Executive Summary

This report examines the feasibility of producing biomethane from dairy manure. We investigated a number of possible technologies for producing renewable forms of energy and fuel from dairy wastes as well as applications and markets for these products. Although some of the applications proved to be technically or economically infeasible at this time, we believe that the information gathered could prove useful for other investigators or future studies. With this in mind, we designed this sourcebook for readers and investigators interested in exploring alternate uses of biogas created from dairy wastes.

Summary of Findings

- Biomethane is renewable natural gas. It is made by upgrading biogas that is produced by the controlled decomposition of dairy manure or similar waste products. It can serve as a substitute for natural gas in transportation, heating, cooling, and power generation.
- Producing biomethane from dairy manure is not technically difficult, but it is challenging to produce it cost competitively with natural gas on the relatively small scale of a dairy.
- Dairies can produce more biomethane than they can use. A successful project must identify an off farm use, and provide a means to transport and store the fuel.
- There are institutional and regulatory barriers to transporting biomethane through the natural gas pipeline which will be difficult to overcome. Alternatively, it can be transported by dedicated pipeline or truck.
- Biomethane provides a number of societal and environmental benefits, especially improved energy security and reduced greenhouse gas emissions. Unlike raw biogas which has impurities that corrode exhaust systems, NO_x emissions from biomethane combustion can be easily controlled.
- Current Federal and State programs provide little support for biomethane.
- The estimated cost of producing biogas and upgrading it to biomethane on farm can be competitive with the price the dairy would pay for natural gas. Added to the production cost is the cost of transportation and storage.
- Electrical generation from biogas is more cost effective than upgrading the biogas to biomethane, but current regulations make it difficult for the farmer to realize the economic value of the electricity he/she generates.
- Biomethane is a proven vehicle fuel. Sweden has 20 plants producing biomethane and runs 2,300 vehicles, mostly buses on it.
- Manure from about half the cows in California could provide enough biomethane to power all the natural gas vehicles currently operating in the state.

Summary of Opportunities

- Central Valley cities such as Tulare, Visalia, Hanford or Modesto would be good sites for a biomethane vehicle fuel project because they are in a non-attainment area for ozone, and they each have many dairies in close proximity to existing compressed natural gas filling stations. To make these projects feasible, the cities would need to enlarge their natural gas fleets (natural gas vehicles have lower air emissions than diesel vehicles) and expand or reconfigure their filling stations.

- There are many industrial customers in the Central Valley that could use large quantities of locally produced biomethane, though raw or partially cleaned biogas may suffice in many industrial applications.
- The output of Central Valley liquefied biomethane plants could replace the liquefied natural gas currently trucked in from other states.
- A biomethane industry along California's Highway 99 could serve as the infrastructure for a future "hydrogen highway," should it prove feasible, because it would provide a renewable fuel to replace natural gas as a feedstock for the on-site manufacture of hydrogen.

Structure of Report

The report deals with five major areas of investigation:

- *Producing biogas from California dairy wastes*. We considered the theoretical maximum production potential, the technical and economic considerations, and the technologies and systems most suitable for producing biogas on dairy farms.
- *Upgrading biogas to biomethane*. We use the term "biomethane" to describe an upgraded form of biogas similar to natural gas in composition and energy capacity, and we investigated the various technologies that can be used to create biomethane by removing hydrogen sulfide, moisture, and carbon dioxide from biogas.
- *Using and distributing biogas and biomethane*. We investigated various traditional and non-traditional uses of biogas and considered potential on- and off-farm uses of biomethane. An important consideration is the means of storing and transporting the fuel to its final place of consumption. We considered the technical and economic implications of the various means of distribution.
- *Meeting regulatory requirements and obtaining access to government incentives*. Most existing government policies and incentives for renewable energy focus either on renewable electricity sources or two forms of alternative vehicle fuels: ethanol and biodiesel. We examined federal and state (California) policies and programs now in place to determine their current or potential applicability to the dairy biogas and biomethane industry. We also considered the various permits and regulatory requirements needed to build a dairy digester and/or biomethane upgrading plant, whether on an individual farm or at a centralized location.
- *Determining the financial, economic, and business environment for the development of a biomethane industry*. We estimated the costs of building a biomethane plant and considered these in the context of existing and potential markets for biomethane. Despite some favorable economic conditions, such as the currently high price of natural gas, we concluded that public (i.e., governmental) policy support of the industry is needed to help move it beyond the pioneering stage, and we concluded that the various environmental, social, and economic benefits associated with the development of such an industry justify this support. We also determined a logical process for analyzing and developing specific biomethane projects and provided some scenarios for five projects that we believe have the best chance for success.

Producing Biogas from California Dairy Wastes

California is the largest dairy state in the USA, with approximately 1.7 million cows that produce over 20,000 pounds of milk per cow each year. These same cows also generate approximately 3.6 million bone dry tons of manure, which must be properly managed to minimize air emissions, prevent water pollution, and control odor, flies, and pathogens.

