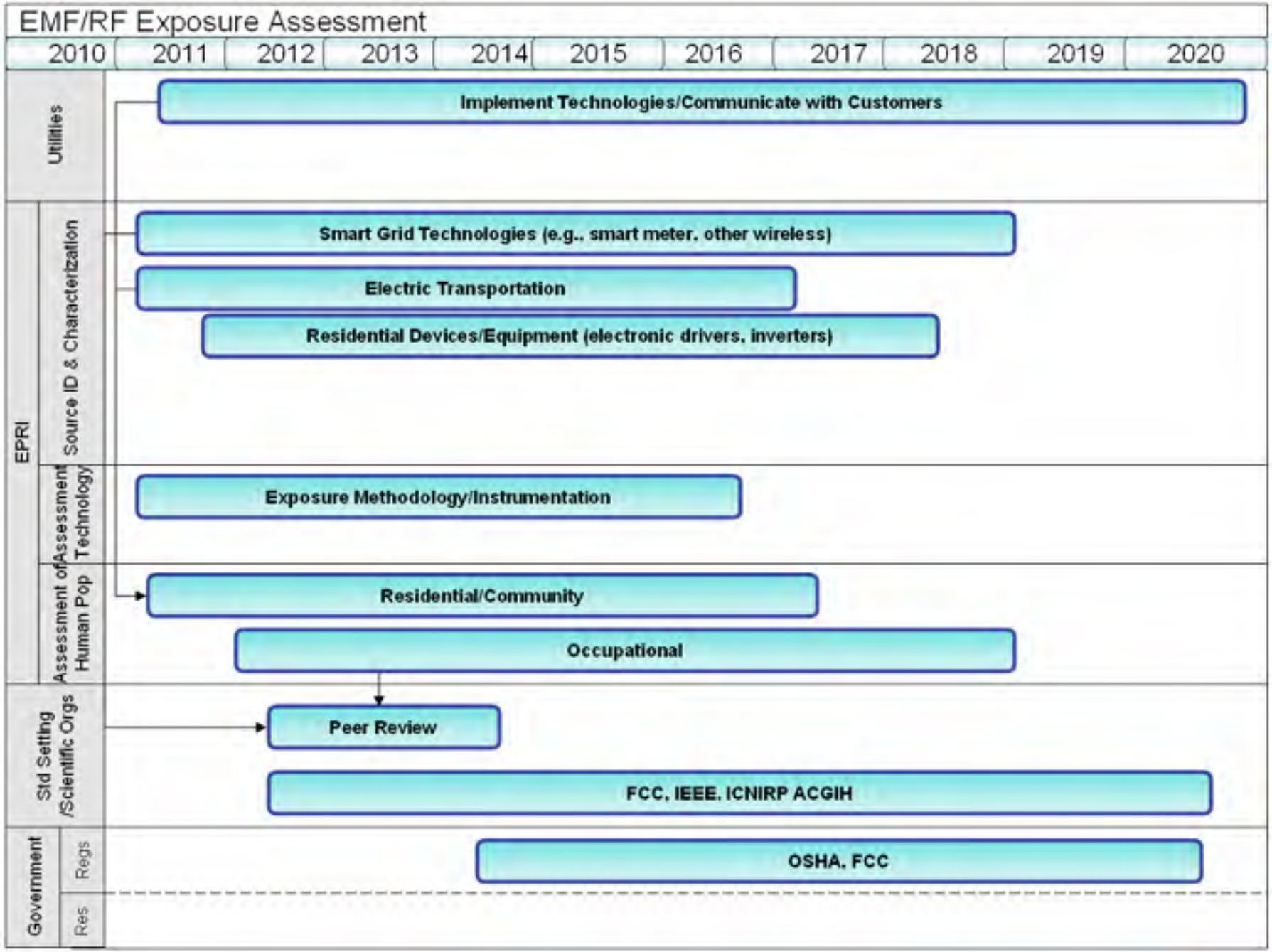
- The research results must reach both public constituencies and the EPRI membership community. This will require publishing in the peer-reviewed literature, which is the gold-standard for acceptability, providing material to the public at no cost, and providing information to members, enabling them to communicate in-house and to their customer base.

The ultimate goal is to have a full understanding of exposure distribution in human populations and complete characterization of human exposure to electric and magnetic field at relevant ELF and RF frequencies.

RISK

Continued objective and independent research is necessary to resolve outstanding and emerging scientific uncertainties regarding ELF/RF EMF health effects. EMF's continued classification as a possible human carcinogen is likely to continue

to fuel public concern and opposition to transmission line siting and expansion of the Smarter Grid. This uncertainty has and is likely to continue to slow opportunities for energy efficient technologies, demand response programs and potential expansion of electric transportation. In the absence of reliable and authoritative research, the EMF issue can become clouded by studies and perceptions that are not scientifically rigorous and authoritative. The result may be overly conservative standards not fully supported by scientific evidence or delays in important projects, which can become costly. Objective, independent research is necessary to credibly address issues that may become the subject of hearings or even litigation. Reducing scientific uncertainties about potential health and environmental risks will be valuable in defining options to mitigate those risks.


EMF/RF Exposure Assessment
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Utilities
Implement Technologies/Communicate with Customers
EPRI
Source ID & Characterization
Smart Grid Technologies (e.g., smart meter, other wireless)
Electric Transportation
Residential Devices/Equipment (electronic drivers, inverters)
Assessment Technology
Exposure Methodology/Instrumentation
Assessment of Human Pop
Residential/Community
Occupational
Std Setting /Scientific Orgs
Peer Review
FCC, IEEE, ICNIRP ACGIH
Government
Regs
OSHA, FCC
Res

DRAFT: INTEGRATED VEGETATION MANAGEMENT (IVM)

ISSUE STATEMENT

The right-of-way (ROW) transmission and distribution system is a major asset for the utility industry and is of very visible regulatory concern. ROW managers strive to balance the goals of providing safe and reliable transport of electricity while at the same time developing and maintaining vegetation that provides critical habitat for birds and other animals. The R&D needs are to identify vegetation management practices that reduce outages through the development of proactive risk reduction management systems; develop practices to improve habitat; and minimize the use of herbicides on transmission ROWs.

DRIVERS

Rules, regulations, and public perception issues are driving the need for research on vegetation management to reduce risks from the use of herbicides (transmission only) to control vegetation; to improve habitat; and to reduce outages through more effective tree trimming on the distribution system.

Public Perception Drivers

- **Herbicide use on the transmission system to control vegetation:** There is interest in reducing the use of herbicides to control vegetation on the transmission system and full implementation of IVM can be effective in reducing use.
- **Sustainable practices for vegetation management:** There is a growing interest on the part of the public to have companies incorporate sustainable practices, as a part of their business operations. While the focus of this interest has been on the transmission system there is interest in sustainable practices for vegetation management on the distribution system.

Regulatory Drivers

- **North American Electric Reliability Corporation (NERC) transmission vegetation management standards:** Evolving NERC vegetation management standards can provide an incentive for application of IVM practices, which if fully implemented can be an effective outage risk reduction strategy.

Non-Regulatory Drivers

- **Costs for outages on the transmission and distribution system:** There is a need to reduce outage costs. For the distribution system, which has more outages than the transmission system, it is also a significant public relations issue for the industry.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed to address the near- and longer-term research needs to reduce outage risks and improve habitat.

- Research results are available to participants to help prioritize their options in a cost effective and environmentally protective manner, and to make objective scientific information available to their customers on a timely basis.
- Results are available to other stakeholders, including federal and state regulatory agencies, to inform the appropriate rulemaking activities; some information also is available to non-governmental agencies as well as to the public.

A body of scientific research is being transferred to industry and the public in several forms:

- EPRI approaches and models are being used by many utility companies to update vegetation management plans for the transmission and distribution systems.
- EPRI transmission research, particularly the IVM Assessments, is being used to demonstrate the effectiveness of IVM as an outage risk reduction strategy. IVM can also meet cost reduction, environmental, including sustainability, and customer satisfaction goals.
- EPRI distribution research, particularly Reliability Centered Maintenance, is being used to reduce outages and costs of vegetation trimming.

PLAN

Over the next 5 years, IVM research will address the needs presented by evolving regulations and continuing vegetation management operations on the transmission and distribution

systems. Regulators and the public must be satisfied that operations minimize risk to human health and the environment and are sustainable. Research needs fall into the following major areas:

Sustainable Practices

- Further develop IVM and other methods to promote sustainable vegetation management practices on the transmission and distribution systems, with attendant ecological and cost benefits.
- Develop economic business case for IVM on a preventive vs. corrective maintenance basis.
- Support the development of a transmission vegetation management sustainable and certification program with a third party, such as the Utility Arborist Association.
- Develop practices to reduce the spread of invasive species on the transmission system, with a focus on using IVM as a tool to reduce spread.
- Identify natural occurring herbicides as alternatives to traditional herbicides for vegetation control on the transmission system.

Carbon Emissions & Climate Change

- Develop information on CO_2 storage potential emissions impacts for commonly used transmission and distribution vegetation management practices to support sustainability decisions.
- Evaluate potential changes in vegetation dynamics, and resultant costs, under varying assumptions of changes in regional climate.

Technology Transfer

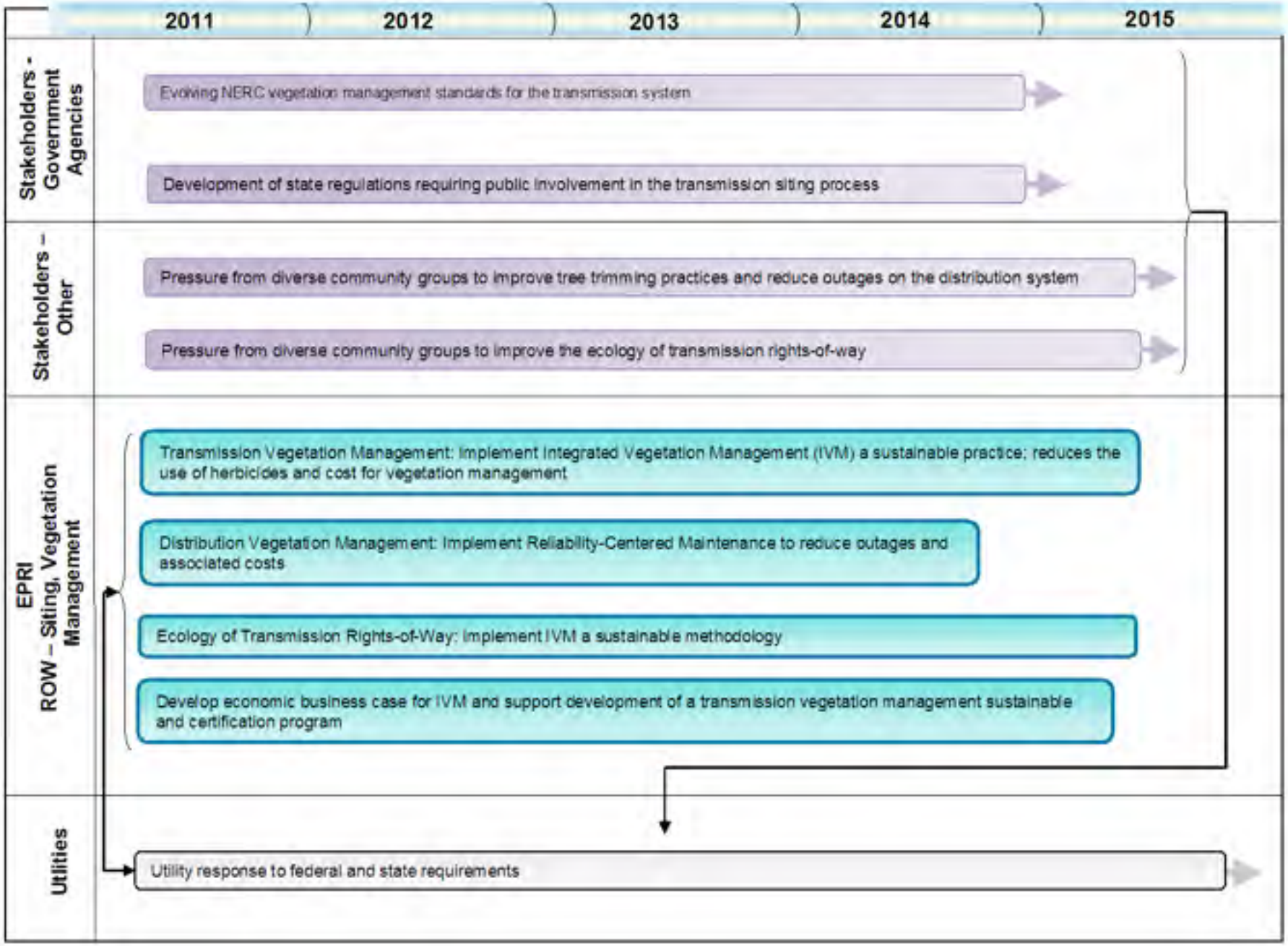
- Work with utilities to increase the use of EPRI developed models and guidelines, such as the Reliability Centered Maintenance tool and the IVM Principles and Criteria.

Case Studies

- Continue to conduct the transmission IVM Assessments, which are a significant activity for identifying transmission research needs and for instilling the benefits of IVM, such as cost reduction for vegetation control and development of sustainable practices.
- Conduct Reliability Centered Maintenance assessments on the distribution system, using the EPRI modeling framework, to demonstrate cost and reliability benefits
- Develop tree failure risk reduction strategies for the distribution system, in concert with Reliability Centered Maintenance concepts, to reduce outages.

RISK

Reliability of the transmission and distribution systems and improvement of the habitat within these systems is very much of concern to regulators and the public. Violations of NERC vegetation management standards on the transmission system can result in significant fines and burdensome reporting requirements. Reducing potential risk from the use of herbicides on the transmission system to control vegetation is upper most in the minds of regulators and the public. Reducing outages on the distribution system, where most outages occur, is also important from a customer point of view. EPRI research will focus on understanding and mitigating these risks to reduce operational costs, improve public relations and ecological conditions.


2011
2012
2013
2014
2015
Stakeholders - Government Agencies
Evolving NERC vegetation management standards for the transmission system
Development of state regulations requiring public involvement in the transmission siting process
Stakeholders – Other
Pressure from diverse community groups to improve tree trimming practices and reduce outages on the distribution system
Pressure from diverse community groups to improve the ecology of transmission rights-of-way
EPRI ROW – Siting, Vegetation Management
Transmission Vegetation Management: Implement Integrated Vegetation Management (IVM) a sustainable practice; reduces the use of herbicides and cost for vegetation management
Distribution Vegetation Management: Implement Reliability-Centered Maintenance to reduce outages and associated costs
Ecology of Transmission Rights-of-Way: Implement IVM a sustainable methodology
Develop economic business case for IVM and support development of a transmission vegetation management sustainable and certification program
Utilities
Utility response to federal and state requirements

DRAFT: PCB CHARACTERIZATION AND MITIGATION

ISSUE STATEMENT

PCB-containing dielectric fluids were used extensively in electrical equipment until their use was banned in the late 1970s. Utility companies are continuing to remove equipment that contains PCBs. This equipment can be difficult to identify, so strategies for identification and removal are needed. PCBs can also be difficult to remediate, so approaches to cleanup of contaminated surfaces, soil, and water are needed. Some regulators and risk assessors are focusing on individual PCB congeners, especially the dioxin-like congeners, and may require congener-specific monitoring. Information about congener-specific monitoring methods and risk assessment approaches will be needed. Implications of new regulations must be understood.

DRIVERS

Rules, regulations, and public perception issues are driving the need for research on identifying, mitigating, and remediating PCBs in electrical equipment and in the environment.

Public Perception Drivers

- **Public opposition to perceived toxic chemicals:** The public is becoming increasingly concerned about exposure to toxic chemicals and the potential impacts on human health, ecological systems, and the environment.
- **Public pressure on regulatory agencies:** Public citizen organizations have intervened with regulatory agencies, such as the United States Environmental Protection Agency, calling for removal of PCB-containing equipment and remediation of PCBs in the environment.

Regulatory Drivers

- **PCB rulemaking under the Toxic Substances Control Act:** PCB issues are of continuing concern and regulatory interest, particularly the various types of PCB compounds. In 2010, USEPA issued an Advanced Notice of Proposed Rulemaking to reassess use authorizations for PCBs. The rulemaking is likely to be finalized in 2013.

Non-Regulatory Drivers

- Risk studies on PCB exposure and toxicity: Both academic and industry studies on risks from PCB use and exposure continue to contribute to the large body of conflicting information on PCBs.

RESULTS IMPLEMENTATION

A comprehensive research plan has been developed to address the near term and longer-term research needs on PCBs.

- Research results are available to participants to help manage their needs in a cost effective and environmentally protective manner, and to make objective scientific information available to their customers on a timely basis.
- Results are also available to other stakeholders, including federal and state regulatory agencies, to inform the appropriate rulemaking activities; information also is available to non-governmental agencies as well as to the public.

The body of scientific research developed has been transferred to industry and the public in several forms:

- EPRI research has been used by utility companies to train both environmental and operations staff on procedures for assessing and removing PCB-containing equipment, as well as for supporting communications staff in addressing stakeholder concerns.
- EPRI results have been incorporated into industry comments on proposed rules, supporting or challenging proposed rule changes consistent with the science.

PLAN

Over the next 5 years, the PCB research will focus on addressing the needs presented by the evolving rules and continuing operations. Regulators and the public must be satisfied that PCB use, mitigation, and removal pose no unacceptable health or environmental impacts. Research needs are divided into 4 major areas:

Identification of Equipment Containing PCBs

- Improved ability to identify transformers that contain PCBs without analytical testing by correlating ranges of PCB concentrations with information commonly found on equipment faceplates and related records.
- Improve ability to identify electrical equipment that contains PCBs butt cannot be tested without compromising performance, including liquid-filled bushings and capacitors, by correlating ranges of PCB concentrations with information commonly found on equipment faceplates and related records.

Impacts of Regulating PCBs as Dioxin-like Compounds

- Enhance understanding of proposed rules by analyzing and comparing the expected requirements for dioxin-like PCBs with current requirements for Aroclor PCBs.

Congener-specific PCB Issues

- Track and investigate regulatory and risk issues related to congener-specific treatment of PCBs in risk assessments, proposed rules, and regulatory requirements.
- Support industry response and compliance by providing objective understanding of risk.

PCB Remediation

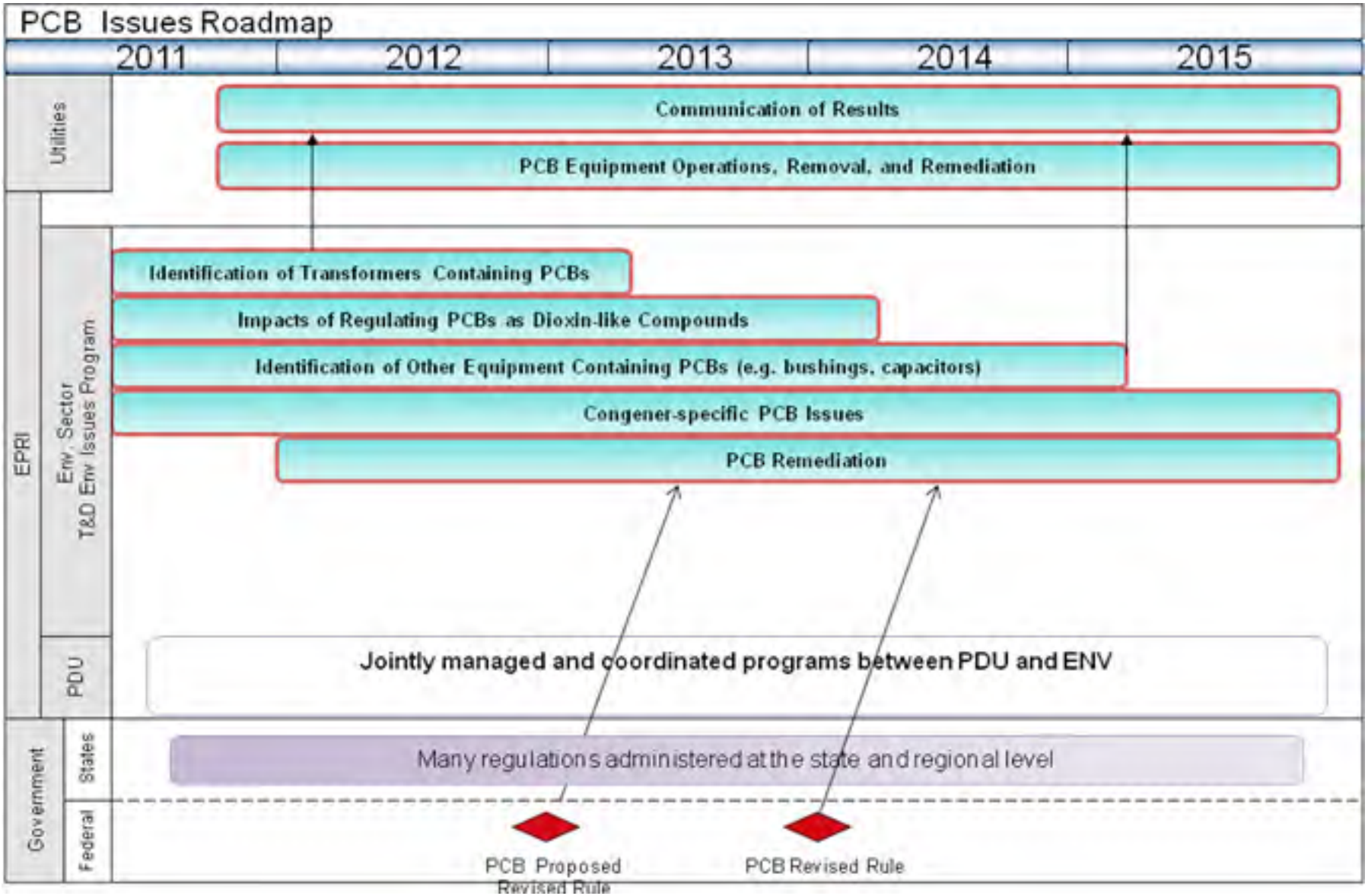
- Expanded options for remediation of PCB-contaminated surfaces, soil, and water by investigating and demonstrating chemical, biological, and physical approaches.

RISK

Continued objective and independent research is necessary to resolve outstanding and emerging scientific uncertainties regarding PCB identification, mitigation, and remediation.

The risks that will be mitigated by this work include:

- Environmental Compliance – Regulation of PCBs under the Toxic Substances Control Act, with potential augmentation or substantial change to the regulatory scheme, as well as continuing publicity and resulting public pressure will force additional removal and cleanup of PCBs. This research is focused on reliably identifying equipment that contains PCBs, so operations can be environmentally sound. The research also addresses risks, to encourage improved decision making toward protection of human health, ecological systems, and the environmental by optimal use of resources.
- Costs – Identification, removal, and remediation of PCBs must be conducted in a cost-effective manner. This research is focused on streamlining and facilitating those processes.


PCB Issues Roadmap
2011
2012
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Utilities
Communication of Results
PCB Equipment Operations, Removal, and Remediation
EPRI
Env. Sector
T&D Env Issues Program
Identification of Transformers Containing PCBs
Impacts of Regulating PCBs as Dioxin-like Compounds
Identification of Other Equipment Containing PCBs (e.g. bushings, capacitors)
Congener-specific PCB Issues
PCB Remediation
PDU
Jointly managed and coordinated programs between PDU and ENV
Government
States
Many regulations administered at the state and regional level
Federal
PCB Proposed Revised Rule
PCB Revised Rule

DRAFT: TRANSMISSION AND DISTRIBUTION – RADIOFREQUENCY HEALTH ISSUES

ISSUE STATEMENT

Public confidence in safe and reliable operation of the power delivery system will be crucial as the power grid is expanded, upgraded, and modernized to accommodate emerging transmission and distribution (T&D) technologies. New smart grid technologies are also being integrated into the power grid to further increase energy efficiency and reliability. These technologies include two-way, radio-frequency (RF) wireless communications (e.g., smart meters), along with a growing number of antenna types (for cell phones, pagers, etc.) installed on the grid infrastructure. The public is becoming increasingly concerned with potential health effects associated with RF exposures. This public concern, originally related to wireless cell phones, has now extended to other applications employing wireless communications. The recent International Agency for Research on Cancer (IARC) classification of RF fields as a Class 2B possible carcinogen will continue to raise concerns of potential RF exposure health effects for workers and the public. In spite of extensive research effort to investigate potential health effects of RF exposure, significant scientific uncertainties remain. The World Health Organization (WHO), similarly to other organizations, has called for further research in this area. Ensuring public and worker safety in new exposure environments will be critical to the success the future grid as it is built out, upgraded, and maintained.

DRIVERS

A number of underlying rules, regulations, and public perception issues are driving the need for research on enhancing and improving the environmental compatibility of the T&D system.

Public Perception Drivers

- **Public opposition to new technologies including smart meters:** As new grid technologies are implemented (e.g., smart meters), the public is becoming increasingly concerned about potential health effects which is causing delays in some locations. The RF health issue is driven heavily by public perception and public health concerns.
- **Stakeholder and ad hoc policy reports:** Organizations, such as the Bioinitiative Working Group, are taking a strong stance on the potential health hazards of RF exposures, including new smart grid technologies.
- **Public pressure on regulatory agencies:** Public citizen organizations have intervened with regulatory agencies, such as the Federal Communications Commission and the California Public Utilities Commission, calling for more stringent EMF limits and other regulations, guidelines, and/or standards.

Regulatory Drivers

- **U.S. Occupational Safety and Health Administration (OSHA) requirements:** OSHA establishes and enforces workplace regulatory exposure limits (e.g., RF energy based on tissue heating).
- **State and local regulations:** Ordinances have been proposed recently to label mobile phones based on specific absorption rates.
- **U.S. Federal Communications Commission (FCC):** The FCC develops enforceable public and occupational maximum exposure limits for RF.

Non-Regulatory Drivers

- **World Health Organization (WHO):** The International Agency for Research on Cancer (IARC), a WHO specialized agency, has classified RF fields as a possible human carcinogen (Group 2B) based on scientific evidence from mobile phone and glioma epidemiologic studies.
- **International Committee on Non-Ionizing Radiation Protection (ICNIRP) and IEEE:** These two organizations establish RF exposure guidelines and standards (IEEE) that are used world-wide to establish recommended human exposure levels.
- **Development of precautionary policies internationally:** The precautionary principle is aimed at avoiding or minimizing harm, if such indications exist and reasonable avoidance can occur. Its application is strong in Europe and is growing in the U.S.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed to address the near term and longer-term research needs on RF health issues. Research results are being and will be used to contribute to better understanding of potential health effects of RF exposure. The results will be used for informing the standard setting scientific and regulatory process, decision makers, industry and the public.

- Research results are available members to help manage their needs in a cost-effective manner and to make objective scientific information available to their customers on a timely basis.
- Results are accessible to other scientific organizations to inform the appropriate standard and guideline setting processes; the health effects information also is available to non-governmental agencies as well as to the public.

EPRI work on RF research has been transferred to industry and the public in several forms:

- Results from the occupational health research have been integrated into electric utility RF safety programs.
- The results from EPRI RF exposure assessment have been included in the report issued by the California Council on Science and Technology on potential RF health effects and smart meters in 2011.
- The California Public Utility Commission has extensively relied on EPRI results in several of their proceedings.

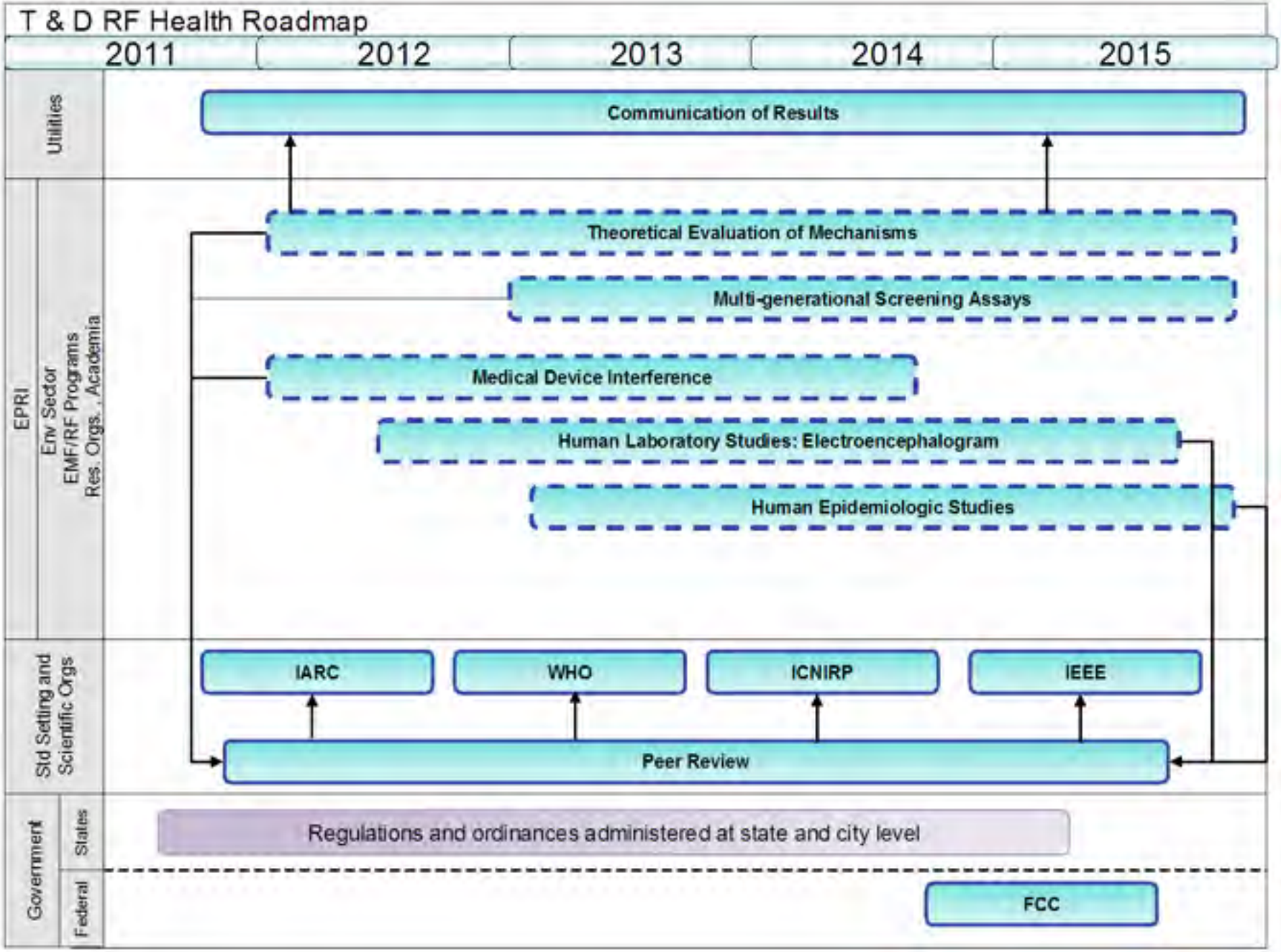
PLAN

EPRI's RF Health research will focus on addressing the needs presented by the evolving T&D infrastructure of the future electric grid. Regulators and the public must be satisfied that the grid can be operated safely and pose no unacceptable health impacts. The ultimate research goal it to resolve remaining scientific uncertainties about potential biological and health effects at low level exposure to RF fields.

- Investigate occupational health and safety issues relevant to RF environments, including interference with implanted medical devices (such as cardiac pacemakers).
- Conduct human laboratory studies and explore whether observed physiologic effects may result in adverse health outcomes. Human laboratory studies include investigations of cognitive function, sleep and electroencephalography changes.
- Investigation of potential long-term effects of RF exposures on laboratory animals.
- Conduct epidemiologic studies to understand potential long-term effects of environmental exposures to RF.
- Address other health priorities, including those deemed relevant for RF exposures that impact efficient power delivery and reliability.
- Understand the general population distribution of RF exposures resulting from technologies introduced and supported by the Smarter grid.

RISK

Continued objective and independent research is necessary to resolve outstanding and emerging scientific uncertainties regarding RF EMF health effects. The recent classification of RF as a possible human carcinogen is likely to fuel public concern and opposition to the expansion of the Smarter Grid. This uncertainty has and is likely to continue to slow opportunities for energy efficient technologies, demand response programs and potential expansion of electric transportation. In the absence of reliable and authoritative research, the RF EMF issue can become clouded by studies and perceptions that are not scientifically rigorous. The result may be overly conservative standards not fully supported by scientific evidence or delays in important projects, which can become costly. Credible research is necessary to objectively address issues that may become part of hearings or even litigation It is critical that any potential RF health issues are identified and addressed as grid modernization proceeds.


T & D RF Health Roadmap
2011
2012
2013
2014
2015
Utilities
Communication of Results
EPRI
Env Sector
EMF/RF Programs
Res. Orgs., Academia
Theoretical Evaluation of Mechanisms
Multi-generational Screening Assays
Medical Device Interference
Human Laboratory Studies: Electroencephalogram
Human Epidemiologic Studies
Std Setting and Scientific Orgs
IARC
WHO
ICNIRP
IEEE
Peer Review
Government
States
Regulations and ordinances administered at state and city level
Federal
FCC

DRAFT: TRANSMISSION LINE SITING AND PERMITTING

ISSUE STATEMENT

Transmission line siting is complex and it involves many departments within a utility. A comprehensive understanding of the siting process and issues is essential to acquiring permits in a timely manner. An application for a new line may trigger Federal Energy Regulatory Commission (FERC) or North American Electric Reliability Corporation (NERC) regulations, in addition to state standards and guidelines. The applicant must therefore be aware of all these requirements and demonstrate due diligence in justifying a new line as the best choice when compared to alternatives, such as upgrading or up rating existing lines. Research is needed to address the major challenges involved in the process of siting new lines, and to identify the range of mitigating measures to alleviate potential impacts that may be caused by the new lines.

DRIVERS

New rules, regulations, and public perception issues are driving the need for research on transmission line siting. The public, in particular, has become more sophisticated in questioning the need for new transmission lines. Utilities need more information and tools to address regulations and stakeholder concerns to assure the reliability of the transmission system is not jeopardized from the delay of the siting approval process.

Public Perception Drivers

- **Public opposition to the siting of new transmission lines:** The public is becoming increasingly vocal and sophisticated in analyzing the need for new transmission lines.
- **Public pressure on federal agencies and state legislatures:** Public citizen organizations lobby federal agencies and state legislatures to develop regulations to guide transmission line siting.

Regulatory Drivers

- **FERC and NERC:** To support the siting of new transmission lines and the upgrading of existing lines, FERC and NERC have developed new standards and guidelines requiring strict adherence.

Non-Regulatory Drivers

- **Transmission system reliability:** Utilities must assure the reliability of the transmission system, including the need to develop additional capacity in a cost and environmental effective and expeditious manner.

RESULTS IMPLEMENTATION

A comprehensive plan has been developed to address the near- and longer-term research needs to assist utilities in siting new transmission lines and upgrading existing transmission lines.

- Research results are available to participants to help prioritize their options in a cost effective and expeditious manner, and to make objective scientific information available to their customers on a timely basis.
- Results are available to other stakeholders, including federal and state regulatory agencies, to inform the appropriate rulemaking activities; information also is available to non-governmental agencies as well as to the public.

A body of scientific research is being transferred to industry and the public in several forms:

- EPRI approaches and case studies are used by utility companies to aid in the siting of new transmission lines and upgrade existing transmission lines, such as the EPRI-GTC Siting Manual.
- Workshops are conducted to gain an understanding of research needs and transfer information.
- EPRI's transfer of knowledge emphasizes cross departmental coordination within a power utility to assure that all factors (electrical, engineering and environmental) are shared and addressed adequately.

PLAN

Over the next 5 years, transmission line siting research will focus on addressing the needs presented by evolving regulations and continuing input from public citizen organizations. Regulators and the public must be satisfied that a proposed transmission line or upgrade to an existing line is required,

that concerns have been addressed and impacts have been mitigated. Research includes the following:

New Transmission Line Siting

- Explain the technical basis for current various regulatory requirements that must be met in justifying and siting new transmission lines and provide out reach to various stakeholders.
- Keep abreast of regulatory developments and provide comments on proposed regulations, as appropriate, based on EPRI research.

Alternatives to New Transmission Line Siting

- Evaluate alternatives to new transmission line siting, such as operating voltage/current capacity, new circuits and use of underground cables will be undertaken to support decision-making.
- For alternatives, provide an objective and clear evaluation of capital investment and costs, electrical losses and maintenance, reliability, environmental effects, etc. to support decision-making.

New Methodologies/Technologies as Related to Regulatory Requirements

- There are new methodologies developed through EPRI research that can be applied to exiting power systems to increase transmission capacities instead of building a new line. These methodologies require evaluation in order to justify an up rating of a transmission line and satisfy regulatory requirements.

Case Studies

- Present and evaluate utility case studies at workshops as a learning tool.

