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Offshore California Wind & Wave Resources and Implications for 100% Wind, Water, Solar (WWS) in State

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Stanford University

Offshore RE Workshop
CEC, Sacramento, California
May 25, 2016

J. G. Swanepoel/Dreamstime.com

Wind farm near Middelgrunden, Denmark

Wind, Water, Solar (WWS) All-Sector Solutions to Air Pollution, Global Warming, Energy Security

ELECTRICITY	TRANSPORTATION	HEATING/COOLING	INDUSTRY
Wind	Battery-electric	Electric heat pumps	Electric resistance
Solar PV/CSP	Hydrogen fuel cell	Electric resistance	Electric arc furnaces
Geothermal	Cryogenic H_2	Solar water preheat	Induction furnaces
Hydro			Dielectric heating
Tidal/Wave			Hydrogen

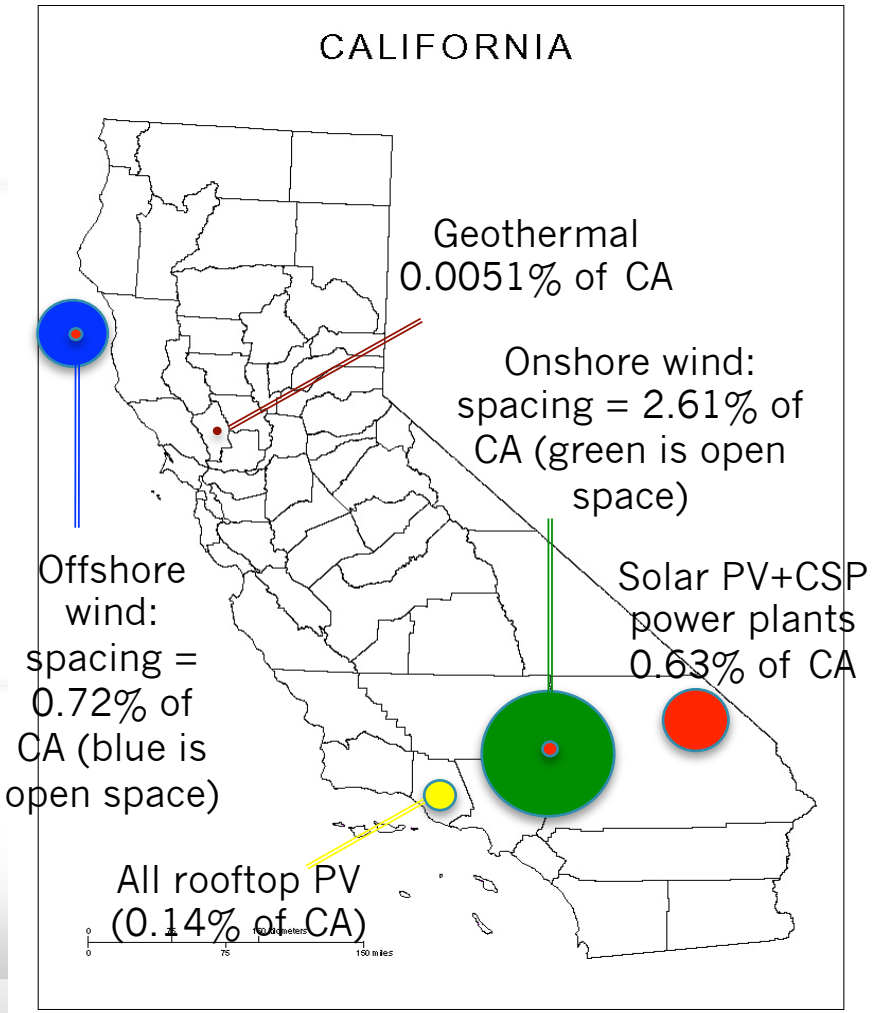
Energy & Env. Sci, 2, 148 (2009)

End-Use Power Demand For All Energy Purposes

Year and Fuel Type	139-Countries	CA
2012 (TW)	12.0	0.205
2050 with current fuels (TW)	19.4	0.229
2050 WWS (TW)	12.0	0.128
2050 Reduction w/ WWS (%)	38.3	44.3