Biogas, a mixture consisting primarily of methane and carbon dioxide, is produced from dairy wastes through anaerobic digestion, a natural process that breaks down organic material in an oxygen-free environment. This process occurs unaided at dairies that store their wastes in covered piles or lagoons, with the resulting biogas and its greenhouse gases typically released into the atmosphere. Anaerobic digesters allow dairies to produce and capture biogas that can be used as a renewable source of energy. Most dairies currently using anaerobic digesters for energy production capture the biogas and burn it as a source of renewable electricity for on-farm operations. Anaerobic digesters also help control odors, flies, and pathogens.

Methane Production Potential of Dairy Wastes and Other Biomass

Nearly two-thirds of all cows in California are on dairies that use a flushed management system; the others use a scrape system. In practice, flush dairies are the best candidates for biogas production because manure that is scraped and stored typically decomposes aerobically, which inhibits the development of the bacteria that create biogas. Potentially, California dairies could generate nearly 14.6 billion ft^3 of methane each year (which corresponds to 140 megawatts of electrical capacity); however, this figure does not reflect the practicalities of manure collection and storage.

Dairy wastes can be co-digested with other biomass, such as agricultural residues or food-processing wastes, to augment methane production. Co-digestion of animal manures with food processing wastes in community digestion facilities is practiced in a number of European locations and could be applicable also in some dairy areas in California. The practical potential methane production from all biodegradable sources in California is about 23 billion ft^3 per year (220 megawatts); dairy wastes make up nearly two-thirds of this amount. If all theoretically available feedstocks were used and better technologies were developed, the potential is five or six times greater.

Technical Considerations for Anaerobic Digestion

Key considerations in the design of an anaerobic digester include the amount of water and inorganic solids that mix with manure during collection and handling. The anaerobic digester itself is an engineered containment vessel designed to exclude air and promote the growth of methanogenic bacteria. The three digester types most suitable for California dairies are ambient-temperature covered-lagoon, complete-mix, and plug-flow digesters.

Collection and Use of Biogas

Biogas formed in the anaerobic digester bubbles to the surface where it is captured. Sometimes the biogas is scrubbed to reduce the hydrogen sulfide content. Depending on the application, biogas may be stored either before or after processing, at low pressures. More often recovered biogas is fed directly into an internal combustion engine to generate electricity and heat, or it can be used only for heating. If the biogas is upgraded to biomethane, additional uses are possible.

Upgrading Dairy Biogas to Biomethane and Other Fuels

By removing hydrogen sulfide, moisture, and carbon dioxide, dairy biogas can be upgraded to biomethane, a product equivalent to natural gas, which typically contains more than 95% methane. The process can be controlled to produce biomethane that meets a pre-determined standard of quality. Biomethane can be used interchangeably with natural gas, whether for electrical generation, heating, cooling, pumping, or as a vehicle fuel. Biomethane can also be pumped into the natural gas supply pipeline. High pressures can be used to store and transport biomethane as compressed biomethane (CBM), which is analogous to compressed natural gas (CNG), or very low temperatures can be used to produce liquefied biomethane (LBM), which is analogous to liquefied natural gas (LNG).

Technologies for Upgrading Biogas to Biomethane

The technologies for upgrading biogas are well established. They are used in the natural gas industry to “sweeten” sour gas, i.e. natural gas that is low in methane content. They have also been used at a few US landfills, but in all cases the scale is much larger than the average dairy.

There are three steps to upgrading biogas to biomethane. They are: (1) removal of hydrogen sulfide, (2) removal of moisture, and (3) removal of carbon dioxide. The simplest way to remove moisture is through refrigeration. H_2S can be removed by a variety of processes:

- Air injected into the digester biogas holder
- Iron chloride added to the digester influent
- Reaction with iron oxide or hydroxide (iron sponge)
- Use of activated-carbon sieve
- Water scrubbing
- Sodium hydroxide or lime scrubbing
- Biological removal on a filter bed

The following processes can be considered for CO_2 removal from dairy manure biogas. Some of them will also remove H_2S. The processes are presented roughly in the order of their current availability for and applicability to dairy biogas upgrading:

- Water scrubbing
- Pressure swing adsorption

- Chemical scrubbing with amines
- Chemical scrubbing with glycols (such as Selexol™)
- Membrane separation
- Cryogenic separation
- Other processes

Some technologies are more suitable for dairy farm operations than others, typically because of cost considerations, ease of operation, and other concerns such as possible environmental effects. A possible design for a small dairy biogas upgrading plant might consist of the following:

- Iron sponge unit to remove hydrogen sulfide
- Compressors and storage units
- Water scrubber with one or two columns to remove carbon dioxide
- Refrigeration unit to remove water
- Final compressor for producing CBM, if desired

Operation and maintenance of this system would be relatively simple, which is one reason it is recommended over other, possibly more efficient, processes. Electricity for the compressors could be produced from an on-site generator using biogas, which could also generate power for other on-site uses, or from purchased power. If purchased power were used, the major operating costs for this process would be for power for gas compression. Our research suggests that a farm of about 1,500 dairy cows is the lower limit of scale for this technology.