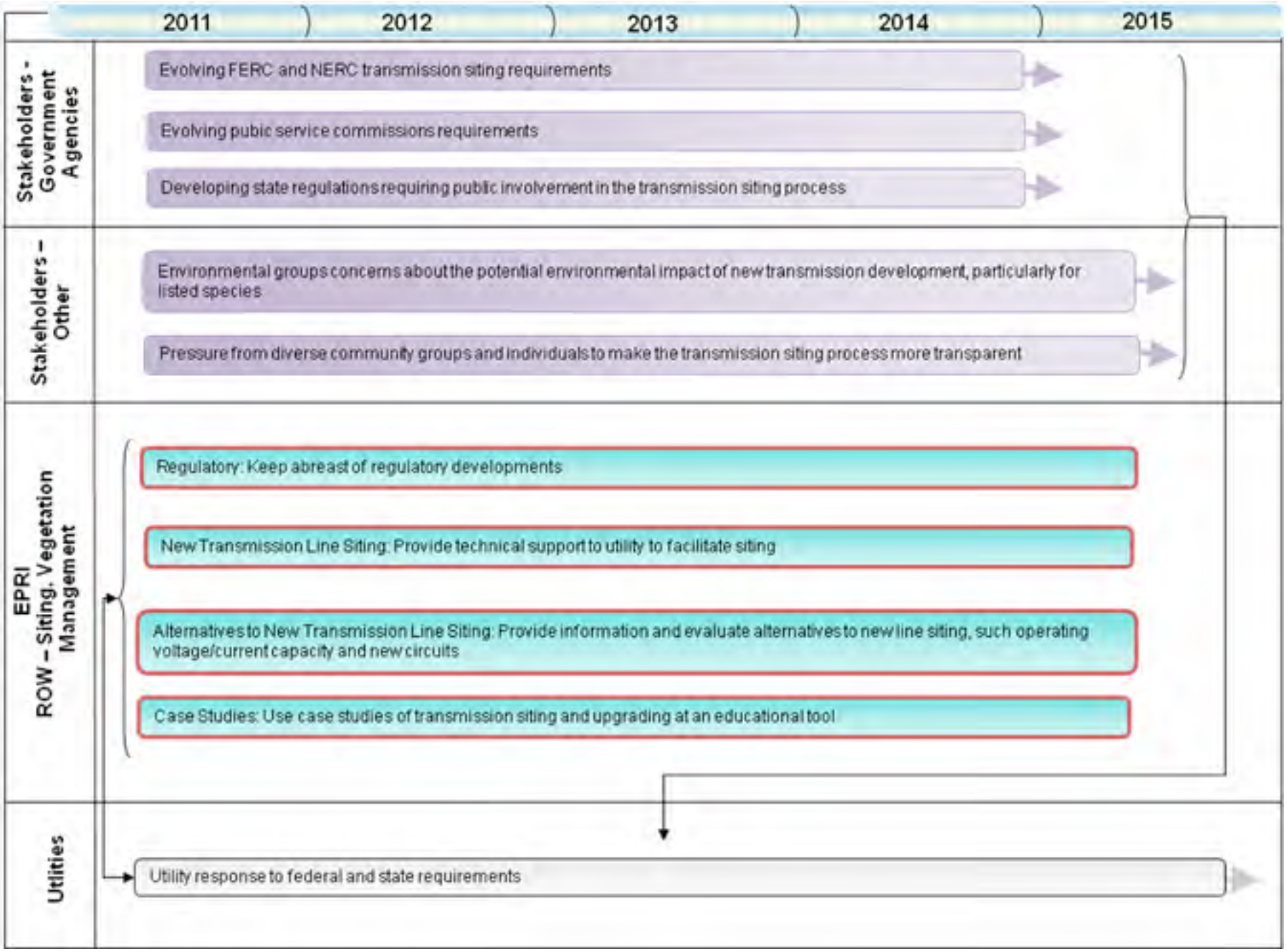
Reporting

- A guide for successfully siting new lines will be prepared. The guide will provide information on transmission line siting requirements and process; methodologies that are used to evaluate options in justifying new lines and, a siting manual that can be shared among various departments within a power company providing insight into the complete transmission line siting process. Lessons learned from past siting cases will be incorporated into the guide.
- A guide or technical report on new methodologies/technologies for up rating existing transmission line to assist utilities in addressing technical and regulatory issues.

RISK

As the US population shifts geographically and continues to grow and remote renewable generation (such as wind) is built, an expansion of the transmission system is needed to satisfy demand and assure system reliability. Continued objective and independent research is necessary to support development of the transmission system to preclude failure. Regulatory oversight at the federal and state levels and continuing public pressure require an all inclusive process to assure developmental success. Any transmission siting decision must be based on minimizing societal and environmental impacts, while also being cost-effective from an engineering and electrical standpoint.

The risk of not having this research is delays in acquiring right-of-ways for new lines or upgrading existing lines. The consequences are lowering the reliability of power systems and increasing power interruptions to customers.


2011
2012
2013
2014
2015
Stakeholders - Government Agencies
Evolving FERC and NERC transmission siting requirements
Evolving pubic service commissions requirements
Developing state regulations requiring public involvement in the transmission siting process
Stakeholders – Other
Environmental groups concerns about the potential environmental impact of new transmission development, particularly for listed species
Pressure from diverse community groups and individuals to make the transmission siting process more transparent
EPRI ROW – Siting, Vegetation Management
Regulatory: Keep abreast of regulatory developments
New Transmission Line Siting: Provide technical support to utility to facilitate siting
Alternatives to New Transmission Line Siting: Provide information and evaluate alternatives to new line siting, such operating voltage/current capacity and new circuits
Case Studies: Use case studies of transmission siting and upgrading at an educational tool
Utilities
Utility response to federal and state requirements

DRAFT: WATER AND ECOSYSTEMS

ISSUE STATEMENT

The electric utility industry is a large stakeholder in freshwater use, second only to agriculture in freshwater withdrawals. Over the past two decades, utilities have met load growth requirements while simultaneously lowering freshwater requirements. Utilities also discharge wastewater, which can be contaminated with metals and other dissolved and suspended solids. The withdrawal, use and discharge of water by utility generators contribute to adverse aquatic impacts and human health effects. As a result, industry faces a myriad of new federal and state regulations and community pressures that will affect how utilities use and discharge water. Utilities also face challenges from water quality and quantity reductions due to urbanization, population growth, droughts and potential climate variability. These pressures are already impacting the uprate and operation of exiting plants and permitting of new generating units. Over the next decade, new air quality control technologies and new fuels (e.g., biomass) will be deployed, changing the character of power plant wastewater discharges and raising a host of new issues. As air emissions are controlled to satisfy more stringent requirements for air pollutants under existing and future regulatory scrutiny, pollutant releases to wastewater and solid waste streams also become more important.

Key issues that need to be addressed include:

- Reduction of water needs for power generation and power generation needs for water transport and treatment (Energy-Water Nexus).
- Characterization and reduction of entrainment, impingement and thermal discharge impacts.
- Understanding water and wastewater requirements of new generation and control technologies such as carbon dioxide (CO_2) controls employing ammonia, amines, and other compounds.
- Evaluation of liquid and solid waste streams as flue gas is cleaned to greater levels, i.e. flue gas desulphurization and mercury controls.
- Accurate measurement of low level wastewater contaminants.
- Assessment and management of fate and transport of air emissions and their transport and cycling in aquatic ecosystems (e.g., air-water linkages).

DRIVERS

There are a number of specific state and federal regulatory and legislative drivers affecting water use and discharge by the electric sector. There also are numerous locally-based agencies with water use regulatory powers.

Fish Protection Regulations –These regulations will require new entrainment and impingement reductions at cooling water intakes for once through cooled plants. New plants must meet a cooling tower performance standard, and many existing plants may be required to meet the same performance. Thermal limits for cooling water discharge are also being tightened.

Effluent Guidelines – EPA is currently revising the effluent guidelines for the steam electric power generating industry. These new guidelines are expected to result in tighter limits for power plant discharge and may require plants to install new wastewater treatment technologies. Since coal properties can significantly influence treatment effectiveness, there is significant need for a variety of cost effective and reliable treatment systems and understanding of what wastewater properties affect treatment efficiency.

Total Maximum Daily Loads (TMDLs) – EPA has a principal strategic objective to use a watershed approach to achieve protection of water resources through the implementation of Total Maximum Daily Loads (TMDLs) and watershed-integrated National Pollution Discharge Elimination System (NPDES) permits. TMDLs can lead to discharge permits more restrictive than current NPDES permits. Regional TMDLs are

being developed for nutrients, mercury and other pollutants. Reduction of atmospheric emissions is being considered by states and EPA to satisfy a variety of TMDLs including pH, nitrogen, nutrients and mercury. The electric power industry needs proven scientific tools to critically evaluate the calculation, allocation, and implementation plans of regular and regional TMDLs.

National and State Air Quality Regulations – As air quality regulations are adopted for ozone, PM, SO_2, NOx, and HAPS, new control technologies and fuels will continue to impact water and wastewater quality and quantity.

Water Quality Criteria – EPA develops national ambient water quality criteria, which are then implemented by the states. Utilities are subject to limits on metals and other substances in their discharge permits based on existing criteria and any new criteria that are developed and implemented. EPA has plans to review all ambient water quality criteria for possible revision over the next 5 to 10 years. EPRI research is needed to demonstrate the non-linear dose-response of certain metals in the environment to reduce reliance on default assumptions and uncertainties in the scientific basis for human health risk assessments, leading to sounder regulatory decisions for wastewater discharges by EPA. Research into aquatic impacts and human health effects will also support the development of science-based criteria and site specific water quality criteria.

Safe Drinking Water Act (SDWA) – The SDWA establishes Maximum Contaminant Levels (MCLs) for compounds such as arsenic that may cause adverse health effects. Arsenic is a component of coal that is captured by environmental controls systems and thus is found in solid or liquid by-products. MCL levels have implications for storage or use of by-products, discharge of waste water and groundwater contamination.

State Rules and Permits – States issue NPDES permits to meet EPA mandates. States always have the option of going beyond EPA rules by adopting stricter limits on water use and discharge. It is critical that states are equipped with the best tools and scientific information to make technical evaluations of the bases of NPDES permits.

Non-Regulatory Drivers; Public Relations/ Environmental Stewardship; Potential Litigation – All EPA rules are subject to litigation by third parties. While many challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Many interveners and third parties continue to push EPA and individual states to reduce water use and discharge to very low levels. Power companies are also vulnerable to pressures from community businesses and customers to take actions to address perceived environmental issues.

RESULTS IMPLEMENTATION

EPRI water and ecosystem research provides high value to the electric industry and society by:

- Anticipating and addressing critical issues well before they become regulatory concerns;
- Collaborating on research with other organizations both financially and scientifically; and
- Providing a unique multidisciplinary approach to addressing issues of scientific and technical importance to the electric sector.

EPRI regularly creates reports, publishes in peer-reviewed journals, and briefs state and federal agencies on its research results. EPRI researchers are frequently asked to participate in joint research programs. State and federal agencies often incorporate EPRI research results into the decision-making process. Several examples include:

- EPA has acknowledged many of EPRI's research results in the development of new fish protection regulations.
- EPRI research on the cancer slope factor for arsenic (including a joint project with EPA) has been crucial in clarifying the science and providing comments to EPA to reconsider its proposal. This research includes demonstration of the non-linearity of the cancer slope factor, and pathways into the human food chain.
- EPRI data and results have been used to inform regulators on several site-specific water quality criteria that have prevented overly conservative permit limits.
- EPRI collaborated with the U.S. Department of Energy to investigate the energy/water nexus and evaluate the impact limited water resources have on existing and future electric power generation.
- USEPA and USDA have funded EPRI research on water quality trading as a tool for meeting water quality goals, similar to other air and carbon trading programs.

PLAN

Water and ecosystem issues must be addressed in a comprehensive manner including characterizing water requirements and discharges; reducing impacts of withdrawals; assessing how contaminant concentrations and speciation affects treatment and bioavailability; and evaluating impacts on human health and the environment. This involves careful data collection and analysis, understanding of overall water use within the plant, understanding chemical transformation and transport in the aquatic environment and food chain, and the ultimate affects on aquatic communities and human health. This will also require deployment of sophisticated analytical measurement methods, development of advanced environmental models, and execution of detailed studies to elucidate the role of power plants versus other sources in contributing to potential human health and ecosystem impacts. Specific actions that need to be undertaken to address current and anticipated issues include:

1. *Conduct research on aquatic impacts of once-through cooling as input to regulatory and legislative rulemaking:* Concern for aquatic communities is the primary driver for regulations governing entrainment and impingement at cooling water intakes and thermal discharges. Scientifically rigorous, objective and peer-reviewed studies are critical to demonstrate level of impact, and cost-effective methods for minimizing such impacts.

2. *Effectively characterize wastewater discharges from current and emerging technologies and identify treatment alternatives:* Characterization of wastewater from current and emerging fossil fuel-fired generation technologies will continue to be a critical need for understanding treatment technology performance, conducting health risk studies, and supporting effluent guidelines revisions.

3. *Conduct basic research on aquatic impacts and human health effects from wastewater discharges as input to regulatory and legislative rulemaking:* Concern for aquatic environments and human health effects are primary drivers for controls on wastewater discharge from all industrial sources, including power plants. Thus, it is critical that the role of the electric sector in contributing to any adverse environmental and health effects be clearly delineated. Scientifically rigorous, objective and peer-reviewed studies become the foundation for establishing regulations and discharge limits. Aquatic impact and health based reviews are conducted by EPA on an ongoing basis, requiring EPA and states to continuously find means to reduce emissions if the science requires lower pollutant concentrations. Understanding the role of the electric sector in contributing to adverse aquatic impacts or health consequences will continue to be a critical need.

4. *Develop methods to evaluate and address the impacts of water availability to the power generation sector and other stakeholders, with conservation technologies to reduce watershed impacts:* Water is a shared resource critical to economic and community development and ecosystem sustainability. Pressures on water resources from population increases, coupled with regional population shifts, and competing demand among municipalities, agriculture, and industry are focusing more attention on water availability. These pressures are increasing the demand on the electric utility industry to improve its water use efficiency and minimize overall water usage. In addition, water availability is a critical element of power plant siting processes and will continue to be a key driver as competition for surface and groundwater supplies increases. An important aspect of future water policy and regulation will be the integration of the approach to developing water and energy infrastructures.

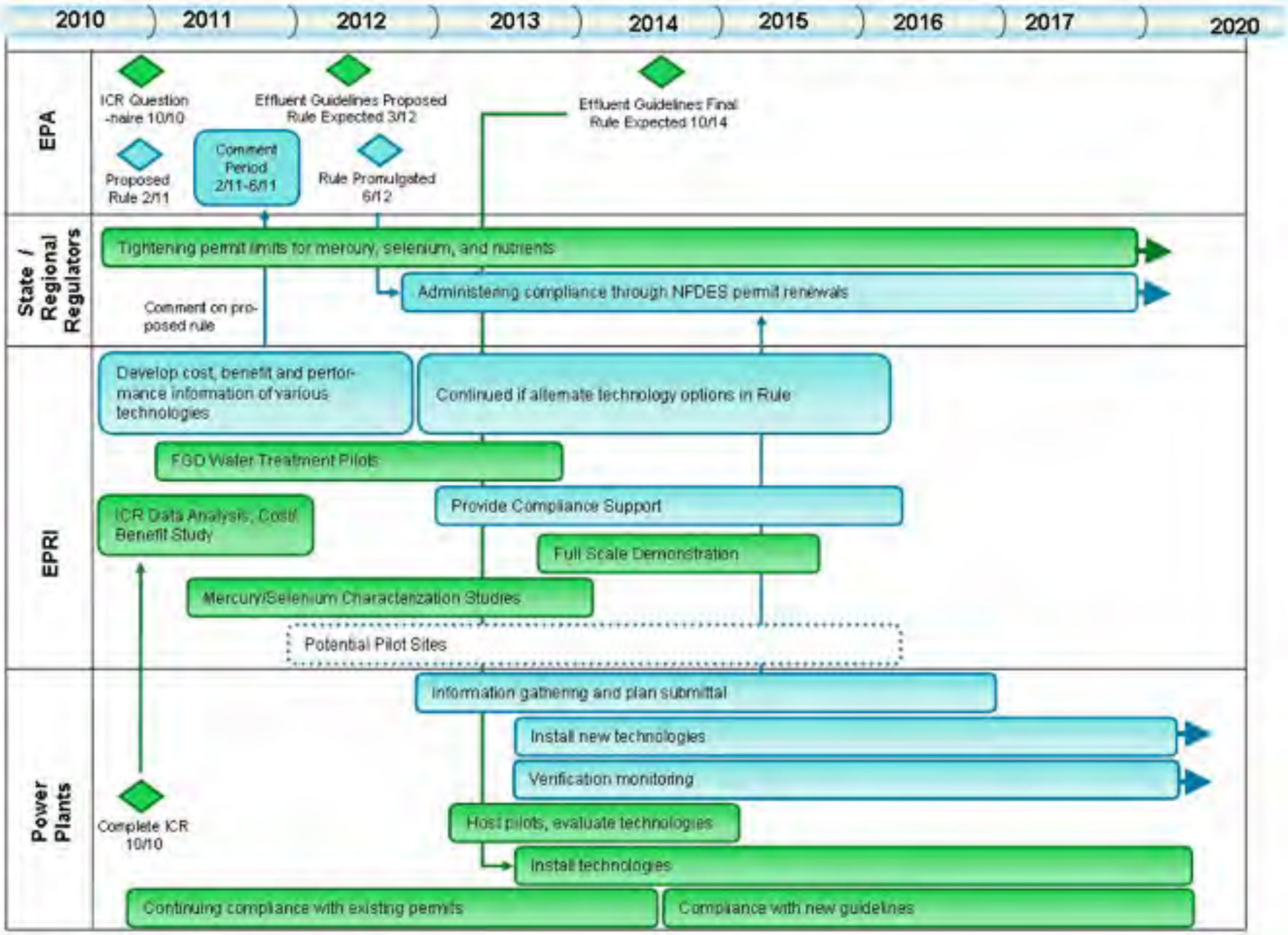
RISK

EPRI water and ecosystem research is a critical factor in providing society, state and federal agencies and industry with high quality, credible information and tools. EPRI research provides a system of "checks and balances" and a valuable perspective on behalf of the electric sector that otherwise would not exist.

- *Addressing water availability impacts the industry:* Without EPRI research, the utility sector would not have the tools to predict how future water constraints will impact current and planned generation assets.

- *Cost-effective management of wastewater discharges:* The advent of new air quality controls, new fuels, and fuel switching can change wastewater streams. As these changes occur, it is important that EPRI research continue to help power plants manage risks and implications of such changes.

- *Water quality standards based on sound science:* EPRI research provides comprehensive aquatic and health impacts information for wastewater pollutants to help members, regulators, and other stakeholders develop scientifically sound policies, standards and permit limits for achieving acceptable water quality to protect aquatic environments and public health. Without such information, there is the potential for regulators to promulgate overly conservative rules resulting in high compliance costs for utilities and the public they serve.
- *Effective water quality management:* EPRI research ensures that models and scientific information used by regulators in the development of water quality regulations include the best available science and accurate treatment of power plant emissions. Without EPRI research on improved modeling tools and information, regulations and policy decisions will rely on inferior methods and sources.
- *The ability to construct key collaborations across multiple topics and issues to address water quality and other related environmental concerns:* One of the key advantages of participating in EPRI research is that technical staff members work cooperatively across EPRI programs and sectors as well as with their colleagues in other research organizations. Collaboration with external colleagues allow for the development of additional collaborative opportunities, such as the Water Quality Trading Program.


2010
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2016
2017
2020
EPA
ICR Question -naire 10/10
Effluent Guidelines Proposed Rule Expected 3/12
Effluent Guidelines Final Rule Expected 10/14
Proposed Rule 2/11
Comment Period 2/11-6/11
Rule Promulgated 6/12
State / Regional Regulators
Tightening permit limits for mercury, selenium, and nutrients
Administering compliance through NPDES permit renewals
Comment on pro-posed rule
EPRI
Develop cost, benefit and perfor-mance information of various technologies
Continued if alternate technology options in Rule
FGD Water Treatment Pilots
ICR Data Analysis, Cost/ Benefit Study
Provide Compliance Support
Full Scale Demonstration
Mercury/Selenium Characterization Studies
Potential Pilot Sites
Power Plants
Information gathering and plan submittal
Install new technologies
Verification monitoring
Complete ICR 10/10
Host pilots, evaluate technologies
Install technologies
Continuing compliance with existing permits
Compliance with new guidelines

DRAFT: FISH PROTECTION AT STEAM ELECTRIC POWER PLANTS

ISSUE STATEMENT

A primary challenge for power plant owners is to ensure adequate water supplies for operations while protecting aquatic life living in the lakes, streams, rivers, estuaries, and oceans those operations impact. In the United States, the Clean Water Act §316(b) requires plant owners to install fish protection technologies on cooling water intake structures, while §316(a) requires management of thermal discharges. This program assesses the effects of thermal power plant cooling system operation on fish and other aquatic life. Results support the development of effective intake and discharge protection approaches for workable operating permits at individual facilities. By improving the technical basis for regulatory, permitting, and operating decisions, this program serves the public interest in effective resource management while meeting industry-wide imperatives to control costs, ensure or even exceed environmental compliance, and manage business risks.

DRIVERS

The U.S. Environmental Protection Agency as a result of a 1995 Consent Decree with environmental organizations has been writing rules implementing the requirements of §316(b) of the Clean Water Act. This section applies to new and existing power plants and other industrial facilities that use surface water for cooling. In 2001, EPA promulgated a rule for new facilities. The New facilities Rule basically requires new facilities to use closed cycle cooling systems, although there are limited opportunities to use once-through cooling. The Existing facility Rule has faced a number of legal hurdles since it was first promulgated in 2004 including a decision at the Supreme Court level. The legal issues resulted in a remand and re-write of the regulation. On April 20, 2011, EPA released a revised proposed rule for existing power plants and other industrial facilities. A final Rule will be promulgated by July 27, 2012.

This program also deals with fish protection issues associated with the discharge of heated cooling water as regulated under §316(a) of the Clean Water Act. As a result of recent extended droughts in many areas of the country, increased societal demands for water withdrawals, continued concern about protection of aquatic biota, and growing demand for more electric power, there is renewed interest in the management and consequences of thermal discharges. In the fall of 2007, the EPRI-organized Second Thermal Ecology and Regulation Workshop was held at Tri-State Generation's headquarters in Westminster, Colorado. The workshop drew about 120 domestic and international participants. Key topics of discussion included the convergence of thermal discharge issues with other issues such as §316(b), total maximum daily loads (TMDLs), effluent guidelines, water availability, and climate variability; the need to reconcile field and laboratory observations of fish response; interactions of thermal discharges with other pollutants; and responses of macroinvertebrates.

RESULTS

Program R&D supports current and future industry compliance efforts as well as updates to guidance on thermal discharge assessment variance procedures. The information is expected to support a regulatory structure that is informed by sound scientific and engineering information. Additional Program accomplishments include:

- Information on performance of intake fish protection technologies in identifying best technology available (BTA) for new and existing power plants, as required under §316(b);
- Impingement mortality and entrainment sampling information in support of §316(b) compliance;
- Technical resource documents on fish protection technology performance and costs;
- Technical information on the impacts and the environmental and economic benefits of reducing impingement mortality and entrainment; and
- Technical workshops and symposia for technical information and technology transfer.

EPRI R&D on closed cycle cooling has provided key scientific and engineering information to inform EPA on the cost and potential consequences associated with a possible national retrofit of closed-cycle cooling systems. In 2011, EPRI published five key reports on this issue including:

- National cost estimate for retrofit of U.S. power plants with closed-cycle cooling.
- Adverse social and environmental impacts associated with a potential retrofit of closed-cycle cooling systems
- Economic impact (plant retirement) impacts associated with a potential retrofit of closed-cycle cooling systems
- Transmission system impacts associated with a potential retrofit of closed-cycle cooling systems; and
- Economic benefits associated with a potential retrofit of closed-cycle cooling systems valuation

PLAN

The EPA proposed Rule for existing facilities provides some direction for future research relative to §316(b); however, clarity on R&D needs will not be completely apparent until the final Rule is promulgated by July 27, 2012. Our current plan is to continue to develop fish protection performance data for various types of technologies for controlling impingement and entrainment. Research will also focus on sampling methods and methods and information resources for estimating the economic value of fish and shellfish losses. The proposed Rule did not identify closed-cycle cooling as "Best Technology Available", however, EPA did consider other regulatory options that included closed cycle cooling and those options could still be selected as part of the final Rule. In the absence of regulatory clarity, the following R&D plan has been established:

- Laboratory flume analysis of the performance of various types of fine mesh traveling screens.
- Laboratory flume analysis of fish return design factors that effect fish transport and safe return.
- Field testing of the performance of entrainment technologies such as fine mesh traveling screens and cylindrical wedge wire screens.
- Laboratory analysis of traveling screen operational parameters affecting fish and shellfish survival (e.g., screen rotation speed, pressure wash, emersion time).
- Assessment of improved methods for entrainment and entrainment survival sampling.
- Improved methods for use and non-use economic valuation of fish losses.
- Conferences and workshops for technical information transfer.
- Development of methods and information resources for site-specific assessment of closed-cycle system cost, environmental and social impacts, and economic impacts.

Approximately 15% of program funds will be continued to be directed at R&D associated with thermal or §316(a) issues. The primary focus will be directed at research that will provide information to better understand the actual behavior of fish in thermal plumes. Laboratory experiments yield predictions of behavior; however, these behaviors are rarely observed in field conditions. Using the latest telemetry techniques for tracking fish, EPRI will partner with a member to conduct several years of field monitoring to gather tracking data under various seasonal and flow conditions. The ultimate goal of EPRI thermal ecology research is to provide data to support the development of thermal discharge permit conditions based on sound science. EPRI will also continue to support technology transfer by sponsoring thermal ecology conferences, the most recent held in 2011 and the next planned for 2014.

The current planned schedule for R&D activities is as follows:

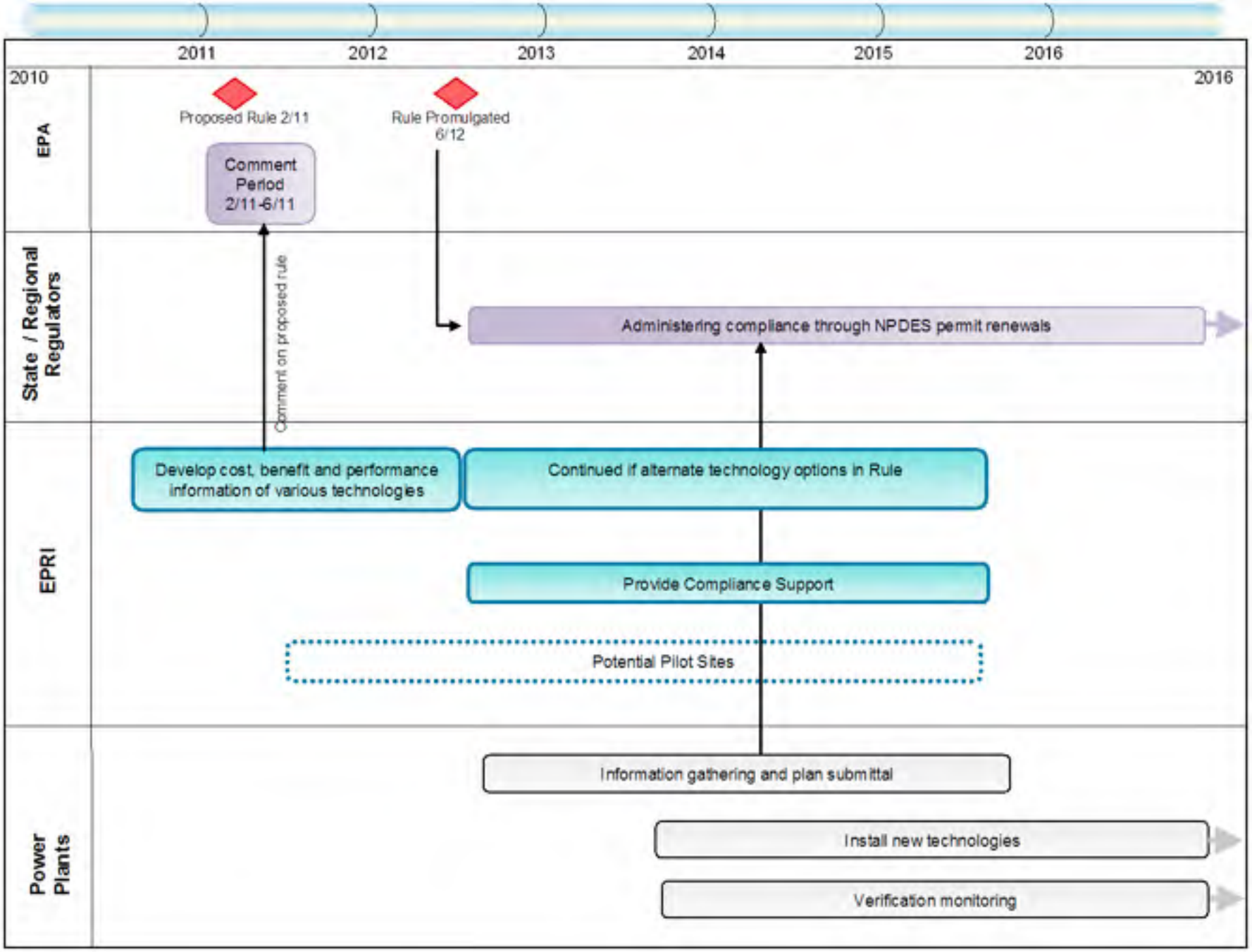
RISK

EPRI fish protection research has been, and continues to be, a critical factor in providing society, EPA, state agencies and EPRI members with high quality, objective and credible information and tools. Credible EPRI research provides a system of "checks and balances" and provides a valuable perspective on behalf of the electric sector that otherwise would not exist. The proposed Rule requires complex and expensive study requirements and eventually the implementation of fish protection technologies which will affect plant O&M and economic

performance. The latest information, therefore, on sampling, economic assessment, and technology performance – both for fish protection and for managing debris – is required. Changes in water availability and increasing regulatory focus on thermal discharge effects presents a significant risk of cooling system modifications including complete retrofits to closed-cycle systems.

A national and site-specific risk of retrofits of closed-cycle cooling systems – a cost that could range from 25 million to more than 1 billion per facility will continue into the future. In the proposed Rule, EPA noted that closed-cycle cooling (CCC) systems were not a national "Best Technology Available" for reducing adverse environmental impacts of cooling water intake structures; however, entrainment standards developed on a site-specific basis could require retrofits of CCC systems. In fact, as part of a potentially EPA-required Comprehensive Technical Feasibility and Cost Evaluation Study, the owner or operator of the facility must conduct a study to evaluate the technical feasibility of closed-cycle recirculating systems such as natural draft cooling towers, mechanical draft cooling towers, hybrid designs, and compact or multicell arrangements. Costs of retrofits, impacts to plant operations, environmental and social impacts, and potential impacts to system reliability may also need to be investigated if the Rule is promulgated as proposed.

Furthermore, although EPA rejected CCC as BTA and selected a regulatory option that provides for site-specific development of entrainment standards for protecting aquatic life, EPA did consider two options that included requirements for CCC, and one of these options could be adopted for the final Rule. Up-to-date scientific and engineering information on the potential ramifications of a CCC system retrofit, therefore, remains an important R&D issue to inform permit considerations and serve the public interest.


2011
2012
2013
2014
2015
2016
2010
2016
EPA
Proposed Rule 2/11
Rule Promulgated 6/12
Comment Period 2/11-6/11
State / Regional Regulators
Comment on proposed rule
Administering compliance through NPDES permit renewals
EPRI
Develop cost, benefit and performance information of various technologies
Continued if alternate technology options in Rule
Provide Compliance Support
Potential Pilot Sites
Power Plants
Information gathering and plan submittal
Install new technologies
Verification monitoring

DRAFT: THERMAL DISCHARGE

ISSUE STATEMENT

States continue to modify their thermal discharge regulations, either on their own or in response to pressure from regional EPA offices, resulting in more stringent thermal discharge criteria. In addition to fish thermal tolerance limits, regulatory issues being considered include: rate of temperature change; impacts on growth; effects on macroinvertebrates; and thermal interactions with other stressors; such as, metals, nutrients and climate. Thermal related issues are being raised not only with once-through cooling systems, but recycling cooling systems as well. Field and laboratory research are needed to help resolve these issues. In addition, thermal tolerance criteria are based on laboratory experiments. Often healthy fish populations are observed in plumes that laboratory data predict the fish populations cannot tolerate. Field experiments utilizing new fish tagging and telemetry technologies are needed to fully understand how fish interact with thermal plumes and how thermal stress recovery physiology functions in the field.

DRIVERS

With passage of the Clean Water Act (CWA) in 1972, the U.S. water quality-based control program was born. Under this program, the U.S. federal government, under the EPA, is responsible for providing water quality recommendations, approving state-adopted standards for interstate waters, evaluating adherence to the standards, and overseeing enforcement of standards compliance. States are responsible for developing water quality standards that establish water quality goals for interstate waters and enforcement of standards compliance, including granting of thermal discharge limits and variances.

Section 316(a) of the Clean Water Act (CWA) regulates thermal effluents and provides for a variance from both technology-based limits and water quality standards if it can be demonstrated that the thermal discharge "will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water." The 316(a) program was very active in the 1970s as thermal dischargers conducted studies to determine whether they might qualify for a variance. Over the past decade, increased interest in 316(a) regulations is evidenced by two well-attended workshops sponsored by EPRI, as well as U.S. Environmental Protection Agency (EPA), state, and utility activity on the subject.

Although the Clean Water Act has not changed over approximately 40 years, the world has, and continues to do so. New scientific, technical and regulatory issues concerning thermal discharges are constantly arising; creating the need for new research to cost efficiently protect ecological resources.

RESULTS

Power company environment, generation, and planning staff can already extract information from extensive EPRI research available in the form of technical reports, peer reviewed open literature scientific journal papers, EPRI issue briefs, and EPRI presentation materials. The third Thermal Ecology and Regulation workshop is planned for October 11-12, 2011 and EPRI will continue to organize and sponsor a major thermal workshop every three to four years. Electric power companies are already using EPRI results to address thermal discharge issues for existing plants, and guide the design and siting of new generation. The research results, utility case studies, reports and presentations have all been collocated in a thermal impacts website (www.epri.com/etherm). In addition, EPRI will facilitate broader use and awareness of the results by presenting webcasts; briefing key stakeholders, including the U.S. Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (USFWS) and state agencies; developing materials for the trade press/media; and continuing service on various government, academic, and professional organization advisory panels.

PLAN

EPRI research plans will continue the development of results to help the industry understand the true impacts of thermal discharges and how various mitigation methods can be used. The results will support realistic but protective thermal permit limits. EPRI work will include:

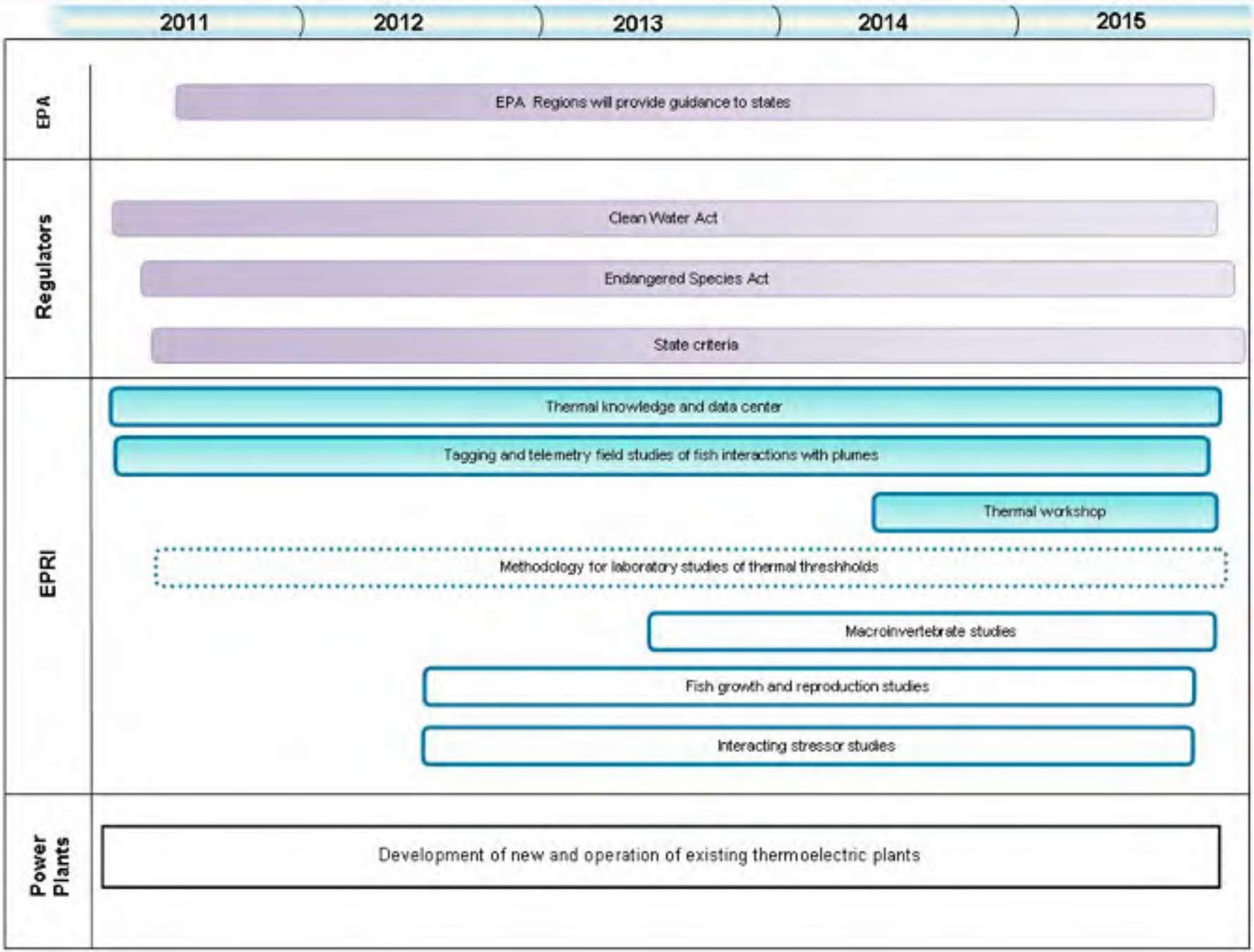
- Organize and execute open workshops every three to four years. Speakers to include industry, government, consulting company and academic representatives.

- Establish appropriate protocol for laboratory studies of thermal fish responses. Older methodologies tend to produce overly conservative thermal tolerance limits.
- Establish network of experimental field sites at diverse thermal discharge locations and conduct experiments using fish tag and telemetry technology to understand fish interactions with thermal discharge plumes.
- Conduct integrated laboratory/field studies to determine thermal discharge effects on fish growth and reproduction.
- Conduct integrated/laboratory field experiments to determine thermal discharge effects on macroinvertebrates.
- Establish and test methodologies to classify natural aquatic communities for sites where thermal discharges are present.
- Conduct integrated laboratory/field experiments to understand how aquatic organisms respond to elevated temperatures in combination with other potential stressors such as nutrients, mercury, and climate.
- Establish and maintain web-based knowledge and data center for thermal discharges.

RISK

Without scientifically sound knowledge and data on thermal discharge effects, electric power companies are vulnerable to:

- Overly conservative and expensive permit limits or loss of once-through cooling options.
- Revenue impacts of lost capacity due to thermal excursions.
- Adversarial relations with customers and water resource stakeholders.
- Inability to meet current and future demand for electricity, resulting in both economic and reliability losses.


2011
2012
2013
2014
2015
EPA
EPA Regions will provide guidance to states
Regulators
Clean Water Act
Endangered Species Act
State criteria
EPRI
Thermal knowledge and data center
Tagging and telemetry field studies of fish interactions with plumes
Thermal workshop
Methodology for laboratory studies of thermal threshholds
Macroinvertebrate studies
Fish growth and reproduction studies
Interacting stressor studies
Power Plants
Development of new and operation of existing thermoelectric plants

DRAFT: WASTEWATER CHARACTERIZATION

ISSUE STATEMENT

EPA is currently revising the effluent guidelines for the steam electric power generating industry. As EPA moves forward with this process, the available data will be used to broadly characterize the applicability of characterization of trace elements in power plant wastewater steams and to evaluate the overall performance and costs for wastewater treatment options for trace metals and nutrients. Science-based analyses and extrapolation of the data will be necessary to help inform the various stakeholders, including EPA, industry and the public. In parallel, some states and regions (such as the Great Lakes) are considering low parts-per-trillion (ppt) limits for mercury, while some power plants are unable to achieve selenium permit limits based on traditional removal processes.

