Potential for Creating Bioenergy and Biofuels from Landfill-Bound Residuals and Landfill Gas
California Integrated Waste Management Board

Introduction

California has diverse, widespread and substantial biomass resources, which include residues from forestry, agriculture, and municipal solid wastes. Significant amounts of these materials are disposed in landfills that must be managed for decades after closure as a precaution against environmental damage. These untapped, renewable resources could support greater use for electricity generation, transportation fuels, chemical manufacturing, and the production of valuable co-products.

In signing Executive Order S-06-06, Governor Schwarzenegger directed state agencies participating in the Bioenergy Interagency Working Group to "advance the use of biomass resources for electricity generation and biofuels for transportation." Furthermore the Governor stated "Turning waste products into energy is good for the economy, local job creation and our environment."

The Governor's Bioenergy Action Plan is designed to achieve the following five broad policy objectives:

1. Maximize the contributions of bioenergy toward achieving the state's petroleum reduction, climate change, renewable energy, and environmental goals;
2. Establish California as a market leader in technology innovation, sustainable biomass development, and market development for bio-based products;
3. Coordinate research, development, demonstration, and commercialization efforts across federal and state agencies;
4. Align existing regulatory requirements to encourage production and use of California's biomass resources; and
5. Facilitate market entry for new applications of bioenergy including electricity, biogas, and biofuels.

As part of its contribution to achieving the objectives described in the Bioenergy Action Plan the California Integrated Waste Management Board (CIWMB) was directed to complete the following tasks by December 31, 2006.

- Identify and quantify the amount of material currently being landfilled and assess the potential for its conversion to biofuels and other bio-based products.
- Establish goals for 2010 and beyond for the use of landfill-bound residuals to be used for bioenergy production.
- Identify state and private revenue sources of grant and incentive program research activities related to bioenergy production from landfill-bound residuals.
- Identify and quantify the potential of using landfill gas as a biofuel.

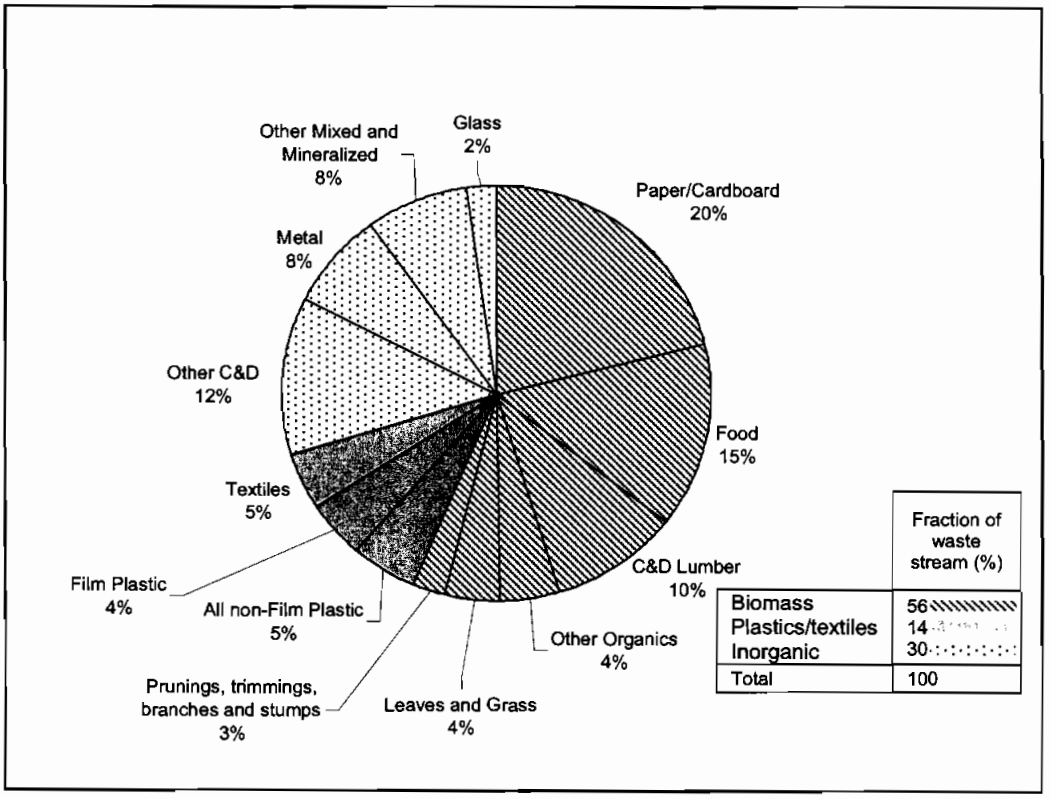
Materials currently being landfilled and their potential for conversion to biofuels and other bio-based products