Potential for Upgrading to Fuels other than Biomethane

Other potential high-grade fuels that could possibly be produced from biogas include (1) liquid hydrocarbon replacements for gasoline and diesel fuels (created using the Fischer-Tropsch process), (2) methanol, and (3) hydrogen. At present, however, technological constraints, poor economies of scale for small operations, and—in the case of methanol—a lack of markets, make these processes impractical for dairy operations.

Storing, Distributing, and Using Biogas and Biomethane

Dairy manure biogas is generally used in combined heat and power applications that combust the biogas to generate electricity and heat for on-farm use as it is created. Because of its highly corrosive nature (due to the presence of hydrogen sulfide and water) and its low energy density (as obtained from the digester, biogas contains only about 600 Btu/scf), the potential for off-farm use of raw biogas is extremely low.

Biomethane, which was upgraded from biogas by removing the hydrogen sulfide, moisture, and carbon dioxide, has a heating value of about 1,000 Btu/scf. Because of this high energy content, biomethane can be used as a vehicular fuel. It could also be sold for off-farm applications to industrial or commercial users or for injection into a natural gas pipeline.

Storage of Biogas and Biomethane

The least expensive and easiest to use storage systems for on-farm applications are low-pressure systems; these systems are commonly used for on-site, intermediate storage of biogas. Floating gas holders on the digester form a low-pressure storage option for biogas systems.

The energy, safety, and scrubbing requirements of medium- and high-pressure storage systems make them costly and high-maintenance options for biogas. They can be best justified for biomethane, which is a more valuable fuel than biogas.

Biomethane can be stored as CBM to save space or for transport to a CNG vehicle refueling station. High-pressure storage facilities must be adequately fitted with safety devices such as rupture disks and pressure relief valves. Typically, a low-pressure storage tank is used as a buffer for the output from the biogas upgrading equipment and would likely have sufficient storage capacity for around one to two days worth of biogas production. Since CNG refueling stations normally provide CNG at 3,000 to 3,600 psi, biomethane is compressed and transported at similar or higher pressures to minimize the need for additional compression at the refueling station.

Biomethane can also be liquefied to LBM. Two advantages of LBM are that it can be transported relatively easily and it can be dispensed to either LNG vehicles or CNG vehicles. However, if LBM is to be used off-farm, it must transported by tanker trucks, which normally have a 10,000-gallon capacity. Since LBM is a cryogenic liquid, storage times should be minimized to avoid the loss of fuel by evaporation through tank release valves, which can occur if the LBM heats up during storage.

Distribution of Biomethane

Biogas is a low-grade, low-value fuel and therefore it is not economically feasible to transport it for any distance, although occasionally it is transported for short (1 or 2 mile) distances via a dedicated pipeline. In contrast, biomethane can be distributed to its ultimate point of consumption by dedicated biomethane pipelines, the natural gas pipeline grid, or in over-the-road transportation as CBM or LBM.

If the point of consumption is relatively close to the point of production, the biomethane could be distributed via dedicated pipelines (buried or aboveground). For short distances over property where easements are not required, this is usually the most cost-effective method. Costs for laying dedicated biomethane pipelines can vary greatly, and range from about $100,000 to $250,000 per mile.

The natural gas pipeline network offers a potentially unlimited storage and distribution infrastructure for biomethane. Once the biomethane is injected into the natural gas pipeline network, it becomes a direct substitute for natural gas. There is at least one location in the US (at the King County South Wastewater Treatment Plant in Renton, Washington) where this is done.

The gas can be sold to a utility, or wheeled to a contracted customer. However there are substantial regulatory and other barriers involved in using the natural gas pipeline.

If distribution of biomethane via dedicated pipelines or the natural gas grid is impractical or prohibitively expensive, over-the-road transportation of compressed biomethane may be a distribution option.

Over-the-road transportation of liquefied biomethane is a potential way of addressing many of the infrastructure issues associated with biomethane distribution. In California, where almost all LNG is currently imported from other states, in-state production of LBM would gain a competitive advantage over LNG with respect to transportation costs.

Biogas as a Fuel for On-Farm Combined Heat and Power Applications

At present, dairy manure biogas is used on-farm for direct electrical generation, and some of the waste heat is recovered for other uses. Because of its highly corrosive nature (due to the presence of hydrogen sulfide and water) and its low energy density, the potential for off-farm use of biogas is limited.