These new guidelines are expected to result in tighter limits for power plant discharge and may require plants to install new wastewater treatment technologies. One wastewater stream of concern is the blowdown from wet flue gas desulfurization (FGD) systems, which contain concentrations of mercury, selenium, arsenic and other trace elements which may require further treatment. Plant/FGD design and coal and limestone properties may significantly influence wastewater constituents and treatment effectiveness; thus there is significant need to characterize and understand these factors and how they impact the wastewater and its treatability. Accurate and reliable analytical methods are required to support monitoring and permit compliance for trace metals such as mercury and selenium. Measuring these elements at very low ppt and part-per-billion (ppb) levels has proven to be very difficult.

DRIVERS

There are a number of specific regulatory and legislative drivers at the regional, state and federal levels affecting wastewater management and discharge by the electric sector.

Effluent Guidelines – EPA is currently revising the effluent guidelines for the steam electric power generating industry. These new guidelines are expected to result in tighter limits for power plant discharge and may require plants to install new wastewater treatment technologies as well as monitoring for trace metals such as mercury and selenium at very low ppt and ppb levels in a very complex matrix with many possible interferences.

State and Regional – A number of states and regions are currently regulating power plant discharges. For example many states along the Great Lakes and Ohio River are considering or have implemented low ppt discharge limits for mercury. New wet FGD systems in Pennsylvania and North Carolina are regulated for selenium. Some states are considering limits for other trace elements such as boron, arsenic and nutrients as well as TDS (total dissolved solids) and chlorides.

Total Maximum Daily Loads (TMDLs) – EPA has used a watershed approach to achieve protection of water resources through the implementation of Total Maximum Daily Loads (TMDLs) and watershed-integrated National Pollution Discharge Elimination System (NPDES) permits. Regional TMDLs are being developed for nutrients, mercury and other pollutants, and may lead to discharge permits more restrictive than NPDES permits.

RESULTS

EPRI delivers credible data to characterize power plant wastewaters and conducts scientifically sound data interpretation to inform potential revisions to the effluent guidelines for the steam electric industry. EPRI also develops sound guidelines for effective management of power plant wastewater streams and develops practical tools for biofouling control using non-toxic alternatives to oxidizing biocides such as chlorine.

EPRI research provides high value to the electric industry and society in many ways:

1. Characterized trace element and other key water constituents in various power plant wastewaters such as FGD wastewater and ash handling waters.
2. Developed analytical methods for characterizing the various species of selenium, as this is critical in treatability.
3. Improved understanding of how and why selenium chemistry in wet FGDs varies. Identified several key metals in wastewater which affects selenium chemistry as well as several possible "additives" which may help manage the selenium chemistry, while not adversely affecting the sulfur chemistry and removal in the wet FGD.

4. Identified that mercury treatability in wastewater varies significantly due to mercury being present as different compounds, with the potential that organically bound mercury will be more challenging to treat.
5. Developed initial guidelines for managing FGD wastewater.
6. Evaluated the application and limitations of zero liquid discharge (ZLD) systems to evaporate wastewater.

PLAN

EPRI research plans will effectively characterize wastewater discharges from current and emerging technologies and identify treatment alternatives. The characterization of wastewater from current and emerging fossil fuel-fired generation technologies will continue to be a critical need for understanding treatment technology performance, conducting health risk studies, and supporting effluent guidelines revisions. Examples of specific actions to be conducted include:

Short-term (1-3 years) activities:

- Develop standard operating procedures for low level analytical methods to accurately quantify trace metals in challenging water matrices, e.g., FGD wastewater.
- Characterize wastewater discharges from existing plants and anticipated changes with new fuels and air emissions controls.
- Characterize how speciation of contaminants impacts treatment effectiveness and costs.
- Evaluate the impact of limestone on mercury FGD chemistry and treatability in wastewaters.
- Develop guidelines for management of selenium chemistry in wet FGDs.
- Develop guidelines for low-volume wastewater management without ash handling waters.
- Continue evaluation of thermal evaporation and ZLD systems, including characterization of solid wastes and possible wastewater streams.
- Evaluate nontoxic alternatives to oxidizing biocides.

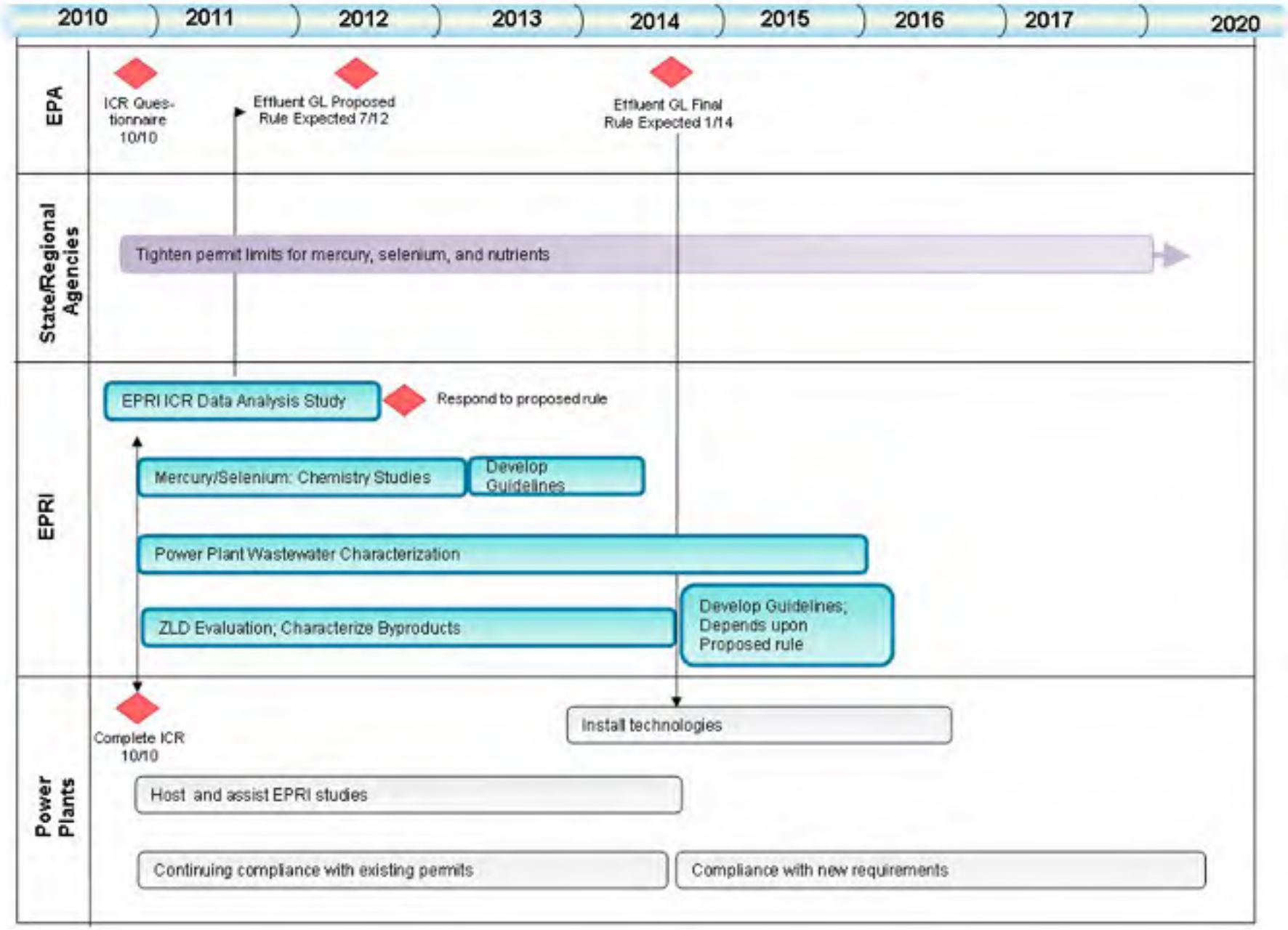
Long-term (beyond several years) activities:

- Develop guidelines for management and treatment of mercury and selenium from FGD wastewaters.
- Develop guidelines for management of solid wastes and potential wastewater streams from thermal evaporation and ZLD systems.
- Identify other issues of concern for other trace elements (e.g. boron, arsenic) and develop water management strategies.
- Develop a predictive model for FGD chemistry for mercury, selenium and other key parameters.
- Investigate wastewater reuse and treatment options.
- Characterize wastewater discharges from advanced power plants and control technologies, such as IGCC, CO_2 capture.

RISK

EPRI research has been, and continues to be, a critical factor in providing society, EPA, state and local agencies, and EPRI members with high quality, objective and credible information and tools. Credible EPRI research provides a system of "checks and balances" and provides a valuable perspective on behalf of the electric sector that otherwise would not exist.

- Cost-effective management of wastewater discharges: The advent of new air quality controls, new fuels, and switches in fuel sources can change wastewater streams. As these changes occur, it is important that EPRI research continue to help members manage their risk and to understand the implications of such changes.
- Limitations in the ability to discharge wastewater: Some states are considering stringent limits which may not allow power plants to cost-effectively discharge wastewater, and thus require thermal evaporation or ZLD systems. As this occurs, power plants need independent and reliable information on the application, limitations, reliability, costs, and solid waste management of such systems.
- Compliance monitoring: As permit limits include low ppb and ppt levels for various trace elements, reliable and accurate analytical methods and procedures are needed to comply with permit limits.


2010
2011
2012
2013
2014
2015
2016
2017
2020
EPA
ICR Ques-tionnaire 10/10
Effluent GL Proposed Rule Expected 7/12
Effluent GL Final Rule Expected 1/14
State/Regional Agencies
Tighten permit limits for mercury, selenium, and nutrients
EPRI
EPRI ICR Data Analysis Study
Respond to proposed rule
Mercury/Selenium: Chemistry Studies
Develop Guidelines
Power Plant Wastewater Characterization
ZLD Evaluation; Characterize Byproducts
Develop Guidelines; Depends upon Proposed rule
Power Plants
Complete ICR 10/10
Install technologies
Host and assist EPRI studies
Continuing compliance with existing permits
Compliance with new requirements

ISSUE STATEMENT

Exposure to trace and transition metals such as arsenic and chromium may lead to an array of adverse outcomes, in both humans (including cancer) and ecosystems. Therefore, the ability to assess the potential for environmental exposure to such metals from power generation wastewater releases remains of critical importance to the industry. Electric utility power plants discharge wastewater from the management of by-products, which can be contaminated with metals and other dissolved and suspended solids. Of current concern, the USEPA will promulgate new arsenic limits based upon a linear cancer slope factor despite the fact that research indicates arsenic has a non-linear dose response. USEPA is also considering revisions to limits for other metals (e.g., chromium), and an understanding of the dose response and increased health risk is imperative to setting a protective, but reasonable limits. The R&D needs are to reduce reliance on default assumptions and uncertainties in the scientific basis for aquatic life and human health risk assessments, leading to sounder regulatory decisions for wastewater discharges by USEPA. Research into aquatic impacts and human health effects will also support the development of science-based criteria and site-specific water quality criteria.

DRIVERS

Rules, regulations and guidance at the federal and state levels, including public perception issues dictate wastewater discharge constituent limits from electric utility power plants.

Integrated Risk Information System (IRIS) – The USEPA IRIS program develops dose-response values for cancer and non-cancer health effects associated with exposure to trace for use in risk assessments under a range of federal and state regulatory programs. These dose-response values are required health assessments to demonstrate risk and establish environmental media guidelines, regulatory standards, permit levels and public health goals. Currently, the agency has multiple IRIS values under review including for arsenic (cancer and non-cancer) and chromium (cancer). If chemical-specific toxicological and epidemiological data are not available to support derivation of an IRIS value, then USEPA defaults to conservative modeling assumptions, and generally resulting in more health conservative, stringent assessments.

Water Quality Criteria – USEPA develops national ambient water quality criteria (AWQC), which are then implemented by the states. Utilities are subject to limits on metals and other substances in their discharge permits based on existing criteria and any new criteria that are developed and implemented. USEPA has plans to review all ambient water quality criteria for possible revision over the next 5 to 10 years. As part of the USEPA AWQC review, supporting data on exposure and underlying metal dose-response are required to develop scientifically supported values for use in risk assessment that often drive guideline development and regulatory permitting.

Total Maximum Daily Loads (TMDLs) – USEPA has a principal strategic objective to use a watershed approach to achieve protection of water resources through the implementation of Total Maximum Daily Loads (TMDLs) and watershed-integrated National Pollution Discharge Elimination System (NPDES) permits. TMDLs can lead to discharge permits more restrictive than current NPDES permits. Regional TMDLs are being developed for nutrients, mercury and other pollutants, growing interest on developing arsenic specific TMDLs requires additional understanding of both the exposure, health and ecological implications.

Safe Drinking Water Act (SDWA) – The SDWA establishes Maximum Contaminant Levels (MCLs) for compounds such as arsenic and chromium that may cause adverse health effects. As coal constituents, such trace metals are captured by environmental controls systems thereby entering generation waste streams, including solid and/or liquid by-products that have implications for wastewater discharge.

State Rules and Permits – States issue NPDES permits to meet USEPA mandates. States always have the option of going beyond USEPA rules by adopting stricter limits water discharges. It is critical that states are equipped with the best tools and scientific information to make technical evaluations of the bases of NPDES permits.

RESULTS IMPLEMENTATION

EPRI research into the risk associated with wastewater handling and discharge provides high value to the electric industry and society by:

- Anticipating and addressing critical issues well before they become regulatory concerns;
- Collaborating on research with other organizations both financially and scientifically; and
- Providing a unique multidisciplinary approach to addressing issues of scientific and technical importance to the electric sector.

EPRI regularly creates reports, publishes in peer-reviewed journals, and briefs state and federal agencies on its research results. EPRI researchers are frequently asked to participate in joint research programs. State and federal agencies often incorporate EPRI research results into the decision-making process. Several examples include the following:

- EPRI research on the cancer slope factor for arsenic has been crucial in clarifying the science and providing comments to USEPA to reconsider its proposal to modify the cancer slope factor. This research includes demonstration of the non-linearity of the cancer slope factor, and pathways into the human food chain.
- EPRI is working closely with USEPA to collect laboratory data to support a revision of the ambient water quality criteria for arsenic.
- EPRI data and results have been used to inform regulators on several site-specific water quality criteria that have prevented overly conservative permit limits.

PLAN

Water and ecosystem issues related to wastewater risk assessment require a comprehensive and cross-disciplinary approach incorporating toxicology, ecology, exposure and risk modeling. Specific projects are required to characterizing water discharges (by contaminant type, concentrations and speciation); to identify the determinants driving these levels; to assess the ultimate exposure drivers at human and ecological levels; and ultimately, to model impacts on human health and the environment. Quantitatively estimating risk, for both human and ecological health, requires utilizing models with multiple inputs and assumptions on intake, fate and transport, and other biological effects, particularly in order to elucidate the attributable levels (and thereby) risk assignment to power plants. Specific actions that need to be undertaken to address current and anticipated issues include the following:

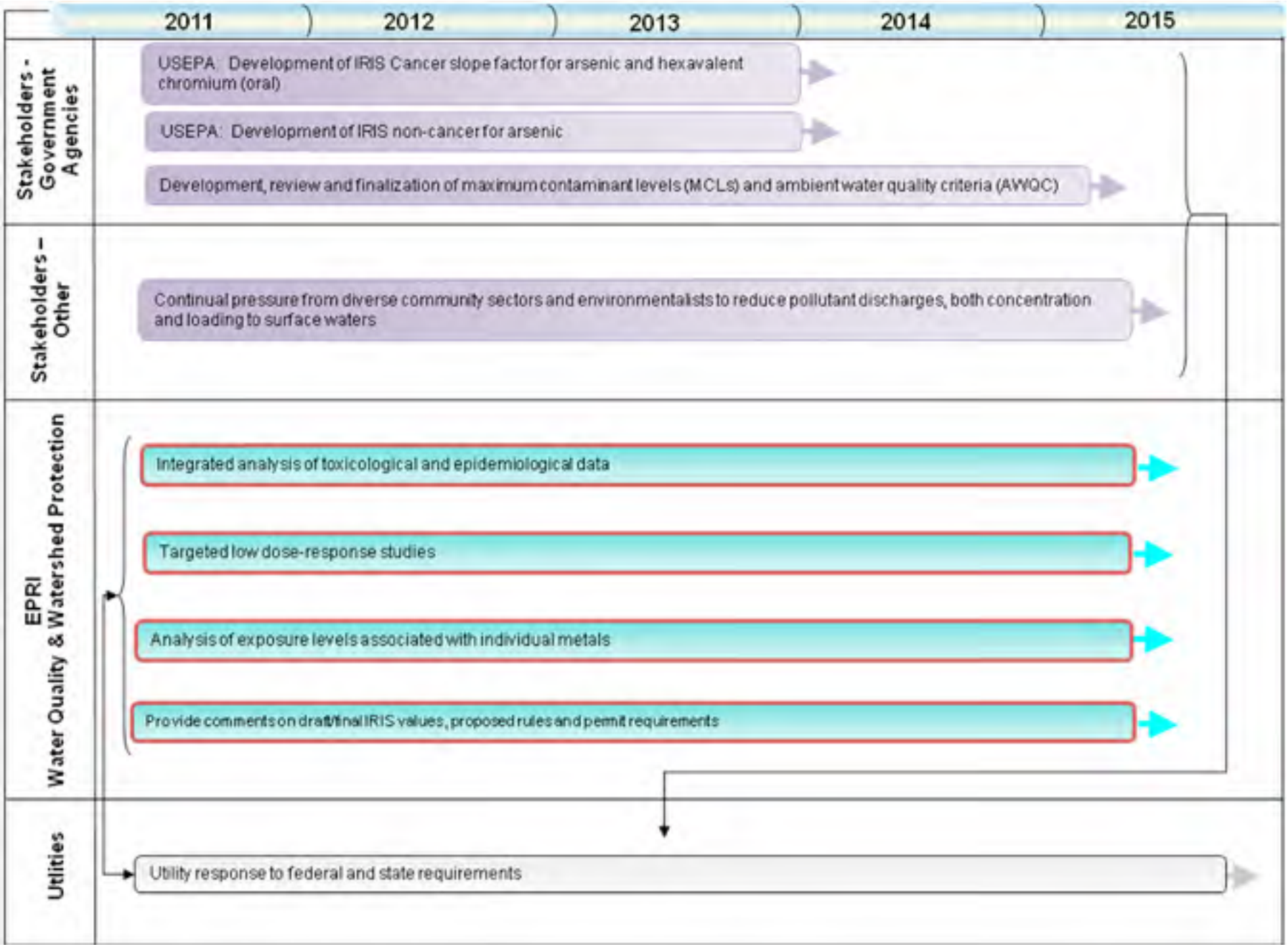
1. *Effectively characterize wastewater discharges from current and emerging technologies and identify potential toxicity across the environmental spectrum due to important trace metals:* Characterization of wastewater from current and emerging fossil fuel-fired generation technologies for trace metals will continue to be a critical need for understanding data inputs required for scientifically supported risk assessments.
2. *Conduct basic research on aquatic impacts and human health effects from wastewater discharges as input to regulatory and legislative rulemaking:* Scientifically rigorous, objective and peer-reviewed studies become the foundation for establishing regulations and discharge limits. Aquatic impact and health-based reviews are conducted by USEPA on an ongoing basis, requiring USEPA and states to continuously find means to reduce emissions if the science requires lower pollutant concentrations.
3. *Develop modeling methods to better evaluate and address the impacts of wastewater release:* The data required to estimate the human and ecological risk associated with wastewater discharges, particularly those associated relatively common, yet toxic trace metals such as arsenic and chromium, requires integration of complex inputs. Research into understanding the dose-to-toxicity relationship, particularly at environmentally relevant lower doses, needs to be integrated with exposure and other data to fully characterize the risk (population and ecologic), to fully inform regulatory mandates or other controls.

RISK

EPRI water and ecosystem research is a critical factor in providing society, state and federal agencies and industry with high quality, credible information and tools. EPRI research provides a system of "checks and balances" and a valuable perspective on behalf of the electric sector that otherwise would not exist.

- *Cost-effective management of wastewater discharges:* The advent of new air quality controls, new fuels, and fuel switching can change the characteristics of wastewater streams. As these changes occur, it is important that EPRI research continue to help power plants manage risks and implications of such changes.

- *Water quality standards based on sound science:* EPRI research provides comprehensive aquatic and health impacts information for wastewater pollutants to help members, regulators, and other stakeholders develop scientifically sound policies, standards and permit limits for achieving acceptable water quality to protect aquatic environments and public health.
- *Effective water quality management:* EPRI research ensures that models and scientific information used by regulators in the development of water quality regulations include the best available science and accurate treatment of power plant emissions. Without EPRI research on improved modeling tools and information, regulations and policy decisions will rely on inferior methods and sources.


2011
2012
2013
2014
2015
Stakeholders - Government Agencies
USEPA: Development of IRIS Cancer slope factor for arsenic and hexavalent chromium (oral)
USEPA: Development of IRIS non-cancer for arsenic
Development, review and finalization of maximum contaminant levels (MCLs) and ambient water quality criteria (AWQC)
Stakeholders – Other
Continual pressure from diverse community sectors and environmentalists to reduce pollutant discharges, both concentration and loading to surface waters
EPRI Water Quality & Watershed Protection
Integrated analysis of toxicological and epidemiological data
Targeted low dose-response studies
Analysis of exposure levels associated with individual metals
Provide comments on draft/final IRIS values, proposed rules and permit requirements
Utilities
Utility response to federal and state requirements

ISSUE STATEMENT

Power plants discharge wastewater from the management of by-products, which can be contaminated with metals and other dissolved and suspended solids. The discharge of wastewater contributes to adverse aquatic and human health effects. As a result, the industry faces a myriad of new federal and state regulations and community pressures that will affect how utilities use and discharge water. Over the next decade, new air quality control technologies and new fuels (e.g., biomass) will be deployed, changing the character of power plant wastewater discharges and raising a host of new issues. Research is needed to reduce reliance on default assumptions and uncertainties in the scientific basis for aquatic life and human health risk assessments, leading to sounder regulatory decisions for wastewater discharges by USEPA. Research into aquatic impacts and human health effects will also support the development of science-based criteria and site-specific water quality criteria.

Key issues that need to be addressed include the following:

- Understanding wastewater characteristics of new generation and control technologies such as carbon dioxide (CO_2) controls employing ammonia, amines, and other compounds.
- Evaluation of aqueous streams as flue gas is cleaned to greater levels, i.e. flue gas desulphurization and mercury controls.
- Assessment and management of fate and transport of air emissions and their transport and cycling in aquatic ecosystems (e.g., air-water linkages).
- Assessment of the toxicity of storm water discharges.
- Collection of data to support the evaluation of wildlife criteria

DRIVERS

Rules, regulations and guidance at the federal and state levels, including public perception issues dictate wastewater discharge constituent limits from power plants. There also are numerous locally-based agencies with water regulatory powers, e.g., Ohio River Valley Water Sanitation Commission (ORSANCO).

Water Quality Criteria – USEPA develops national ambient water quality criteria, which are then implemented by the states. Utilities are subject to limits on metals and other substances in their discharge permits based on existing criteria and any new criteria that are developed and implemented. USEPA has plans to review all ambient water quality criteria for possible revision over the next 5 to 10 years. EPRI research is needed to demonstrate the non-linear dose-response of certain metals in the environment to reduce reliance on default assumptions and uncertainties in the scientific basis for human health risk assessments. These results will lead to sounder regulatory decisions for wastewater discharges by USEPA. Research into aquatic impacts and human health effects will also support the development of science-based criteria and site specific water quality criteria.

Total Maximum Daily Loads (TMDLs) – USEPA has a principal strategic objective to use a watershed approach to achieve protection of water resources through the implementation of Total Maximum Daily Loads (TMDLs) and watershed-integrated National Pollution Discharge Elimination System (NPDES) permits. TMDLs can lead to discharge permits more restrictive than current NPDES permits. Regional TMDLs are being developed for nutrients, mercury and other pollutants. Reduction of atmospheric emissions is being considered by states and USEPA to satisfy a variety of TMDLs including pH, nitrogen, nutrients and mercury. The electric power industry needs proven scientific tools to critically evaluate the calculation, allocation, and implementation plans of local and regional TMDLs.

National and State Air Quality Regulations – As air quality regulations are adopted for ozone, PM, SO_2, NOx, and HAPS, new control technologies and fuels will continue to affect water and wastewater quality.

Safe Drinking Water Act (SDWA) – The SDWA establishes Maximum Contaminant Levels (MCLs) for compounds such as arsenic that may cause adverse health effects. Arsenic is a component of coal that is captured by environmental controls systems and thus is found in solid and/or liquid by-products. MCL levels have implications on the discharge of wastewater.

State Rules and Permits – States issue NPDES permits to meet USEPA mandates. States always have the option of going beyond USEPA rules by adopting stricter limits for water discharges. It is critical that states are equipped with the best tools and scientific information to make technical evaluations of the basis of NPDES permits.

Non-Regulatory Drivers; Public Relations/ Environmental Stewardship; Potential Litigation – All USEPA rules and guidance are subject to litigation by third parties. While many challenges are legal, some are technically based and thus relevant research results are often used as part of the litigation process. Many interveners and third parties continue to push USEPA and individual states to reduce discharge limits to very low levels. Power companies are also vulnerable to pressures from community businesses and customers to take actions to address perceived environmental issues.

RESULTS IMPLEMENTATION

EPRI water and ecosystem research provides high value to the electric industry and society by:

- Anticipating and addressing critical issues well before they become regulatory concerns;
- Collaborating on research with other organizations both financially and scientifically; and
- Providing a unique multidisciplinary approach to addressing issues of scientific and technical importance to the electric sector.

EPRI regularly creates reports, publishes in peer-reviewed journals, and briefs state and federal agencies on its research results. EPRI researchers are frequently asked to participate in joint research programs. State and federal agencies often incorporate EPRI research results into the decision-making process. Several examples include the following:

- EPRI research on the cancer slope factor for arsenic (including a joint project with USEPA) has been crucial in clarifying the science and providing comments to USEPA to reconsider its proposal to modify the cancer slope factor. This research includes demonstration of the non-linearity of the cancer slope factor, and pathways into the human food chain.
- EPRI is working closely with USEPA to collect laboratory data to support a revision of the ambient water quality criteria for arsenic.
- EPRI data and results have been used to inform regulators on several site-specific water quality criteria that have prevented overly conservative permit limits.
- EPRI supported METALICUS research results will play a key role in assessing how mercury reductions in air emissions will affect water deposition, bioavailability and fish tissue concentrations.

PLAN

Water and ecosystem issues must be addressed in a comprehensive manner including characterizing water discharges; assessing how contaminant concentrations and speciation affects bioavailability; and evaluating impacts on human health and the environment. This involves careful data collection and analysis, understanding chemical transformation and transport in the aquatic environment and food chain, and the ultimate affects on aquatic communities and human health. This will also require development of advanced environmental models, such as further enhancement of the Biotic Ligand Model (BLM) and execution of detailed studies to elucidate the role of power plants versus other sources in contributing to potential human health and ecosystem impacts. Specific actions that need to be undertaken to address current and anticipated issues include the following:

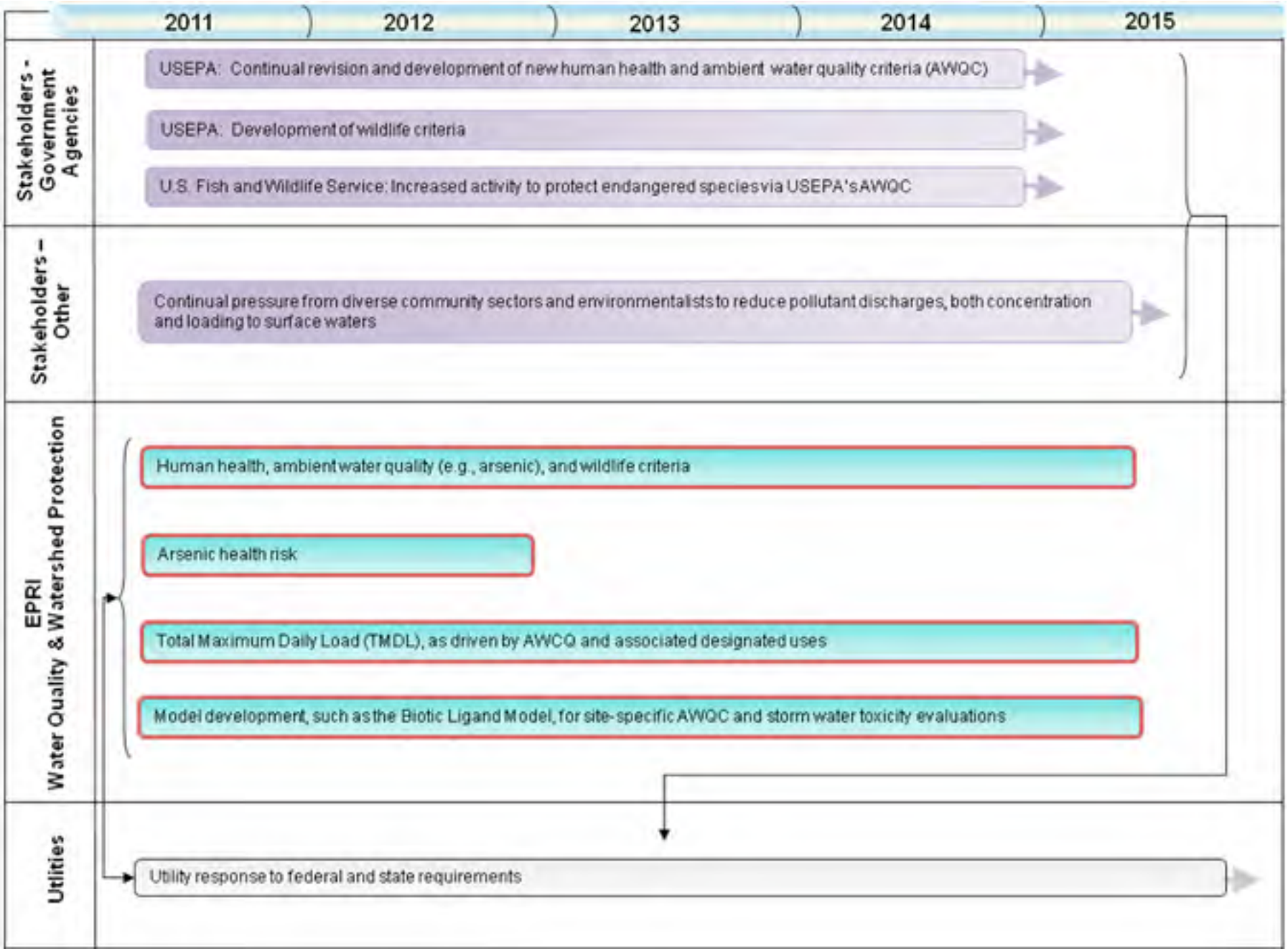
1. *Effectively test and characterize wastewater discharges from current and emerging fossil fuel-fired generation technologies and identify potential toxicity to aquatic life:* Characterization of wastewater from current and emerging technologies will continue to be a critical need for understanding potential toxicity to support risk assessments.
2. *Conduct basic research on aquatic impacts and human health effects from wastewater discharges as input to regulatory and legislative rulemaking:* Concern for aquatic environments and human health effects are primary drivers for controls on wastewater discharge from all industrial sources, including power plants. Thus, it is critical that the role of the electric sector in contributing to any adverse environmental and health effects be clearly delineated. Scientifically rigorous, objective and peer-reviewed studies become the foundation for establishing regulations and discharge limits. Aquatic impact and

health-based reviews are conducted by USEPA on an ongoing basis, requiring USEPA and states to continuously find means to reduce emissions if the science requires lower pollutant concentrations. Understanding the role of the electric sector in contributing to adverse aquatic impacts or health consequences will continue to be a critical need.

RISK

EPRI water and ecosystem research is a critical factor in providing society, state and federal agencies and industry with high quality, credible information and tools. EPRI research provides a system of "checks and balances" and a valuable perspective on behalf of the electric sector that otherwise would not exist.

- *Cost-effective management of wastewater discharges:* The advent of new air quality controls, new fuels, and fuel switching can change the characteristics of wastewater streams. As these changes occur, it is important that EPRI research continue to help power plants manage risks and implications of such changes. Failure to understand these changes could lead to overly conservative permit limits, permit violations, fines, and/or loss of operations.
- *Water quality standards based on sound science:* EPRI research provides comprehensive aquatic and health impacts information for wastewater pollutants to help members, regulators, and other stakeholders develop scientifically sound policies, standards and permit limits for achieving acceptable water quality to protect aquatic environments and public health. Of particular interest is the growing influence of the US Fish and Wildlife Service over USEPA's development of water quality criteria that are protective of endangered species. Without such information, there is the potential for regulators to promulgate overly conservative rules resulting in high compliance costs for utilities and the public they serve.
- *Effective water quality management:* EPRI research ensures that models and scientific information used by regulators in the development of water quality regulations include the best available science and accurate treatment of power plant emissions. Without EPRI research on improved modeling tools and information, regulations and policy decisions will rely on inferior methods and sources.
- *The ability to construct key collaborations across multiple topics and issues to address water quality and other related environmental concerns:* EPRI technical staff members work cooperatively across EPRI programs and sectors as well as with their colleagues in other research organizations. Collaboration with external colleagues allow for the development of additional collaborative opportunities, such as partnering with USEPA. Such partnerships are invaluable in providing in depth knowledge of research results to regulatory agencies and other stakeholders, leading to protective and scientifically sound regulations.


2011
2012
2013
2014
2015
Stakeholders - Government Agencies
USEPA: Continual revision and development of new human health and ambient water quality criteria (AWQC)
USEPA: Development of wildlife criteria
U.S. Fish and Wildlife Service: Increased activity to protect endangered species via USEPA's AWQC
Stakeholders – Other
Continual pressure from diverse community sectors and environmentalists to reduce pollutant discharges, both concentration and loading to surface waters
EPRI Water Quality & Watershed Protection
Human health, ambient water quality (e.g., arsenic), and wildlife criteria
Arsenic health risk
Total Maximum Daily Load (TMDL), as driven by AWCQ and associated designated uses
Model development, such as the Biotic Ligand Model, for site-specific AWQC and storm water toxicity evaluations
Utilities
Utility response to federal and state requirements

DRAFT: WATER RESOURCE MANAGEMENT

ISSUE STATEMENT

Rapidly growing demands for clean, fresh water, coupled with the need to protect and enhance the environment, have made many areas of the United States vulnerable to water shortages. Such shortages have already caused some reductions in existing supplies of electricity and will have direct impacts on power system planning and expansion. Water and energy shortages can occur relatively suddenly and can have adverse impacts on local and regional economies. To address this critical issue, research needs include creation and demonstration of decision-support tools for watershed management and power plant water use, development of water resource knowledge bases, and integrated sustainability assessments of regional power and water supply. Such research must include newly developing knowledge about water recycling and reuse, alternative non-traditional water sources, advanced cooling technologies and novel methods and technologies for reducing water use in the water supply, agricultural and industrial sectors.

DRIVERS

Water is a shared resource critical to economic and community vitality. Population increases coupled with regional population shifts and competing demand among municipalities, agriculture, and industry are focusing more attention on water availability and are putting pressure on the electric power industry to increase its water use efficiency and minimize overall water use. Other contributing factors are climate variation and increased demand for aquatic ecosystem protection. In addition, water availability is a critical element of power plant siting processes. Agencies at the federal, regional, state, and local levels are increasing scrutiny of water resource use and developing long-term water allocation plans for both typical climate scenarios and severe drought. This is often compounded by stakeholder intervention over water issues for new power plants. The power sector is also receiving increased scrutiny of its water use by financial institutions and investors (water disclosures). This scrutiny has significant implications for generation and transmission operations and growth. An integrated approach to developing water and energy infrastructures will be an important aspect of future water and electric power policy and regulation.

RESULTS

Power company environment, generation, and planning staff are already benefiting from the research results in EPRI technical reports, peer reviewed open literature scientific journal papers, EPRI issue briefs, and EPRI presentation materials. This information has also been disseminated to community water resource stakeholders and government agencies to provide a better understanding of how our water resources are used, and the role water plays in electricity generation as well as electricity requirements for the pumping and treating of water and wastewater. Members are already using results to support decision making with respect to meeting community, financial institution and government pressures to increase water use efficiency and reduce water use in both existing and new plants. Members have also used results to guide design and siting of new generation. In addition, EPRI has facilitated broader use and awareness of the results by presenting webcasts; briefing key stakeholders, including the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE) and state agencies; developing materials for the trade press/media; and continuing service on various government, academic, and professional organization advisory panels.

PLAN

EPRI will continue to build on its extensive research in this area with the development of additional tools and information to assist the industry in assessing and mitigating the risks associated with water availability and use. This will be done through the following steps:

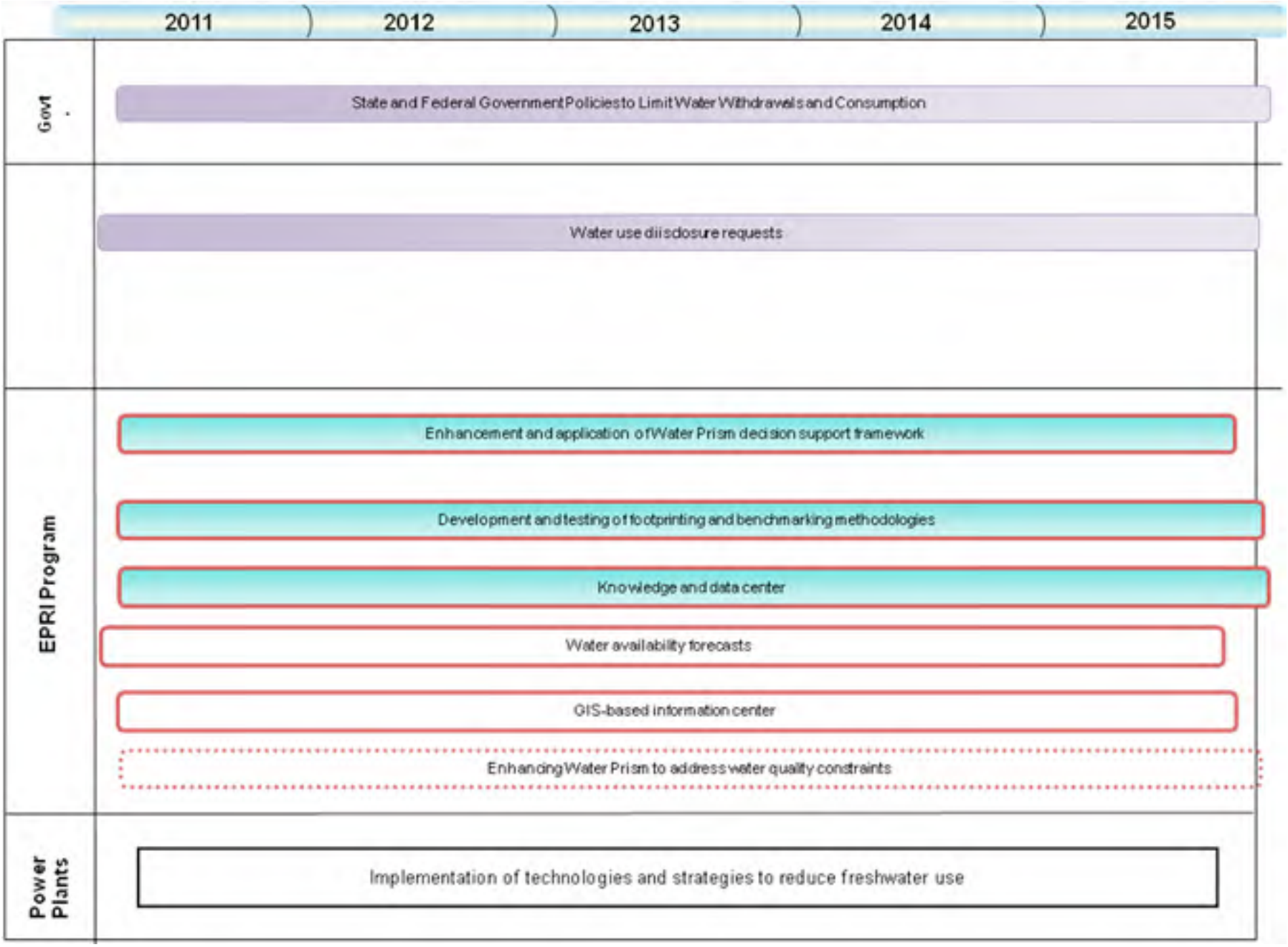
- Test robustness of advanced decision support systems on diverse communities/watersheds throughout the U.S.
- Evaluate alternative management strategies for scenarios using a variety of advanced water saving technologies, non-traditional and recycled water sources, generation types, climate regimes, and policy/regulatory frameworks.
- Develop, test and apply footprinting and benchmarking methods for water use by the electric power and other water using sectors.