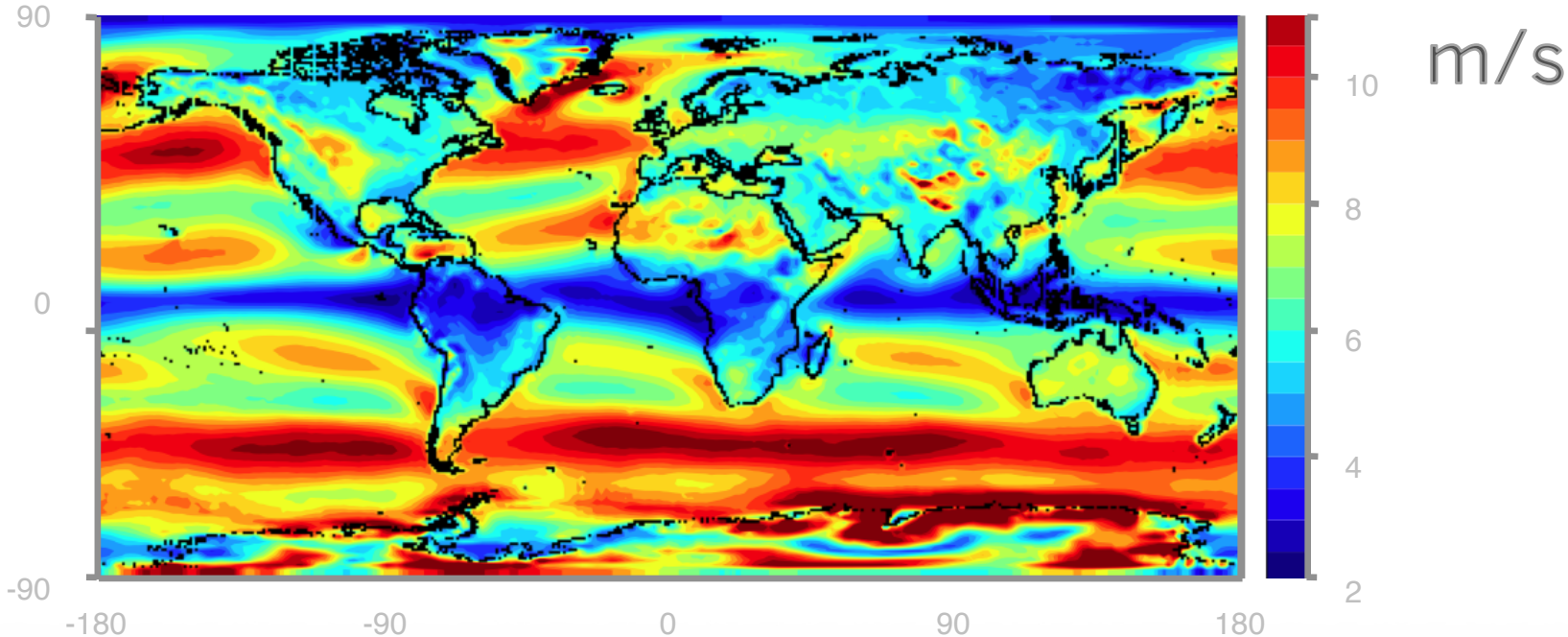
Number New Plants for All-Purpose California Power in 2050

TECHNOLOGY	PCT SUPPLY 2050	NUMBER
5-MW onshore wind turbines	25%	23,760
5-MW offshore wind turbines	10	6,570
5-kW res. roof PV systems	7.5	9.43 mil
100-kW com/gov roof PV systems	5.5	312,000
50-MW Solar PV plants	26.5	2,450
100-MW CSP plants	15.0	330
100-MW geothermal plants	5.0	55
1300-MW hydro plants	4.5	0
1-MW tidal turbines	0.5	2,600
0.75-MW wave devices	0.5	3,940
	100%	