Electricity generation using biogas on dairy farms is a commercially viable, proven renewable energy technology. Typical installations use spark-ignited natural gas or propane engines that have been modified to operate on biogas. Gas treatment to prevent corrosion from hydrogen sulfide is usually not necessary if care is taken with engine selection and proper maintenance procedures are followed, though it may become necessary in the future to help control NO_x from combustion.

Burners and boilers used to produce heat and steam can be fueled by biogas if the equipment is modified to ensure the proper fuel-to-air ratio during combustion and if operating temperatures are maintained at a high enough level to prevent condensation and the resultant corrosion from the hydrogen sulfide contained in the biogas.

For combined heat and power (CHP) applications, the key to energy savings is recovering heat generated by the engine jacket and exhaust gas. Nearly half of the engine fuel energy can be recovered through this waste heat by, for example, recovering hot water for process heat, preheating boiler feedwater, or space heating.

Alternative On-Farm Uses of Biogas

Theoretically, biogas can replace other fuels for on-farm non-CHP applications such as irrigation pumps and engine-driven refrigeration compressors, but this is unlikely. Raw biogas cannot be used as a vehicular fuel because of engine and performance maintenance concerns.

Spark-ignited gasoline engines may be converted to operate on biogas by changing the carburetor to one that operates on gaseous fuels (some gas treatment may be necessary). Diesel engines can also be modified to operate on biogas; the high compression ratio of a diesel engine lends itself to operation on biogas.

Irrigation pump use is intermittent and highly seasonal and therefore would not consume biogas on a steady basis throughout the year. Also, it would probably be more cost-efficient to switch remote diesel-powered irrigation pumps to electrical power (which could be provided by a generator set using “raw” biogas as fuel) than to upgrade the biogas and transport it via pipeline to feed the remote irrigation pumps.

Refrigeration accounts for about 15% to 30% of the energy used on dairy farms; most of this is for compressors used for chilling milk. Since dairy cows are milked daily, a steady source of energy is required for refrigeration needs. However, natural-gas driven motors are significantly more expensive than electrical motors with similar output power ranges and therefore have not been traditionally considered as economically desirable choices for this application. Thus, the use of biogas as a direct fuel for on-farm refrigeration compressors is not likely.

Potential On-Farm Uses of Biomethane

All the equipment described above that can run on biogas or natural gas can run on biomethane. In addition biomethane is suitable as a fuel in vehicles converted or designed to run on natural gas. Biomethane could be moved around a farm more easily than biogas because it is a cleaner fuel; however, it will likely still be more cost-effective to use biogas to generate electricity to run irrigation pumps than to convert the pumps to run on biomethane. The same is true of refrigeration equipment which could be run by electricity or driven by waste heat.

Although it is technically feasible to use biomethane as a fuel for on-farm alternative-fueled vehicles, there are currently no commercially available CNG- or LNG-fueled non-road agricultural vehicles. Commercial versions of some on-road agricultural vehicles such as pickup trucks are available, but the lack of convenient refueling infrastructure, makes it difficult to use CNG or LNG vehicles for on-farm applications.

Off-Farm Uses of Biomethane

There are two main potential off-farm uses of biomethane: to sell it to a nearby industrial user with heavy natural gas requirements or to sell it as a vehicular fuel. The major considerations for the first use is (1) to locate an industrial user willing to buy biomethane and (2) to transport the biomethane to the industrial user economically. There are many industrial users in the Central Valley that could use very large amounts of biomethane. Dairy cooperatives use large amounts of natural gas to dry milk into powder.

The medium- and heavy-duty CNG vehicle market is expected to be fueled by continued strong demand for CNG transit buses and to a lesser extent, school buses and refuse trucks. Given the potential variability in the medium- and heavy-duty market, a range of projections has been given based on a conservative annual growth rate of 15% to 20%.

The heavy-duty market accounts for the vast majority of the LNG vehicles in California. In general, the growth in this market is expected to be fueled by continued niche demand for LNG transit buses, refuse trucks, and Class 8 urban delivery trucks (regional heavy delivery). Growth is limited by the lack of a refueling infrastructure and of in-state LNG production facilities. The market is expected to grow from its small base by 5% to 10% a year.

The combined annual market for CNG and LNG vehicle fuel in California is approximately 80 million gasoline gallon equivalents. To put this in perspective, it would take methane from about 900,000 cows, about half the cows in the state, to provide this amount of fuel.

Meeting Regulatory Requirements and Gaining Access to Government Incentives

The successful development of a California biomethane industry will require supportive government policies and financial incentives. The production and use of biomethane as a replacement for fossil fuels could potentially provide numerous benefits such as reduced greenhouse gas, reduction of odors and flies on the dairy, less dependence on fossil fuel supplies, better energy security, stimulation of rural economies, and could possibly improve water quality. These are benefits to society rather than financial benefits for the farmer who produces the biomethane. Consequently, it is appropriate for the government to provide support for the development of the biomethane industry.