- Produce water availability forecasts for watersheds throughout the U.S.
- Develop national GIS-based data sets for climate, land use, natural resources, and non-traditional water sources to be used by advanced decision support systems.
- Develop a database on efficacy and cost of advanced water saving technologies for all sectors.
- Enhance advanced decision support systems to address thermal and other water quality constraints on water use.

RISK

Without ability to properly manage for potential future constraints on water use, electric power companies risk:

- Unplanned curtailment of generation due to water constraints, resulting in significant financial impacts (risk to capital investment).
- Potential stranded assets in cases where water constraints severely impact existing or planned generation.
- Credit risk assignment by financial and insurance industries that adversely impacts borrowing potential.
- Water constraints in service region that limit growth, financial stability, recreational opportunities, etc.
- Adverse financial impacts to customers, resulting in an unfavorable economy for electricity sales.
- Unnecessary and costly delays, or cancellation of new generation.
- Damage to business reputation.
- Overly restrictive government regulation.


2011
2012
2013
2014
2015
Govt.
State and Federal Government Policies to Limit Water Withdrawals and Consumption
Water use diisclosure requests
EPRI Program
Enhancement and application of Water Prism decision support framework
Development and testing of footprinting and benchmarking methodologies
Knowledge and data center
Water availability forecasts
GIS-based information center
Enhancing Water Prism to address water quality constraints
Power Plants
Implementation of technologies and strategies to reduce freshwater use

DRAFT: WATERSHED MANAGEMENT/TMDLS

ISSUE STATEMENT

A principal strategic objective of EPA is to use a watershed approach through the implementation of Total Maximum Daily Loads (TMDLs) and watershed-integrated National Pollutant Discharge Elimination System (NPDES) permits to achieve protection of water resources. This action creates a growing number of new, complex research needs. Research is needed to:

- Understand how to effectively manage stormwater runoff.
- Couple watershed and air quality models to address TMDLs and endangered species protection where atmospheric deposition is a major source of pollutants such as nitrogen, mercury and other heavy metals.
- Derive, allocate, and implement complex TMDLs (involving, for example, thermal, selenium, and arsenic).
- Derive regional TMDLs and secondary standards.
- Establish watershed protective water quality trading programs.
- Build and maintain a web-based watershed management issue knowledge center.

DRIVERS

Significant improvement in the state of waters in the state of waters throughout the county has been achieved, since the Clean Water Act was passed in 1972, as a result of implementation of the NPDES; however the NPDES only addresses point sources of pollution. Tens of thousands of impaired waterbodies are subject to nonpoint source loadings of pollutants. Examples of principal nonpoint sources are atmospheric deposition, agricultural runoff, and stormwater runoff. USEPA has espoused a watershed-based approach to remove these impairments. The major regulatory mechanism is the TMDL which integrated both point and nonpoint loadings. States are required to calculate, allocate and implement TMDLs for impaired waters. Other federal agencies such as the U.S. Forest Service (USFS) and the U.S. Fish and Wildlife Service (USFWS) have also adopted watershed approaches. In addition to TMDLs, endangered species protection can also drive watershed management actions. Water quality trading is a non-regulatory driven method that can potentially be used to achieve environmentally effective and cost efficient watershed management. Waterbody impairments that are likely to be of concern to the electric power industry include: mercury, nitrogen, selenium, arsenic, sulfur, acidity, thermal and PCBs. Recent events have included efforts to promulgate regional TMDLs and secondary standards. In regions where there are many impaired waters subject to fairly uniform atmospheric deposition, regulatory agencies have started to derive and implement regional TMDLs. Secondary air quality standards, historically have been dormant since they were no more stringent than the primary standards, have suddenly been a major subject of interest for USEPA. They are developing secondary standard criteria for sulfur and nitrogen based on acidic deposition effects. Both the derivation of regional TMDLs and secondary standards are extremely complex and there are major questions about how to derive them in a manner that is technically and scientifically sound.

RESULTS

Power company environment, generation, and planning staff will extract information from EPRI technical reports, peer reviewed open literature scientific journal papers, EPRI issue briefs, and EPRI presentation material. This information will also be disseminated to community water resource stakeholders and government agencies. Electric power companies will use results to address impaired water, endangered species and water quality trading issues. Electric power companies will also use results to guide design and siting of new generation. In addition, EPRI will facilitate broader use and awareness of the results by presenting webcasts; briefing key stakeholders, including the U.S. Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (USFWS) and state agencies; developing materials for the trade press/media; and continuing service on various government, academic, and professional organization advisory panels.

PLAN

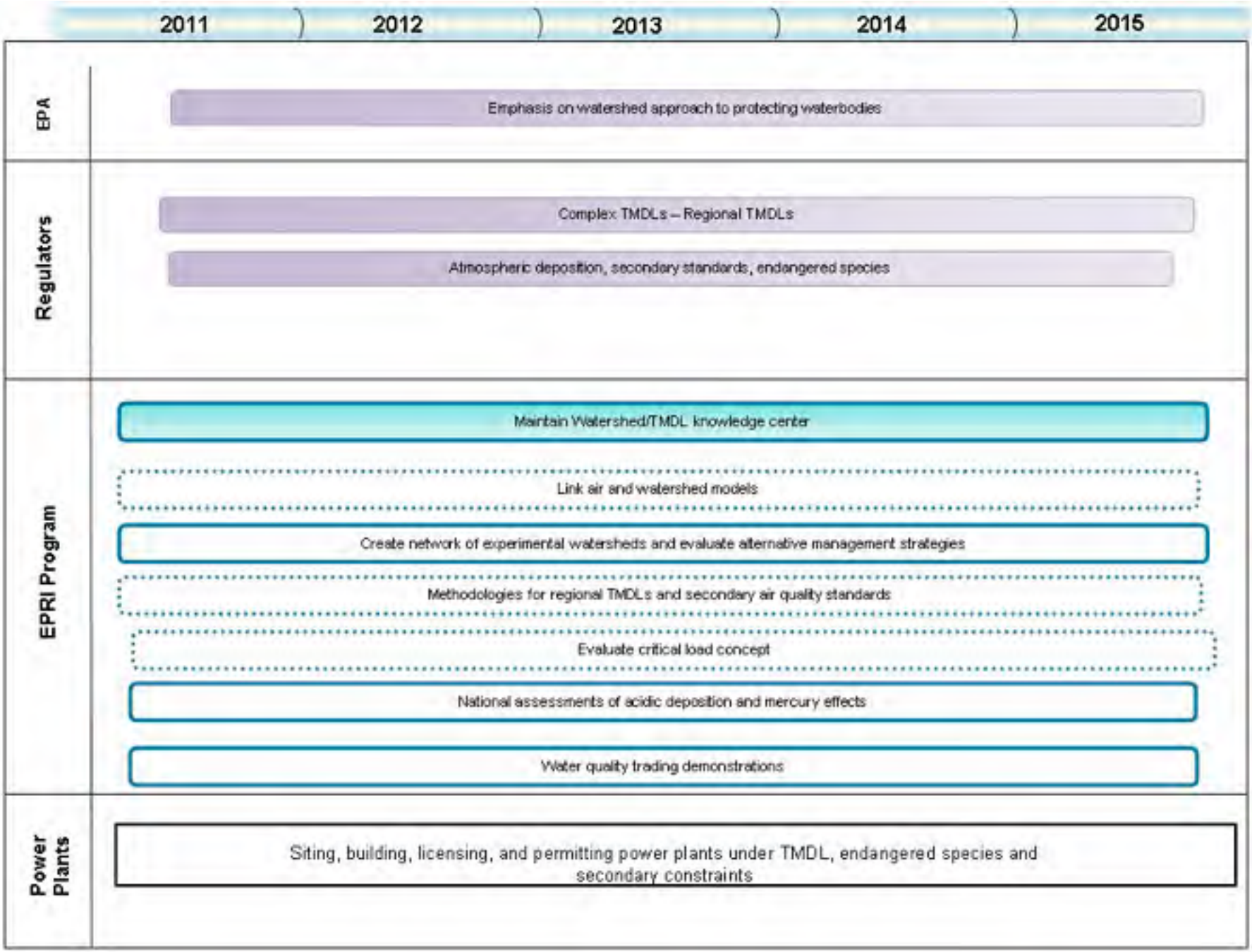
EPRI's research will contribute to the understanding of how air deposition and water quality are linked, and how regional TMDLs can be developed to accurately account for loadings from point and non-point sources. The elements of this research include:

- Linkage of state-of-the art atmospheric and watershed models to assess the ecological impacts of single atmospheric emission point sources. The linked models should be able to address nitrogen, sulfur, alkalinity, mercury, selenium, aluminum, arsenic, bioaccumulation and endangered species.
- Establish a network of watershed sites in diverse environments to test linked atmospheric and watershed models.
- Illustrate how to test alternative emission management strategies for the watershed network above to address waterbody impairment, endangered species and terrestrial community health issues. These strategies should include water quality trading opportunities.
- Evaluate the scientific foundations of proposed methodologies for regional TMDLs and secondary air quality standards.
- Develop and test scientifically sound methodologies for derivation or regional TMDLs and secondary air quality standards.
- Establish and maintain a web-based knowledge center(s) for watershed management, TMDLs, and water quality trading.
- Rigorously evaluate and test the concept of critical loads.
- Provide a national assessment of surface water vulnerability to acidification.
- Provide a national assessment of effect of current levels of atmospheric deposition of mercury on mercury levels in fish.
- Evaluate the effect of sulfate deposition on mercury methylation.
- Incorporate ecological asset management into water quality trading and watershed management approaches.

RISK

Without scientifically sound and proven TMDL and water quality methodologies, electric power companies are vulnerable to:

- Economic stagnation resulting from impaired waterbody imposed limitations on community growth and development.
- Overly conservative and expensive environmental regulations.
- Financial risks associated with non-compliance fines, lost capacity, etc.
- Adversarial relations with customers and water resource stakeholders.
- Inability to meet growing demand for electricity, resulting in both economic and reliability losses.


2011
2012
2013
2014
2015
EPA
Emphasis on watershed approach to protecting waterbodies
Regulators
Complex TMDLs – Regional TMDLs
Atmospheric deposition, secondary standards, endangered species
EPRI Program
Maintain Watershed/TMDL knowledge center
Link air and watershed models
Create network of experimental watersheds and evaluate alternative management strategies
Methodologies for regional TMDLs and secondary air quality standards
Evaluate critical load concept
National assessments of acidic deposition and mercury effects
Water quality trading demonstrations
Power Plants
Siting, building, licensing, and permitting power plants under TMDL, endangered species and secondary constraints

DRAFT: WATER QUALITY TRADING

ISSUE STATEMENT

Water quality trading (WQT) can be a crucial tool to achieve water quality goals and greater environmental benefits when combined with other existing regulatory programs. Trading is unique in that there is a compelling business case for all stakeholders to participate. It also provides an incentive for agricultural stakeholders to participate without the threat of additional regulation. However, to date WQT has not been broadly implemented at a scale that has produced significant environmental outcomes. Because there are many sources of nutrient loading affecting water bodies in the United States, improving water quality will require collaboration among national and state agencies, power plants, industrial facilities, wastewater treatment plants, farmers, environmental groups, and others. With resources applied, the approach will move from having great potential to having real natural resource benefit and reduce the costs for permit compliance.

EPRI's research intends to demonstrate water quality trading as an economically, socially, and ecologically viable approach, and pilot test a specific methodology in the Ohio River Basin that will serve as a model for other efforts across the country. Because WQT frequently involves the installation of conservation practices, there is great potential to not only reduce nutrient loading, but to support many other ecosystem improvements. EPRI research will document and measure the broader benefits to ecosystems for using WQT, compared to a purely technological approach. Specifically, EPRI is working collaboratively across its research programs to document the benefits that WQT can provide for reducing greenhouse gas emissions, supporting biodiversity, and establishing wetlands, among other ecosystem benefits.

Key issues that need to be addressed include:

1. Complete pilot tests to demonstrate that WQT can be used for effective permit compliance.
2. Develop and vet calculation tools for accurately estimating nutrient load reductions and ecosystem service benefits.
3. Establish rules and a framework for legal trades, verification, and trading ratios for reductions.
4. Demonstrate the use of a watershed model for supporting credit trading analysis and development.
5. Inform upcoming regulations, including nutrient criteria development and effluent guidelines, on the benefits and potential of WQT as an effective and ecologically beneficial compliance tool.
6. Determine the extent to which water quality credits can be "stacked" with carbon credits, and develop associated methodology and regulatory approvals.

DRIVERS

There are a number of regulatory and legislative drivers at the state and federal levels that are driving the interest in WQT.

Effluent Guidelines – EPA is currently revising the effluent guidelines for the steam electric power generating industry. These new guidelines are expected to result in tighter limits for power plant discharge and may require plants to install new wastewater treatment technologies. Since coal properties can significantly influence treatment effectiveness, there is significant need for a variety of cost effective and reliable treatment systems and understanding of what wastewater properties affect treatment efficiency. It is possible that nutrients will be included in these guidelines, requiring loading reductions to be met with technologies alone. Demonstrating that WQT can serve as a viable alternative to technologies could be beneficial for informing EPA decision on including nutrients in the guidelines, thereby increasing power industry flexibility and effectiveness of compliance with nutrient limits.

Total Maximum Daily Loads (TMDLs) – EPA has a principal strategic objective to use a watershed approach to achieve protection of water resources through the implementation of Total Maximum Daily Loads (TMDLs) and watershed-integrated NPDES permits. TMDLs can lead to discharge permits more restrictive than current NPDES permits. Regional TMDLs are being developed for nutrients, mercury and other pollutants. Reduction of atmospheric emissions is being considered by states and EPA to satisfy a variety of TMDLs including pH, nitrogen, and mercury. Accessibility to WQT could prove valuable to power plants that may have difficulty meeting more stringent nutrient and temperature requirements.

Water Quality Criteria – EPA develops national ambient water quality criteria, which are then implemented by the states. Utilities are subject to limits on metals and other substances in their discharge permits based on existing criteria and any new criteria that are developed and implemented. EPA has plans to review all ambient water quality criteria for possible revision over the next 5 to 10 years. EPRI research is needed to demonstrate the application of WQT for meeting new criteria.

State Rules and Permits – States issue National Pollution Discharge Elimination System (NPDES) permits to meet EPA mandates. States always have the option of going beyond EPA rules by adopting stricter limits on water use and discharge. WQT can provide a compliance option for meeting NPDES permit limits.

Markets for Ecosystem Services – Interest in the use of markets for protecting ecosystems have spurred rapid growth in research and pilot testing of various tools and approaches for market-based environmental trading programs. WQT is one of these markets which holds promise, but needs additional research and on-the-ground validation to understand opportunities for the electric power industry.

RESULTS

EPRI has advanced the research on WQT in the following ways:

1. Completing 6 years of vetting and research, including a comprehensive feasibility study on WQT.
2. Organizing and launching the largest WQT project in the world in the Ohio River Basin (www.epri.com/ohiorivertrading).
3. Establishing critical collaborations with agencies, states, and stakeholders necessary to advance WQT science and pilot testing.
4. Executing a joint MOU with USEPA and USDA to coordinate research in the Ohio River Basin.
5. Receiving over $2M of external funding to establish the framework for a long-term WQT program.

PLAN

EPRI will advance the research on WQT by:

- Executing pilot trades in the EPRI-led Ohio River Basin Trading Program.
- Investigating compliance options.
- Informing discussion on upcoming nutrient criteria, effluent guidelines, and watershed-based approaches for reducing nutrients.
- Maintaining collaborative relationships with federal and state agencies that will support discussions of WQT and the execution of pilot trades.
- Establishing the framework and rules for trading and achieving reductions.
- Developing the Watershed Analysis Risk Management Framework as a watershed model for supporting the evaluation of environmental benefits of trading.
- Developing robust calculation equations for estimating nutrient, greenhouse gas, and other ecosystem service benefits.

RISK

EPRI water and ecosystem research has been, and continues to be, a critical factor in providing society, EPA, state agencies and EPRI members with high quality, objective and credible information and tools. Credible EPRI research provides a system of "checks and balances" and provides a valuable perspective on behalf of the electric sector that otherwise would not exist. Building on this past history, EPRI is well positioned to inform the effective and appropriate use of WQT for the electric power industry, as well as many others.

SCHEDULE

- Execute pilot trades in the Ohio River Basin Trading Program (2011-2013).
- Investigate compliance options (2012).
- Inform nutrient criteria, effluent guidelines, and watershed-based approaches for reducing nutrients (2012-2015).
- Establish the framework and rules for trading and achieving reductions (2012).
- Develop the Watershed Analysis Risk Management Framework as a watershed model for supporting the evaluation of environmental benefits of trading (2012).
- Develop protocol for stacking water quality and carbon credits (2014).

September 2011

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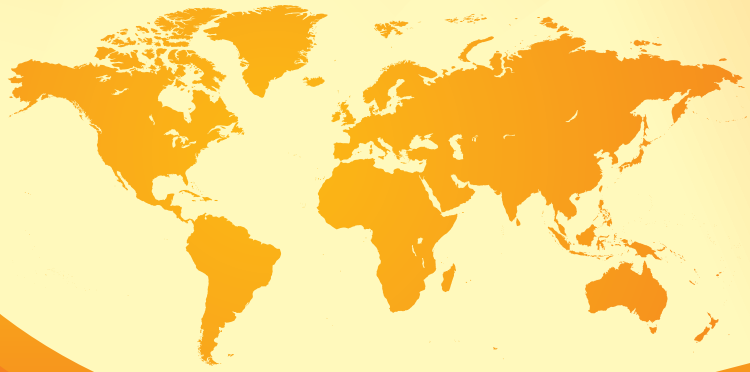
GENERATION SECTOR ROADMAPS



JUNE 2012

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ENERGY EFFICIENCY (END-TO-END): IMPROVING THE EFFICIENCY OF AUXILIARY LOADS AT FOSSIL-FUEL POWER PLANTS

ISSUE STATEMENT

The total efficiency of fossil-fuel power plants can be substantially improved through two types of activities: heat-rate improvement projects, which improve the thermodynamic efficiency of the combustion of fossil fuel (whether coal or gas) into energy, and projects that improve the efficiency of auxiliary power loads at the plant, such as pumps, fans, and other motor-driven applications, as well as ancillary loads such as heating, ventilation, and air conditioning and lighting.

Many potentially cost-effective techniques for improving overall power plant energy efficiency exist, but the industry lacks a well-established framework to measure and verify energy savings from generation loss-reduction activities and to account for their associated costs and benefits. In particular, the focus of this challenge is improved energy efficiency of auxiliary loads at power plants, because fundamental heat-rate improvement activities are under the scope of the Increase Energy Conversion Efficiency roadmap. Auxiliary loads consume 6%–10% of gross electricity generated at fossil-fuel power plants.

Success will be establishment of a robust analysis framework that would satisfy regulatory requirements, enabling energy savings from generation loss-reduction measures to apply toward mandated energy-savings goals, which, in turn, would stimulate such projects and yield greater overall energy savings.

DRIVERS

Increasing fuel costs for coal-fired plants have put added pressure on plant owners to improve plant efficiency to be more competitive. Lower gas prices have further exacerbated market pressures.

Currently, CO_2 capture technology costs are high and the technologies are relatively unproven. No full-scale CO_2 capture processes are operating on commercial electricity generation units, and the technologies that would be used if mandated today could double the cost of electricity. On the margin, plant efficiency improvement is the most cost-effective way to reduce CO_2 emissions, even though only a few percentage points of reduction potentially are available with this approach at each plant.

RESULTS IMPLEMENTATION

A methodology to assess and then reduce auxiliary power could be used by all utilities to improve their overall efficiency. Plant managers can implement heat-rate audits, including an assessment of auxiliary power, to determine areas for improvement.

PLAN

The near-term plan incorporates two supplemental projects that address auxiliary power. First, the Production Cost Optimization (PCO) project, started in 2007, has conducted more than 15 site appraisals, including baseline and follow-up heat-rate determinations. Auxiliary power is included as part of the heat-rate determination. Phase 1 of the PCO project identifies low-cost operational changes and capital projects. Phase 2 provides cost-benefit assessments for major capital projects, including maintenance projects.

The second project, begun in 2012, is A Systematic Approach to Reduce Power Plant Auxiliary Power. The objective is to develop a methodology to assess the potential for reductions in auxiliary power use at a specific plant. This effort could involve operational or process changes, alternative equipment recommendations, or the shutdown of unnecessary equipment, especially at low loads.

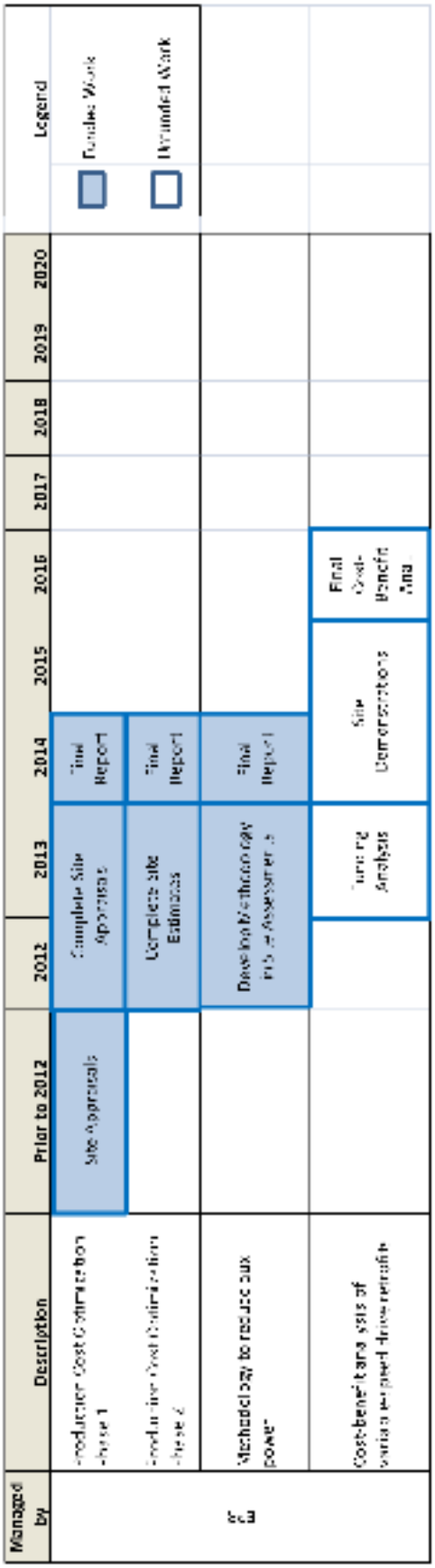
GAPS

On paper, the most obvious opportunity for reducing auxiliary power demand is turning off redundant equipment not needed at low loads, such as circulation pumps and cooling tower fans. However, the possibility of forced outages resulting from equipment failure during restart is a major disincentive that keeps many plant operators from taking advantage of this approach. The costs are perceived as being too great.

Given the more reliable designs now available for two-speed and variable-speed drives, there is a need for thorough cost-benefit analyses for a number of these applications to determine whether the potential savings can justify the inherent risks.

RISKS

Cycling components at lower loads can increase wear and tear on equipment, rendering it more vulnerable to failure. It also can result in increased maintenance costs. Furthermore, unit derates and trips can be very costly. Unless the potential decrease in reliability of key components required for plant operation can be addressed, it will be difficult to persuade plant engineers and operators to take the necessary risks. Finally, regulatory uncertainties associated with plant equipment upgrades can impact implementation decisions.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LONG-TERM OPERATIONS: AGING MANAGEMENT OF FOSSIL ASSETS UNDER CONDITIONS OF FLEXIBLE OPERATION

ISSUE STATEMENT

High-temperature components in gas- and coal-fired generating plants experience material degradation resulting from the combined effects of thermal cycling and high-temperature creep. Thermal fatigue, in particular, has emerged as a major risk to long-term operation of fossil assets due to increased plant cycling and load ramping. Many plants that will be required to operate flexibly over the next decade already have accumulated 25–35 years of operation. The expected increased rate of component life consumption will be added to existing damage already accumulated by these assets. For this reason, it is essential that a comprehensive approach to aging management be developed and implemented industrywide. This approach must include an assessment of existing component conditions, new degradation modeling algorithms that reflect the current operating regimes of fossil units, and unit-specific material properties to use in these models. With an improved aging management process in place, plant owners can make more informed decisions about run/repair/replace and capital projects.

DRIVERS

Need for long-term operation

Supercritical coal and gas combined-cycle assets will be required to operate well beyond their original design life. U.S. Environmental Protection Agency regulations, new plant costs, site permits, and access to water and transmission are key factors driving this trend.

Increased demand for flexible operation

The combined impact of increased renewable generation and fuel price dynamics will force coal and gas plants to dispatch in operational modes that create more equipment damage. The design basis for most existing fossil plants does not include operating modes such as frequent starts, deep load following, or fast ramping. These modes of operation increase the risk of future unplanned outages, emergent work, and capital spending.

Uncertainty in material condition of existing assets

Decades of operation have resulted in component damage in the form of thermal cracking and material property degradation in the existing fleet. These factors must be better quantified on a unit-specific basis to better predict remaining life and manage component aging under long-term operations.

RESULTS IMPLEMENTATION

Upon completion of this work, the following is expected:

- A new set of internationally accepted standards will be developed to determine actual material properties (tensile strength, yield strength, fracture toughness, creep strength, and so forth) of in-service components using miniature sampling methods with correlations to standard full-size tests.
- Plant operators will have methods to monitor material damage in service. This will allow for continued safe operation with knowledge of changing material conditions in advance to permit a controlled shutdown.
- Proven new, nondestructive examination (NDE) techniques will allow detection of damage across a broader range of boiler and piping components much earlier in the operating cycle. This will permit extended operating durations between inspections and/or more confidence in correlations between damage and risk of failure.
- A better understanding of the effect of the interaction between creep and fatigue damage mechanisms in high-temperature components operating in cyclic scenarios will improve the prediction of damage accumulation.
- Options will exist for the repair of large complex pressure-boundary components, such as casings and valve bodies, many of which no longer can be replaced in kind. This will include repairs to new, high-strength, corrosion-resistant alloys.
- Improved manufacturing techniques for replacement components, including near-net-shape powder metallurgy methods, will improve material performance and ease of inspection.

PLAN

Research into the different material, NDE, remaining life, repair, and replacement options will identify the technologies to address long-term operation issues in the current fleet of fossil power plants.

The R&D challenge for long-term operations will be met through a combination of current and future EPRI research, including the following:

- Investigation and development of small sample testing methods to determine material properties with minimal affect on the operating component. This will be performed through detailed laboratory characterization of various materials in EPRI's Small Sample Characterization Laboratory, as well as through an international collaboration with research organizations and universities.
- Evaluation and development of real-time, on-line diagnostic equipment with substantially improved capabilities over existing technologies (high-temperature strain gages, acoustic emission, and high-temperature ultrasonic inspection techniques). Projects will be developed in conjunction with inspection and engineering services companies to facilitate commercialization. Laboratory analysis and field demonstrations will be necessary to prove concepts.
- Improved component flaw inspection methods that will cover larger areas in a timely manner while detecting damage at early stages of progression. Current plans center on digital radiography and enhancements to guided wave ultrasonic technologies. Other emerging technologies will be evaluated as they become available.
- Application and development of new life-prediction models that incorporate an improved understanding of damage accumulation for the more aggressive operation cycles anticipated in aging units. A series of projects, international conferences, and subject matter workshops will be hosted to develop a better understanding of creep-fatigue interaction and other damage mechanisms.
- Novel methods for quickly repairing degraded components will be researched. This might include development of new welding or repair procedures, improved filler metals, high-deposition welding techniques, and application of existing technology in new scenarios. Alternate methods to perform or eliminate the need for heat treatment will be explored, as well as methods to repair degraded materials and components.
- Further developments and commercialization of manufacturing methods for new replacement components. The key technology currently being investigated is the use of powder metallurgy for components that allow for improved inspection and material properties. This technique also provides reduced tooling costs compared with conventional castings. Coatings to allow for better protection from steam-side oxidation, corrosion, and solid particle erosion will be developed and evaluated. New high-strength alloys will continue to be developed and evaluated for power generation service.

GAPS

The following gaps in current research need to be addressed:

- Small sample testing is essential for unit-specific assessment of aged material. Current methods such as small-punch and impression creep are not controlled by a standard, resulting in differing types of instrumentation and testing procedures in use around the world. None of the current methods for sample removal, testing, and data analysis is commercially available.
- Acoustic emission still is unproven for online detection of creep and creep-fatigue detection, although the technology has been commercially applied for pure fatigue damage. Relationships that link signal features to damage and remaining life still need to be understood and developed.
- The operating temperature range, drift characteristics, and service life of existing high-temperature strain gauge technology must be improved for application to new ultra-supercritical plants. Significant challenges exist to online detection of damage in turbines, due to the challenges in accessing locations on rotating components inside very thick turbine shells and large pressure boundaries.
- New approaches for detection of material life consumption during routine inspections are needed to overcome the inherent limitations of ultrasonic methods. These limitations include the inability to detect precrack damage and the outage time required to cover all component areas at risk in the boiler, piping, and turbine systems in a typical outage window.
- Gaining an improved fundamental understanding of creep-fatigue interaction is hampered by the current inability to perform accelerated material testing in a controlled environment. The synergies between these two damage mechanisms must be evaluated to more

accurately characterize observed damage, as well as develop predictive models. Although creep and fatigue are well understood, the combination of these two damage mechanisms is not well understood, including design, inspection, and prediction of damage. The research focus should be on addressing new alloys, thick boiler piping, and turbine components, as well as high-temperature rotating components in steam and combustion turbines.

- Weld repair methodologies will require improvements to meet the needs of an aging fleet. The primary challenges will remain the need for improved filler material, elimination of the need for post-weld heat treatment, and increased automation to reduce human errors. In addition, the repair needs of today's new alloys must be anticipated and developed in advance.
- Replacement of critical components, such as valve and turbine casings, will require emerging technologies, such as powdered metallurgy and hot isostatic processing, to become Code-approved and widely available on a commercial basis.

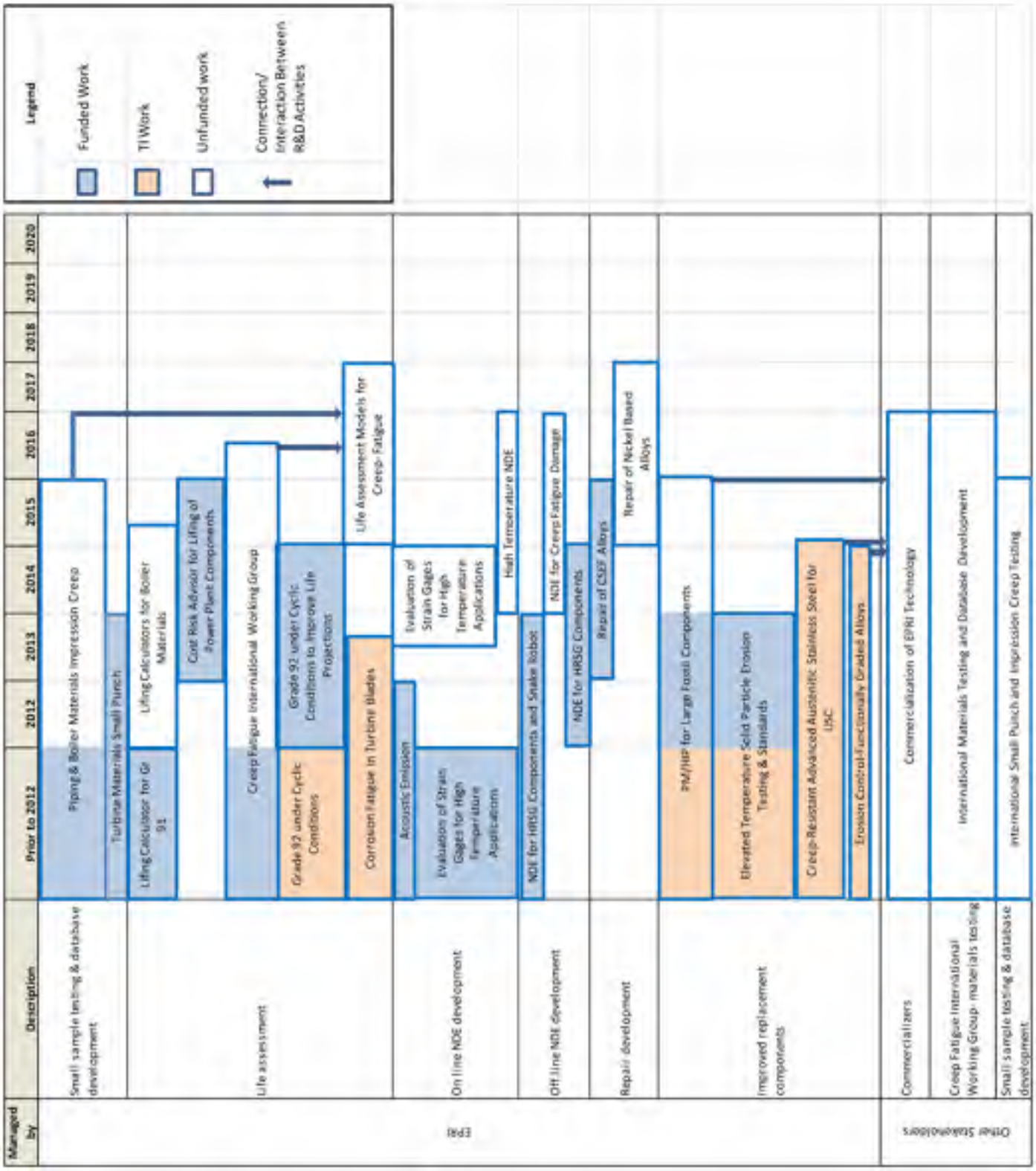
RISKS

The risks of not addressing aging management of fossil plant components include the following:

- Increased unit unavailability as plants are forced to perform unplanned repairs or replacements of major boiler and piping components. Long procurement lead times will extend these repair outage durations, significantly impacting unit economic viability and security of the bulk electric system.
- Increased risk of injury to plant staff from fatigue or creep-related failure of high-temperature and high-pressure steam circuit components.
- Without a repair strategy or new options for replacements, failure of obsolete components will drive up maintenance costs, reducing long-term viability of existing plants.

The risks associated with performing the proposed research include the following:

- Inability to coordinate and standardize small specimen test procedures and data analysis performed by multiple organizations internationally.
- Technology limitations on the ability of new damage monitoring devices to substantially improve online monitoring of material condition.
- NDE capabilities that provide increased coverage and detection of early damage are not developed in time to be applied to aging assets.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Elevated Temperature Solid Particle Erosion Testing & Standards
Creep-Resistant Advanced Austenitic Stainless Steel for USC
Erosion Control-Functionally Graded Alloys
Other Stakeholders
Commercializers
Commercialization of EPRI Technology
Creep Fatigue International Working Group- materials testing
International Materials Testing and Database Development
Small sample testing & database development
International Small Punch and Impression Creep Testing

NEAR-ZERO EMISSIONS: COST-EFFECTIVE AND RELIABLE NZE HAZARDOUS AIR POLLUTANTS COMPLIANCE

ISSUE STATEMENT

Hazardous air pollutants (HAPs) consist of all constituents found in coals known to cause health impacts, such as mercury and other trace metals, total particulate matter, acid gases (such as HCL, HCN, and HF), organics, and dioxins. Achieving near-zero emission (NZE) levels for HAPs poses dual challenges: achieving further reductions in HAPs that already are regulated, such as mercury and particulate matter, and finding solutions for HAPs that currently are not regulated but might be in the future, such as organics and other trace metals.

Technologies that show the most promise for HAPs removal include sorbents and catalysts. Novel sorbents developed to date include sulfur-impregnated activated carbon fiber cloth. Development of advanced sorbents and catalysts requires a better understanding of fundamental gas-solid reaction mechanisms for each target gas-phase pollutant as a function of solids chemistry and pore structure. This can lead to sorbents and catalysts with enhanced gas-sorbent capacity and reactivity, yielding improved emission reductions.

The next step will be to prove that these sorbents are technically and commercially feasible when applied to the existing and future fleet of coal-fired power generating boilers. The key challenge will be to develop NZE-level sorbents or catalysts that are cost-effective and exhibit long-term durability in a coal-fired boiler environment.

DRIVERS

To meet impending regulations, fossil-fired power generators need information on performance, applicability, and costs of controls for achieving the HAPs emission limits in the U.S. Environmental Protection Agency's Mercury and Air Toxics Standard rule for electricity generation units (EGUs). Reasonable-cost solutions remain a challenge in some cases, such as mercury capture in units that burn medium- or high-sulfur coal, as well as acid gases, selenium, and other pollutants across a wider choice of fuels. This situation is especially true for power plants that cannot justify investment in selective catalytic reduction (SCR) for NOx and flue gas desulfurization (FGD) SO_2 control, or, for those with wet FGDs, to avoid excessive costs and complexity in treating FGD wastewater discharges.

Beyond impending regulations, it is anticipated that future regulations will require stricter limitations on currently regulated pollutants (such as NOx, SO_2, SO_3, acid gases, mercury, and filterable particulates) and regulations on additional pollutants, which might include other HAPs, condensable particulates, CO, organics, and so forth.