Area to power 100% of CA for all purposes

World Wind Speeds at 100m

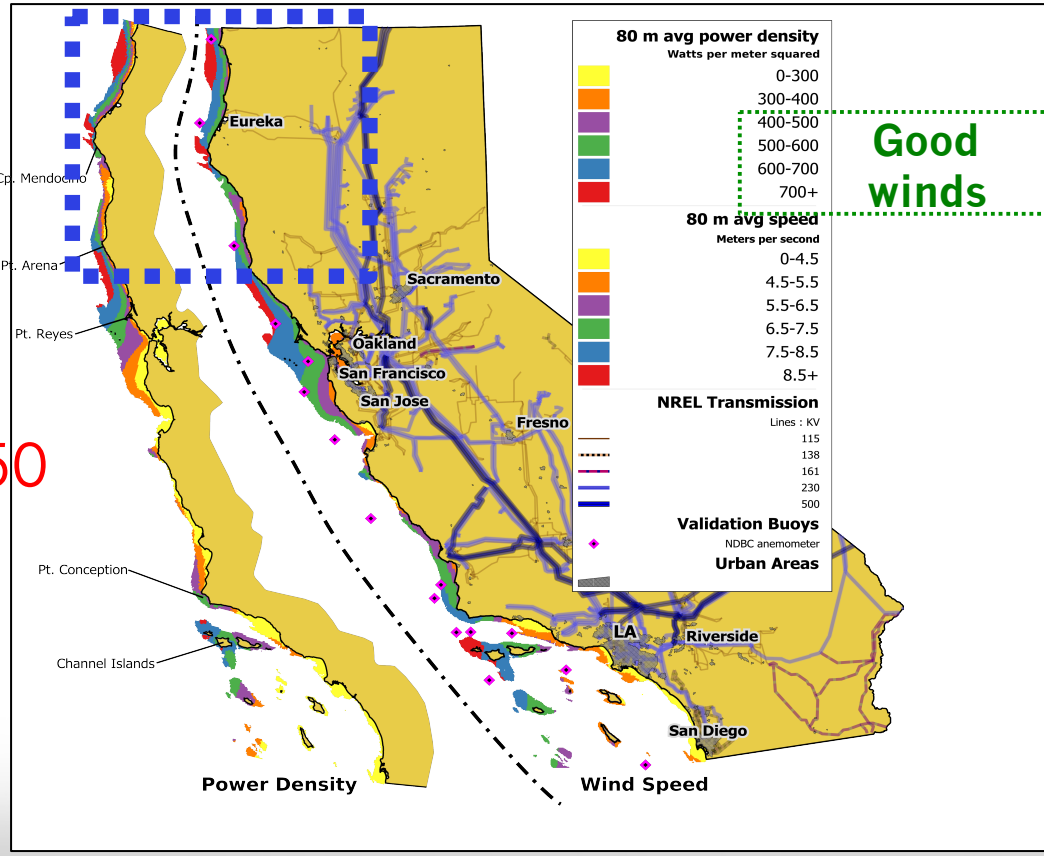


All wind over land in high-wind areas outside Antarctica ~70-80 TW
= ~5-6 times world end-use WWS power demand 2050 of 12.6 TW

California Offshore Wind Resources

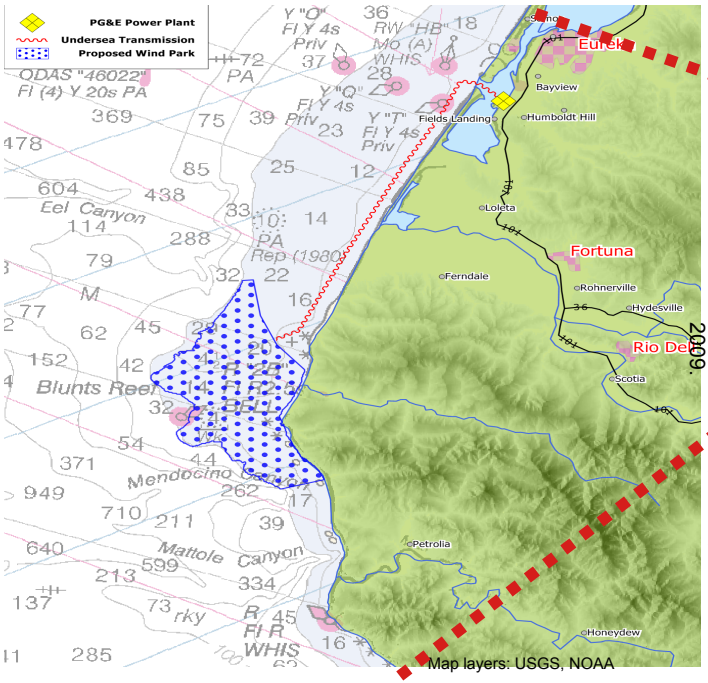
Delivered power potential:
1.4-2.3 GW monopile (<20 m)
4.4-8.3 GW multi-leg (<50 m)
53-65 GW floating (<200 m)
0.8 GW – Cape Mendocino

CA all-purpose power need 2050
128 GW
CA offshore output need 2050
12.8 GW
CA wave output need 2050
0.64 GW