Unfortunately biomethane does not get as much governmental support as other renewable energy sources. Most federal and state policies that support renewable energy and alternative fuels focus either on renewable electricity, often referred to as renewable energy, or on two specific liquid biofuels: ethanol and biodiesel. With a few exceptions, they do not provide specific support for biomethane production. If the biomethane industry is to prosper, it must help launch policy initiatives that will provide the same direct financial incentives or tax credits that are now earned by programs that focus on renewable electricity, ethanol, and biodiesel.

Policy Responses to Environmental Issues

Public policy is moving to address emissions from dairy biogas; it remains to be seen whether this takes shape as increased regulatory efforts, market incentives such as a carbon trading market or an emission reduction credit market, or the development and promotion of technologies that will help dairies or other sources voluntarily reduce their emissions.

Regulation to Control Dairy and Vehicle Emissions

Federal and state policies are already in place to help regulate air quality. Although, the application of these policies to agricultural activities such as dairy farming has been minimal to date, recent changes in California law require California air districts to regulate dairies in accordance with the federal Clean Air Act. Since the San Joaquin Valley and the South Coast are extreme non-attainment areas for ozone, major sources of pollution in those air districts need to control their volatile organic compound emissions. As a result both districts have considered anaerobic digesters to control VOC as a possible requirement in some cases, or as a mitigation measure. However, anaerobic digesters should be viewed primarily as a renewable energy technology rather than as an air quality control technology.

Market Incentives to Reduce Pollution

Two types of emission trading permits could impact the biogas/biomethane industry in the USA: carbon trading and emission reduction credits. Although carbon trading is unlikely in the near future unless the USA ratifies the Kyoto Treaty, California has a market in place for emission reduction credits. As currently structured, this market does not allow agricultural enterprises to participate effectively; however, if such participation were possible, dairies might be provided with an incentive to collect biogas, thus potentially reducing volatile organic compound (VOC) emissions and gaining emission reduction credits.

Promotion of New Energy Technologies and Fuels

There are several approaches that can help encourage new technologies: tax credits or incentives, subsidies through direct funds, and long-term contracts that guarantee market and/or price. For example, in response to concerns about the contribution of methane to climate change, the US EPA set up the AgSTAR program to develop and disseminate information about anaerobic digesters for animal waste. The California Energy Commission has also funded research on anaerobic digestion for electrical production and has a new program natural gas research program that may fund biomethane research.

Financial Incentives

Renewable electricity, ethanol, and biodiesel are supported by direct financial incentives and mandates that increase their usage, while biomethane does not.

California is committed to renewable electricity and has a variety of programs that provide direct benefits for electrical generation, but the dairy loses them when it chooses to use its biogas for biomethane instead of electricity.

Ethanol has direct cash incentives in excise tax exemptions that began in 1978. Both ethanol and biodiesel are also supported by producer incentive funds under the 2002 Farm Bill. The ethanol market is also supported by oxygenation mandates under the Clean Air Act amendments of 1990.

Traditional biofuels and biomethane receive some market support through the alternative fuel program created by the Energy Policy Act of 1992, which may be expended in the proposed Energy Policy Act of 2005. Vehicles that run on biomethane fulfill alternative vehicle fleet requirements as mandated in federal, state, and local law and should be able to earn various federal, state, and local incentives.

Biomethane receives no direct financial incentives, although it can qualify for some of the benefits available to alternative fuels. The federal government has programs to promote farm-based and rural renewable energy, and biomethane projects can compete for such awards. The federal government's efforts are concentrated in the Farm Bill of 2002. In addition, biomethane research and development funds are available through competitive grant programs.

Government Permits and Regulations for Biogas Upgrading Plant

A biogas upgrading facility is subject to federal, state, and local regulatory requirements. The dairy itself is subject to a number of air and water quality regulations, whether or not it produces biogas. Even if a dairy has a water permit, a new permit is required for the installation of an anaerobic digestion system. If a dairy has a digester that combusts biogas, or upgrades biogas to biomethane, an air permit will be required from the local air district. Depending on the county, a local administrative permit or conditional use permit may also be required.

No specific additional permits are needed by an upgrading facility to compress or liquefy biomethane to produce CBM or LBM. However, there may be emission or safety issues associated with the production of these fuels that will make it more difficult to meet permitting requirements.

Regulations pertaining to over-the-road transportation of CNG and LNG are assumed to be fully applicable to over-the-road transportation of CBM and LBM, respectively.

No known federal, state, or local regulations expressly prohibit the distribution of dairy based biomethane via the natural gas pipeline network, though there is a California regulation that blocks landfill generated biomethane from the natural gas pipeline. Yet only one US biomethane plant, the aforementioned wastewater treatment plant in Renton, Washington, puts biomethane into the natural gas pipeline. Regulatory barriers and utility resistance are likely to make this alternative very challenging.