California's Integrated Waste Management Act of 1989 (IWMA) set forth policy to reduce the state's reliance on landfills. The IWMA required each local jurisdiction to implement diversion programs to achieve a 50 percent diversion from landfilling of all solid waste generated within that jurisdiction by 2000. Statewide diversion reached 52 percent in 2005. Achieving the 50 percent target has been the result of increased diversion programs implemented by local jurisdictions, investment in processing and recycling facilities by both the private and public sectors, and market demand for recycled-content materials and products. However, this remarkable achievement has only managed to keep pace with increased waste generation over the same period. As a result, even with a plethora of diversion programs, 43.5 million tons of material are still being disposed, an amount that will likely continue to grow as a result of population growth.

- **Amount and types of material landfilled**

As shown in Figure 1, 56 percent (25.7 million tons) of the 43.5 million tons landfilled are biomass, 14 percent (5.7 million tons) are plastics and textiles and the remaining 30 percent (12.1 million tons) are mineral and other inorganic material (glass, metal, non-wood construction/demolition waste).

Figure 1. Landfilled Waste Stream by Material Type



Source: Cascadia Consulting Group. (2004). "Statewide waste characterization study." Contractor's report to IWMB. Publication #340-04-005

- **Potential for conversion**

The University of California Riverside and Davis conducted a technical evaluation of conversion technologies, addressing issues related to technical viability and environmental impacts and summarized findings in their September 2004 report "*Evaluation of Conversion Technology Processes and Products*". The study concluded that primary or chemical energy available in material landfilled in California in 1999 was equivalent to the energy in 67 million barrels of crude oil. Table 1, adapted from the Universities' report, summarizes the total energy and the electricity generation potential of the municipal solid waste (MSW) stream currently being landfilled in California.