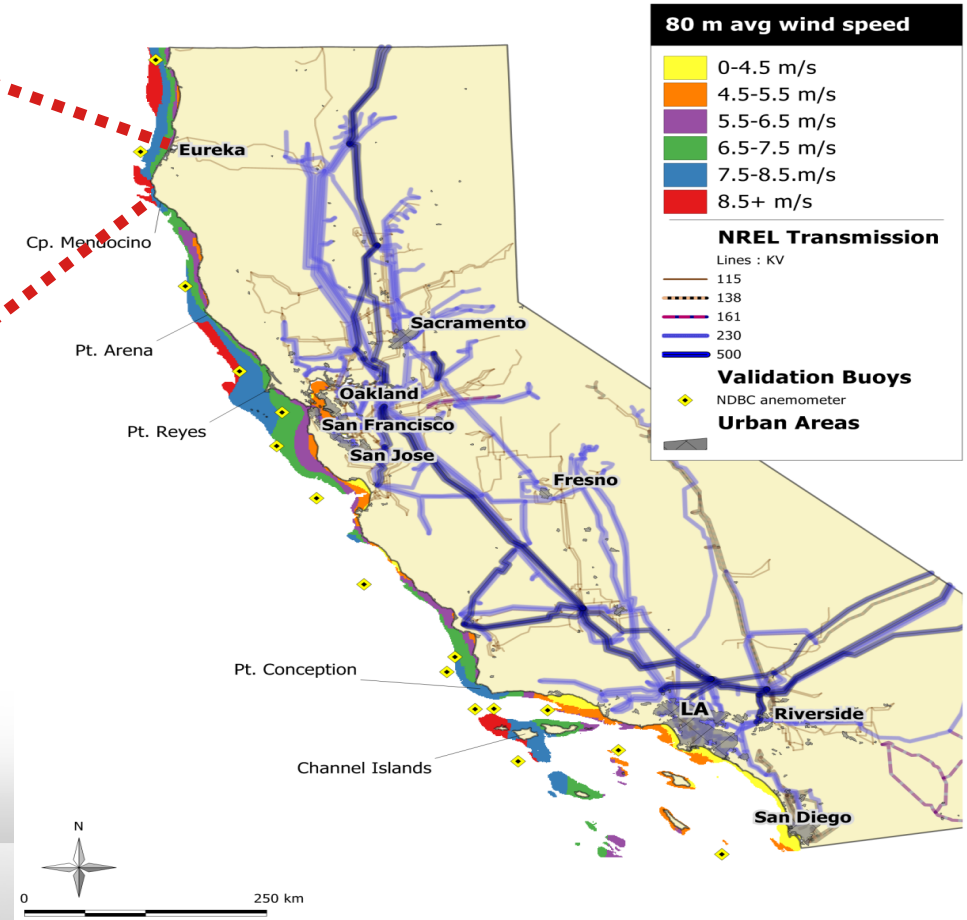


Dvorak, Acher, Jacobson: California offshore wind energy potential, *Renewable Energy* (35, 1244, 2010)

Proposed *Cape Mendocino Wind Park*



Source: Dvorak, Archer, Jacobson, 2009.



300 Repower 5.0 MW turbines
0.6 GW average output (40% CF)

Dvorak, Acher, Jacobson: California offshore wind energy potential, *Renewable Energy* (35, 1244, 2010)

Wind speed versus time of day by month at Cape Mendocino

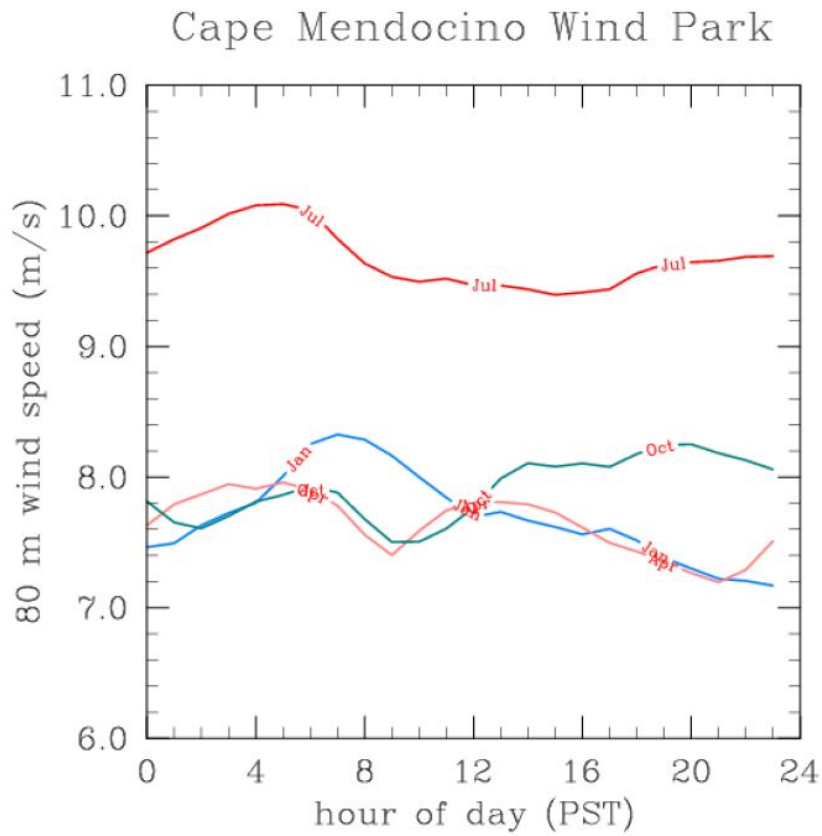


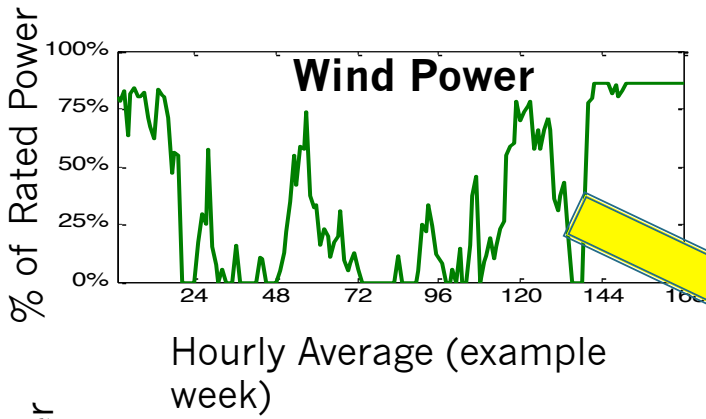
Figure 3.5: Mean $\bar{v}_{80\,\mathrm{m}}$ winds grouped by hour of the day (PST) for the proposed wind farm off the NCA coast (Figure 3.4), based on the MM5 output for the 2005/2006 months of January, April, July, and October.