It is unclear whether state and county regulations pertaining to local pipeline distribution of natural gas would be applicable to the local distribution of biomethane (or biogas) via dedicated pipelines. More than likely, the use of a dedicated pipeline to transport biogas or biomethane in a gas utility service area would be subject to the standard city and county regulations and permitting process for underground pipe installations. Some local regulations specify that permits for underground pipelines carrying gas can only be granted to public utilities. For this reason, having a local utility company as a partner in a biogas/biomethane project could be an important asset during the permitting process.

Obtaining the necessary permits for siting, constructing, and operating dedicated biogas/biomethane pipelines could be a complex, time-consuming, and expensive process depending on the location of the proposed pipelines (i.e., what land they will cross). Permits from state, local, and possibly federal agencies may be required.

Determining the Financial, Economic, and Business Environment for the Development of a Biomethane Industry

As sources of renewable energy, biogas and biomethane compete in one of two markets: electricity and natural gas (including natural gas vehicle fuels). To be viable energy sources, they must be able to compete in these markets from a financial and economic standpoint.

California's Electricity and Natural Gas Markets

Electricity is different from all other commodities in that it cannot be stored; it must be generated on demand, when it is needed. Thus the capacity of the system is as important as the quantity of electricity that is generated. Despite the 1996 restructuring of California's electricity market, it remains regulated and strapped by complex rules.

Electricity price analysis in California is complex because the retail price includes many components in addition to charges for electricity generation. In addition, dairies that use biogas from anaerobic digesters to generate electricity face market barriers. Under California's current market structure, most dairies cannot sell their electricity. Their best alternative is to use it on-farm availing themselves of opportunities presented under California's net metering legislation (AB 2228, proposed AB 728). Inasmuch as they use the electricity on-farm without sending it through the grid, they save the full retail price of electricity.

California consumes about 6 billion ft^3 of natural gas per day. This gas is burned directly as a fuel, used as a feedstock in manufacturing, or used to generate about one-third of California's electricity (the share used in electricity generation is increasing). Eighty-four percent of the natural gas used in California originates outside the state.

Most dairies are not on the natural gas grid. If they were most of them would be in PG&E territory and would be charged prices on the small commercial gas tariff. Those prices have varied considerably over the last several years, and are currently at a very high price historically.

In all likelihood, biomethane production will be cost effective only if it can be sold to an off-dairy customer, either by distributing it through a natural gas pipeline grid, or by transporting it by private pipeline or vehicle to a site where it can be used or sold. The most promising off-site customers would be a nearby alternative vehicle fueling station (for CBM or LBM) or an industrial user of large amounts of natural gas.

Estimated Costs for Building a Biogas Fueled Electric Plant or Biomethane Upgrading Plant

A dairy anaerobic digester that will be used to create biogas for electrical generation has two major components. The first is the system to generate and collect the biogas. The second component is the system to generate the electricity.

A dairy anaerobic digester whose ultimate purpose is to produce biomethane uses the same sort of digester to generate and collect biogas. The biogas is then upgraded to biomethane by removing the hydrogen sulfide, moisture, and carbon dioxide. Finally, the biomethane is compressed or liquefied, stored, and/or transported to a location where it can be used.

Estimated Costs for Anaerobic Digesters for Electricity Generation

We analyzed the published costs for 12 dairy digesters larger than 50 kW and found that the average cost for building the anaerobic digester systems for electrical generation was about $4,500 per average kilowatt generated. In contrast, an analysis of four projects completed under California’s Dairy Power Production Program showed average costs of $6,100 per nameplate kilowatt. Based on these “high” and “low” averages, we calculated cost ranges for the various digesters, both with and without equipment to remove nitrogen oxide emissions. Of course costs for specific projects vary considerably from these averages based on local conditions.

At the lower average cost of $4,500 per average kilowatt generated, the capital costs for a digester-generator with a capacity of about 100-kW would be about $450,000 (without NO_x controls). At 28% efficiency, with operating costs included and with the plant fully amortized over 20 years at 8%, this plant would have a levelized cost of electricity of $0.067/kWh. If controls for NO_x emissions were added (another $90,000 in capital costs), the levelized cost of electricity would go up to about $0.077/kWh. If waste heat is used for some on-farm uses, the estimated costs for both ranges will decrease. The most likely scenario for California is an anaerobic generator with NO_x controls and co-generation, which gives a cost range of $0.062 (for a $4,500/kw digester) to $0.077/kWh (for a $6,100/kw digester). These costs compare favorably with the retail price the farmer is paying, currently $0.09 to $0.11/kWh, but they are not competitive in the wholesale market.

Estimated Costs to Upgrade Biogas to Biomethane

Estimating the costs of a biogas to biomethane plant is more speculative than for a digester-generator. Although several large-scale upgrading plants have been built and operated at landfills, to date, no biogas upgrading facility has been built on a dairy in the USA. Sweden, however, has 20 plants that produce biomethane from various sources of biomass. Several of the authors of this report visited Sweden in June 2004 to tour biomethane plants and were able to obtain cost data on four biomethane plants. All four plants were municipally run centralized plants that processed a variety of feedstocks.