Accordingly, the industry should be proactive in initiating environmental controls technologies in anticipation of future mandates. This is because of the strong likelihood that, after additional regulations are announced, there will be insufficient time to derive solutions to comply with these mandates.

RESULTS IMPLEMENTATION

Technologies will be implemented on existing and new fossil-fired EGUs to comply with envisioned environmental regulations. This will require that the technologies, following full-scale demonstration, be successfully commercialized. It is envisioned that this will be done by licensing arrangements and strategic alliances between the technology developers (for example, EPRI) and the commercializers (for example, existing vendors of environmental controls systems).

PLAN

For mercury and other trace toxic species, the plan will be to seek better understanding of the fundamental gas-solid reaction mechanisms for each target gas-phase pollutant as a function of solids chemistry and pore structure. This improved understanding will be applied to develop and demonstrate sorbents with enhanced gas-sorbent capacity and reactivity, yielding improved emission reductions. Novel sorbents developed to date show promise, including sulfur-impregnated activated carbon fiber cloth. The next step is to prove that these sorbents are technically and commercially feasible.

Success will be the deployment of commercially available sorbents and catalysts capable of achieving NZE levels (defined as greater than 98% removal) of all currently regulated HAPs, as well as HAPs anticipated to be regulated in the future. Similar to NOx, NZE HAPs levels should be achievable for all coals, coal blends, and opportunity fuels (such as biomass). Systems should be capable of operation over the load range without upset to system performance and reliability.

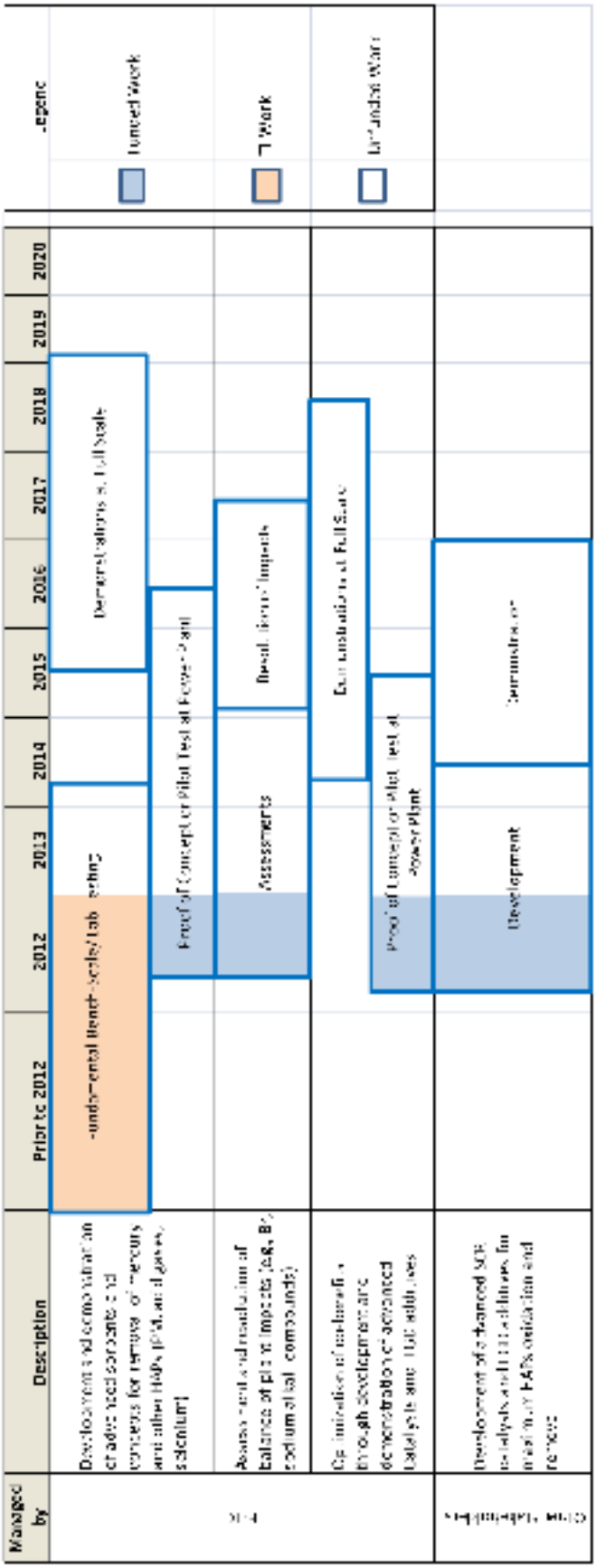
GAPS

Existing gaps that will need to be addressed include the following:

- Development and large-scale demonstration of advanced sorbents for HAPs controls. Advanced sorbents are defined as sorbents capable of more efficient removal of mercury and acid gases, as well as sorbents capable of removal of other HAPs not currently regulated. This will require a more thorough understanding of the relevant chemical mechanisms and, perhaps, utilization of alternative sorbent materials (for example, other than activated carbon).
- Minimization of HAPs while controlling byproduct streams. The impact of HAPs control on byproduct streams (for example, bromine contamination of water effluent from flue gas scrubbing systems) will need to be resolved.
- Optimization of SCR co-benefits to control HAPs. It is anticipated that the vast majority of fossil fuel-burning power plants in the future will be equipped with SCR systems. Although the primary function of an SCR system is to control NOx emissions, SCR systems have proven co-benefits with respect to oxidation of HAPs for later removal in downstream scrubbing systems. As HAPs levels become more restrictive, SCR catalyst formulations will need to be developed that will more efficiently oxidize HAPs while concurrently improving NOx removal levels.

RISKS

If unsuccessful, future HAPs regulations might curtail the use of coal as a cost-effective power generation option. As detailed in EPRI's Prism analysis, this would have a significant impact on future average wholesale electricity costs.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NEAR-ZERO EMISSIONS: COST-EFFECTIVE AND RELIABLE NZE NO_X LEVELS

ISSUE STATEMENT

Selective catalytic reduction (SCR) currently is the only commercial technology that can achieve 90% reduction of NOx emissions from baseline levels on coal-fired units. For most coals, this would result in SCR outlet NOx levels in the range of 15–40 parts per million (ppm), depending upon boiler firing configuration and the degree of low-NOx combustion modifications implemented. Near-zero emission (NZE) levels for NOx emissions are defined as close to 99% removal or, for most coals, less than 5 ppm. Improvements to currently available SCR systems offer the greatest promise for achieving NZE levels for NOx.

Key areas in which R&D is needed to overcome limitations to current SCR NOx reduction technologies while maintaining an acceptable ammonia (NH3) discharge (or slip) level include the following:

- Advanced SCR process control methods to achieve and maintain a more uniform NH_3/NOx ratio at the SCR inlet, in response to spatial and temporal NOx variations that can result from different mill firing patterns, changes in overfire air biases in response to combustion optimizer's control of CO, fuel switches, and changes in load demand.
- More optimal reactor designs that limit catalyst plugging through optimization of two-phase (ash/flue gas) flow patterns and arrangement of catalyst elements of varying pitch.
- Advanced catalyst formulations/combinations that are capable of limiting SO_2, oxidation while maximizing/maintaining mercury oxidation, as well as eliminating/minimizing SCR catalyst deactivation through catalyst masking and poisoning from harmful ash species.

Success will be the deployment of commercially available SCR systems capable of achieving, and maintaining on a sustainable basis, less than 5 ppm NOx levels with less than 2 ppm ammonia slip for all coals, coal blends, and opportunity fuels (such as biomass). Systems should be capable of operating over the load range without degradation of system performance and/or reliability.

DRIVERS

Although current SCR systems are capable of achieving NOx limitations that would be required by pending regulations, such as the Cross State Air Pollution Rule, it is anticipated that future regulations (for example, as what might be required in the 2020 timeframe) will mandate even more stringent NOx regulations that are fuel neutral (that is—no difference in NOx emission requirements between coal and natural gas) and that would require significant advances in current NOx control capabilities for coal-fired boilers. Accordingly, the industry needs to be proactive in environmental controls technology R&D in anticipation of these more stringent future mandates. By conducting these R&D activities now, the industry will be in a stronger position to implement potential solutions in a timely manner.

An additional driver is the likelihood that future regulations will include further limits on SO_3 and NH_3 emissions. Consequently, future SCR systems will need to improve NOx removal efficiency while simultaneously reducing SO_2 oxidation to SO_3, as well as reducing resultant NH_3 slip levels.

Finally, there is the likelihood that future regulations will include CO_2 capture. Most carbon capture systems require that the incoming flue gas streams contain no more than trace levels of NOx, which will provide additional impetus for increased reductions in NOx levels, irrespective of potential future NOx emission mandates.

RESULTS IMPLEMENTATION

Coal-fired boilers represent nominally 50% of the electrical generation in the United States and 40% worldwide. Technologies will need to be applicable to existing and new fossil-fuel fired electrical generating units for compliance with envisioned environmental regulations. This will require that the technologies be successfully demonstrated at full scale with an identified path for commercialization. Where EPRI develops commercializable intellectual property, transfer of technology to the marketplace is envisioned to be performed through licensing arrangements and strategic alliances between the technology developers (for example, EPRI), and the commercializers (for example, existing vendors of environmental controls systems).

PLAN

Advanced NOx control concepts currently are being addressed as part of EPRI's Technology Innovation NZE Strategic Program. This effort includes the development of tunable diode laser- (TDL-) based ammonia and NOx monitors, needed for application of advanced process control based optimizers. As of this writing, a research NOx monitor has been successfully field tested and a commercial prototype is being fabricated.

In EPRI's Post-Combustion NOx Control Program, plans are underway for applications of TDL systems in process control loops. In addition, holistic assessments of the long-term viability of advanced SCR catalysts that are being developed for reduced SO_2 oxidation, enhanced mercury oxidation, and ammonia slip control will be conducted. Holistic assessments review catalyst performance from a multipollutant perspective to better enable a review of potential performance and cost/benefit characteristics.

Successful technology transfer will be the deployment of commercially available NOx control systems and catalysts capable of achieving NZE NOx levels for all coals, coal blends, and opportunity fuels (such as biomass). Advanced NOx control systems should be capable of operation over the load range without upset to system performance and reliability.

GAPS

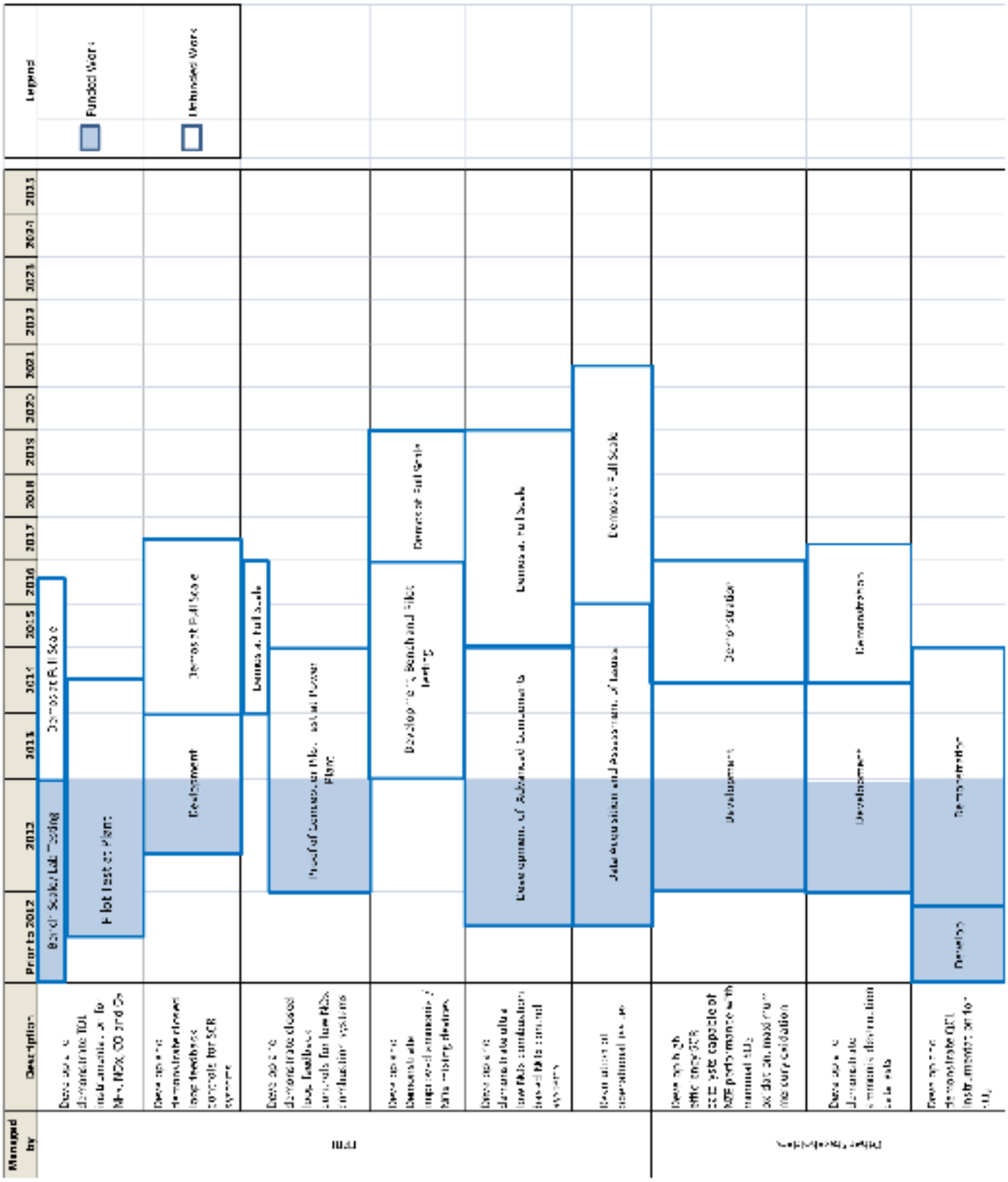
Regarding development and deployment of advanced process controls, an existing gap is the ability of existing NH_3 and NOx monitors to quantify representative gas molar concentration levels to the accuracy needed over the load range, and during periods of rapid transition.

Regarding advanced catalysts, an existing gap is the development of SCR catalyst formulations capable of increased NOx efficiency while concurrently minimizing increases in SO_2 oxidation and maximizing oxidation of mercury and other hazardous air pollutants.

A final gap is the development and demonstration of more sophisticated NH_3/NOx ratio control schemes that are capable of achieving an rms nonuniformity of less than 1%.

RISKS

If unsuccessful, future NOx regulations might curtail the use of coal as a cost-effective power generation option. As detailed in EPRI's Prism analysis, this would have a significant impact on future average wholesale electricity costs.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NEAR-ZERO EMISSIONS: COST REDUCTIONS FOR ADVANCED CYCLES

ISSUE STATEMENT

Some advanced technologies that generate power from coal more efficiently while also capturing CO_2 are ready for commercial demonstration/deployment (for example, integrated gasification combined cycle [IGCC] and ultra-supercritical oxy-combustion power plants), but they pose significant cost premiums over traditional coal-fired power plants, as well as low CO_2-emitting baseload power options, such as nuclear power.

Based on today's technologies, it is predicted that the cost of electricity from advanced pulverized coal plants with CO_2 capture and IGCCs with CCS will be in the range of \$105–\$120 per megawatt-hour (MWh)[1], whereas the cost of electricity from nuclear power plants and natural gas combined-cycle plants (NGCCs) with CCS will be in the range of \$80–\$90 per MWh. Significant capital cost improvements (>20%) will be needed to achieve cost-competitive coal power generation that meets near-zero emission (NZE) targets.

DRIVERS

Continued increases in worldwide CO_2 emissions could cause governments to place restrictions on those emissions in the future, but, currently, the cost of coal power generation technologies that could meet those restrictions is high.

RESULTS IMPLEMENTATION

If the cost of coal power with low CO_2 emissions can be lowered to the range of \$80–\$90 per MWh, the deployment of this technology most likely will first occur in regions where captured CO_2 can be used for enhanced oil recovery. As costs decline further with multiple applications of the technology, or if CO_2 emissions restrictions become severe, the technology likely would be deployed in non-oil-producing regions.

PLAN

EPRI's IGCC R&D has two primary goals: to facilitate the transition from every IGCC being a first-of-a-kind plant to a mode in which each new IGCC looks more like the ones that came before it and incorporates the lessons learned from those pioneer plants and to identify and nurture new technologies that could have a significant impact on the economics of IGCCs.

The design guidelines effort will help remove the first-of-a-kind cost premium from IGCCs. First designs of power plants require many more engineering hours during the design phase and often face long startup periods while operators get the kinks out of new equipment. EPRI typically estimates that for so-called Nth-of-a-kind power plants, the engineering costs are equal to 10% of the cost of the plant. For a first-of-a-kind IGCC, engineering costs have been 20% of the total plant costs. Consequently, the end result of the IGCC Design Guidelines effort could be a 10% reduction in IGCC capital cost.

A 10% reduction would not be sufficient to achieve the desired target of >20% capital cost improvement. Technology improvements also are needed. One such improvement EPRI first developed in its Technology Innovation Program and is now investigating with the U.S. Department of Energy is the mixing of captured and liquefied CO_2 with coal to form the slurry that is pumped into the gasifier. Because of the favorable thermodynamic and fluid properties of liquid CO_2, compared with water, initial estimates show that this could improve the overall efficiency of the process by up to 3 percentage points. This would reduce the size of the gasification equipment needed to produce a given amount of power, which should reduce capital cost.

EPRI's oxy-combustion R&D principally is focused on monitoring the status of oxy-combustion technology worldwide. EPRI also is supporting ongoing development of advanced ultra-supercritical (A-USC) steam power cycles. A-USC cycles will operate at much higher temperatures and pressures than today's coal power plants, and that will improve thermal efficiencies. The NZE roadmap on increasing energy conversion efficiency provides additional detail on the A-USC R&D effort. A-USC technology will help oxy-combustion economics in several ways. First, a more efficient plant will consume less coal, which means the oxy-combustion plant also will need less oxygen to produce a given amount of power. Smaller oxygen plants mean lower capital costs. Second, because the advanced materials being developed for A-USC plants can withstand hotter temperatures, the fireball inside the boiler can operate at a hotter temperature. That will create a larger driving force for heat transfer, which means that the total number of steam tubes in the boiler can be reduced.

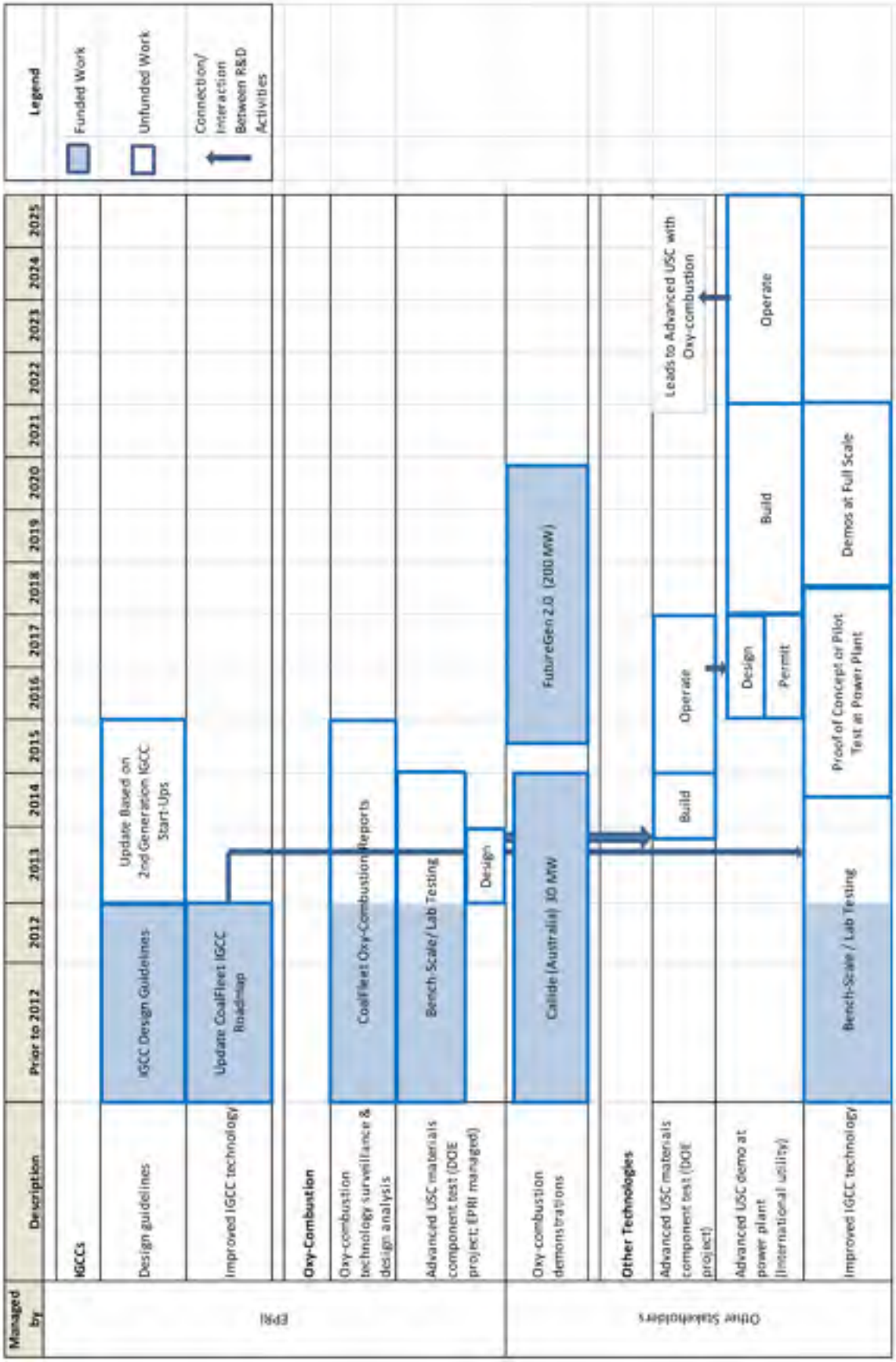
[1] *Program on Technology Innovation: Integrated Generation Technology Options*. EPRI, Palo Alto, CA: 2011. 1022782.

GAPS

EPRI's existing R&D program is not sufficient to ensure that this challenge will be successfully met. Scale-up of both the liquid CO_2 coal slurry and the A-USC technologies is needed. For the latter, a component test facility is needed to provide the level of confidence investors will require before buying a full-scale plant, which in turn builds up the required supply chains for full-scale applications. In addition to scale-up, cost savings could be derived from optimizing construction techniques of IGCCs and oxy-combustion power plants. The potential of using modular construction as a way to reduce the cost of building advanced coal power plants should be investigated. Developing detailed 4-D (including time) construction models of these plants is another potential pathway to lower costs. EPRI's Nuclear Sector has used this approach to identify significant cost and time savings for advanced nuclear power plants. A similar effort for IGCCs and oxy-combustion plants also could yield valuable outcomes.

RISKS

A basic principle of risk management is to diversify a portfolio. If cost-competitive, low-CO_2-emission coal power generation technology is not developed and proven, there will be fewer options for power generation in a CO_2-constrained world. This will place more price pressure on other generation options and increase the probability of unwanted outcomes (for example, high natural gas prices and high costs for coal with CCS and no lower-cost alternatives).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Advanced USC materials component test (DOE project; EPRI managed)
Bench Scale/Lab Testing
Design
Oxy-combustion demonstrations
Callide (Australia) 30 MW
FutureGen 2.0 (200 MW)
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Advanced USC materials component test (DOE project)
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Advanced USC demo at power plant (International utility)
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Operate
Improved IGCC technology
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Demos at Full Scale

NEAR-ZERO EMISSIONS: DEMONSTRATE PERMANENCE AND SAFETY OF GEOLOGIC CO_2 STORAGE

ISSUE STATEMENT

Development and demonstration of affordable and environmentally safe CO_2 capture and storage (CCS) technologies might be required for new and existing fossil power plants.

The perception is that the main costs for CCS are in the CO_2 capture system; however, a significant uncertainty exists as to whether the captured CO_2 can be stored underground in a safe and environmentally benign manner. Even if capture systems can be developed, the CCS process cannot be implemented if storage is not demonstrated and proven storage locations are not available.

DRIVERS

After the CO_2 is captured, it must not be released to the atmosphere. Currently, no products based on using CO_2 have been identified that would consume significant amounts of CO_2. This has led to the concept of storing the CO_2 in underground saline reservoirs. Although studies have shown that this is possible at small scale, it will require large-scale demonstrations to prove that all of the issues of concern are addressed.

Recently, the use of CO_2 in enhanced oil recovery (EOR) has been receiving increased attention. However, although EOR is commercially proven, confirming that the injected CO_2 will be stored properly is still to be demonstrated if credit for storing CO_2 is desired; in addition, even if CO_2 used in EOR is certified as stored, the potential capacity of EOR operations is not sufficient to meet all of the world's CO_2 storage needs, and the oil fields are not available everywhere fossil fuel power is produced. Consequently, storage in saline or geologic formations is needed.

RESULTS IMPLEMENTATION

Assuming that demonstrations of storage of CO_2 are successful, storing CO_2 will commence consistent with the needed reductions of CO_2. Early adopters likely will be existing coal plants followed by new plants. The regions of adoption will be where power plants exist and storage opportunities for EOR and saline reservoirs are available.

PLAN

Testing large-scale CO_2 storage permanence and assessing risks involves projects such as those planned by the U.S. Department of Energy's (DOE's) Regional Carbon Sequestration Partnerships and comparable programs in Canada, the European Union, Australia, and China. Developing and demonstrating the ability to monitor the footprint of the injected CO_2, anticipate any risks, and develop/demonstrate mitigation strategies are critical to reducing the risk of geological storage and informing the public and regulatory agencies about the safety of CCS.

Resources required for these demonstrations are beyond those EPRI can bring to bear. EPRI's efforts will focus on the following:

- Ensuring that the needs of the industry are incorporated into the R&D demonstrations through participation in the DOE regional partnership program and promoting demonstrations that focus on storing CO_2 from fossil-fired power plants in saline reservoirs
- Identifying research areas in which EPRI can provide information critical to addressing the issue, such as the potential impact of CO_2 on drinking water (if a leak were to reach a drinking water reservoir)
- Other issues such as well-bore integrity, induced seismicity, fault activation, remediation options, seal integrity, and strategic monitoring

The newest issue in CCS is a focus on EOR as a method of using captured CO_2. There are challenges with ensuring that the CO_2 is stored in an acceptable manner, and EPRI is likely to initiate a project to review these issues and identify what R&D might be needed and whether EPRI can play a useful role.

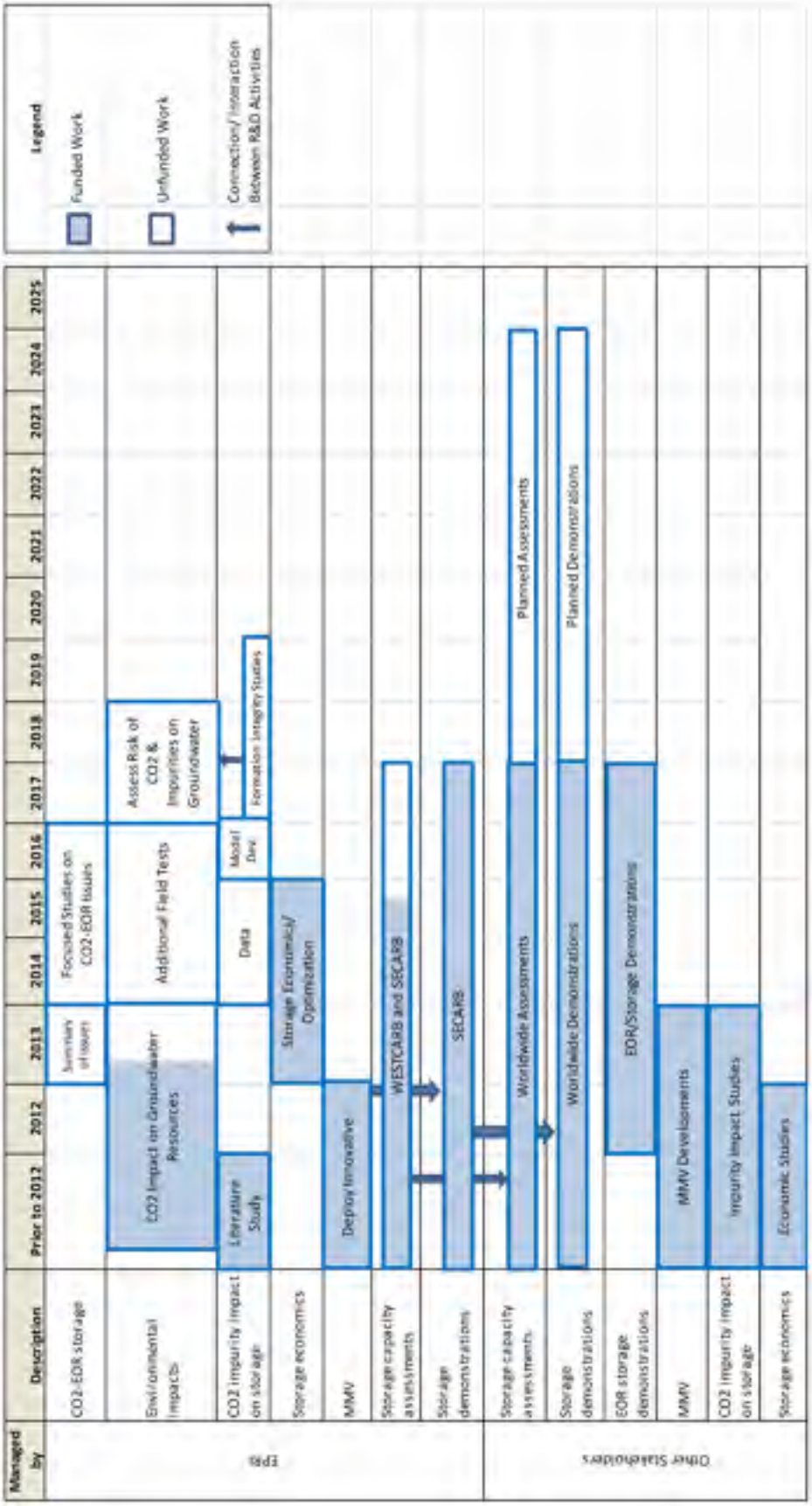
GAPS

The path to conducting the desired number of large-scale demonstrations is becoming more difficult. In addition, with the changing focus to EOR, saline storage is beginning to take a back seat in large-scale storage projects. The use of CO_2 in EOR is commercially proven but not when storage is included. A significant amount of R&D and a number of demonstrations might be needed before this concept can be considered as proven. However, EOR projects can provide a stepping stone to lower-cost CO_2 capture by helping to subsidize the cost of early, large-scale CO_2 capture projects.

The other area of need is for qualification of storage sites. Significant work is ongoing to identify potential sites but work has not begun to confidently ensure that locations will be ready as needed. The issue is that costs to develop sites can exceed $100 million.

RISKS

If cost-competitive, low CO_2 emission coal power generation technology with CO_2 storage or utilization is not developed and proven, there will be fewer options for power generation in a low-carbon world.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NEAR-ZERO EMISSIONS: INCREASED ENERGY CONVERSION EFFICIENCY

ISSUE STATEMENT

Increasing the energy conversion efficiency of coal-fired plants offers multiple benefits. They are as follows:

- Based on independent engineering analyses by the U.S. Department of Energy (DOE) and EPRI, increasing the generating efficiency of coal-based power plants is a cost-effective means of lowering their CO_2 emissions. Also, as less CO_2 per megawatt-hour (MWh) is produced, the cost of CO_2 capture and storage (CCS) is reduced.
- As the amount of coal required is reduced, the environmental impact of mining and transportation is reduced proportionately.
- The environmental impact of the power plant is reduced by lowering cooling water use and the emission of criteria pollutants, such as SO_2 and NOx, as well as hazardous pollutants, such as mercury.

Deploying the technologies required to achieve the goal of improving heat rates by a desired minimum of 20% will involve first-of-a-kind costs and varying degrees of technical risk that will deter their acceptance by the power industry. To overcome these obstacles, these risks and uncertainties need to be quantified and reduced—technical and economic justification will need to be developed. If the economic effectiveness of efficiency improvement technologies is not demonstrated prior to 2020, they will not be commercialized rapidly enough for widespread deployment after 2025, when it is anticipated that they will be needed in new coal-based power plant designs.

DRIVERS

Factors driving the need for increased energy conversion efficiency include the following:

- Reducing environmental impacts related to coal-based generation, including air emissions (criteria and hazardous air pollutants), water use, and solid wastes
- Reducing fuel use to lower costs and conserve fossil-fuel resources
- Reducing CO_2 emissions from coal, the highest carbon intensity fuel, by improving efficiency, which can help with the following issues:
  - If CCS is required, costs currently are high but are expected to be reduced through technological advances. Reducing the volume of CO_2 emitted from the power plant per MWh can contribute to lowering the cost impact of adding CCS.
  - Uncertainty over gaining public acceptance to transport and store CO_2. Technology that improves efficiency can significantly reduce CO_2 emissions potentially without resorting to CCS.

IMPLEMENTATION STRATEGY

Demonstrating technologies that increase energy conversion efficiency is essential in ensuring that they are incorporated in new coal-based power plant designs.

- For pulverized coal (PC) power plants (and equally applicable to circulating fluidized bed plants), dramatic increases in the strength and corrosion resistance of boiler tube materials have made feasible advanced ultra-supercritical (A-USC) steam temperatures as high as 1400°F (760°C). Compared with a conventional supercritical PC plant, the heat rate of the A-USC plant (and so, too, the CO_2 per MWh) is up to 20% lower. The efficiency of oxy-combustion power plants also can be improved by using A-USC technology. To advance A-USC technology, the first step most probably will be implementing 1300°F (700°C) steam temperatures. Additional improvements can be incorporated, such as raising steam temperature to 1400°F (760°C), double reheat, and the replacement of water with CO_2 as the working fluid. After A-USC technology is demonstrated, a challenge will be ensuring that there is sufficient manufacturing capacity for the materials and components to sustain widespread deployment.
- For integrated gasification combined cycle (IGCC) plants, several elements are contained in the EPRI IGCC roadmap[2] that contribute to improving efficiency. These include a novel oxygen separation technology that can improve the generating efficiency (and potentially for oxy-combustion) and currently is being demonstrated. Another concept under evaluation involves using a CO_2 slurry to feed coal (CO_2's thermodynamic properties have advantages over water that can improve efficiency; for example, its heat of vaporization is 20% less). Also, hydrogen transport membranes, which can significantly increase efficiency when CO_2 capture is required for IGCC, are being developed. Finally, gas turbines that use higher firing temperatures, already available for natural gas-fired plants, need to be developed and demonstrated for firing coal-derived syngas.

[2] *CoalFleet Integrated Gasification Combined Cycle Research and Development Roadmap*. EPRI, Palo Alto, CA: 2011. 1022035.

- Energy conversion efficiency can further be increased through the use of cost-effective, low-temperature heat recovery measures and the use of working fluids other than water, such as CO_2.
- Waste heat/lower-temperature heat recovery technologies that can cost-effectively improve efficiency need to be demonstrated and their reliability established. One advanced cycle that EPRI is investigating is a supercritical CO_2 Brayton cycle that can improve efficiency by drawing waste heat from processes such as the compression of CO_2 prior to storage (current research also indicates that this technology can be used in a variety of ways, including as a topping cycle retrofitted to existing coal-fired units). Demonstrating this technology at scale is a key part of the implementation strategy.
- Other technologies that are less mature but ultimately might yield even better efficiencies include pressurized oxy-combustion, chemical looping, fuel cells (for example, direct-carbon fuel cells and coal gasification solid oxide fuel cells), and a reevaluation of magneto-hydrodynamic economics for low-carbon applications. The implementation plan is to continue to perform R&D and assess costs and risks while advancing these technologies from smaller-scale demonstrations to commercial scale.

EPRI's role for these cases (EPRI already is engaged in many of them) is to develop economic and engineering information, support test programs, and identify strategies that mitigate risks and help potential users understand the benefits of the technology for their particular circumstances.

It should be noted that some more mature efficiency improvement technologies are already proven to have acceptable technical risks, but their deployment cannot currently be justified economically because of high costs. Lowering their costs is the focus of another key NZE challenge: Cost Reductions for Advanced Cycles.

PLAN

The elements of the plan to implement increased energy conversion efficiency measures include the following:

- EPRI will continue to provide technical leadership to the DOE's Advanced Boiler and Steam Turbine Materials Program. To date, this program has characterized strength and corrosion-resistance properties of materials suitable for use at 1400°F (760°C). Satisfactory fabrication procedures have been developed, and material properties have been adjusted to overcome microfissures in welds for nickel alloys. American Society of Mechanical Engineers Code approval was received for Inconel 740, an exceptional boiler tube alloy, and data for Code approval of Haynes 282, an equally exceptional turbine rotor alloy, are in preparation. Remaining work includes developing alloys in castable form for large components such as valves, establishing repair procedures for aged materials, and demonstrating A-USC at scale (work is ongoing in India and China in this arena). All work might be completed by 2014/15, but a shortfall in funds could delay this.
- EPRI's CoalFleet for Tomorrow Program[3] has embarked on a series of projects to identify the most cost-effective design for an A-USC power plant. This will help advance the technology to demonstration. This work will evaluate the following:
  - The thermal and economic benefits of going to 1400°F (760°C) steam conditions
  - The thermal and economic benefits of double reheat
  - Sources of low-grade heat and how to integrate them into an A-USC design (A supplemental project is offered on this topic, coupled with water recovery.)
  - Cost-effective integration of the A-USC power plant with a post-combustion capture (PCC) plant (Alternative CO_2 capture technologies will be investigated as they emerge.)
  - Rather than accepting PCC as an add-on to the power plant, a fresh approach to the arrangement of heat transfer circuits when the power plant is integrated with CCS
  - Retrofitting A-USC technology in an existing coal power plant while maximizing the use of the existing infrastructure
- For IGCC technologies, EPRI's CoalFleet for Tomorrow Program has multiple ongoing projects including the following:
  - EPRI is leading a collaborative assessing a novel oxygen separation technology that can improve the efficiency of IGCC by lowering auxiliary power requirements. A demonstration of this technology at intermediate size is imminent, with a plan to have it ready for commercial-scale applications in the 2015 timeframe.
  - In a project sponsored by the DOE, EPRI currently is testing at bench scale the concept of using CO_2 slurry to feed coal to IGCC gasifiers and also is developing plans for a larger-scale demonstration.

[3] *CoalFleet for Tomorrow* is a registered trademark of EPRI.

- EPRI is pursuing being part of the team helping to advance hydrogen transport membranes, which can significantly improve IGCC efficiency when CCS is required.