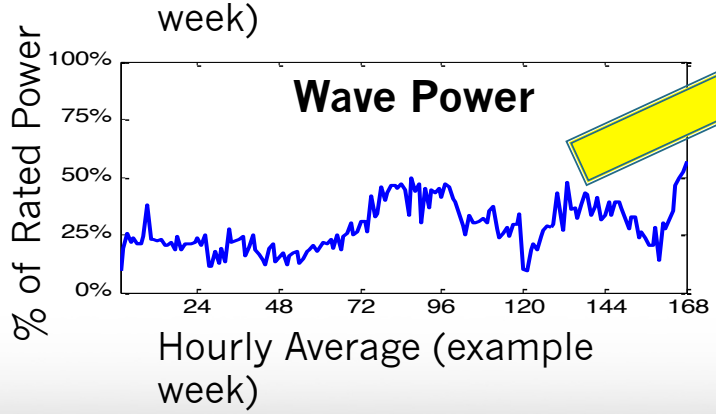
Dvorak, Acher, Jacobson: California offshore wind energy potential, *Renewable Energy* (35, 1244, 2010)

BUNDLING MARINE RENEWABLE RESOURCES

V90 Vestas Wind Turbine

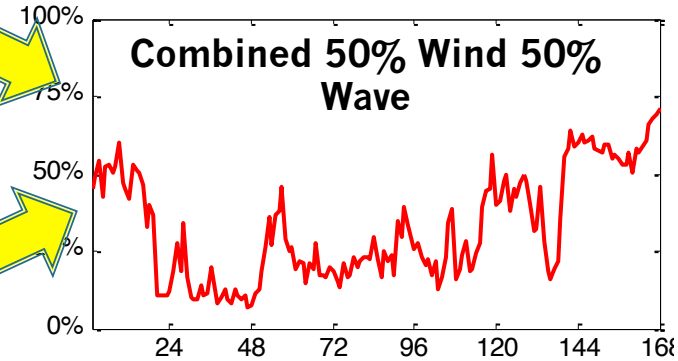
Pelamis Wave Energy Converter





Combined Farms:

- Lower variability
- Fewer hours of zero power

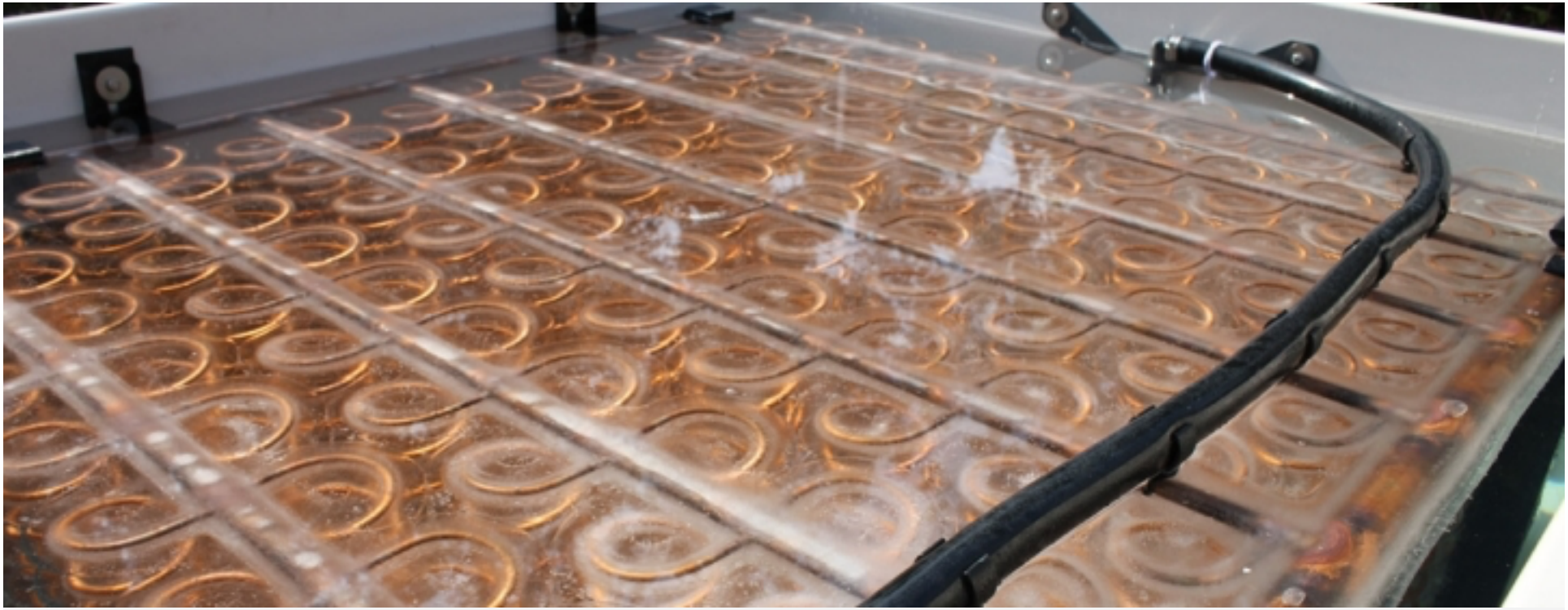


Stoutenburg, E.D., Jenkins, N., Jacobson, M.Z., *Renewable Energy*, doi:10.1016/j.renene.2010.04.033, 2010. Photo credit: NOAA NDBC, Vestas Wind Systems A/S, Pelamis Wave Power Ltd