The scale of the Swedish biomethane plants is smaller than the few landfill-gas upgrading plants in the USA, but larger than what would be required for most dairy facilities. For example, the largest plant we visited would require raw biogas from 27,000 cows to generate the amount of biomethane they produce, while the mid-sized plants would require 7,000 to 10,000 cows each, and the smallest plant could operate with manure from 1,500 to 2,000 cows. Each of these plants removes hydrogen sulfide, moisture, and carbon dioxide from the raw biogas and places the resultant biomethane into a pipeline, or compresses it for storage and/or transportation.

The capital costs of the smallest Swedish biogas upgrade plant were $2.20 per thousand ft^3 of biomethane produced, while capital costs were for the largest plant were $0.74 per thousand ft^3. In contrast to electricity generation, where the capital costs exceed the operating costs, the operating and maintenance costs for the Swedish plants exceeded capital costs by a significant margin, ranging from $5.48 to $7.56 per thousand ft^3. These costs did not include the anaerobic digester.

To estimate the cost of a US biomethane facility that includes an anaerobic digester and a biomethane plant, we combined US costs for anaerobic digestion with Swedish costs for biogas upgrade. The total costs of the combined digester and biomethane plant varied from $8.44 to $11.54 per thousand ft^3.

We also estimated the cost of a digester combined with LBM plant that generated its own electricity from some of its biogas and liquefied biomethane from the remainder. We estimate that the plant could produce LBM for $1.26 per gallon, or 2.10 per diesel gallon equivalent. To these costs must be added the costs of storage and transportation to a fueling station and taxes.

Estimated Costs for Storage and Transport of Biomethane

In addition to the costs of generating biogas and upgrading it to biomethane, a biomethane producer must add the costs of storing and transporting the biomethane. If the biomethane could be put into a pipeline, there would be no storage expense. If the biomethane were purchased by the pipeline owner, there would be no transportation expense. Otherwise these expenses must be paid by the producer or the buyer.

Storage costs vary considerably with the length of time for which the gas must be stored. For example, enough storage capacity to store a day’s worth of CBM produced from a plant that produces 45,000 ft^3 of biomethane per day would add $100,000 to $225,000 to the cost of the facility ($0.60 to $1.40 per thousand ft^3 of gas) to the cost of the biomethane production.

Estimates for U.S. piping costs vary from $100,000 to $250,000 per mile depending on the number of landowners involved, the need to cross public rights-of-way, the terrain, and similar factors. If an 8,000 cow dairy built a dedicated pipeline for $150,000 per mile, that would add about $.90 per thousand ft^3 of biomethane to the cost. Trucking requires more on-site storage than piping because enough biomethane must be accumulated to fill a tanker. Other than for LBM, transportation of biomethane by truck costs more per volume than pipeline transport and should be considered as an interim solution.

Summary of Estimated Costs for Dairy Digester and Biomethane Plant

Based on costs for similar, albeit larger, plants in Sweden, as well as discussions with equipment suppliers and other industry personnel, our best estimates for the various capital and operating costs associated with a dairy digester and biogas upgrading plant are as shown below:

Component or Process	**Cost ($ per 1,000 ft^3) Low Estimate**	**Cost ($ per 1,000 ft^3) High Estimate**
Anaerobic digester		
Capital cost	2.50	4.65
Operating cost	0.50	0.60
Biomethane (Upgrading) Plant		
Capital cost	1.55	3.10
Operating cost	3.70	6.80
Biomethane storage	0.00	2.80
Biomethane transport	0.00	0.90

Like other pioneering renewable energy technologies, the production and distribution of dairy biomethane is not currently cost effective for the private developer without a public subsidy. In time, after a number of small-scale plants are built, costs are likely to come down.

Our estimated costs for producing biogas and upgrading it to biomethane can compete only marginally with today’s natural gas prices. Pioneering plants may have higher costs due to inexperience. At today’s market prices, a large dairy could likely produce biomethane for a price lower than that paid by small retail commercial users (like dairies); while a smaller dairy’s cost of production would be higher than the going market rate. Added to the cost of production is the cost of storage and transportation.

Costs of Digestion and Upgrade to Biomethane			Current Natural Gas Prices	
Cost Category	Cost ($ per 1,000 ft^3) biomethane Low Est.	High Est.	Price Category	Price ($ per 1,000 ft^3)
Production cost	$8.44	$11.54	Wellhead	$6.05
Storage	$0.00	$2.80	City gate	$7.44
Transportation	$0.00	$0.90	Distribution	$9.84

In contrast, generating electricity from biogas can offset retail electric purchases and can be simpler and more profitable than biomethane production. However, the farmer may produce more electricity than he can use; if this occurs, the farmer cannot be compensated for the excess dairy biogas electricity under California's current market structure, and the present net metering program in California is not as attractive for the small biogas electric generator as it is for the solar generator. Also, obtaining an interconnection agreement is time-consuming and expensive.