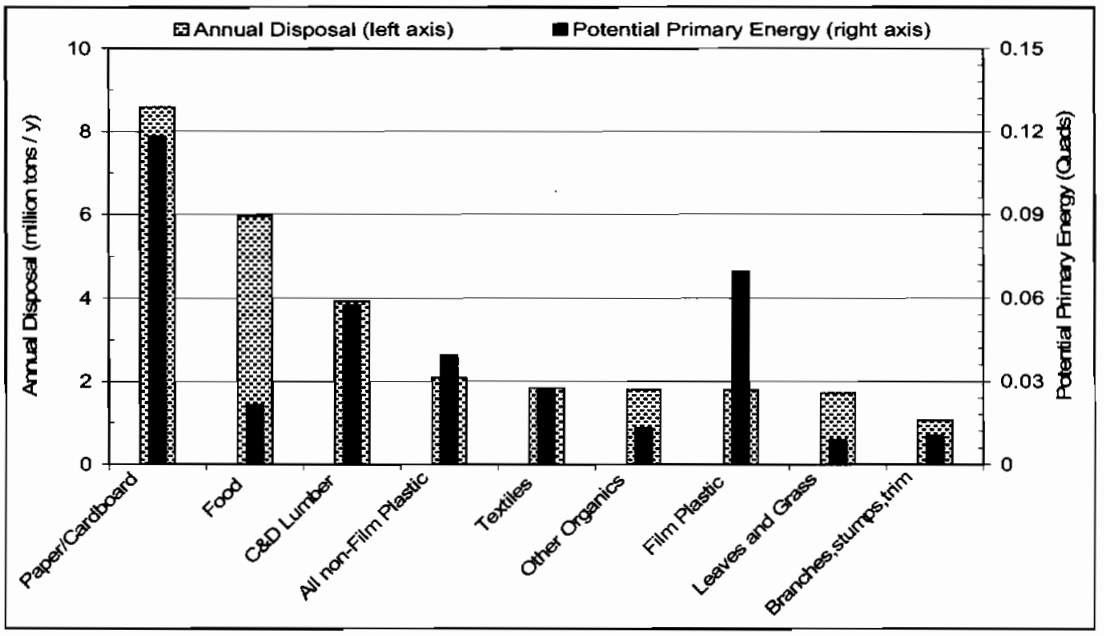
As can be seen in Table 1, the biomass components of solid waste are not only the largest fraction of the waste stream; but, they also have the largest potential for production of biofuels or bio-based products, including electricity. Although non-biomass organic materials constitute a much smaller portion of the waste stream, they have more than twice the potential, pound for pound. Figure 2 compares each material type by tonnage disposed to its potential energy content.

Table 1. Characterization and Potential Energy of Waste Disposed Annually

	Landfilled *(million tons)*	Fraction of total chemical energy *(%)*	Oil equivalent *(million barrels)*	Electricity potential *(MWe)*
Paper/Cardboard	8.6	30	20.2	791
Food	6.0	6	3.7	204
Leaves and Grass	3.9	2	1.5	42
Prunings, trimmings, branches, stumps, and Green ADC	3.7	9	6.1	240
Other Organics	1.8	3	2.3	88
C&D Lumber	1.7	15	9.8	384
Biomass Components (Subtotal)	**26**	**65**	**44**	**1750**
All non-Film Plastic	2.1	10	6.8	264
Film Plastic	1.8	18	11.9	466
Textiles	1.8	7	4.7	184
Non-Biomass Organic Components (Subtotal)	**6**	**35**	**23**	**914**
Other C&D	4.9	–	–	–
Metal	3.1	–	–	–
Other Mixed and Mineralized	3.1	–	–	–
Glass	0.9	–	–	–
Inorganic Components (Subtotal)	**12**	–	–	–
TOTAL	**44**	**100**	**67**	**2664**

Source: Adapted from "***Biomass In Solid Waste In California, Utilization and Policy Alternatives.***" Rob Williams, California Biomass Collaborative. Prepared under contract to California Energy Commission, Publication Number 500-01-016

Figure 2. Waste Material Disposed and Energy Content



Source: Adapted from "***Biomass In Solid Waste in California, Utilization and Policy Alternatives.***" Rob Williams, California Biomass Collaborative. Prepared under contract to California Energy Commission, Publication Number 500-01-016.

Goals for the use of landfill-bound residuals in bioenergy production

The IWMB proposes the following goals for the use of landfill-bound residuals in bioenergy production.

- **By 2010, divert 10 percent of the biomass residuals and 20 percent of the non-biomass organic residuals** currently being landfilled for generation of bioenergy. Achieving this goal would provide the equivalent of nine million barrels of oil or 358 megawatts of electricity.
- **By 2020, divert 40 percent of the biomass residuals and 60 percent of the non-biomass organic residuals** currently being landfilled for the generation of bioenergy. Achieving this goal would provide the equivalent of 31 million barrels of oil or 1,248 megawatts of electricity.