Types of Storage for 100% WWS System

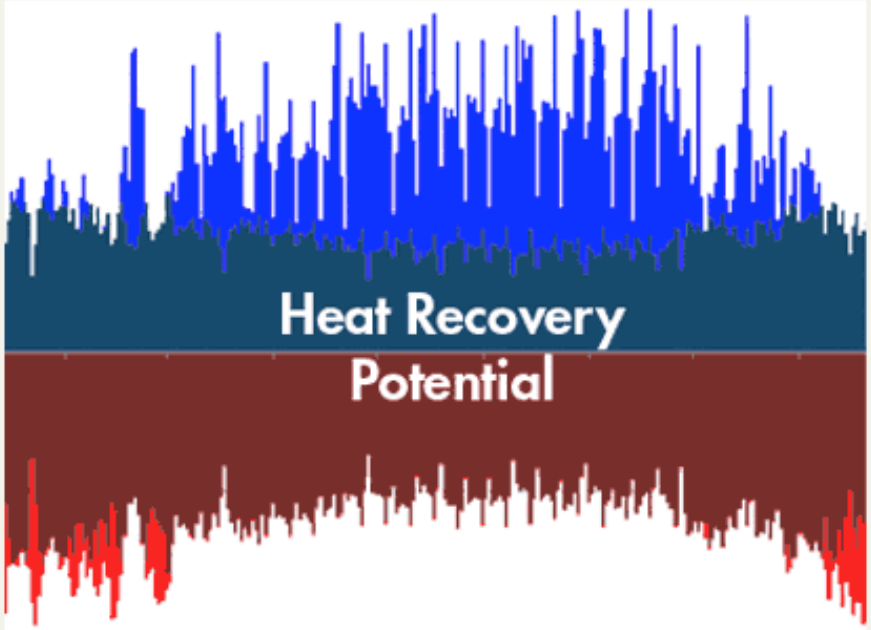
ELECTRICITY	HEATING/COOLING	OTHER
CSP with storage	Water	Hydrogen
Pumped hydro	Ice	Demand-response
Existing hydroelectric	Rocks in soil	

Nighttime Storage in Ice for Daytime Air Cooling



https://www.torontohydro.com/sites/electricsystem/electricityconservation/businessconservation/Pages/IceBearEnergyStoragePilot.aspx

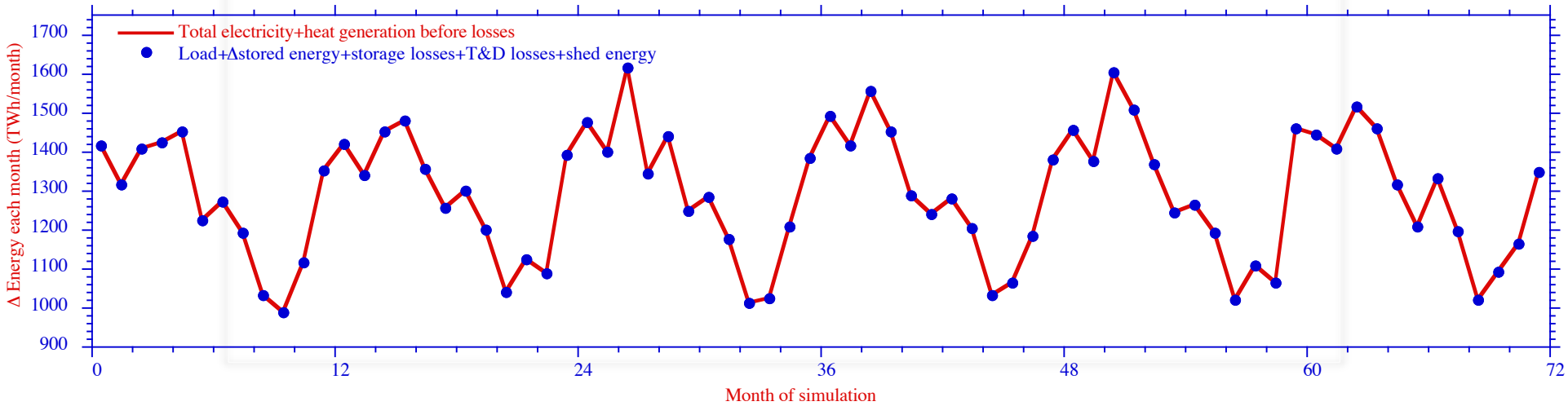
Stanford Boilers/Chillers & Heat/Cold Demand & Recovery Over Year



https://sustainable.stanford.edu/sites/default/files/SESI_Condensed_factsheet_0.pdf