- Although it is outside of EPRI's scope, the greatest impact on IGCC efficiency will come from demonstrating higher-firing-temperature G-, H-, and J-class gas turbines in IGCCs. The DOE currently is funding a project to ready H-class turbines for use in IGCCs, and a J-class turbine is under development by vendors. However, an actual demonstration of a high-efficiency IGCC is a current gap.
- Work to quantify the benefits of using CO_2 as the working fluid in a power cycle is in progress through EPRI's CoalFleet for Tomorrow Program and the Technical Innovation (TI) Program. Supercritical CO_2 Brayton cycles are close to being demonstrated at 8–10 megawatts (MWe) in multiple projects, and EPRI is working with technology developers by giving guidance on how to best test the technology, assess its benefits, and advance demonstration of the technology at a more commercially representative size (100 MWe).
- For less mature technologies, such as pressurized oxy-combustion, chemical looping, fuel cells, and others, EPRI has published several due diligence-type reports. TI funds are required to continue R&D efforts on these technologies until they are ready for smaller-scale demonstrations; however, this is a current gap.

EPRI will provide technical and economic insights and support power producers in selecting the most cost-effective technologies for use in their systems. Approaches will be established to help mitigate the technical and financial risk associated with first-of-a-kind demonstrations.

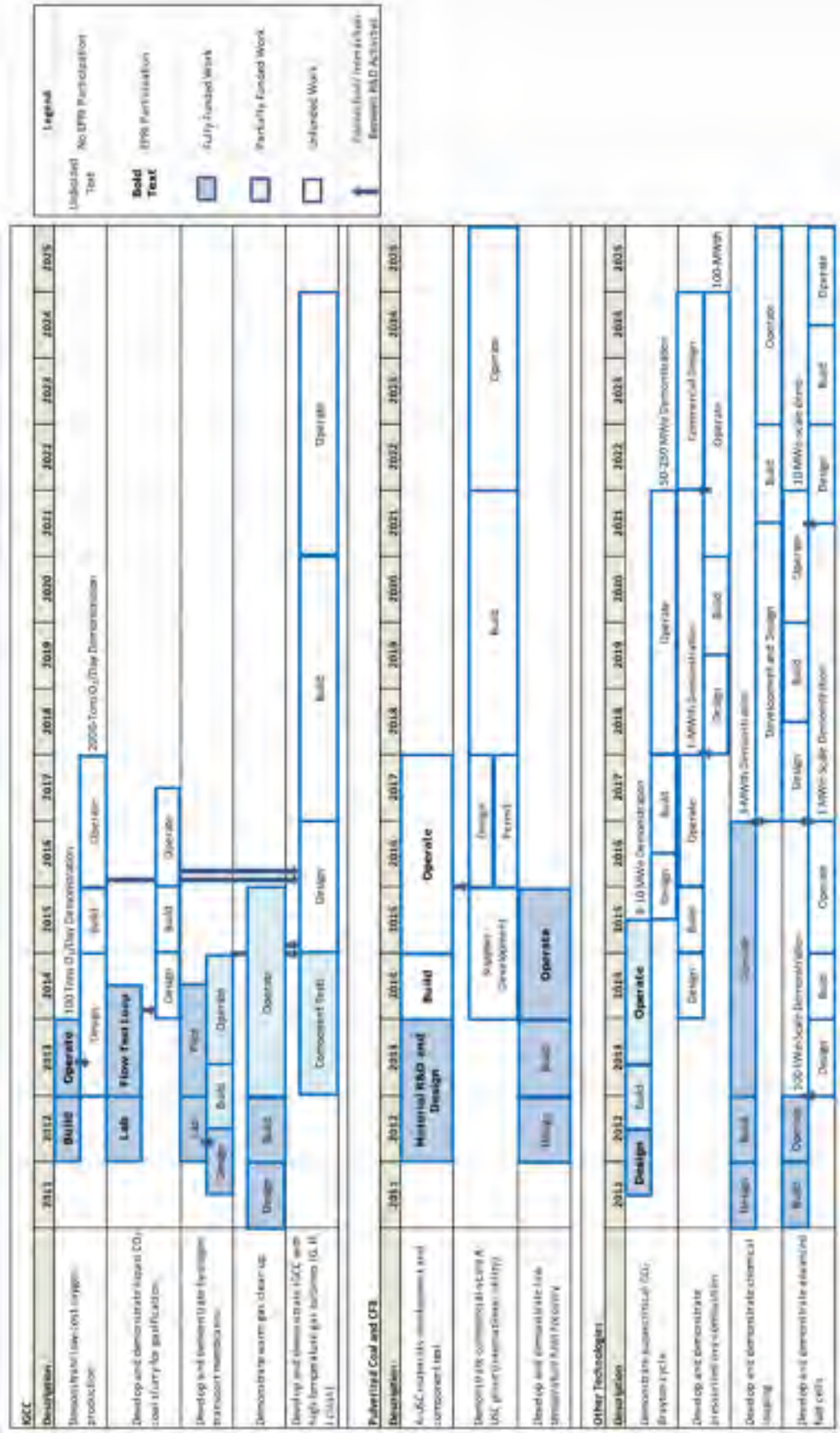
GAPS

Because the demonstration of efficiency-improving technologies, particularly large-scale projects such as implementing A-USC or H-class IGCCs, will cost more than a conventional plant, a power producer could not afford to build it without a subsidy, particularly if the plant is integrated with CCS. This extra cost normally is offset by government funds, and although some action is occurring (for example, the governments of China and India have announced plans to pursue building 1300°F [700°C] A-USC PC plants), most budgets have tightened worldwide. In the United States, this has resulted in more limited demonstration projects, with goals being changed to concentrate on less-expensive development and R&D programs. The gap in demonstrating technology means that they will not advance rapidly enough to meet the desired timeline for their commercial implementation.

RISKS

The demand for electricity is certain to grow worldwide; therefore, generating capacity will need to increase accordingly. If coal generation is prevented from fulfilling a portion of this demand, power production could become overly dependent on natural gas and power prices could rise dramatically. The price of gas also might rise as demand increases; therefore, two major sources of energy could be subject to price hikes. This outcome already is being seen across Europe.

The price increase in gas and electricity can be moderated by developing and deploying efficient coal-based technologies with CCS. However, to be effective, this approach must be achieved within a specific time. Currently viable coal plants will be retired increasingly following 2025. If coal plants with CCS are not commercially available by then, alternative generating technologies will be used, which will exert inflationary pressures on those other options.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NEAR-ZERO EMISSIONS: MAINTAIN NEAR-ZERO EMISSIONS THROUGHOUT FLEXIBLE OPERATIONS

ISSUE STATEMENT

Near-zero emission (NZE) levels for most pollutants likely will be required throughout unit operations, including transient operations such as startup, load following, and shutdown. During transient operation, first-order parameters impact the performance of most environmental controls systems, which are designed for steady-state operations. For example, changing upstream conditions such as air/fuel ratios will impact NOx, SO_3, particulates, and organics emissions. Operational transients for coal units that traditionally have served baseloads are anticipated to increase in future years, as a result of increased use of natural gas and renewables for power generation. To reduce all criteria pollutants to NZE levels, post-combustion controls will need to continue to operate at peak performance during load transients, through changing fuel blend ratios and qualities, and during a variety of upset conditions (for example, boiler tube leaks and mill malfunctions).

Technologies that show the most promise include advanced laser-based sensors capable of continuous monitoring of all criteria pollutants down to NZE levels over the load range and during accelerated changes in operating conditions and control feed-forward and feedback loops capable of accelerated response times.

Success will be the deployment of commercially available feed-forward and feedback optimization systems capable of controlling all post-combustion pollutant control systems to NZE levels during load transients, changes in operation, and upset conditions.

DRIVERS

Increased dependency on renewable resources (the majority of which are intermittent), along with increased use of natural gas, has resulted in increased load following, cycling, and low-load operation of the coal-fired fleet. This trend is anticipated to continue in future years. In addition, economic considerations have provided, and will continue to provide, incentives to fossil boiler operators to seek alternative fuels and blends.

These considerations, together with the anticipated ratcheting down of emissions levels for hazardous air pollutants, NOx, SO_2, and particulates, will serve as the drivers for the development and demonstration of technologies that enable NZE while maintaining flexible operation.

RESULTS IMPLEMENTATION

Technologies that address flexible operation will need to be developed and implemented on existing and new fossil-fired electricity generation units to comply with environmental regulations. In a number of cases, it is envisioned that NZE technologies will need to be installed, and NZE performance proven, before these technologies can demonstrate performance during flexible operation. In this case, add-on technologies (for example, advanced instrumentation and controls) might need to be retrofitted onto pre-existing NZE hardware technologies.

PLAN

Some components of flexible operations (for example, advanced tunable diode laser- (TDL-) based instrumentation), currently are being addressed as part of EPRI's Technology Innovation NZE Strategic Program. This effort includes the development of TDL-based ammonia and NOx monitors, needed for application of advanced process control-based optimizers, a necessary component for flexible operation of selective catalytic reduction (SCR) systems. Current plans are to move these projects into the base environmental controls programs in 2013 and beyond.

In EPRI's Post-Combustion NOx Control Program, strategies to better manage low-load operation, including operation below the temperature at which ammonium bisulfate (ABS) condenses, are being assessed. In addition, there are a number of supplemental projects that assess the performance of advanced controls at full scale.

EPRI's Integrated Environmental Controls Program will reexamine flue gas desulfurization (FGD) performance issues during low and transient loads in light of changing FGD designs and equipment. This effort also will investigate impacts on FGD chemistry control and operations, oxidation air, byproduct handling, and wastewater treatment.

Success will be the deployment of commercially available emissions control systems for all current and future regulated pollutants that are capable of achieving NZE levels over the load range and during load transients without upset to system performance and reliability.

GAPS

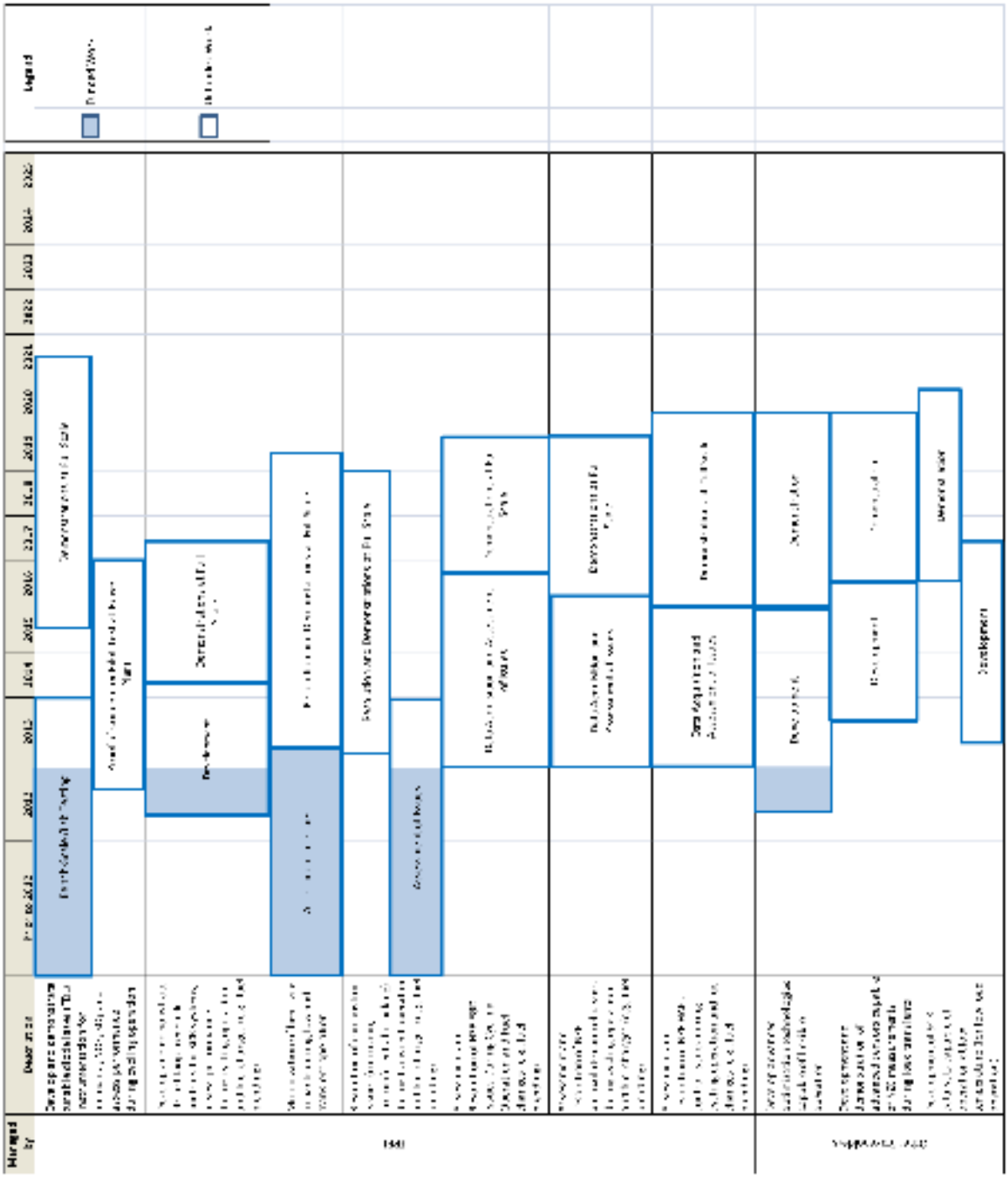
Because flexible operation will require rapid responses of all environmental control equipment, advances in instrumentation and controls will be needed. These will include laser-based sensors capable of continuous monitoring of all criteria pollutants down to NZE levels over the load range and during accelerated changes in operating conditions and control feed-forward and feedback loops capable of accelerated response times. In addition, flexible operation will require that all environmental control hardware be able to function at peak capacity as the flue gas stream experiences rapid changes in temperature, flow rate, velocity, particle loading, and, for the case of changes in fuel composition, gaseous and ash compositions.

Issues specific to key environmental control hardware include the following:

- SCR. A key issue that will need to be resolved is the ability of SCR systems to operate at temperatures below which ABS condenses, without deactivation of the catalyst. In addition, the SCR system will need to maintain NOx and ammonia slip levels during periods of rapid load change.
- Low NOx burners. Issues associated with fuel/combustion air distribution will need to be resolved during load transients and lower loads without impacting NOx, SO_3, heat rate, and boiler tube reliability issues, such as fireside corrosion and circumferential cracking.
- Electrostatic precipitators. Opacity excursions need to be avoided during rapid load ramp-up. In addition, issues associated with startup (for example, when oil is used as the startup fuel) will need to be resolved.
- Activated carbon and reagent injection. Issues associated with over/under injection rates during transient loads will need to be avoided.
- FGD. Water management will need to be addressed, along with gypsum quality issues.
- Heat rate. Because future regulations might calculate emissions on a mass basis (as opposed to a concentration basis), heat-rate penalties during low and transient loads will need to be minimized.

RISKS

If unsuccessful, future environmental control regulations might curtail the use of coal as a cost-effective power generation option or, as a minimum (for example, in the case that NZE levels are realized for all regulated pollutants but flexible operation issues are not), will limit the use of coal to base loaded applications. As detailed in EPRI's Prism analysis, this would have a significant impact on future average wholesale electricity costs.



ISSUE STATEMENT

When used with advanced combustion and post-combustion emissions mitigation technologies, advanced coal-cleaning processes (also termed precombustion fuel beneficiation) might enable more cost-effective attainment of near-zero emission (NZE) levels. Although coal cleaning has been used for decades, the focus has been limited to improving the quality of low-rank coals by removing sulfur, ash, and moisture.

Advanced combustion cleaning refers to those technologies that go beyond conventional coal cleaning, beneficiation, and dewatering and can include thermal, mechanical, or chemical treatment of the coal to remove pollutant precursors, including mercury and other hazardous air pollutants (HAPs). The challenge for the industry is to assess how advanced coal-cleaning technologies would be deployed in concert with combustion and post-combustion environmental controls to significantly reduce the overall cost of NZE compliance levels and then to initiate the development and demonstration of those technologies.

Success will be the deployment of commercially available coal-cleaning systems that work in concert with combustion and post-combustion-based environmental controls to achieve NZE levels at a significantly lower cost.

DRIVERS

Historically, environmental compliance for fossil-fired electricity generation units (EGUs) has been achieved by the deployment of combustion and post-combustion environmental control technologies. However, as regulators further ratchet down allowable levels for NOx, SO_2, SO_3, and HAPs, fuel cleaning prior to combustion might need to be part of the overall environmental controls plan, when deployed in series with environmental controls.

Another driver is impending water regulations. For example, HAPs currently are released into the flue gas stream during the combustion process and then scrubbed out in wet flue gas desulfurization units downstream of the combustion process, leading to potential issues with HAPs leaching from the effluent water. It is anticipated that future environmental controls regulations will include more stringent requirements not only for air but for water as well. If a portion of the HAPs could be removed prior to combustion, the additional cost of the cleaning might be more than offset by the reduced duties of the air as well as the water environmental control systems.

RESULTS IMPLEMENTATION

Advanced coal-cleaning technologies will be deployed on existing and new fossil-fired EGUs to comply with envisioned environmental controls regulations. This will require that the technologies, following full-scale demonstration, be successfully commercialized. It is envisioned that this will be done by licensing arrangements and strategic alliances between the technology developers (for example, EPRI) and the commercializers (for example, coal-cleaning technology suppliers).

PLAN

Precombustion fuel beneficiation currently is being addressed as part of EPRI's NZE Technology Innovation Strategic Program. Concepts will be assessed and further developed and tested at bench and pilot scale. Following success of pilot-scale tests, full-scale demonstrations will be sought.

GAPS

Advanced coal cleaning currently is at an early-to-intermediate stage of development, and technology gaps and implementation barriers are numerous. Specific technology gaps for coal-cleaning processes have been identified, including the following:

- Limited data are available to understand the extent of the removal of HAPs pollutant precursors other than sulfur and ash from the many coal types.
- There is a need to conduct coal characterization studies on particles smaller than those traditionally cleaned at coal preparation plants.
- Although flotation technologies are widely used in coal-cleaning operations, they are capacity-constrained and likely too large for implementation on a power plant.
- Flotation technology is not fully understood; therefore, its maximum efficiency is not realized at many operating plants.
- More mineral matter can be removed from coal if the stock feed is pulverized; however, process limitations, shipping, handling, and safety concerns need to be addressed.
- For technologies developed for post-pulverization, additional demonstration of their capabilities is needed at pilot or plant scale. These include magnetic and triboelectric separation.

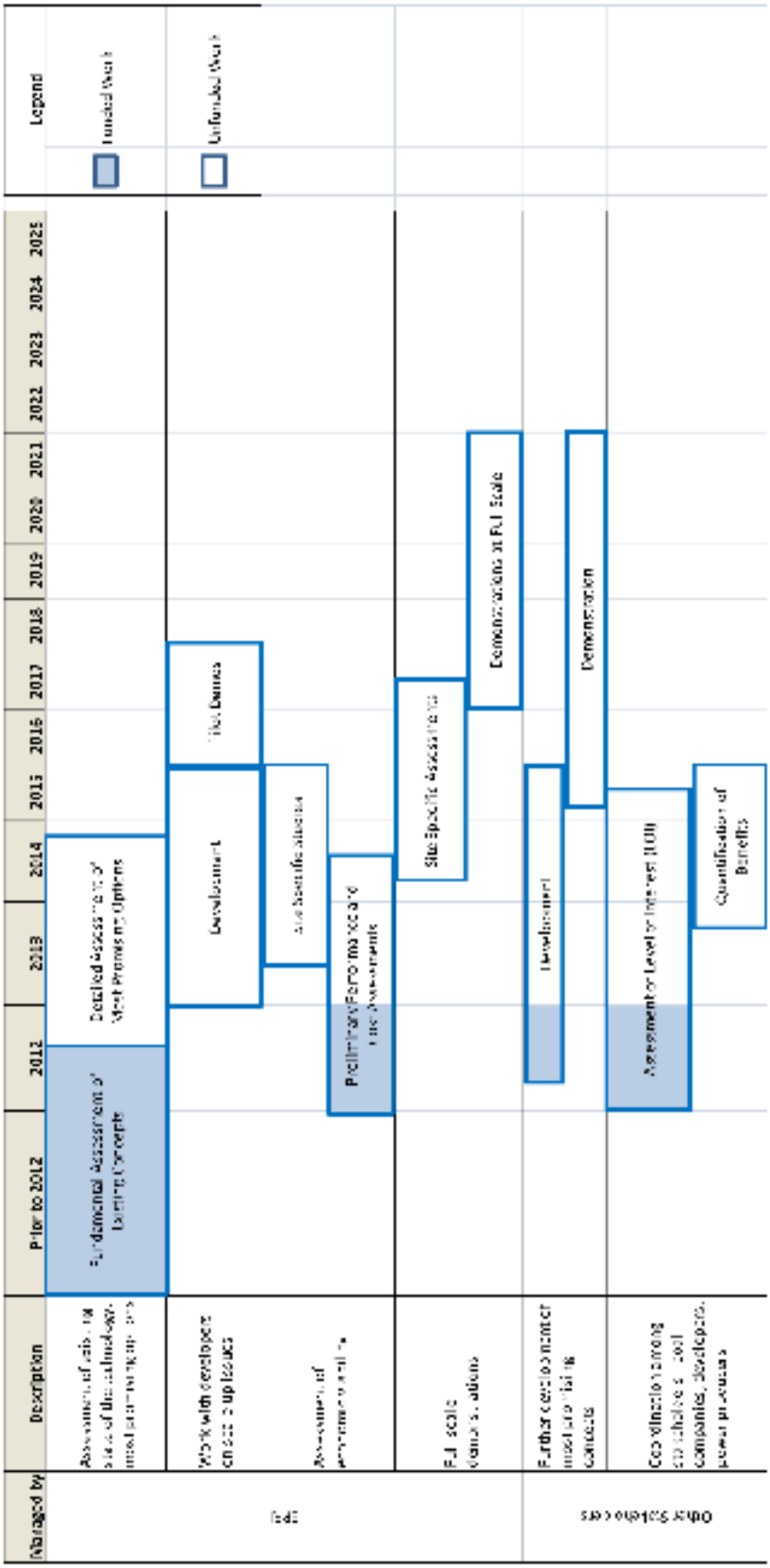
Implementation barriers for the coal-cleaning processes also have been identified and categorized in three groups: coal producers, end users, and technology developers/promoters:

- Coal producers (mine and coal prep)
  - Coal companies prefer to mine and ship raw coal or coal cleaned with existing technologies, rather than adding complicated processes or chemical plants to their operation. Coal producers consistently have preferred to do less work on the product, sell a common commodity, compete on price, and let the end user perform advanced cleaning.
  - The most advanced precombustion coal preparation technologies require pulverization in order to remove sufficient pollutants so as to render the coal an NZE fuel. If this is done at the coal mine or coal preparation plant, issues with handling and shipping the pulverized coal become a problem. Although a potential solution to the dust issue is to agglomerate the fine coal through a briquetting process, this adds significant cost.
- End users (power producers)
  - Although EPRI has developed industry awareness about fuel quality impacts, in some instances there continues to be insufficient dialogue within power-producing companies among the fuels, operations, and environmental departments.
  - Because coal is the single largest annual operating expense, fuel departments are mandated to reduce costs. Without an in-depth understanding of fuel quality effects on boilers and emissions, fuel buyers tend to purchase the lowest-cost fuel, failing to take into account the emissions impacts as well as additional maintenance, down time, and reduced load costs associated with off-spec-quality coal.
  - Power producers often do not have knowledge of technologies that can transform the coal purchased as a commodity into the fuel for their plants.
  - Power producers also lack the knowledge of what coal quality will be burned on a real-time basis. The lack of this information creates an uncertainty for verifying the fuel specification and impedes proper planning of furnace and post-combustion control adjustments.
  - Another barrier for end users is the risk of sole-sourcing their single largest expense. Until there are several options for purchasing NZE fuel, power producers will be hesitant to purchase all their fuel from a single source. Similarly, if NZE precombustion coal-cleaning technologies are developed, the fuel must be sufficiently available.
- Technology developers. There are three barriers identified with commercialization by third parties as technology promoters. They are the following:
  - Technology developers do not necessarily seek industry support before they proceed with development of new and novel ideas. Although this can add to an already difficult and a lengthy process, coal producers and end users will have a much greater vested interest in the technology if they have financially contributed to its success. Lacking this industry support makes selling the technology much more difficult.
  - Universities or laboratories that have excellent coal preparation research activities often lack combustion facilities to verify the end result of their fuel beneficiation research. The opposite also is true; laboratories with combustion facilities often do not have equivalent precombustion coal-cleaning facilities. Therefore, researchers of precombustion, combustion and post-combustion technologies generally do not collaborate to understand and improve the fuel quality and enhance combustion by lowering ultimate emissions.
  - There is limited commonality of equipment manufacturers and A&E firms that serve producers and consumers of coal. As a result, each firm optimizes its own part of the process rather than optimizing the entire process (mine site to busbar and stack) as one. This is compounded by the fact that there are no organizations or forums that facilitate collaboration between coal producers and coal users.

RISKS

If unsuccessful, future environmental control regulations (including HAPs, NOx, SO_2, particulates, and water effluent) might curtail the use of coal as a cost-effective power generation option. As detailed in EPRI's Prism analysis, this would have a significant impact on future average wholesale electricity costs.

At present, byproducts from coal-cleaning processes are considered by regulation to be less hazardous than coal combustion products; therefore, the regulatory climate favors the removal of ash-forming minerals before they go through the boiler and become ash with more stringent disposal regulations. However, if the refuse materials from producing NZE fuel were labeled as hazardous because of the chemicals added and/or materials removed from the coal, disposal costs and environmental concerns would increase.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NEAR-ZERO EMISSIONS: REDUCE POWER AND COST IMPACTS OF CO_2 CAPTURE SYSTEMS

ISSUE STATEMENT

CO_2 capture and storage (CCS) likely will be needed for coal and natural gas generation to meet potential future limits on emissions of CO_2. Current technologies for capturing CO_2 from fossil-fired power plants consume too much of the plant's gross power output and are too expensive. The latest engineering feasibility study on a state-of-the-art post-combustion CO_2 capture process shows that it would decrease a coal power plant's output by 28%. Coupled with the high cost of its installation, this causes the levelized cost of electricity to roughly double. The development and demonstration of more affordable, efficient, and environmentally safe CCS technologies, combined with higher-efficiency power cycles, will be needed to help moderate the power and cost impacts of CCS and to keep fossil-fired generation cost-effective and viable.

DRIVERS

Several factors drive the need for significant reductions in the power and cost impacts of CO_2 capture systems. They are as follows:

- Desire for/attractiveness of a diverse generation portfolio. EPRI's Prism analysis has shown that developing a broad array of low-emission-generation technologies could significantly moderate the cost impact of achieving an 80% reduction in CO_2 emissions by 2050.
- Currently, CO_2 capture costs are high and the technologies are relatively unproven. No full-scale pre-, post-, or oxy-combustion CO_2 capture processes are operating on commercial electricity generation units, and the technologies that would be used if mandated today could double the cost of electricity. However, many promising advances are in the R&D pipeline that could dramatically decrease the cost of generating power from coal while limiting CO_2 emissions.
- A call by G-8 country leaders to implement 20 large-scale CCS demonstrations by 2020.
- China has undertaken a massive increase in coal-fired generation and other coal technologies that will need improved CO_2 capture technologies if the goal of a worldwide 80% reduction of CO_2 emissions by 2050 is to be attained.

RESULTS IMPLEMENTATION

The diverse nature of the world's coal resources (from lignite to anthracite) dictates that a one-size-fits-all approach is not appropriate. EPRI's Advanced Coal Generation Program has stressed the need to develop multiple options for advanced coal power generation with CO_2 capture. Several critical milestones are part of the implementation strategy that will enable the overall goal of making cost-effective fossil-fired power plant technology with CCS available for units that start operation in the 2025–2030 timeframe. Integrated CCS demonstrations involving multiple types of technologies (that is, pre-, post-, or oxy-combustion; coal; and natural gas) in operation at sizes greater than 10% of commercial scale will be needed by 2017 (to provide three years of testing before design decisions for commercial plants need to be made in 2020). That requires multifaceted R&D and demonstration programs involving many entities, including EPRI, national governments, international research organizations, power generators, and technology suppliers.

PLAN

The U.S. Department of Energy (DOE), the European Union, Canada, Australia, and China plan to support the demonstration of CO_2 capture technologies at 25%–100% commercial size by 2015–2017. Both this roadmap and the joint Coal Utilization Research Council–EPRI 2012 Coal Technology Roadmap recognize the need for early demonstrations of commercial-scale power plants with CCS, which develop confidence and build the knowledge base for wider-scale deployment of a future generation of plants based on more advanced technologies. In each case, a pathway identifies advances in power plant thermal efficiency, which then provide the headroom to allow implementation of CO_2 capture and compression without uneconomically high heat rates. The roadmaps also include advancement of technologies that will decrease the cost and energy penalty of CO_2 capture.

Achieving the ultimate goal of the pre-, post- and oxy-combustion roadmaps will require up to 20 years, but many tasks already are underway and many more must begin in the next five years.

Successful development of cost-effective technologies that reduce the energy penalty would provide huge benefits in all three CO_2 capture areas, as follows:

- Precombustion capture of CO_2 already has been demonstrated at commercial scale in coal gasification plants used in nonpower generation applications. The project plan for IGCCs focuses on advancing technologies that will decrease capital cost while also demonstrating advanced H_2-fired gas turbines. Pre-combustion capture could be made more efficient with

separation systems that operate at temperatures closer to those of the water-gas shift reaction (500°F–700°F [260°C–370°C]) rather than at ambient temperature; however, that also will require the development of higher temperature cleanup processes for other undesirable species in the syngas, such as sulfur and mercury. Membrane-based separation systems also could reduce the energy penalty if they can produce CO_2 at higher pressures than current physical solvent-based processes.

- Post-combustion capture can be improved by finding solvents or solid sorbents that minimize the energy required to release captured CO_2. Better capabilities are needed to rapidly analyze a wide range of chemicals to assess their suitability to capture CO_2, as are ways to synthesize new chemicals and test them under realistic conditions. Much of this work will be led by EPRI's CO_2 Capture and Storage Program and is supported through the CO_2 Capture Technology Innovation strategic program. Paving the way for integrated CCS demos at greater than 1/10th full-scale to be in operation by 2017 requires smaller-scale technology tests under realistic conditions (that is, on flue gas) in the near term. These developments must occur in parallel with active surveillance of emerging lower-cost/energy penalty technologies and nurturing of the most promising ones up the nine-step Technology Readiness Level ladder.
- Oxy-combustion capture could be improved with more energy-efficient processes that separate oxygen from air and that remove impurities from the CO_2-rich flue gas. Process designs that minimize the amount of flue gas that must be recycled to the boiler also could lower overall costs but will require new boiler materials to withstand higher temperatures within the firebox. Pressurized oxy-combustion systems could provide additional efficiency improvements.
- The DOE has substantial programs that address potential improvements in all three capture categories. The National Carbon Capture Center (NCCC), which has the DOE as the major funder, provides the opportunity to test promising capture technologies on representative gas streams from coal gasification and coal combustion. EPRI is a co-sponsor of the NCCC and has an active role in its management.

Success will be the development of coal technologies with CCS that compete economically with natural gas-based power and that contribute to meeting cost-of-electricity criteria defined by the DOE for combustion (increase resulting from CCS less than 35%) and for gasification (increase resulting from CCS less than 15%).

For integrated CCS demonstration plants to be in operation by 2017, smaller-scale technology tests under realistic conditions will be required in the near term. These developments must occur in parallel with active surveillance for emerging lower-cost/energy penalty technologies and nurturing of the most promising ones.

GAPS

EPRI's existing R&D program is not sufficient to ensure that this challenge will be successfully met. Larger government and international programs are necessary to achieve the desired goals. Additional funding for more projects that are nurturing promising technologies would increase the probability of overall success.

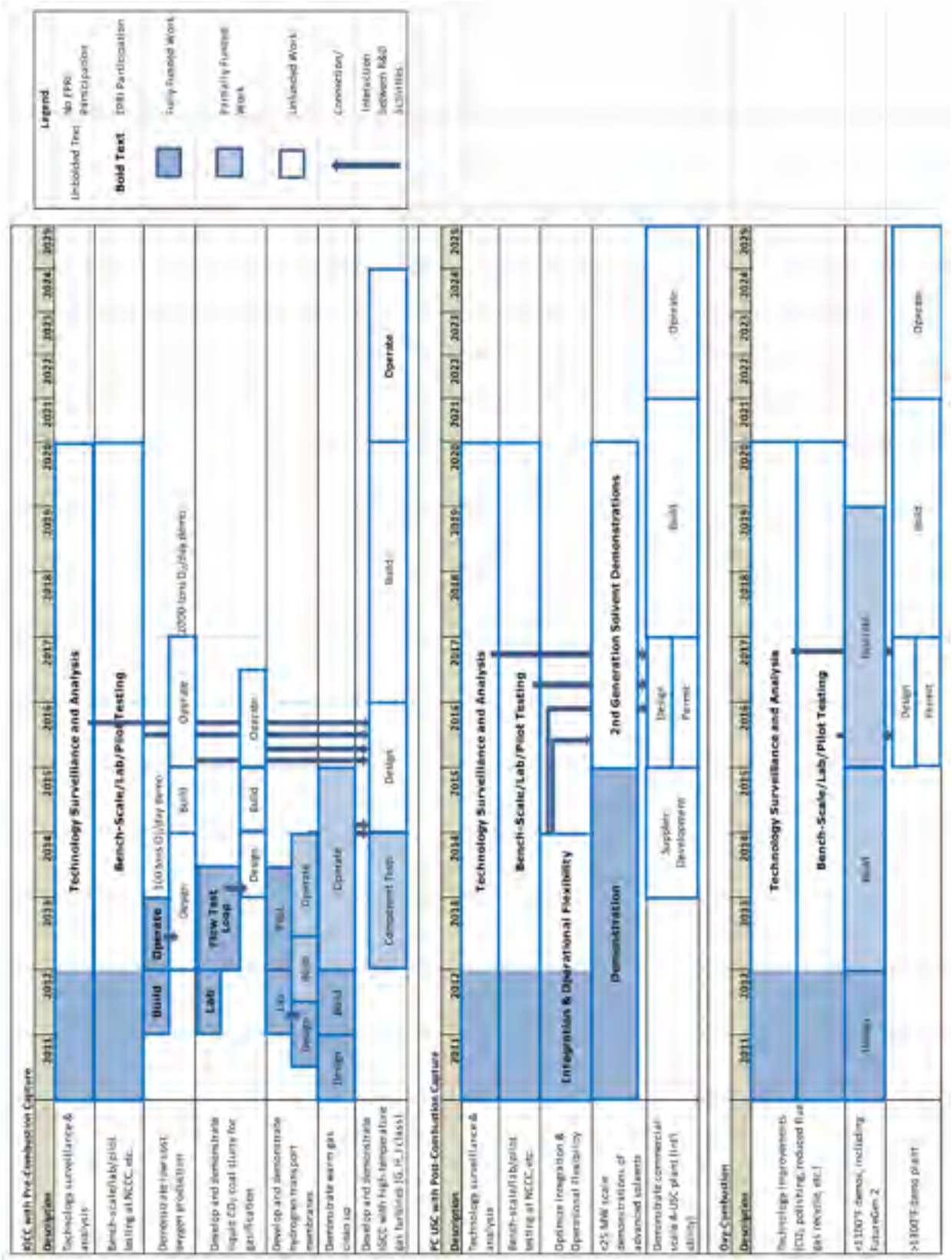
Most of the work to date has focused on reducing the cost and energy penalties from coal-fired power plants. The requirements for future reductions of CO_2 emissions also could require capture from gas-fired power plants. The CO_2 content of the flue gas from natural gas combined-cycle (NGCC) plants is only 3%–4% compared with the 10%–12% from pulverized coal plants. Preliminary evaluations have estimated that the costs for capture of CO_2 from the low CO_2 content NGCC flue gases will be much higher per tonne of CO_2 captured and that solvent use with the higher oxygen content flue gases from NGCC will be significant. In the future, additional solvents/sorbents will need to be developed that are better suited for the NGCC post-combustion capture application.

RISKS

If the tasks in the roadmap are delayed or abandoned, coal power generation might not be a feasible option in the period when many existing coal power plants will be retired. This will place inflationary pressures on the other options for power generation and drive up the cost of electricity. Trimming back the roadmap to only one or two CO_2 capture approaches (pre-, post-, or oxy-combustion) would limit the choices for power generators in the future and decrease the probability of ultimate success because of the many barriers facing individual technologies. In addition, because of the immature status of the technologies, it is difficult at this point to know with certainty which one(s) ultimately could offer the lowest cost of electricity. Focusing on demonstrations of the most mature technologies and neglecting emerging technologies could lead to missed breakthroughs that could dramatically decrease cost.

SCHEDULE

The attached timeline outlines advances in reduction of the costs and energy penalties for CO_2 capture as well as the associated cost and energy benefits of improved efficiency and lower cost designs.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PC USC with Post-Combustion Capture
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Demonstration
2nd Generation Solvent Demonstrations
Supplier Development
Permit
Oxy-Combustion

WATER RESOURCE MANAGEMENT: COOLING TECHNOLOGY INNOVATION

ISSUE STATEMENT

Electric power generation requires reliable access to large volumes of water. This need continues at a time of declining supply, when regions around the globe are experiencing water constraints as a result of population growth, precipitation fluctuations, and changing demand patterns. For typical Rankine-cycle steam plants, the majority of water use (~90%) is for cooling. Reducing the water requirements for thermal power plant cooling represents the greatest opportunity for water conservation.

DRIVERS

Reports of vulnerability to water shortages throughout the world are ever-present in today's media with decreasing stream flows in some areas; lower volumes in lakes, ponds, and reservoirs; declining groundwater levels; increasing surface water temperatures; and variable precipitation. Such water constraints could affect future-generation technology selection, plant siting, and plant operation. Competing industry and social demands for water dictate the need to use less because of limited availability. A key to curtailing power plant water consumption is to reduce the largest single use—cooling water.

RESULTS IMPLEMENTATION

Power plants typically are cooled using either once-through cooling or recirculating cooling. Alternatives to these technologies are dry cooling or hybrid cooling (a cooling system with both wet- and dry-cooling components, which significantly reduces cooling water requirements). Although dry-cooling systems achieve large water savings, their initial cost is three to five times the cost of wet-cooling systems, their operating power requirements for cooling system pumps and fans are 1.5 to 2.5 times higher than wet-cooling systems, and they impose an energy penalty on the power plant. Hybrid cooling is intended to use substantially less water than wet cooling and to have less impact on plant performance and cost less than dry cooling.

Another option for reducing freshwater consumption is to use degraded water sources for cooling. Power plants have used such sources for years, particularly sewage effluent. A recent study identified 57 U.S. facilities that use reclaimed municipal wastewater for cooling. If they are located close enough to a power plant, these sources are attractive because of their year-round availability, familiar treatment practices, and minimal plant impacts. To increase the use of degraded water from other sources, EPRI has identified needed research on better and cheaper treatment options, wastewater disposal options, and technologies to prevent scaling and fouling.