Local jurisdictions have for the most part reached the 50 percent diversion levels mandated by the IWMA. A number of alternative waste management approaches could be considered to encourage further diversion of currently landfilled materials for use in bioenergy production. Approaches could include:

- Working closely with other State agencies to provide a streamlined regulatory framework for siting, permitting and regulating facilities that turn waste into bioenergy, including landfill gas-to-energy facilities.
- Seeking statutory change to provide incentives that could include grants, low-interest loans and tax incentives for projects proposing to create bioenergy using material currently being landfilled.

- Limiting the amount or types of material landfilled.
- Tracking the progress of waste-to-bioenergy technology, with a focus on ascertaining the most viable technologies and projects.

Revenue sources and incentives for bioenergy research

There are a number of potential federal, State and other revenue sources of grant and incentive programs for research activities related to bioenergy production from landfill-bound residuals. The following are examples of funding sources that may or may not be ongoing.

Private revenue sources

Energy Foundation
http://www.ef.org/home

The Energy Foundation is a partnership of major donors interested in solving the World's energy problems. Their goal is to advance energy efficiency and new renewable energy. Current Foundation partners include William and Flora Hewlett Foundation, John D. and Catherine T. MacArthur Foundation, McNight Foundation, Mertz Gilmore Foundation, David and Lucile Packard Foundation, and Pew Charitable Trusts.

Federal revenue sources

- **U.S. Department of Energy (DOE)**

  This web site is a gateway for energy technology developers for information about bringing energy technologies to market.

  DOE's comprehensive Toolbox for Energy Technology Developers was created by New Horizon Technologies, Inc. with funding from the U.S. Department of Energy, and is a core collection of information and resources, including a comprehensive collection of public financing sources

  http://www.eere.energy.gov/inventions/energytechnet/funding/public_sector.html and private financing sources.

  http://www.eere.energy.gov/inventions/energytechnet/funding/private_sector.html for individuals engaged in developing and commercializing advanced energy technologies.

  US Department of Energy (DOE) -- Energy TechNet
  http://www.eere.energy.gov/inventions/energytechnet/introduction.html

  The Inventions & Innovation Program and National Industrial Competitiveness through Energy, Environment and Economics (NICE^3) Technology Demonstration Partnerships are offered through DOE's Office of Information Technology.

  Inventions & Innovation Program
  http://www.eere.energy.gov/inventions/

  Bioenergy development projects appear to qualify for the DOE's Inventions & Innovation program, which offers financial and technical support for promising energy-saving

concepts and technologies. The program offers competitive grant funding for research and development of innovative, energy-saving ideas and inventions. Grants are available in amounts up to $50,000 for technologies in early-stage development and up to $250,000 for technologies approaching the prototype stage.

NICE^3 Technology Demonstration Partnerships
http://www.eere.energy.gov/inventions/docs/financial_brch.pdf

Bioenergy development projects also appear to qualify for the NICE^3 Technology Demonstration Partnerships. This program provides grant funding to state and private sector partnerships to demonstrate emerging, energy efficient technologies that will benefit the state Industries of the Future program. The program provides up to $525,000 (50 percent cost sharing is required) for the first commercial demonstration of innovative industrial technologies that reduce energy consumption, waste generation, and operating costs. Applications must be submitted by an authorized state agency with an appropriate industrial partner. The California Energy Commission administers the Industries of the Future program in California.

- **Department of Commerce**

Advanced Technology Program (ATP)
http://www.atp.nist.gov/atp/charter.htm

The ATP funds high-risk research by accelerating the development of new-to-the-world technologies—including new energy technologies. The ATP supports projects that industry cannot fully fund on its own because of significant technical risks. ATP awards are made on the basis of rigorous, competitive peer review considering scientific and technical merit of each proposal. In addition, awards are based on the potential for broad-based economic benefits, the need for ATP funding, and evidence of a clear commercialization pathway and broad diffusion. The ATP is administered by the National Institute of Standards and Technology.