Seasonal Heat Storage in Rocks, Okotoks, Canada

Matching 100% 2050-2055 U.S. Load With WWS for 6 Years

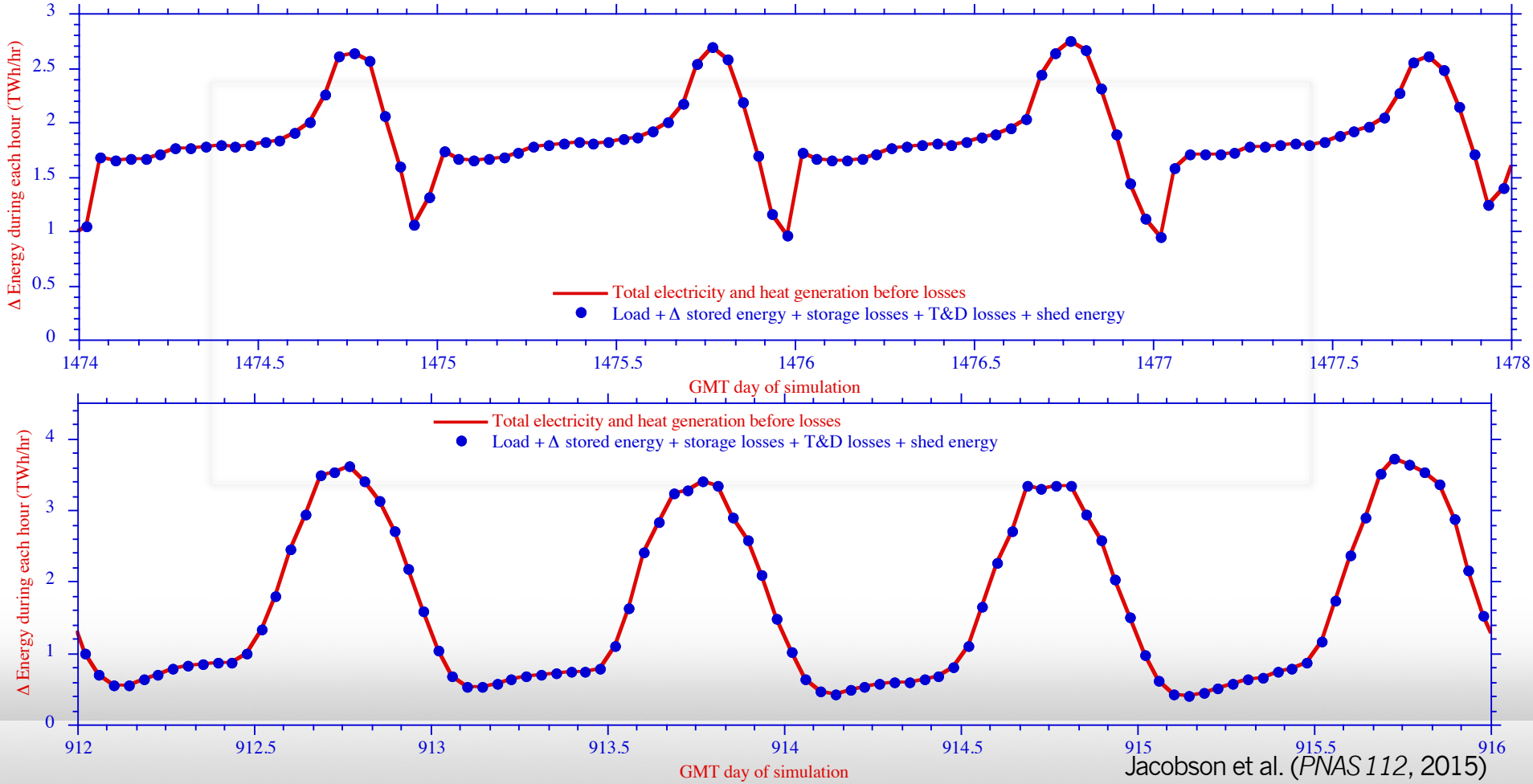


Red = Energy supply

Blue = Energy demand + change of storage + losses

Jacobson et al. (*PNAS 112*, 2015)