PLAN

- Air-cooled condensers. EPRI research is addressing operational and cost issues associated with air-cooled condensers. High and gusty winds can cause stalling of the air flow in leading-edge fans, creating a sudden drop in cooling capacity. A recent EPRI study performed wind tunnel tests on scale models of power plants with air-cooled condensers to determine how wind affects air flow around and within condenser cells. Also associated with air-cooled condensers is the high steel corrosion rate seen on the steam condensing surfaces. EPRI has launched a supplemental project to investigate, identify, and mitigate these corrosion mechanisms.
- Advanced hybrid cooling. EPRI is exploring new and advanced designs of hybrid cooling systems, which configure dry and wet loops in parallel to cool the recirculating condenser water. These systems reduce cooling water volume by using dry cooling during cooler periods and wet cooling during hotter periods, when dry systems cannot maintain low turbine-exhaust pressure. EPRI's Advanced Cooling Technology project is developing a software tool that allows utilities to project the operational impacts of installing hybrid cooling.
- Technology Innovation. EPRI's Technology Innovation (TI) Program is exploring early-stage technologies that could be alternatives to current wet cooling options. In early 2011, EPRI released a request for information to researchers and developers pursuing water-efficient technologies with potential power industry applications. From more than 70 responses, EPRI selected four projects. One is a technology for enhancing thermophysical properties of heat transfer fluids used in wet cooling towers. The process adds heat-absorptive nanoparticles to the coolant stream, enabling the same volume of coolant to absorb more heat in the condenser and to dissipate the increased heat in the cooling tower. Also under investigation are an absorption chiller, which supplements a dry cooling-type technology with a refrigerant cycle for evaporative cooling to lower temperatures than dry cooling; a thermosyphon cooler,

which employs a refrigerant in a gravity-feed cycle to reduce evaporative losses; and dew point cooling for the purpose of gaining cooling efficiency.

- Water Research Center. A major focal point for future research in cooling innovation will be the new Water Research Center (WRC), being developed by Georgia Power (a subsidiary of Southern Company) in collaboration with EPRI and supported by over a dozen electric generating companies. Located at Georgia Power's Plant Bowen near Cartersville, Georgia, the center will provide insights on best practices for sustainable water management and meeting wastewater restrictions. It also will evaluate technologies for reduced water consumption, advanced cooling, and improved water treatment for degraded water supplies.
- Wastewater reuse. EPRI has joined with the American Society of Mechanical Engineers for the development of Municipal Wastewater Use Workshop by Electric Utilities: Best Practices and Future Direction. This workshop is designed to identify, evaluate, document, and disseminate best practices for the use of municipal wastewater in electric utilities for cooling applications.
- New Water Management Technology Program. Encompassing all of these planned and future research activities is the introduction of a new research program focused on water management technologies in power plants in the EPRI Generation sector. The new program to be launched at the start of 2013 will have cooling innovation as a key target in the portfolio.

GAPS

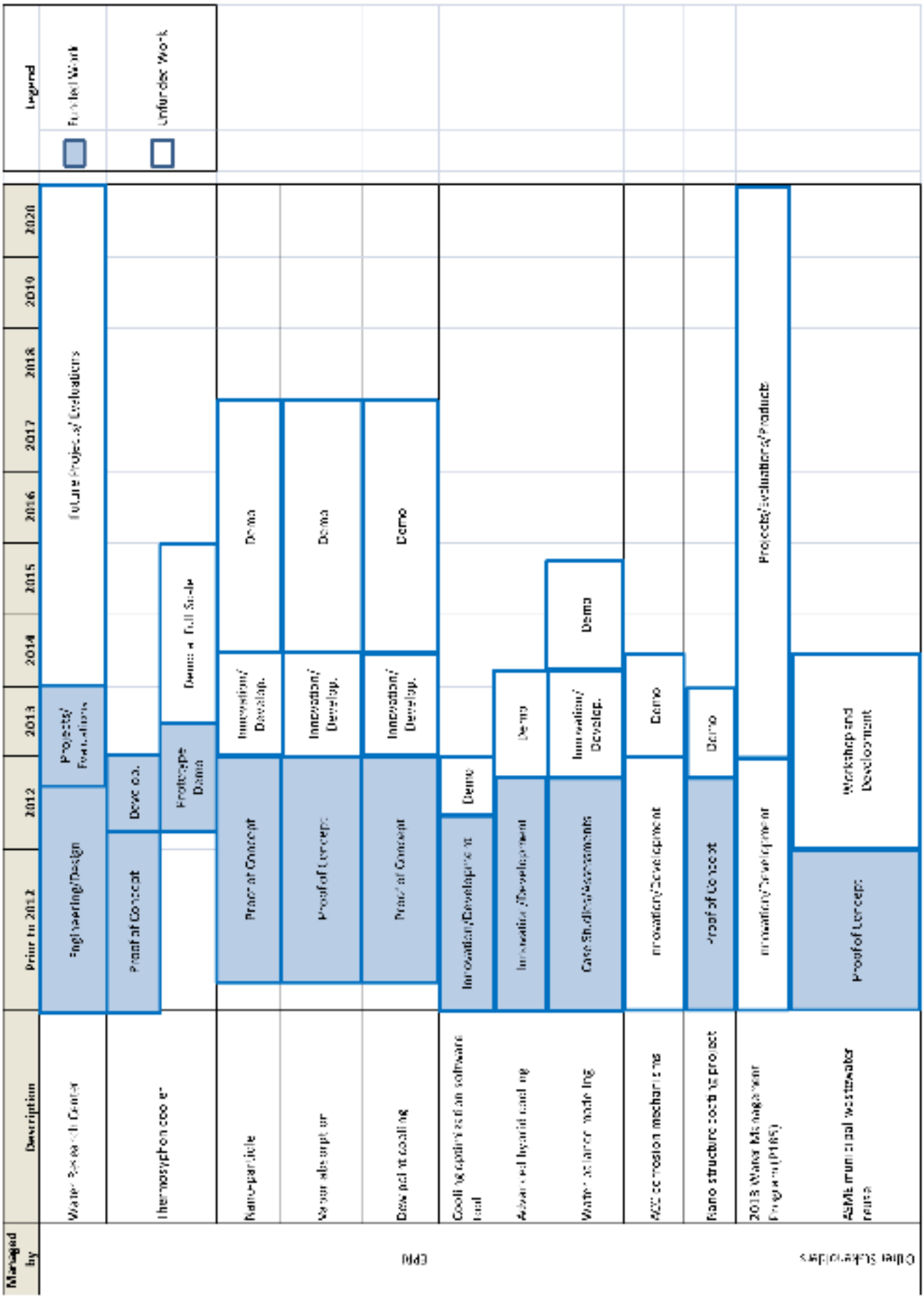
To date, little public information has been available on the design, cost, and performance of hybrid systems. Results of a recent EPRI study that surveyed existing hybrid systems showed that they typically are sized to consume 30%–70% less water than a closed-cycle wet-cooling system and can be expected to cost 75%–90% of the cost of an all-dry system with an air-cooled condenser. The major gaps for cooling technology innovation are the operation and performance aspects of these systems.

Despite the extensive science and research in flow-accelerated corrosion during recent decades, the corrosion mechanisms seen in air-cooled condensers have not yet been adequately identified and sufficiently resolved for a variety of plant configurations.

Though more degraded sources are being used in the industry for plant cooling, there is a gap in the application knowledge. Treatment guidelines are needed for optimum use by reducing tower blowdown, which directly reduces total power plant water consumption.

RISKS

The most prevalent risk to future power generation in water resource management is having sufficient water to cool and operate the plant. As water resources become more scarce, communities might find themselves competing for water supply and power production may become a secondary priority. Alternative cooling technologies address the risk of future operations. Additionally, current water conservation efforts often come with penalties—capital equipment cost and performance losses because of inefficiency. By not addressing these challenges, the industry will be forced to accept the high cost of lost generation and increased operations and maintenance expenses.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Advanced heat exchanging
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Water saver modeling
Case Studies/Assessments
Innovation/ Develop.
Demo
Other Stakeholders
ACC corrosion mechanisms
Innovation/Development
Demo
Nano structure coating project
Proof of Concept
Demo
2013 Water Management Program (P165)
Innovation/Development
Projects/Evaluations/Products
ASME municipal wastewater reuse
Proof of Concept
Workshop and Development

WATER RESOURCE MANAGEMENT: WASTEWATER TREATMENT TECHNOLOGY INNOVATION

ISSUE STATEMENT

Water discharge permits are becoming increasingly stringent, allowing for release of only very low concentrations of pollutants in plant effluents. This trend could accelerate, as the U.S. Environmental Protection Agency (EPA) is expected to determine best-available technology (BAT) and propose revised effluent guidelines by November 2012. As new air pollution controls (such as selective catalytic reduction for NOx and flue gas desulfurization [FGD] for SO_2) are installed, their impact on wastewater (especially FGD discharge water) could require removal of trace metals and other compounds (such as mercury, selenium, arsenic, boron, total suspended solids, and ammonia). The industry will need technologies to cost-effectively and reliably achieve these stringent permit levels. Some states already require low parts-per-trillion mercury discharge levels and low parts-per-billion selenium discharge levels, and these limits are at or beyond the capabilities of current technologies. Further complicating the challenge, several forms of selenium could be present in FGD wastewater (according to EPRI and other data), some of which cannot be treated with today's well-accepted physical/chemical methods. If more pollutants are regulated at very low levels, the ability to discharge wastewater could become so difficult that zero liquid discharge (ZLD) technology options might be needed. Their costs and energy penalties for treating power plant process streams (for example, FGD discharge water) are not well understood. The industry needs to learn how to maintain operational reliability and minimize cost and energy penalties, as well as to find and demonstrate potential treatment alternatives for cost- and energy-efficiency, effectively achieving very stringent discharge limits.

DRIVERS

In the United States, several federal, state, and local regulatory and legislative drivers are likely to strongly affect water use and discharge by the electric sector:

- Effluent guidelines. The EPA currently is revising the effluent guidelines for the steam-electric power generating industry. These new guidelines are expected to result in tighter limits for power plant liquid discharges and could require plants to install newly emerging, costly and/or energy-intensive wastewater treatment technologies in the near term. Longer term, the industry needs technologies that can meet the discharge limits with much less impact on power plant performance, cost, and efficiency. Because coal properties can significantly influence treatment effectiveness, the industry needs a variety of cost-effective and reliable treatment systems and understanding of the effects of wastewater properties on treatment efficiency.
- National and state air quality regulations. As air quality regulations are adopted for ozone, fine particulate matter, SO_2, NOx, and hazardous air pollutants, new control technologies and fuels will continue to impact water and wastewater quality and quantity.
- Water quality criteria. The EPA develops national ambient water quality criteria for use by states to develop water quality standards and to serve as the basis of permit limitations regulating the discharge of pollutants into surface waters under the National Pollutant Discharge Elimination System (NPDES). Utilities are subject to limits on metals and other substances in their discharge permits based on existing criteria, in addition to any new quality criteria implemented for a given water basin.
- State rules and permits. States issue NPDES permits to meet EPA mandates. States always have the option of going beyond EPA rules by adopting stricter limits on water use and discharge.

Cost is another driver, especially as the discharge limits become more stringent, and R&D is expected to yield lower-cost solutions than those available today.

RESULTS IMPLEMENTATION

Power companies will be able to use the results of successful R&D aimed at meeting the challenges/gaps to identify and evaluate next-generation wastewater treatment technologies that enable zero or near-zero discharges of liquid pollutants to receiving waters, cost-effectively, reliably, and with minimal energy penalty. EPRI will document its efforts to seek or develop, evaluate, and demonstrate such advanced processes to help power plants make decisions on hosting near-commercial scale demonstrations with reasonable confidence of success.

PLAN

Addressing industry needs for wastewater treatment in power plants will involve collaboration across EPRI programs in several sectors, including Environmental Controls and Effluent Guidelines and Water Quality Management. In several cases (for example, technologies to enable recycle/reuse of plant process waters), EPRI's Technology Innovation program is seeking novel approaches; the results will lead to further evaluations and development if needed under

Program 185—Water Management Technology. Major elements of the strategy for advancing the state-of-the-technology of wastewater treatment in power plants include the following:

- Development of water balance modeling, monitoring, and management tools for power plants
- Evaluation of the chemical mechanism of biological treatment approaches
- Search for and evaluation of emerging treatment technologies focused on removing pollutants from FGD wastewater discharges (Initial focus will be on mercury and selenium, soon to be followed by work on treatment for the removal of other species as EPA announces its regulatory intentions; these could include one or more of ammonia/nutrients, arsenic, boron, bromide, chloride, total dissolved solids, and other trace metals.)
- Evaluation of treatment and management approaches for plant/process wastewaters (non-ash and non-FGD), including recycling and reuse
- Evaluation of ZLD approaches (thermal and nonthermal) to evaporate and reuse wastewaters, including solid waste management and brine concentrate and materials of construction to address corrosion issues
- Field testing and demonstration of new tools and technologies addressing the preceding issues

A major focal point for future research in wastewater treatment will be the new Water Research Center, being developed by Georgia Power (a subsidiary of Southern Company) in collaboration with EPRI and supported by more than a dozen electricity generating companies. Located at Georgia Power's Plant Bowen, near Cartersville, Georgia, the center will provide facilities and crews for conducting tests of treatment technologies, such as new reagents or membranes, at various scales from bench to pilot.

GAPS

Because the proposed effluent guidelines revisions are not expected until November 2012, there is uncertainty as to which technologies will be considered as BAT, which wastewaters and pollutants are to be regulated, and the stringency of the proposed limits. Based on discharge permits issued recently, it is possible that federal and local regulatory agencies will require ultra-low discharge limits for Hg and Se now and for arsenic, boron, bromine, and nutrients in the not-too-distant future. The technology gaps for the three types of treatment that could exist for complying with stringent BAT determinations are as follows:

- Physical/chemical treatment is preferred by many power plant owners, because it is seen to be more operationally friendly. However, the issue likely will be whether physical/chemical approaches (precipitation, chemisorption, solids settling, and filtration) can achieve the proposed limits for mercury, selenium, other metals, and nutrients. Current work is evaluating promising processes, while recognizing that even more effective and/or less costly approaches could be needed. The most promising approaches will require future power plant demonstrations.
- Biological-based approaches currently are more effective for selenium and mercury wastewater treatment than physical/chemical separation, although the chemical and physical processes by which mercury is captured are not well understood. Current EPRI work is evaluating these mechanisms, and additional work will be needed to further evaluate biological-based approaches to fully characterize their applications and robustness in a range of inlet water characteristics.
- ZLD technology might be required for very stringent pollutant discharges limits that cannot be cost-effectively achieved with physical/chemical- and biological-based approaches. Current thermal ZLD processes require further evaluation at full scale on the difficult power plant wastewaters, such as FGD discharge; lower cost and energy penalties; improved reliability through understanding and managing scaling and corrosion processes; and safe disposal of the solid residues from these processes. An alternative to current thermal ZLD processes—injecting the wastewater into the flue gas stream where it is evaporated and the residual solids captured in a particulate control—should be evaluated. A next generation of ZLD technologies will be needed to overcome the cost, energy penalty, and operational difficulties of current processes. This could require fundamental breakthroughs in water reuse science for treatment technologies to significantly increase membrane transport efficiencies, increase salt rejection, and decrease scaling and fouling. Breakthroughs in these separation mechanisms also could reduce costs and parasitic energy loads for treating degraded water to enable its use as cooling water in lieu of fresh water.

RISKS

The importance of water and anticipated growth in requirements to more effectively manage the water infrastructure, coupled with the tremendous amount of water use in the power sector, creates significant potential for new regulations and uncertainty in future policies. Coupled with increasing costs for new generation capacity, as well as even moderate demand growth, the previously stated risks, if unaddressed, could lead to substantial limitations in ability to use existing generation assets.

Managed by	Description	Prior to 2012	2012	2013	2014	2015	2016	2017	2018	2019	2020
EPRI	New EPRI Power Plant Water Management Program (PWM) Launches										
	Water balance models with auto feedback										
	FGD discharge waters – right										
	FGD discharge waters – other sources (e.g. coal yard, bottom ash)										
	Plant process wastewaters recycle/reuse										
	Conventional thermal ZLD – operational reliability, solids management										
	Advances from thermal ZLD										
	Field Demonstrations (pre-commercial)										

Legend

- Funded Work
- Unfunded Work
- Cross-cut/ intersection between R&D activities

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ELECTRIC POWER RESEARCH INSTITUTE

R&D CHALLENGES

Energy Efficiency (End-to-End)

Long-Term Operations

Near-Zero Emissions

Renewable Resources and Integration

Smart Grid

Water Resource Management

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Energy Efficiency (End-to-End)

TOP R&D CHALLENGES

MISSION STATEMENT

Accelerate the market-readiness of innovative technologies and techniques to increase end-to-end energy efficiency across the generation, delivery, and end-use of electricity, to yield energy savings and greater demand response capability without compromising the quality of electric service.

PERSPECTIVE

Energy efficiency is widely acknowledged as a resource to help maintain reliable and affordable electric service, reduce emissions and save resources. Efficiency goals are mandated in 24 states and under consideration in others. The continued development and adoption of energy-efficient technologies and best practices is essential to realize these goals. Utility energy efficiency activities have focused on incentives to end-use customers to adopt relatively mature technologies, most notably compact-fluorescent lamps (CFLs).

To realize the full potential of energy efficiency, however, requires the development and availability of a wider variety of efficient end-use technologies in homes, buildings, and industrial facilities . It also requires a more holistic view that includes power generation and delivery. Improving the efficiency of auxiliary loads in power plants and reducing energy losses in electricity transmission and distribution can yield significant energy savings within acceptable costs, but these also require validation through extensive assessment, testing, and demonstration.

R&D CHALLENGES

Challenge 1: Advancing Efficiency Gains in Air Conditioning, Heat Pump and Refrigeration Technology

Air conditioning, heat pump and refrigeration equipment collectively represent about one third of electricity use in homes and commercial buildings, and are principal drivers of peak demand. Virtually all such equipment operates using a vapor compression process by which a circulating refrigerant fluid absorbs and rejects heat to provide cooling or heating. Most vapor compression equipment operates at efficiencies significantly below the governing thermodynamic limits of the Carnot cycle and do not employ control technology that regulates operation without energy waste.

Success will be realized through R&D innovation to improve the efficiency of vapor compression equipment: 1) improved heat exchanger coil design and topology to provide more efficient heat transfer; 2) improved compressor systems designs to more efficiently pressurize and superheat the refrigerant fluid for the subsequent condenser and evaporator stages of the vapor compression cycle; 3) alternative, thermodynamically-favorable refrigerants to provide better media for heat absorption and transfer, and that are, non-corrosive, chemically unreactive, and safe; and 4) apply superior controls technology for more precise equipment operation.

Challenge 2: Advancing Efficiency in Advanced Lighting Technologies

A new wave of advanced lighting technologies are being commercialized, includings solid state (, light emitting diode or LED), electronic high-intensity discharge (HID), and plasma lighting. This has been driven in part by federal standards in the Energy Independence and Security Act of 2007. However, if lighting performance is too narrowly defined by efficiency or efficacy alone, the total lighting product performance can be overlooked, leading to sub-optimal performance in the field and disappointed customers.

For example, some advanced lighting sources have "hot spots" in components that can lead to premature failure and customer frustration. Other advanced lighting products do not exhibit the smooth dimming profile that customers expect. Significantly, some advanced lighting products are more susceptible to power quality disturbances, which can adversely affect product life, or even propagate such disturbances to affect other devices. Accelerating the availability and performance of advanced lighting technologies through testing, demonstrations, and coordinated deployments that

qualify the technologies' electrical, mechanical, thermal, and photometric properties will advance customer acceptance and deployment of these energy-saving devices.

Challenge 3: Advancing Efficiency in Motors and Drives

According to the U.S. Department of Energy (DOE), 11% to 18% of current annual energy consumption could be saved by replacing the U.S. installed base of 90 million electric motors with more efficient motors and motor-drive systems. This represents 62 to 104 billion kWh per year in potential savings for the industrial manufacturing sector alone, in which 40 million motors are employed. These savings would come in large part from replacing current motors with "ultra-" and "super-" premium efficiency electric motors, and from variable-speed drive retrofits for motive applications in which partial output is sufficient for most of the duty cycle. In addition, some new motors can couple directly to the end load in lieu of traditional mechanical coupling or gearing arrangements, yielding additional energy savings and system reliability.

"Ultra-" and "super-" premium efficiency electric motors are not consistently available or cost-effective across all horsepower ranges. This impedes deployment and limits realized savings in embedded motor applications in appliances, in heating ventilation and air conditioning (HVAC) systems. R&D is needed to address the cost of raw materials (notably rare-earth permanent magnets and copper) and the expense of automating manufacturing. Moreover, the lack of an application guide or software tool to estimate the net energy savings of adjustable speed drives when coupled with electric motors results in customers choosing sub-optimal options.

Success will be realized through: 1) accelerating the availability of high-efficiency motors via testing, demonstrations, and coordinated deployments to qualify technical performance and energy savings; and 2) the availability of application guides and software tools to help customers and utilities make informed decisions on the use of adjustable speed motor drives to yield energy savings.

Challenge 4: Advancing Energy Management and Control Systems to Improve Energy Efficiency and Demand Responsiveness of Buildings

Building owners/occupants can realize benefits from automated building energy management control systems. These include savings from integrated occupancy, temperature, and daylight sensors that optimize energy use, and the ability to participate more effectively in utility demand response events, capturing economic incentives while minimizing occupant inconvenience.

The availability and application of such control systems requires improved sensors and standard (open) communications protocols to convey both utility signals (such as pricing or grid conditions) to the building premises and instructions between control devices within a building. Without open communications standards, building owners will continue to struggle with proprietary system choices that impede interoperability.

As a category, information technology /Internet data centers are the most energy-intensive buildings, based on kWh-per-square-foot. Experts project that electricity consumption in data centers could double every five years, at which rate data centers would represent 20% of total U.S. electricity use by 2030. Improving the thermal performance of data center buildings can yield considerable energy savings, through systems that optimize airflow management; high-efficiency computer room air conditioners (CRACs); and techniques that capture waste heat from devices and components.

Challenge 5: Advancing Thermal Efficiency of Buildings

The integrity of a building's thermal envelope is the foundation of its overall energy efficiency. While a building's design, stock of energy-consuming equipment, and presence of control devices affect its energy intensity, the primary determinant of building efficiency is performance of building materials and shell measures to provide a thermal buffer – walls, doors, windows, ceilings, roofs, attics, associated insulation, and weather-sealing. A "tighter" thermal envelope minimizes HVAC loads and helps "right-size" equipment for HVAC as well as on-site generation such as photovoltaics.

Innovations in building shell materials, including thermally-resistive insulation and embedded phase-change materials in wallboards to better absorb heat transfer, hold the promise of significant energy savings.

Just as significant, the industry lacks software tools sophisticated enough to simulate the performance of innovative building shell measures in occupied buildings while accounting for the interactive effects of building design, local climate, and stock of end-use equipment.

Compounding the issue, the path to market for fundamental advances in more thermally efficient building shell measures lacks a natural pull from end users. The willingness of building materials fabricators to invest the R&D in more efficient materials depends on the willingness of architects, engineers and contractors to specify, design and build with these new materials. Demonstration of inherent life-cycle economic benefits can increase that willingness.

Challenge 6: Advancing Electrotechnologies to Reduce Energy Intensity and Curb Carbon Emissions

Converting equipment and processes from traditional fossil-fueled, end-use technologies to more efficient electric end-use technologies (i.e. electrotechnologies) has the potential to reduce overall energy use and cut CO2 emissions significantly, even accounting for losses in power generation and delivery. According to an EPRI report, the realistic cumulative potential for saving energy and reducing CO2 emissions through electrotechnologies from 2009 through 2030 is 21.0 quadrillion BTUs and 1,490 million metric tons of CO2, respectively. (The Potential to Reduce CO2 Emissions by Expanding End-Use Applications of Electricity, EPRI, Palo Alto, CA 2009 1018871)

For example, heat pump technologies which capture ambient heat, residual heat from the earth, or waste heat from a process, can attain efficiencies exceeding 200%, while fossil fuel-fired processes cannot approach 100%. Many electrotechnologies also offer ancillary benefits to end users, such as the greater precision and controllability inherent in process heating using the electromagnetic spectrum. Compared to any fossil fuel-fired process, an electrotechnology will reduce or eliminate on-site emissions, eliminating the need for on-site environmental controls. As the electricity generation sector decarbonizes over time, the net carbon reduction from switching from gas to electric for selected heating, cooking, or materials handling applications becomes even more pronounced.

Another iImpediment to developing new electrotechnologi es:manufacturers may be risk-averse to retool existing industrial plants to accommodate electrotechnologies, despite the inherent value propositions. In such cases field demonstrations in industrial and commercial applications can validate electrotechnologies' performance and reduce the perceived risk of investment.

Challenge 7: Advancing Battery Technology for Transportation and Storage Applications

Lowering the cost and improving the performance of battery technology for both mobile (transportation) and stationary energy storage applications are critical challenges that, if addressed, could radically alter the operation of the electric power system. Vehicle electrification represents a substantial opportunity for improving the efficiency and reducing the carbon footprint of the economy. Battery capability will be a key factor in the adoption of plug-in electric vehicles because of its direct connection to vehicle performance and cost. In stationary application, enhanced integrated storage electric energy systems could improve the efficiency of power delivery and utilization along the entire value chain.

Improvement in battery technology and cost is expected to occur through three activities: learning curve and economy-of-scale effects as batteries are manufactured in larger quantities; improved understanding of how to design and use batteries based on data from real-world use; and new battery chemistries and technologies that propel better performance.

The development and deployment of integrated storage systems decouples energy supply from demand, offering substantial opportunity to improve the reliability and efficiency of the grid. Available electric energy storage technologies are

expensive and relatively difficult to construct in large quantities. Substantial work is necessary to bring these technologies to a suitable level of maturity for the grid. Because most storage technologies operate under direct current, power electronics components and integrated storage products must be developed to optimize cost and performance.

For electric vehicles, success will be achieved when battery technology attains sufficient energy density to eliminate driving range concerns, and to meet the requirements of high-performance vehicles, at cost parity with comparable conventional vehicles. For stationary battery technology, success will be achieved when clear guidelines for grid deployment and operation are established to enable grid integration to improve system reliability and facilitate greater utilization of off-peak renewable resources.

Challenge 8: Advancing Distribution Technologies and Controls

Recent research by EPRI, Pacific Northwest National Labs, and others has shown there is significant potential to achieve both energy conservation and demand management through the control of distribution system voltage. Estimates show there is a potential to save more than 3% of the energy use across the country. The voltage optimization is achieved through more advanced voltage and VAR control systems that also may integrate with system monitoring, reconfiguration control, and advanced metering systems. Overall, these new intelligent field devices and control systems will operate to maintain maximum efficiency, reliability, and performance while improving safety and protection of distribution assets. These facilities must perform properly in dynamic operating environments due to increasing penetrations of distributed generating resources and new types of loads such as electric vehicle chargers.

Distribution system operators also must be able to analyze and act on rapidly expanding distribution system information. To address this need, distribution control centers are changing to computer-assisted, electronic decision support systems. Distribution management systems (DMS) are pivotal to this transformation and to enable smart grid roadmaps to become reality. DMS technology still is in its infancy; few products are field-proven. A major challenge is the lack of industry standards to guide the development and implementation of DMS products. Modeling and integration standards, such as the Common Information Model (IEC 61968), which have been under development for many years must be finalized, demonstrated, and included as a standard feature of every DMS vendor's product suite. In addition, industry standards for advanced distribution functions such as distribution voltage optimization (which offers numerous opportunities for efficiency improvement and energy conservation) do not exist. Addressing these challenges will stimulate the development of the DMS, an essential piece of the distribution smart grid "puzzle."

Success will be realized when advanced distribution control functionality and technologies enable DMS that optimizes system performance, reduces losses, optimizes voltage and VAR control, improves reliability through system reconfiguration and fast restoration, and integrates efficient distribution of resources and enables plug-in electric vehicles.

Challenge 9: Reducing Power Losses in Transmission and Distribution Systems

Transmission and distribution (T&D) system losses typically range from 6% to 10%. Those losses, coupled with the electricity consumed by auxiliary loads at power plants, mean that the electric power industry itself is a large user of electricity and there is opportunity for energy efficiency. While most utilities conduct end-use energy efficiency programs, few are engaged in projects to reduce T&D energy losses, despite the fact that for many utilities, the potential energy savings by greater T&D efficiency can approach the magnitude of end-use efficiency savings, and can be realized at a competitive cost per kilowatt-hour saved.

Many potentially cost-effective technologies and techniques are available for reducing T&D system losses, including advanced conductors with lower electrical resistance or larger cross-sections, system power flow controls, more efficient distribution transformers utilizing amorphous cores, and phase balancing. Deploying such capital projects and

improved operations and maintenance procedures is hampered by the lack of a well-established framework to measure and verify potential energy savings from T&D loss reduction and to account for their associated costs and benefits.

Success will be realized through developing a robust analytical framework that establishes, consistent with regulatory requirements, the energy savings from T&D loss reduction measures and allows those measures to apply towards mandated energy-savings goals.

Challenge 10: Improving the Efficiency of Auxiliary Loads at Fossil-Fuel Power Plants

The total efficiency of fossil-fuel power plants can be substantially improved through: 1) heat rate improvement projects, which increase the thermodynamic efficiency of the combustion of fossil fuel (whether coal or gas) into energy; and 2) projects that improve the efficiency of auxiliary power loads at the plant, such as pumps, fans and other motor-driven applications, as well as ancillary loads such as HVAC and lighting.

While many potentially cost-effective techniques for improving overall power plant energy efficiency exist, the industry lacks a well-established framework to measure and verify energy savings from generation loss reduction activities and to account for their associated costs and benefits. In this discussion, the focus of this challenge is improved energy efficiency of auxiliary loads at power plants, as fundamental power generation heat rate improvement activities are included in the scope of the Near Zero Energy Emissions strategic issue (Challenge 3: Increase Energy Conversion Efficiency).

Success will be realized through establishing a robust analysis framework that would satisfy regulatory requirements to enable energy savings from generation loss reduction measures to apply towards mandated energy-saving goals, which would in turn stimulate such projects and yield greater overall energy savings.

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Long-Term Operations

TOP R&D CHALLENGES

MISSION STATEMENT

Achieve high performance in power generation, transmission, and distribution systems beyond their nominal design life, as measured by safety, reliability, and low cost of operations. Such performance must be achieved both for current operating modes and those that may be required in a generating environment with an increasing percentage of renewable generation.

PERSPECTIVE

Long-Term Operations (LTO) efforts seek to maximize the value of existing generation, transmission, and distribution (T&D) assets. Previous research and development efforts have focused on identifying component degradation mechanisms, their root causes, mitigation options to address root cause effects, and repair and replacement approaches. This research will drive a more complete understanding and also address developing operational modes in an evolving electric supply environment.

Obtaining the maximum operational lifetime from current assets can provide an essential economic buffer in utility planning. For example, high capacity factors and low operating costs make nuclear power plants some of the most economical and reliable power generators available. Reliable, long-term performance of current fossil generation and transmission and distribution assets also is essential.

R&D CHALLENGES

Challenge 1: Long-Term Irradiation Effects on Reactor Pressure Vessels and Reactor Core Internal Components

For reactor pressure vessels and reactor core internal structural components in both pressurized water and boiling water reactors, neutron irradiation is a potentially life-limiting degradation mechanism. Material performance data, sufficient to enable a full understanding of irradiation damage and material susceptibility for long-term operation beyond 60 years, has not been developed. That understanding requires more refined knowledge of material behavior that can be incorporated into predictive models for expected life performance of critical components.

Success in this area will be a thorough and documented understanding of material behavior models at the high neutron fluence levels associated with operations beyond 60 years, and the availability of material models to assess the potential for additional degradation modes. Comprehensive understanding of irradiation damage modes and associated predictive models for component life will enable assessment of the expected safe economic life of nuclear assets and a full assessment of options for planning generation portfolios.

Challenge 2: Life Assessment and Management of Concrete Structures

Aging of civil infrastructure in commercial power plants and T&D systems is a potential asset life-limiting issue. The lack of comprehensive data and life-management tools for concrete structures and the already-incurred and potential cost risks related to aging of civil structures have underscored the need for deeper understanding of aging phenomena, including thermal- and irradiation-driven degradation, chloride and borated water attack, alkali silica reaction, and sub-grade corrosion of transmission tower foundations. This must account for the wide range of concrete material composition.

Success will be the development of an assessment process and mitigation approach for all concrete degradation phenomena experienced in utility applications, building on existing knowledge on concrete degradation. Newer mechanisms such as irradiation damage and borated water attack will be addressed and nondestructive evaluation techniques and assessment tools will be developed.

Challenge 3: Cable Aging Management

Power plant equipment, electrical supply and instrumentation cabling, and T&D cables are subject to age and environment-related degradation that may significantly impact generation cost and grid reliability. Given the large number of cables in service, the absence of accurate cable assessment techniques must be addressed to achieve improved cable life management and safe and reliable plant operation.

Success will be a demonstrated and measured shift from reactive cable aging management that addresses failures as they occur, to a life-management process in which in-service failures are prevented via timely replacement based on accurate remaining-life assessment.

Challenge 4: Fatigue Damage Management in Boiling and Pressurized Water Reactors

Long-term operation of nuclear units will entail additional fatigue cycles on selected safety-related components that may exceed current regulatory limits. This situation could be further impacted if intermittent renewable generation is dispatched in preference to nuclear baseload operation. Increased understanding of fatigue cycles and their appropriate limits, and development of rigorous technical bases for evaluation, are needed to ensure sound plant operations and appropriate replacement of plant components.

Success in this area will be a widely-accepted, robust technical basis for fatigue impact assessment. that, in turn, drives consistent code and regulatory processes, and provides a safe and reliable aging management process for fatigue impacted components.

Challenge 5: Modernization of Controls and Sensors

To maintain high plant performance levels over extended operations, the current nuclear power plant fleet will need to address aging and obsolescent plant control systems and sensors. Modernizing those controls will reduce the labor now required to operate and support existing monitoring and control technologies. Modernizing this equipment becomes more pressing as a plant's operating life is extended. Because state-of-the-art digital control technology and sensors have been developed independently of the required nuclear quality assurance design and manufacturing processes, the technologies must be controlled and validated in accordance with the plant license basis.

R&D projects in this area will provide both hardware and implementation solutions for plant control systems. Success will be achieved when multiple plant demonstration projects are completed to comprehensively cover the range of necessary upgrades to control systems and satisfy the associated licensing reviews.

Challenge 6: Buried Pipe Integrity

Buried or underground piping and tanks represent a large number of power plant components whose in-service failure potentially can impact plant operations and safety. Routine aging assessment of such components is hampered by their location; problems typically are not detected until a failure occurs. For LTO, routine and cost-effective aging management of buried piping and tanks will be a critical economic factor should extensive repair or replacement be required to continue plant operation.

Success in this area will be the development of cost-effective and accurate inspection techniques along with remaining life assessment tools that address the unique characteristics of underground power plant infrastructure (valves, lack of access, limited down time, and complex geometries).

Challenge 7: Technology and Options for Extended Used Fuel Storage

Long-term operation of nuclear power plants will result in increasing numbers of used fuel assemblies. In many countries, fuel assemblies are stored at the plant site in the spent fuel pool and in dry casks. Issues requiring greater understanding include degradation of neutron absorbers used in spent fuel pool storage racks; the safety and integrity of spent fuel pools under accident conditions; and optimum dry cask configuration for spent fuel storage and transport.

Success will be the development and demonstration of viable technical options for used fuel storage to fully address safety concerns associated with spent fuel pool and dry cask storage. Those technical options will be sufficiently robust to provide flexibility in addressing the potential range of regulatory requirements associated with disposition of used fuel.

Challenge 8: Aging Management of Fossil Assets under Conditions of Flexible Operation

Large-scale renewable integration and low natural gas prices will increase demand for operational flexibility of both coal and combined-cycle assets. The accelerated life consumption of high-temperature components due to increased thermal fatigue will challenge the long-term economic viability and safety of plants currently in service. Meeting this challenge will require research that supports an integrated approach to life management. Three key elements of this are: 1) improved assessment of material condition during aging; 2) improved prediction of future damage rates under conditions of thermal- and creep-fatigue; and 3) operational changes, as well as new designs and materials that can be retrofitted, to extend the useful life of major high-temperature components.

Successfully meeting this challenge will result in the widespread availability of nondestructive material sampling and testing techniques to periodically determine unit-specific degradation throughout the plant life. In addition, improved incremental life-consumption models will be available that are applicable to a range of basic component geometries (valves, piping, headers, etc.). These models will be considerably less costly and time-consuming than current methods. A compilation of strategies, best practices, and case studies relating to the retrofit of fossil plant major components with more fatigue-resistant components will be available to guide the industry.

Challenge 9: Transmission System Life Extension

Fleet management and life prediction approaches could enable the cost-effective identification of high-risk components prior to failure and maintenance. These high-risk components could include transmission assets such as overhead structures, conductors and insulators, as well as substation components such as transformers, circuit breakers, and converter stations. Fleet management decisions and life prediction approaches also require advanced monitoring and inspection technologies, as well as a more thorough understanding of failure rates and degradation and aging mechanisms.

Success in this area will be the availability of improved methods, tools and materials to extend the life and increase the utilization of existing transmission assets. Success also includes the availability of high-performance remediation technologies such as coatings or chemical treatments that can be applied easily, are environmentally compatible, and have an extended life expectancy. Finally, success entails the development of approaches and technologies to increase the static rating or enable dynamic rating of existing transmission assets and increase power flow through the transmission system.

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Near-Zero Emissions

TOP R&D CHALLENGES

MISSION STATEMENT

Minimize emissions from fossil fuel power plants while maintaining reliable, affordable power by developing and demonstrating cost-effective design and operational improvements, emerging low-emission technologies, and carbon capture and storage systems (CCS).

PERSPECTIVE

To meet existing and expected regulatory requirements, the industry must develop technologies capable of obtaining near zero-emissions (NZE) for all current and anticipated pollutants including CO_2. Those technologies must be affordable, have minimal impact on unit operations, and provide adequate low-load performance during flexible operations (plant cycling).

R&D CHALLENGES

The R&D challenges fall into three categories: energy conversion – minimizing emissions in the energy conversion process; environmental controls – capturing emissions during the conversion process; and advanced generation – developing highly efficient, low-emitting power production technologies.

Energy Conversion - Minimizing emissions in the energy conversion process

Challenge 1: Pre-Combustion Fuel Beneficiation

When used with advanced combustion and post-combustion emissions mitigation technologies, advanced coal cleaning processes may enable NZE more cost-effectively. Although coal cleaning has been used for many decades, the focus has been limited to improving the quality of low-rank coals by removing sulfur, ash, and moisture.