- **Small Business Administration (SBA)**

Small Business Innovation Research Program (SBIR)
http://www.sbaonline.sba.gov/SBIR/

Each year, SBIR requires 11 federal departments and agencies (including the Departments of Commerce, Energy, Transportation, and the Environmental Protection Agency) to reserve a specific percentage of their R&D funds for small business. SBIR funds the critical startup and development stages and encourages commercialization of technology, products and services. SBA collects solicitation information from all participating agencies and publishes it quarterly in a Pre-Solicitation Announcement (PSA). The PSA is a single source for the topics and anticipated release and closing dates for each agency's solicitations.

Selected State funding sources

- **California Energy Commission (CEC)**

The CEC has recently issued three grant offerings through its Public Interest Energy Research (PIER) program. These are examples of research funding opportunities but may not be ongoing programs. Interested parties should contact CEC to determine if these grant programs are available annually.

Energy Innovations Small Grant Program
http://www.energy.ca.gov/research/innovations/index.html

The Energy Innovations Small Grant (EISG) Program provides up to $95,000 for hardware projects and $50,000 for modeling projects to small businesses, non-profits, individuals and academic institutions to conduct research that establishes the feasibility of new, innovative energy concepts. Research projects must target one of the six PIER program areas, address a California energy problem and provide a potential benefit to the state's electric and natural gas ratepayers. Proposals were submitted in early February; the CEC anticipates awarding grants in June 2007. Bioenergy development would appear to qualify for the EISG program.

Biofuels Research, Development and Demonstration
http://www.energy.ca.gov/contracts/pier_biofuels/2006-10-31_BIOFUELS_PON.PDF

The purpose of the grant solicitation is to accelerate research, develop and demonstrate biofuel energy conversion technology and refining using lignocellulosic biomass, food waste, beverages, waste grease, purpose-grown or energy crops. Total funding available for this solicitation is $3,000,000, with a maximum of $1,000,000 per project. Three to four projects are anticipated to be selected for funding, which will be awarded as grants. Proposals were submitted to the CEC in early January; the Commission anticipates awarding grants in April 2007.

Renewables Natural Gas Replacement Alternatives
http://www.energy.ca.gov/contracts/pier_biogas/2006-11-21_PIER_BIOGAS_ANNOUNCEMENT.PDF

The purpose of this grant solicitation is for research development and demonstration of advanced, cost-effective, and environmental friendly technologies using renewable fuels to replace or reduce natural gas applications in California. This research will advance the science, technology and market acceptance by funding industrial and commercial process heating and combined heat and power projects, which provide biogas and/or hybrid renewable alternatives to conventional natural gas applications. Total funding for this solicitation is $1,000,000 with one or two projects selected for funding. Proposals were submitted in early February; the CEC anticipates awarding grants by May 2007.

- **Air Resources Board (ARB)**

ARB Innovative Clean Air Technologies (ICAT)
http://www.arb.ca.gov/research/icat/purpose.htm

Innovative Clean Air Technologies (ICAT) funds are used to help an innovator obtain funds for commercial introduction of a new technology. ICAT funds technically solid projects that can demonstrate the commercial utility in California of technical innovations that will improve emission prevention or control. ICAT assists technologies that can help reduce emissions while promoting new industries and jobs in California, improve industrial productivity and reduce control costs.

Alternative Fuels Incentives Program

An example of one-time funding available for biofuels research is the Alternative Fuels Incentives Program (AFIP). Assembly Bill (AB) 1811 requires the California Air Resources Board (ARB) to develop a joint plan with the California Energy Commission (CEC) to spend $25 million for the purposes of incentivizing the use and production of alternative transportation fuels. It includes $5 million for new biofuel production facilities, digesters, and landfill-

gas based LNG and CNG projects. The AFIP solicitations can be found at the ARB web page at: http://www.arb.ca.gov/fuels/altfuels/incentives/incentives.htm. Project proposals are due March 12, 2007. Proposals will be evaluated by a multi-state agency team comprised of the ARB, CEC, State Water Resources Control Board, Integrated Waste Management Board, California Department of Food and Agriculture, and California Department of Forestry.