Why Support the Development of the Biomethane Industry?

Swedish experience demonstrates that a viable biomethane industry is possible. It is important to note, however, that the economics in Sweden are much more favorable for a biomethane industry than they are in the USA. The most important lesson we learned during our trip to Sweden was that no biomethane plant should be built until a market for the biomethane has been established and a distribution system designed that can move the biomethane to the market.

The current economics for development of the biomethane industry in the USA are challenging if there is no public subsidy. We feel, however, that there are a number of valid reasons to support the development of this industry through publicly funded subsidies, regulation, or tax incentives. Such subsidies and incentives are always necessary to develop a new source of renewable energy or an alternative transportation fuel.

A society that is heavily dependent on fossil fuel energy should be actively developing a wide variety of alternative energy resources. We cannot always predict which technologies will prove the most viable for our future needs. We need to invest in research and development and to build pilot plants for a variety of these technologies. Biomethane production addresses California's commitment to renewable energy and to reducing dependence on imported petroleum. Development of a dairy biomethane industry would help to stimulate California's economy, particularly its rural economy. Biomethane production provides a series of environmental benefits both during the production process and because it can be substituted for fossil fuels. Development of biomethane production technologies and markets today will ensure future preparedness for the growth of this industry should conditions arise that make the production and use of biomethane a more financially viable and/or necessary option.

The biomethane industry, like the rest of the renewable energy sector, needs public subsidies, tax credits, or market rules that will help earn a premium for the product during its start-up phase. Regulators and lobbyists for the industry also need to be aware of the cost structure of the biomethane industry. In contrast to anaerobic digester systems that generate electricity, which have higher capital costs than operating costs, biogas upgrading plants that produce biomethane typically have higher operating costs than capital costs. Subsidies that cover even a large portion of the capital costs may be insufficient to stimulate industry growth. If biomethane facilities are to become viable, ongoing sources of renewable energy, they will likely need the support of ongoing production tax credits, a long-term fixed price contract, and/or market rules that provide a premium for its output.

Considerations for Planning a Biomethane Project

Although there is no magic formula for creating a successful biomethane project, our research indicates that a business plan for a successful biomethane enterprise should demonstrate that the following have been researched and, where possible, completed or obtained:

- Buyer for the biomethane
- Supply of organic waste
- Distribution system—pipeline or storage and subsequent over-the-road transport
- Location for biomethane plant
- Technology and operating plan
- Financial plan
- Permitting and regulatory analysis
- Construction plan

Our research also included a geographic analysis that highlighted the San Joaquin Valley as a focal point for future biomethane projects. By considering factors such as the proximity of dairies to market, existing infrastructure, and regional demand and need, this analysis indicated five promising scenarios that could be further investigated by those interested in developing a biomethane project:

- *Provide fuel to a community vehicle fleet*. A Central Valley community could make a significant environmental contribution by developing an integrated project involving CNG vehicles and a biomethane plant. At least four San Joaquin communities—Tulare, Visalia, Hanford, and Modesto— have both CNG fueling stations and a nearby dense population of dairies. However, the current CNG fleets in these communities are not large enough to support a biomethane plant. An integrated project that increased the number of CNG vehicles on the road and used locally produced CBM would capture a number of environmental and energy security benefits. The first community to do this would be a national showcase.
- *Sell biomethane directly to large industrial customer*. Several areas in the San Joaquin Valley have dairies concentrated near sizable industrial users of natural gas. One or more

of these industrial users could provide a substantial demand for locally produced biomethane, though raw or partially cleaned biogas may suffice in many applications.

- *Distribute biomethane through natural gas pipeline grid*. If the barriers to the use of the natural gas transmission system could be overcome, a biomethane plant could sell directly to the local gas utility, or pay to wheel the biomethane to an industrial or municipal customer on the natural gas grid. The biomethane plant would need to be located along or very close to the distribution line.
- *Build liquefied biomethane plant*. Liquefied biomethane can be used as a direct substitute for LNG. Except for a small pilot project, all LNG vehicle fuel is trucked into California from out-of-state LNG plants. While transportation costs limit a CBM plant to nearby markets, an LBM plant can cost-effectively transport LBM to fueling stations much further away. LBM could also be delivered to liquefied-to-compressed natural gas fueling stations or to customers off the natural gas grid that already receiving gas supplies deliveries in the form of LNG.
- *Use compressed biomethane to generate peak-load electricity*. Because CBM can be stored, a biomethane plant could use its fuel to generate peaking electrical power. Renewable energy that can be dispatched to serve peak demand can earn a substantial premium over non-dispatchable renewable energy resources such as wind and solar.