Advanced pre-combustion cleaning technologies go beyond conventional coal cleaning, beneficiation and dewatering and may include chemical treatment of the coal to remove pollutant precursors, including mercury and other hazardous air pollutants (HAPs). The challenge for the industry is first to assess how coal-cleaning technologies would be deployed in concert with combustion and post-combustion environmental controls to significantly reduce the overall cost of NZE compliance, and then initiate the development and demonstration of those technologies.

Success will be the deployment of commercially available coal cleaning systems that work in concert with combustion- and post-combustion-based environmental controls to achieve NZE levels at significantly lower cost than if coal cleaning was not used.

Challenge 2: Maintain NZE throughout Flexible Operations

NZE levels for most pollutants likely will be required throughout unit operations, including transient operations such as startup, load following, or shutdown. During transient operations, first-order parameters impact the performance of most environmental controls systems, which are designed for steady-state operations. For example, changing upstream conditions such as air/fuel ratios will impact NOx, SO_3, particulates, and organics emissions. Operational transients for coal units that have traditionally served base load are anticipated to increase in future years, due to greater use of natural gas and deployment of renewables for power generation.

To reduce all criteria pollutants to NZE, post-combustion controls will need to continue to operate at peak performance during load transients, through changing fuel blend ratios and qualities, and during a variety of upset conditions (e.g., boiler tube leaks, mill malfunctions, etc.). Technologies that show the most promise include advanced laser-based sensors capable of continuous monitoring of all criteria pollutants down to very low (NZE) levels over the load range and during accelerated changes in operating conditions, and control feed-forward and feedback loops capable of accelerated response times.

Success will be the deployment of commercially available feed-forward and feedback optimization systems capable of controlling all post-combustion pollutant control systems to NZE during load transients, changes in operation, and upset conditions.

Challenge 3: Increase Energy Conversion Efficiency

The most effective way to reduce emissions in fossil fuel power plants is to increase plant thermal efficiency. For every 1 percent increase in thermal efficiency equates to a 2.5% reduction in CO_2. Producing less CO_2 per MW of power also lowers the cost of implementing CCS because there is less CO_2 to capture and store. State-of-the-art coal power plants convert only 40-42% (higher heating value - HHV) of the coal's chemical energy into electricity, while state-of-the-art natural gas-fired combined cycles convert up to 55% (HHV) of its fuel's energy.

Higher thermal efficiencies will yield additional benefits such as reduced water consumption and reduced solid and liquid wastes from the power plants. Moving to higher operating temperatures in traditional power cycles (steam-based Rankine and air-based Brayton) can increase efficiency and reduce emissions, but materials that can withstand those higher temperatures have not been sufficiently validated for use in commercial power plants. Also, techniques for improving condenser performance and recovering low-temperature heat from flue gas may offer opportunities to improve the heat rate in existing plants.

Success will be new design standards for power plants that provide a 20% or greater improvement in heat rate relative to today's state-of-the-art plants.

Environmental Controls - Capturing emissions from energy conversion

Challenge 4: Cost-Effective and Reliable NZE NOx Levels

Selective catalytic reduction (SCR) is the only commercially available technology that can achieve 90% reduction in NOx emissions from coal-fired units compared to baseline NOx levels. For most coals, a 90% reduction from baseline levels put SCR outlet NOx in the range of 40 part per million (ppm).

NZE levels for NOx emissions are defined as approximately 99% removal, or for most coals, less than 5 ppm. Improvements to currently available SCR systems offer the greatest promise for achieving NZE for NOx.

Key areas in which R&D is needed to overcome limitations of the current SCR technology include advanced methods of NOx/reagent mixing and optimal reactor designs; advanced catalyst formulations for NOx reduction, limited SO_2 oxidation, and maximized mercury oxidation; elimination of SCR catalyst deactivation by catalyst masking and poisoning via harmful ash species, through optimization of two-phase (ash/flue gas) flow patterns and arrangement of catalyst elements; and maintaining an ammonia slip level of less than 2 ppm.

Success will be the deployment of commercially available SCR systems capable of achieving less than 5 ppm NOx at less than 2 ppm ammonia slip for all coals, coal blends, and opportunity fuels (such as biomass). Systems should be capable of operation over the load range without upset to system performance and reliability.

Challenge 5: Cost-Effective New Source Hazardous Air Pollutants (HAPs) Compliance

Hazardous air pollutants (HAPs) comprise all constituents found in coals known to cause health impacts, such as mercury and other trace metals, total particulate matter, acid gases (such as HCL, HCN, HF), organics, dioxins, etc. Achieving NZE for HAPs poses dual challenges – further reductions in HAPs that already are regulated, such as mercury and particulate matter, and finding solutions for HAPs that currently are not regulated but may be in the future (such as organics and other trace metals).

Technologies that show the most promise to date for HAPs removal include sorbents and catalysts. Novel sorbents developed to date show promise, including sulfur-impregnated activated carbon fiber cloth. Developing advanced sorbents and catalysts requires a better understanding of fundamental gas-solid reaction mechanisms for each target gas-phase pollutant as a function of solids chemistry and pore structure. This can lead to sorbents and catalysts with enhanced gas-sorbent capacity and reactivity, yielding improved emission reductions.

The next step will be to explore whether these sorbents are technically and commercially feasible when applied to the existing and future fleet of coal-fired power generating boilers. The key challenge will be to develop NZE-level sorbents or catalysts that are cost-effective and exhibit long-term durability in a coal-fired boiler environment.

Success will be the deployment of commercially available sorbents and catalysts that are capable of achieving NZE (defined as greater than 98% removal) of all currently regulated HAPS (such as mercury and total particulates), as well as HAPs anticipated to be regulated in the future (which may include other trace metals, organics, acid gases, etc.). Similar to NOx, NZE HAPs levels should be achievable for all coals, coal blends, and opportunity fuels (such as biomass). Systems should be capable of operation over the load range without upset to system performance and reliability.

Challenge 6: Demonstrate Permanence and Safety of Geologic CO_2 Storage

There is very little experience with storing CO_2 in the volumes required for significant impact on the power generation sector's greenhouse gas emissions. The consensus of industry experts is that multiple storage demonstrations in different geologies of at least 1 million tons of CO_2 will be required to demonstrate permanence and safety of long-term CO_2 storage. Knowledge and confidence gained from these demonstrations, including developing the technical basis for regulations to support permitting and monitoring of storage sites, will be required before CO_2 storage can be implemented in commercial projects beyond enhanced oil recovery.

Success will be defined as 6 or more demonstrations of injection of 1 million tons per year or greater for a minimum of 3 to 5 years which permit and safely store CO_2 within the storage reservoir. The demonstrations also must successfully develop and deploy a monitoring system designed to protect public safety and the environment that accounts for CO_2 in the subsurface for 5 to 10 years after injection ends. Demonstrations should be conducted in different geologic settings to assess how different geologic systems will respond to large-scale injections, determine if monitoring technologies perform adequately for each setting, and to evaluate storage costs.

Advanced Generation - Developing highly efficient, low-emissions generation technology

Challenge 7: Reducing Cost Impact of CO_2 Capture Systems

Current technologies for capturing CO_2 from fossil fuel power are energy intensive and increase the net cost of electricity by an unacceptable amount. For example, the latest engineering feasibility study on a state-of-the-art post-combustion CO_2 capture process shows that it would decrease a coal power plant's output by 28%, causing the levelized cost of electricity to almost double.

The theoretical minimum energy required to remove 90% of the CO_2 from a coal power plant's flue gas and to compress it to pressures suitable for geologic storage is approximately 7% to 8% of the plant's gross power output. Current state-of-the-art systems consume four times that amount. Successful development of cost-effective technologies that reduce this penalty would provide huge benefits in all three CO_2 capture areas:

- Post-combustion capture can be improved by finding solvents or solid sorbents that minimize the energy required to release captured CO_2. Better capabilities are needed to analyze rapidly a wide range of chemicals to assess their suitability to capture CO_2, as are ways to synthesize new chemicals and test them under realistic conditions.
- Oxy-combustion capture could be improved with more energy-efficient processes that separate oxygen from air and that remove impurities from the CO_2-rich flue gas. Process designs which minimize the amount of flue gas that must be recycled to the boiler also could lower overall costs, but that will require new boiler materials to withstand higher temperatures within the firebox.
- Pre-combustion capture could be made more efficient with separation systems that operate at temperatures closer to those of the water-gas shift reaction (500-700°F, 260-370°C) rather than at ambient temperature; however, that also will require the development of higher-temperature cleanup processes for other undesirable species in the syngas such as sulfur and mercury. Membrane-based separation systems also

could reduce the energy penalty if they can produce CO_2 at higher pressures than current physical solvent-based processes.

Success will be the development of coal technologies with CCS that compete economically with natural gas-based power and that contribute to meeting cost-of-electricity criteria defined by the U.S. DOE for combustion (increase due to CCS less than 35%) and for gasification (increase due to CCS less than 15%).

Challenge 8: Cost Reductions for Advanced Cycles

Some advanced technologies which generate power from coal more efficiently while also capturing CO2 are ready for commercial demonstration/deployment (e.g., integrated gasification combined cycle [IGCC] and ultra-supercritical oxy-combustion power plants), but pose significant cost premiums over traditional coal-fired power plants, as well as low-CO_2-emitting baseload power options such as nuclear power.

Based on today's technologies, it is predicted that the cost of electricity from advanced pulverized coal plants (PCs) with CO2 capture and IGCCs with CCS will be $105-120/MWh, whereas the cost of electricity from nuclear power plants and natural gas combined cycle plants (NGCCs) with CCS will be $80-90/MWh (Source: Program on Technology Innovation: Integrated Generation Technology Options, EPRI report 1022782, August 2011). Significant capital cost improvements (>20%) will be needed to achieve cost-competitive coal power generation that meets near-zero emission targets. For example, more effort is needed to modularize the construction of advanced power plants, which reduces labor costs. Specific improvements in the design of advanced power plants could lower their capital costs. In IGCCs, the coal preparation and pressurization systems represent a significant share of the total capital cost and offer opportunities for improvement. Larger-scale gasifiers which match up with the fuel requirement of advanced gas turbines are another need.

For advanced combustion-based power plants, cost-effective coal drying processes would reduce the size of the boiler and all downstream equipment. New approaches to the layout of a pulverized coal plant could reduce the length of the high-temperature steam piping, reducing the amount of high-cost nickel alloy needed. And for oxy-combustion plants, the air separation unit is both a large power consumer and a high-cost item. New ideas for lower-capital-cost oxygen production are needed.

Finally, the lessons learned from early deployment of advanced coal power plants need to be captured to ensure they are incorporated in second-generation plants.

Success will be coal-based power generation options with CO_2 capture technologies with levelized costs of electricity that are competitive with other low CO_2 emitting generation options. At current conditions, this will require a 20% reduction in the capital cost of coal-based options.

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Renewable Resources and Integration

TOP R&D CHALLENGES

MISSION STATEMENT

Conduct research, development and demonstrations that will enable electric power companies to add renewable energy resources to their systems in a cost-competitive, reliable, and environmentally sustainable way.

PERSPECTIVE

Renewable energy is fundamentally changing the electricity industry's strategic landscape, with some projections indicating that by 2030, renewables could account for more than 20% of the electricity generated and delivered globally. The growth of renewable energy poses three main challenges for the electricity industry:

1. Enable renewable generation technology options – wind, water, solar photovoltaic, solar thermal, biomass, and geothermal energy – that are cost-competitive over the long term with other low-carbon forms of power generation,
2. Maintain electric grid reliability with high penetration of variable wind and solar energy, and
3. Understand and minimize environmental impacts of renewable energy resources on a large scale.

R&D CHALLENGES

Challenge 1: Wind Turbine Performance Optimization

The wind industry faces two principal challenges:Achieve grid parity without government support mechanisms and expand wind energy deployment to reach the targets required for a worldwide low-carbon transition in electricity generation. Project performance and capital cost drive wind power prices. RD&D investments in technologies aimed at increasing wind project capacity factors, reducing the installed project costs ($/kW) and optimizing O&M costs ($/MWh) will be key during the next ten years.

Improved tower and foundation technologies; new, larger blades and rotors designs; enhanced controls and electronic converters; and larger, innovative off-shore turbines and foundations will contribute to reducing capital cost and extending wind's future deployment.

O&M costs are a significant part of the overall cost of wind energy. Rising O&M costs and increasing downtime over the life of deployed wind turbines demonstrate that current understanding and management of materials degradation and component failure mechanisms are insufficient. New technologies, knowledge, and tools are required to reduce costs and risks and increase reliability without impacting productivity.

Success will be defined as a greater than 20% reduction in average capital cost per kW, an increase of more than 10% in average capacity factor, and more than a 25% reduction in O&M costs by 2020 for wind turbines, relative to 2011 levels.

To reduce the risk of commercial implementation, field assessment of new wind turbine technology performance and reliability will be required. On the O&M side, commercial services will be available to project operators to monitor the condition of turbines in real time, use best practices for wind turbine maintenance developed from industry experience, and allow for reliability-centered maintenance approaches that fix key components before they fail.

Challenge 2: Solar Photovoltaic Systems

Despite significant technological progress and efficiencies in the supply chain, the need remains for advanced solar photovoltaic (PV) technologies that will provide firm power at reduced cost and improved performance. To reduce balance-of-system costs, lower-cost project designs and implementation approaches -- including use of standardized

designs -- also are needed. In addition, as ownership of PV assets expands, electric power companies will need long-term performance, reliability, and O&M data for different technologies.

Success will be defined as the existence of utility-scale and distributed solar PV systems that are cost-competitive with other low-carbon generation sources. Through large-scale and long-term trials in various operating environments, electric power companies will gain access to unbiased data on PV system performance and reliability, providing substantially increased understanding of potential degradation mechanisms and industry best practices for O&M.

Challenge 3: Concentrating Solar Power Technology

Concentrating solar power (CSP) technologies, including parabolic trough, central receiver, linear Fresnel reflector and dish Stirling, are hindered by a few key issues preventing large-scale commercial adoption: lack of field testing needed to assure reliability and cost-effectiveness; high up-front capital requirements for utility-scale projects; absence of a robust supply chain, particularly for a few critical custom-designed components; and relatively low-temperature operations that reduce CSP power cycle efficiency. Research is needed on high-temperature heat transfer fluids and power cycles, thermal energy storage and hybridization configurations, dry and hybrid cooling technologies, and lower-cost solar collectors. In addition, CSP technologies have unique O&M issues, such as mirror cleaning and maintenance of tracking systems.

Success will be defined as the existence of commercial CSP systems that are cost-competitive with other low-carbon generation sources. High-temperature power cycles, thermal energy storage, and hybridization with other fuels will improve performance and lower costs. Real-world performance and reliability results collected from demonstration projects will provide more informed understanding of the maturity of specific products associated with solar system installation, commissioning, operation, and upkeep.

Challenge 4: Biomass Resource Sustainability

Biomass generation technologies are cost-competitive or nearly cost-competitive in many applications, with fuel supply issues and policy treatment representing key influencing factors. Generally, fuel sources must be collected at diverse locations and then transported to a central facility for processing, resulting in cost pressures and risks that translate into practical limitations on plant siting and sizing. As more biomass enters the electricity sector, there will be internal and external pressure on power companies to ensure that supplies of biomass will last the life of the plant and beyond. A more complete understanding of the existing and future biomass supply market will be necessary to make informed fuel procurement and investment decisions.

Success will be defined as the existence of assessment tools that allow a complete understanding of biomass resource availability and sustainability, fuel cost and market volatility, reliability and security of supply, and strength of supply chain over varying temporal and geographic scales. In addition, technologies such as torrefaction will be cost-competitive and commercial-scale, enabling a significant increase in the flexibility of biomass supply while improving the efficiency of its use.

Challenge 5: Enhanced Geothermal Systems

To date, most geothermal plants have been sited in areas with high subsurface temperatures, high rock permeability, and a naturally occurring water-steam resource. However, the confluence of these three factors is rare, generally occurring in isolated locations within geologically active regions, such as the "Ring of Fire" bounding the Pacific Ocean. To expand the regional availability of geothermal energy, other resources must be harnessed, including "hot, dry rock" resources found in areas offering sufficient heat for power generation but lacking an in situ water steam supply.

Success will be defined as the existence of cost-competitive, safe, and environmentally sustainable commercial-scale options for enhanced geothermal system (EGS) technologies that can access geothermal energy from hot, dry rock resources. Demonstration projects and long-term monitoring studies will support deployment of EGS technologies under varying geological conditions, leading to a gradual expansion in the geographic footprint for utility-scale geothermal energy development.

Challenge 6: Improved Forecasting for Variable Generation

In areas with significant wind penetration, a large fraction of the deviation between the optimal day-ahead unit commitment solution and actual conditions is attributable to the difference between the predicted and actual time-varying output from wind plants. Grid operators typically deal with this by adjusting dispatch schedules and calling on fast-response resources; however, these can involve significant cost or operational impact. Advanced wind forecasting methods and tools, and processes for integrating improved forecasts into scheduling and operations, could provide a means to avoid such impacts.

Success will be defined as the existence of advanced wind generation forecasting tools with vastly reduced mean error beyond that observed today. These tools will rely on high-temporal-resolution wind data, for periods from seconds and minutes, to enhance understanding and modeling of resource variability, ramp rates, and other key factors. Similar tools will need to be developed at the distribution level for variability associated with solar PV, following an intensive effort to characterize the real-world variability of solar PV using consistent, high-resolution monitoring systems under a variety of conditions.

Challenge 7: Grid Infrastructure and Operator Tools for Managing Variable Resources

In some areas, variable wind and solar PV resources now account for 25%– to 50% of the instantaneous load served. The additional variability and uncertainty in output from these new technologies impacts planning, operation, and maintenance activities for both the transmission and distribution systems. Power system planners and operators will require new tools and resources to gain the additional power system flexibility needed to ensure a reliable, secure, and cost-effective electricity supply to consumers. Developing new transmission will be essential to reducing variability and uncertainty across larger geographic footprints and providing access to shared sources of flexibility across the system.

Success will be defined as the commercial use of tools and practices that can reliably and economically integrate high levels of wind and PV into transmission and distribution grid operations. Commercially-available variable wind and PV systems will include power electronics with control options to better support grid reliability needs, and grid operators will have access to validated steady-state, dynamic, and short-circuit models of wind and solar PV units for conducting planning studies.

Challenge 8: Energy Storage Technology Development

New technologies and falling prices have begun to make energy storage practical as a grid control option for adding stability, control, and reliability to the grid, but several questions remain. In particular, electric power companies lack timely, accurate and verified information on the performance, life, and life-cycle costs of existing energy storage technologies, and also have an insufficient understanding of the effects of storage on grid stability, control, and reliability. The economics of energy storage depend on being able to address multiple applications such as peak shifting, reliability, frequency control, and renewable intermittency balancing. Control systems need to be developed for accomplishing this flexibility and integrating it with overall power system control infrastructure.

Success will be defined as a portfolio of energy storage options that are 'grid-ready,' cost-effective, safe, and reliable. Manufacturers will supply storage products that meet certain technical requirements, as demonstrated by standardized factory acceptance tests and long-term field testing. In turn, advanced energy storage options will be able to realize multiple benefits and revenue streams with lower cost, easing their cost-effective adoption for support of renewable energy development.

Challenge 9: Advanced Hydro Turbines

Conventional hydropower and pumped storage currently provide substantial renewable energy generation, and these technologies are poised to increase their contribution through the addition of new hydro generating capacity and the facilitation of grid integration of other renewable energy generation technologies. However, a legacy of fish passage and protection issues at existing facilities adds cost and uncertainty to their continued operation, and may constrain the ability of these facilities to support the expansion of other forms of renewable energy such as wind and solar.

Success will be defined as the completed development and field demonstration of one or more advanced "fish friendly" hydro turbines as a means of safely passing fish at operating hydropower facilities. This can enable refurbishment or redevelopment of existing hydropower and pumped storage units to extend life or add capacity, and it could make new hydro resources available. In addition, field data on the environmental performance of pumped storage will help sustain this important balancing resource.

Challenge 10: Renewables Impacts on Species and Habitat

The production of biomass resources and the construction and operation of utility-scale wind and solar installations and associated transmission pose potential risks to plant communities and wildlife habitat and populations. These risks can influence siting, construction, operation and mitigation practices, and add significantly to project cost and construction time. Yet there are significant gaps in scientific and technical knowledge that hinder the assessment of potential ecological effects and the evaluation of alternative siting, management and mitigation practices to minimize associated risk.

Success will be defined as the development of a comprehensive life-history database for key species vulnerable to impacts from wind, solar and biomass operations. This will be coupled with an integrated field study and modeling methodology that will allow evaluation of population level effects of renewable energy development on key species. Using a network of experimental sites, the methodology and data can be validated and made available to project developers and resource agencies to improve understanding of particular species impacts and aid in the design of alternative practices.

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Smart Grid

TOP R&D CHALLENGES

MISSION STATEMENT

Conduct research, development, and demonstrations to more cost-effectively and securely link electricity supply and demand through advanced information and communication technologies, sensors, and computing capabilities.

PERSPECTIVE

The "Smart Grid" concept infuses information and communications technologies with the electricity grid to increase performance and provide new capabilities. Increasing use of variable generation and controllable loads, combined with an aging infrastructure, will require a greater use of information and communication technology to provide actionable information to and from interactive markets or asset health. Each utility will create its own smart grid through investments in back-office systems, communications networks and intelligent electric devices (IEDs). Smart grid functional requirements, interoperability, and cyber security standards are still evolving, and premature technology obsolescence could strand some investments as transitional technologies need to be replaced before their expected end of life. This strategic issue requires a holistic vision with end-to-end system considerations from transmission, distribution and end use.

R&D CHALLENGES

Challenge 1: Standards and Interoperability

The lack of mature, uniform standards to enable interoperability among systems for efficient end-to-end electric power system interactions has been cited by utilities and regulators as a reason for not moving forward with smart grid applications such as advanced metering infrastructure (AMI). Investments in proprietary systems risk long-term vendor lock-in and costly "fork-lift" upgrades to take full advantage of new smart grid applications. The use of standards to integrate complex systems and components dramatically reduces both implementation and operational costs.

Success will be a small number of mature standards that fit seamlessly with one another, that are embraced by all stakeholders, and that enable systems to interoperate. Commercial services, such as certification and interoperability testing and implementation support and training, will be available in a competitive market with multiple vendors innovating based on the standards.

Challenge 2: Communications Technology

Communication technologies are evolving rapidly, driven by telecommunications, entertainment, and mobile devices with improving performance and falling costs. Wired, wireless, and power line-based systems result in cost-effective access to more data faster than historically has been possible. Systems designed based on requirements that did not consider rapid access to a vast amount of data are challenged to take advantage of these emerging capabilities for advanced smart grid applications such as distribution automation, conservation voltage reduction, automated metering, and integration of all types of distributed energy resources .

This issue is particularly important because of the significant cost of communication systems and associated data integration. Systems generally are not deployed for a single application, so a holistic, architectural approach is required. Success in this area would include open solutions, enabling utilities to build out systems using components from multiple vendors.

Challenge 3: System Architecture, Integration and Next Generation Energy Management Systems

The electric power industry faces increasing complexity in the end-to-end integration of legacy and new enterprise systems, intelligent devices, field personnel, and suppliers. Compounding this, the life cycle of many emerging technologies is measured in months while traditional electric power asset life cycles are measured in decades.

The present grid operating system does not fully address the needs of an increasingly digital society, or the demands of increased renewable power production and controllable demand-side resources (e.g., high penetration of electric vehicles). Tomorrow's grid operating system must facilitate high levels of security, quality, reliability, and availability (SQRA) of electric power; improve economic productivity and quality of life; and minimize environmental impacts while maximizing safety.

Success will be a smart grid architecture that accommodates existing and evolving communications, data, and security factors that can extend the life of legacy assets while integrating emerging systems, taking advantage of the associated efficiencies. The next-generation power delivery energy management system (EMS) must provide hierarchical control for integration and interoperability of the disparate systems and components from appliances, facilities, distribution assets, and transmission control centers. The EMS also should enable management of financial transactions resulting from competitive service offerings in restructured and distributed utility environments.

Challenge 4: Security and Privacy

The increasing interconnectedness, automation, and communication capabilities of the power grid pose several significant challenges in cyber security, resiliency, and privacy. Cyber/physical security is essential to grid reliability. Security threats to the grid come from deliberate attacks by terrorists and hackers, as well as inadvertent user errors and equipment failures. The dramatic increase in data about end-user behavior raises new privacy concerns. To achieve a secure and resilient grid, advances must be made in assessing and monitoring risk, architectures to support end-to-end security, legacy systems security, approaches for managing incidents, and technologies to support privacy.

Success will be a grid that provides both protection and resiliency from cyber incidents, as well as safeguards privacy of end users.

Challenge 5: Bulk Renewable Generation and Distributed Energy Resource Integration

As various bulk renewable generation and distributed energy resources are integrated with the grid , including demand response, photovoltaic (PV), electric vehicles, energy storage and distributed generation, , challenges to reliability arise, as well as opportunities to take advantage of clean-emission generation sources. Challenges include planning and forecasting of weather-dependant intermittent resources, managing high-density generation on the distribution system, and lack of distributed intelligence locally at resources such as integrated smart inverter technologies for PV and storage technologies. From central management to distributed control, all factors must have seamless integration and system operator visibility of all types of distributed energy resources, regardless of their type.

Success will be bulk and distributed generation resource integration that supports national energy goals. Open and standardized interfaces will be adopted for all types of resources, including sending and receiving messages for economic and reliability dispatch. Methods to view and manage resources will bring real-time operational visibility to the system and individual components including decision-aiding models for planning and forecasting with real-time feedback to both electric system operators and customers.

Challenge 6: Advanced Data Management, Analysis and Visualization (Including Wide Area)

The vast amount of data generated by smart grid devices provides the opportunity to manage more reliably the grid and associated operations. However, realizing these opportunities requires that the industry more effectively manage and convert data to actionable information. Data management in smart grid environments requires rapid retrieval and analysis to transform data into information for making effective decisions. Proper analysis of time-series-based data must be linked to a real-time power system model for the most effective analysis. This is a significant challenge; for example, synchrophasor data without an associated time-based power system model does not allow accurate data interpretation. Converting data into actionable information requires a higher-order analysis and visualizations such as data fusion, data mining, pattern recognition, and neural networks to improve business analytics.

Success will enable analyses that provide the business intelligence needed for advancing the operation of the grid, optimizing asset management, and much more.

Challenge 7: Model-Based Management and Planning of the Grid

Existing distribution models and planning tools do not allow distribution planners to account for implementation of smart grid technologies and applications such as distributed energy resources, and lack necessary, accurate system asset information to perform real-time model-based management. Implementation of smart grid technologies for advanced applications and growing penetration of distributed energy resources is expected to significantly alter the nature of the distribution system. However, traditional distribution models and planning methods are not capable of capturing the relevant control, temporal, and spatial characteristics associated with such implementations.

As the distribution system evolves into a smarter grid, the traditional models, software tools, and planning methods will evolve for the most reliable grid management. Success will be new data, models, and analyses that permit distribution planners to assess the real-time impacts and potential benefits of all technologies that affect the grid.

Challenge 8: Smart Grid Cost Benefit Analysis

Factors ranging from evolving technologies, maturity of existing assets, and regulatory policy produce different value propositions for assessing the benefits of smart grid implementation. There also are significant uncertainties associated with new technology, its life-cycle costs, financial and societal benefits, and extrapolating demonstration results to full-scale deployment. Combining the typical life-cycle of decades for grid assets with the life-cycle of months for IT and communications technology poses significant risk in deploying technology that can prematurely become obsolete, resulting in stranded assets that need to be replaced before their expected end of life.

Success will be an industry-accepted and open cost-benefit assessment methodology that results in well-documented case studies, openly shared to facilitate the advancement of beneficial smart grid applications. Sharing lessons will help minimize duplicative research, advance knowledge transfer, and allow extrapolation of demonstrations to full-scale deployments with more certainty. In addition, case studies will openly identify high-priority challenges to guide new research needed to accelerate a smarter grid.

Challenge 9: Customer Integration Strategies including Behavior, Communications and Automation

Historically, balancing has been managed almost exclusively by centralized generation. Advances in information and communication technology enable electric utilities to incentivize consumer behavior and shape the loads or resources they own to help balance supply and demand. Further study is needed to understand the most effective strategies to engage consumers and demand-side resources for both manual and automatic control. Challenges include: What types of customer feedback are most effective, and do varying price levels have a corresponding effect on performance? Are feedback mechanisms persistent? What feedback is most effective to achieve energy savings? What automation technologies can effectively manage loads and resources with no noticeable impact on consumer comfort? How can electric vehicles and other resources be aggregated and managed for fast-acting applications such as ancillary services? What mechanisms are best suited for the measurement and verification of consumer-owned resources?

Success will be smart devices automatically reacting to economic and reliability events. Consumers will be able to prescribe device performance, including modes of operation that do not impact customer comfort and convenience, provide financial incentives and add value to the grid. There will be a clear understanding of the nature and type of wide-area and home-area networks needed, and the types of equipment that customers (of all classes) will utilize effectively. Standardized interfaces will enable innovation to link supply and demand most effectively with an array of options for both utilities and consumers.

Challenge 10: Advanced Technology Development and Assessments including Power Electronics, Energy Storage and Sensors

Transmission and distribution systems have growing constraints as bulk renewable and DER penetration increases

and emerging sensing technologies can improve asset management for emerging smart grid applications. Semiconductor-based power electronics, such as advanced high-voltage direct current converter stations and intelligent universal transformers , along with advanced energy storage technologies, can help improve energy supply and demand efficiencies.

Successful advanced technology developments, assessments and implementations from a combination of semiconductor-based switching devices for power conversion, cost-effective energy storage technologies, and advances in sensor technology will provide an intelligent means to deliver optimal power to loads while integrating data from sensors to communicate the state of the grid.

Water Resource Management

TOP R&D CHALLENGES

MISSION STATEMENT

Develop innovative technical solutions to minimize the environmental impacts of water withdrawal and consumption in the electricity sector; ensure the availability and cost-effectiveness of plant water treatment options; and provide more energy-efficient and demand- responsive options for the transportation, treatment and storage of water.

PERSPECTIVE

Water presents three strategic challenges and opportunities for the electric sector: (1) using less water for power production conserves a scarce resource for other uses; (2) minimizing the environmental impacts on water used for power production preserves environmental resources and protects human health; and (3) using efficient electric technologies for water treatment, transport, desalinization and industrial processes reduces water demand and conserves electricity.

R&D CHALLENGES

Water Resource Management Analytical Tools

Challenge 1: Water Availability and Use Analyses

Water is a shared, finite resource subject to the competing demands of multiple stakeholders. On a national basis, freshwater withdrawals are dominated by power plants (40%) and irrigation (36%), followed by municipal (14%) and industrial (5%) uses. Because sustainable water resource management involves collaborative decision-making across social and economic sectors, what's needed are a water resource knowledge database and methodologies for integrated sustainability assessments and risk management of regional power and water supply. Such research includes new knowledge about water recycling and re-use; alternative non-traditional water sources; advanced cooling technologies; and novel techniques for reducing water use in the water supply, agricultural and industrial sectors.

Utilities will have access to quantitative watershed-based decision support systems for siting and/or retrofitting power plants within five years if the research is successful. These support tools will enable water-saving benefits across industries, understanding and minimizing water risks, and collaborative water management solutions.

Using Less Water for Power Production

Challenge 2: Cooling Technology Innovation

For typical Rankine-cycle steam plants with closed-cycle wet cooling, the majority of water use (~90%) is for cooling. Thus, reducing the water requirements for thermal power plant cooling represents the best opportunity for plant water conservation.

For water cooling systems, typical power plants use either once-through cooling or closed-cycle wet cooling technologies. At a conventional 500-MW combined-cycle power plant, water savings of ~ 900 million gallons per year can be achieved through the use of current dry cooling technologies (such as air-cooled condensers, indirect dry cooling) in place of recirculating wet cooling. However, implementing such water-conserving cooling options will result in higher costs, lower efficiency, and additional operational and maintenance issues.

A collaborative, industrywide effort is needed to evaluate the performance of a number of innovative ideas, lab prototypes and early-stage commercial technologies that have the potential to reduce plant water use by 15% to 100%, and/or to increase power production by reducing condensation temperature. Research must follow to develop the design basis for these technologies and to demonstrate them in power plants.

Successful developments of these ideas, lab prototypes and early stage commercial units within the next five years are expected to lead to new, cost-effective, full-scale, water-saving power plant cooling applications.

Challenge 3: Water Treatment Technology Innovation

To minimize power plant water withdrawal and consumption, and the discharge of pollutants to water bodies, plants use various treatment technologies and management strategies. More efficient water utilization can be achieved, for example, through the reuse of water (e.g., treatment to enable reuse of cooling tower blowdown), the reclamation of alternative water sources, and by identifying use reduction opportunities through water budget modeling.

For example, fundamental breakthroughs are needed in water reuse science for treatment technologies that significantly increase membrane transport efficiencies, increase salt rejection, decrease scaling and fouling, and thus decrease costs for power plant applications. Innovative wastewater treatment technologies that are in early stages of maturity also need pilot testing under realistic plant conditions and first-of-a-kind demonstrations. For example, experience must be acquired with zero liquid discharge as applied to flue gas desulphurization (FGD) water discharge streams (the biggest stream of concern). Research is needed on the development of cost-effective and reliable wastewater treatment technologies for diverse water compositions/streams to meet ultra-low discharge limits (e.g., for mercury and selenium), as well as potential future regulations for arsenic, boron, bromium, and nutrients. Also needed is a focus on safe disposal of solid residue from these water treatment processes. If the challenges are met, innovative treatment technologies with the potential to achieve significant water use reductions, and to meet demanding discharge limits will become available to the industry.

Minimizing Environmental Impacts of Water Use

Challenge 4: Fish Protection & Thermal Discharges

Water withdrawal for power plant cooling can adversely impact aquatic life as the result of fish entrainment and impingement at power plant cooling water intake structures. Performance data for currently available technologies, used under different mitigation strategies designed to reduce entrainment and impingement mortality, is needed to evaluate biological effectiveness, as is continued assessment and improvement of technologies to cost-effectively address impingement mortality and entrainment.

Some plant cooling systems (such as once-through cooling) produce thermal discharges to the source water body that has the potential to adversely impact aquatic life. An accurate understanding of thermal impacts is necessary to ensure that discharge criteria are appropriately protective but not overly conservative. Overly conservative thermal discharge criteria can limit the utility's ability to employ water-saving cooling technologies and to respond to capacity issues during heat waves, droughts, etc. Current thermal tolerance criteria are based on laboratory experiments; however, in the field, healthy fish populations are observed in plumes that laboratory data predict they could not tolerate. Understanding this phenomenon will support the regulatory regime.

The successful outcome of this research will allow utilities to select the best technology to reduce impingement, mortality and entrainment based on the unique site-specific conditions at their plants, and will provide tools to support the required performance monitoring for regulatory compliance verification. Research that provides a more advanced understanding of how thermal discharges impact different fish species will support better decisions to optimize power plant operations and to minimize impacts on aquatic life.

Challenge 5: Water Quality Criteria and Water Quality Trading

Power plants produce aquatic effluents from operational requirements, and these discharges can contain contaminants introduced from sources such as air pollution control technologies. To reduce potential environmental impacts, utilities monitor ultra-low levels of metals and other pollutants in these effluent streams under the U.S. Environmental Protection Agency's (EPA's) Water Quality Criteria regulatory framework. EPA is reviewing its current criteria and is considering the development of new criteria for some metals and other pollutants. Successful research will lead to a better understanding of potential pathways of these pollutants (such as arsenic and selenium) into food chains and the potential impacts on aquatic and human health in order to develop scientifically-based protective limits.

Additionally, watershed ecosystem health may be impacted by concentrations of "limiting nutrients" such as nitrogen and phosphorus that degrade water quality. For this reason, coal-fired power plants are facing more stringent nutrient

environmental effluent National Pollution Discharge Elimination System (NPDES) permit limits. Just as air quality and carbon markets have driven down the expected cost of regulatory compliance, a water quality trading program would provide for cost-efficient, ecological market-driven nutrient reductions. The technical basis for a water quality trading program in an interstate watershed system (such as the Ohio River Basin) needs to be demonstrated, with active participation of the power industry, regulators and other critical stakeholders.

Successful demonstration would pave the way for water quality trading as a cost-effective permit compliance option while providing ecological co-benefits.

Challenge 6: Groundwater Management and Remediation

Over long periods of operation, seepage, leaks and spills of operational byproducts may contribute to contaminants in groundwater at power plant sites. Specific challenges include the management of coal combustion products; detection and remediation of non-aqueous-phase liquids which can be source material for polycyclic aromatic hydrocarbons) in site groundwater; and the characterization and remediation of low levels of radionuclides. Additionally, groundwater represents a significant alternative water resource for cooling and other water uses.

Currently, there is a lack of: 1) groundwater risk assessment, characterization and remediation tools to cost-effectively manage the closing of coal combustion product storage and disposal facilities; 2) cost-effective detection and remediation technologies for non-aqueous phase liquids contamination; and 3) advanced technical tools and guidance for the optimized characterization and remediation of low levels of radionuclides, as part of the industry commitments to the Nuclear Groundwater Protection Initiative.

Success would be better tools for cost-effective groundwater protection and site remediation programs, and for the characterization and utilization of groundwater resources for beneficial uses, will be developed within five years.

More Efficient Use of Electricity in Water Sourcing, Treatment and Transportation

Challenge 7: Energy-Water Utilization Efficiency & Storage Opportunities

The sourcing, treatment and distribution of water require significant energy. About 3.4% of the nation's electricity is used to move and treat water and wastewater. There are opportunities to optimize energy and water consumption in the water sector by deploying technologies such as advanced supervisory control and data acquisition (SCADA) systems, advanced reverse osmosis for desalination, membrane distillation, capacitive deionization, advanced ozonation, and photocatalytic oxidation.

Deploying such energy efficient electro-technologies will require a comprehensive assessment, from lab scale to initial field demonstration, in order to characterize the performance of these technologies in real world applications.

Successful completion of this research would create a pipeline of electro-technologies that can be moved to the market through energy efficiency programs. In addition to the potential for energy and/or water use savings, these technologies also would provide the opportunity to more effectively treat water in municipal and industrial applications that currently use chemical treatment.

Water storage tanks in municipal water treatment facilities and hot water tanks in residential and commercial buildings represent an energy storage opportunity for the electricity grid. There are roughly 53 million homes nationwide with electric water heating; a water heater direct load control program could result in an estimated 0.40 kW savings per home and a peak demand reduction of 5,300 MW, assuming a 25% participation rate.

In order to realize this water-energy storage potential and overcome the lack of standardized communication protocols, the industry must develop ubiquitous communication networks for the secure transmission of energy price and event information for distributed energy resources (e.g., for electric water heaters as an energy storage and demand response resource). In addition to these enabling standards

and communication technologies questions, more research is needed to determine how to best integrate and aggregate large amounts of small resources (such as electric water heaters) in energy management systems (EMS).

Success would be mature protocols accepted and adopted in the electric power industry, that enable manufacturers to develop products that work within a broad range of independent system operator (ISO) environments, electric utility pricing and direct load control programs and with different communication networks.

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