Goods Movement Action Plan
http://www.arb.ca.gov/gmp/docs/gmap-1-11-07.pdf

The November 2006 Transportation Bond approved by the voters (Proposition 1B - the Highway Safety, Traffic Reduction, Air Quality and Port Security Bond Act of 2006) includes $1 billion to accelerate the cleanup of air pollution caused by goods movement activities in California. On appropriation by the Legislature, and subject to such conditions and criteria contained in a statute enacted by the Legislature, the ARB will appropriate this money over the next several years to fund emission reductions, not otherwise required by law or regulation, from activities related to the movement of freight along California's trade corridors. Production of clean fuels, including biofuels from landfill-bound residuals, for use in goods movement may be eligible for funding under Proposition 1B.

Other funding sources

- **California Public Employee Retirement System (CalPERS)**

  Green Investment Program
  http://www.calpers.ca.gov/index.jsp?bc=/member/perspective/2005winter/green-ivo-program.xml&pst=ACT&pca=ST

  In 2004, the CalPERS Board of Administration agreed to commit $700 million of its investment portfolio to invest in clean technologies and public companies that promote clean, environmentally friendly business practices. CalPERS' first green investment initiative was a $200 million program to invest in private equity funds that focus on clean technologies; its second initiative was a $500 million investment in public stocks of companies that practice clean business strategies that reduce damage to the environment.

- **South Coast Air Quality Management District (SCAQMD)**

  Technology Advancement Program
  http://www.aqmd.gov/tao/About/index.html

  The SCAQMD Governing Board established the Technology Advancement Office (TAO) in 1988 to expedite the development, demonstration and commercialization of cleaner technologies and clean-burning fuels to reduce emissions from both mobile and stationary sources. The program uses cooperative partnerships with private industry, academic and research institutions, technology developers and government agencies to cosponsor projects intended to demonstrate the successful use of clean fuels and technologies that lower or eliminate emissions. Although the TAO's high priorities for the next three years are not closely aligned with the goals of Executive Order S-06-06, the program appears to be well matched with bioenergy and biofuels development.

Potential Incentives for Research & Demonstration Activities

Research and demonstration of bioenergy and biofuel technologies could be enhanced by establishing a separate permitting path that would allow for limited term research projects regarding waste handling related to these technologies strictly for purposes of research and demonstration of bioenergy and biofuel production technologies. Another incentive for research and demonstration is by providing grants or loans for bioenergy/biofuel research and demonstration activities. The creation by the Legislature of an investment tax credit to researchers who purchase and place into service equipment for research and demonstration of bioenergy and biofuel production technologies is another potential incentive for research and demonstration. The grant, loans, and tax credit could be funded by statutorily raising the cap on the state's landfill tipping fee, which is currently set at its maximum $1.40 per ton of solid waste disposed in California landfills.

Potential of using landfill gas as a biofuel

Biomass decomposing in landfills produces a methane-rich gas that is both an explosive hazard and a potent greenhouse gas. Regulatory requirements to control methane from landfills have resulted in the development of landfill gas (LFG) collection and control systems that include simple flaring of gas, conversion to electricity, and use for heat and power generation as well as to produce vehicle fuel. This has provided operators a new source of revenue from sale of electricity, heat, or fuel gas while reducing methane emissions to the atmosphere.

- **Current LFG generation and utilization**

Based on information in the CIWMB's Solid Waste Information System, CIWMB staff work conducted in the early 2000s as part of the US EPA Landfill Methane Outreach Program, and continued staff tracking of landfill gas systems implementation, the CIWMB has developed an extensive inventory of landfills and landfill gas systems. This inventory lists 366 landfills in California that are generating landfill gas (the inventory includes all active landfills, along with landfills that were operating as of January 1988 when new Federal standards were adopted but which have since closed; it does not include burn dumps, inert waste sites, or sites having no significant potential for gas generation). The total landfill gas generated is estimated at between 118 and 156 billion cubic feet per year (BCF/y) with an average methane concentration of 50 percent, yielding a methane equivalent of 59 to 78 BCF/y. By comparison, natural gas consumption in the state is 6 BCF per day or 2,200 BCF/y.