Matching 100% U.S. Load With WWS on Two Sets of Four Days



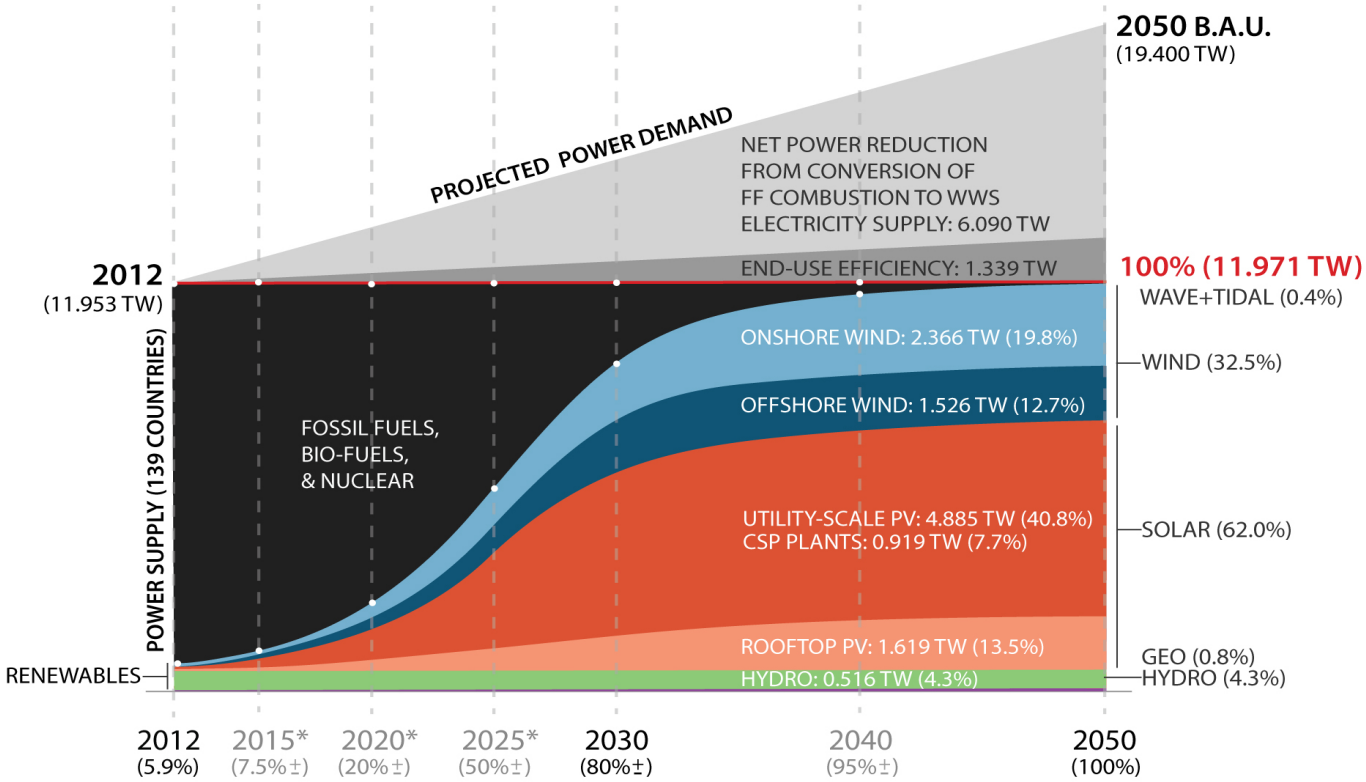
Jacobson et al. (*PNAS 112*, 2015)

2015 U.S. Unsubsidized Costs of Energy (¢/kWh)

Wind onshore	3.2	to 7.7
Wind offshore	11	to 19.4
Geothermal	8.2	to 11.7
Hydroelectric	4	to 6
CSP with 14 hr storage*	9	to 13.5
Utility-scale solar PV	5.0	to 7.0
Community rooftop PV	7.8	to 13.6
Residential rooftop PV	18.4	to 30.0
Gas combined cycle	5.2	to 7.8
Gas peaking	16.5	to 21.8
Advanced pulverized coal	6.5	to 15.0
Nuclear	9.7	to 13.6

Lazard (2015); *Solar Reserve (2016)

Timeline for 139-Country Transition to WWS



Projected Energy Supply & Demand, **139 Countries**

Solutions Project, 2015

House Resolution 540

Expressing the sense of the House of Representatives that the policies of the United States should support a transition to near zero greenhouse gas emissions, 100 percent clean renewable energy, infrastructure modernization, green jobs,…

Summary–Converting California to 100% WWS

→Reduces 2050 BAU power demand by ~44%

→Eliminates ~12,500 air pollution deaths per year (~$130 billion/yr)

→Eliminates ~$240 billion/yr global climate costs 2050 from CA emissions

→Each person saves $160/yr fuel costs; $7200/yr health+climate costs

→WWS w/storage+DRM gives 100% reliability @ ~11-12 ¢/kWh in US

→Creates 45,000 more jobs than are lost

→Requires only 0.63% of land for footprint; 2.6% for spacing

→Makes California energy independent, reducing international conflict

→Creates distributed power, reducing terrorism/catastrophic risk

→Reduces energy poverty of up to 4 billion people worldwide

Barriers : up-front costs, transmission needs, lobbying, politics.

Materials are not limits

Papers / Graphics

web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html

web.stanford.edu/group/efmh/jacobson/Articles/I/Offshore/offshore.html

www.thesolutionsproject.org

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