The largest proportion of LFG is either vented to the atmosphere, flared, or used as a biofuel for electricity generation, though some also is used for heat or process steam (vehicle fuel is currently pilot-scale only). An estimated 1.2 billion tons of waste is in place in California landfills. Fifty-one sites account for 76% of this material, and all of these sites have either gas flaring or gas-to-energy systems. There is a total of 63 existing LFG to electricity facilities in California, with a combined generating capacity of approximately 280 MW. In addition, 10 facilities use LFG directly for heat, steam, or pipeline. Direct use for heat or steam refers to using landfill gas directly as a fuel for industrial, commercial, and institutional boilers, in addition to dryer, kiln, greenhouse, or other thermal applications. This has a relatively low cost because it does not require purification and processing as would a vehicle fuel, but the proximity to users required and variable quality of the gas can affect its utility as an alternative fuel for these applications. Direct use for pipeline refers to purifying landfill gas to natural gas standards and conveying the purified gas for use in natural-gas fired facilities and applications. This is more expensive than direct use for heat or steam, and gas quality still can vary.

Potential LFG to biofuels

Biofuels produced from LFG include compressed natural gas (CNG), liquid natural gas (LNG) and hydrogen. Technologies to produce these fuels are under development and show considerable promise, however the production of vehicle fuel from landfill gas is negligible.

Compressed natural gas

Project cost information for CNG is limited; but, in general it is estimated to be similar to pipeline quality landfill gas recovery, not including the additional associated costs for the fueling station and distribution system. Biomethane as vehicle fuel will work only in vehicles designed to run on CNG or LNG; both require a fueling station that is entirely different from a traditional liquid fuel station. The County Sanitation Districts of Los Angeles has been producing CNG vehicle fuel from landfill gas (250 scfm inlet landfill gas at 55 percent methane) at the Puente Hills Landfill. The total cost of the Puente Hills CNG facility was approximately $1 million. At full production the facility is capable of producing clean fuel at an equivalent gasoline cost of $0.50 per equivalent gallon of gas. In Sonoma County, a $600,000 CNG project will result in a system to fuel six buses. In this case the County already has the well field and blower/flare station. The County intends to potentially expand CNG production and may install a pipeline from the landfill to the County's refueling station.

Liquid natural gas

Producing LNG from landfill gas requires steps beyond CNG to further purify and liquefy the landfill gas. Prometheus Energy, Inc. is currently in the shakedown phase of the first full scale landfill gas to LNG project in California located at the Frank R. Bowerman Landfill in Orange County. Waste Management Inc. and CryoEnergy have proposed and are seeking funding assistance for a demonstration project at the Altamont landfill in Alameda County that would produce 12,400 gallons per day of LNG for heavy-duty trucks. The total capital cost for the Altamont project is estimated at $13-15 million.

Hydrogen

A study being conducted for the CIWMB by the UC Davis Institute of Transportation Studies indicates that the ultimate potential for hydrogen produced from California LFG is equivalent to approximately 315 million gallons of gasoline. This is about two percent of California's current gasoline usage. This statewide LFG hydrogen estimate could potentially fuel 1.3 million fuel cell vehicles in 2005 and up to 1.9 million vehicles in 2025.

While hydrogen from LFG may have future potential, preliminary indications from the study are that additional research is needed on technical aspects of hydrogen production and that such production would not be economically viable at this time. However, it may be more technically and economically feasible to use hydrogen as an enrichment to landfill gas to improve the combustion process for lowering criteria pollutant emissions from engines using the landfill gas to produce electricity.