WestStart-CALSTART

California Biogas Industry Assessment

White Paper

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Executive Summary

Biogas is a renewable energy source similar to natural gas except that it is has a lower heating value and is derived from renewable biomass sources, primarily via a process called anaerobic digestion. The existing biogas industry in the U.S. is focused largely on generation of heat and electrical power via burners and generator-sets modified to operate with biogas. The most common types of biogas projects involve biogas collected at landfills (i.e. landfill gas), waste water treatment plants, and dairy or swine farms where biogas is created from animal manure in anaerobic digesters. The processes and equipment for converting biomass sources (such as dairy manure) into biogas via anaerobic digesters are well known, commercially available and economically reasonable. Due to its lower methane content and high level of contaminants, biogas is unsuitable for use as a vehicle fuel without further processing.

Biogas can also be upgraded to biomethane and used as a direct substitute for natural gas in natural gas-fueled equipment and natural gas vehicles (NGVs). While the technology for upgrading biogas to biomethane has been proven and is commercially available in other parts of the world, its current usage in the U.S. is limited. Compressed biomethane has been used as a vehicle fuel in Sweden successfully with Swedish transit agencies acting as the "anchor customers" for local biomethane plants. In some areas of Sweden, biogas is upgraded to pipeline quality standards and injected into the natural gas pipeline network for general use.

Distribution of biomethane for transportation applications presents major economic obstacles. Biomethane may be distributed via dedicated pipelines, the natural gas pipeline network, over-the-road as compressed biomethane, or over-the-road as liquefied biomethane. Each method involves significant tradeoffs between flexibility, cost and complexity. Distribution via the natural gas pipeline network is potentially very attractive but is likely to encounter resistance from gas utilities. Distribution as liquefied biomethane has several advantages but relies on the commercialization of small-scale liquefaction technology currently in limited use.

Biogas and biomethane usage provide numerous benefits to society including a local source of renewable energy and (potentially) vehicle fuel, reductions in greenhouse gases (GHGs) and improvements in air and water quality among others. Despite these advantages, there is currently no established biomethane industry in the U.S. to speak of. The primary obstacle is that without government support, the business case for upgrading biogas to biomethane is currently very challenging. Generally speaking, the cost of biomethane production and distribution is not cost-competitive with natural gas. It is usually more profitable to use biogas directly in boilers and gen-sets to generate heat and electrical power for local consumption rather than upgrade it to biomethane.

A business case can be made, but it relies on many factors not currently present in the U.S. market. Based on examples of large scale centralized digester and biogas upgrading plants in Sweden, the cost to produce biomethane can be as low as $8 - $9/MMBTU. While this is potentially cost-competitive with retail natural gas prices in the U.S., there

are additional factors such as biomethane distribution and regulatory obstacles which must be taken into account before a realistic business case can be developed. Economically successful biomethane projects (such as in Sweden) have generally benefited from preferential tax treatment, co-digestion of multiple waste sources (often involving “tipping fees”), economies of scale, relative proximity to biomethane consumers and involvement by municipal governments and local utilities.

While the general market conditions for biomethane production and usage relative to natural gas are not favorable in California and the U.S., there may be certain biomethane projects involving combinations of conditions where a positive business case could be developed. In addition, changes in regulatory obstacles, tax incentives, and other political and/or market conditions could create additional opportunities to help establish and expand a biomethane industry in the U.S. To clearly define the necessary conditions to create a successful biomethane industry in California and elsewhere in the U.S., WestStart recommends the following course of action:

- Develop a general economic framework to evaluate proposed biomethane projects.

- Identify several promising potential biomethane projects including the key stakeholders for each project.

- Perform a detailed investigation of the potential business case for each of the identified biomethane project proposals in coordination with key stakeholders.

- Specifically identify those areas where additional support (government, financial, or otherwise) is necessary to overcome regulatory, economic or other obstacles.

- Based on the above investigations, generate a set of key recommendations designed to stimulate development of a California and U.S. biomethane industry.

1 Introduction

1.1 Purpose

The primary purpose of this document is to provide an overview of the current biogas industry in the U.S. with an emphasis on the biogas industry in California, and the potential production and usage of biomethane for transportation applications. The document examines the technologies, environmental benefits, economic factors, regulatory issues, alternative uses for biogas and biomethane, and other factors affecting the potential business case for the production and usage of biomethane for transportation applications.

1.2 Scope

The scope of this document includes the U.S. biogas industry with an emphasis on the biogas industry in California. Information about the biomethane industry in Europe, particularly in Sweden, is included where appropriate but is not intended as the primary focus of this document.

1.3 Definitions

Anaerobic Digestion – A naturally occurring biochemical process in which organic material is broken down by bacteria in a low-oxygen environment resulting in the generation of methane gas and carbon dioxide as its two primary products.

Anaerobic Digester – A device for optimizing the anaerobic digestion of biomass and/or animal manure, often used to recover biogas for energy production. Commercial digester types include complete mix, continuous flow (horizontal or plug-flow, multiple-tank, and vertical tank) and covered lagoon.

Biogas – A naturally occurring gas formed as a byproduct of the breakdown of organic materials in a low-oxygen (e.g. anaerobic) environment. In its raw state, the major components of biogas are methane (typically 60 – 70%) and carbon dioxide (typically 30 – 40%). Additional smaller components of biogas include hydrogen sulfide (typically 50 – 2000 ppm), water vapor (saturated), oxygen and various trace hydrocarbons. Due to its low methane content (and therefore lower heating value) compared to NG, biogas is considered a low quality gas which is only suitable for use in engine-generator sets and boilers specifically designed to combust biogas as fuel.

Biogas Upgrading – A process whereby a significant portion of the carbon dioxide, water, hydrogen sulfide and other impurities are removed from raw biogas (digester gas). The major biogas upgrading technologies currently identified are water scrubbing, membrane separation, pressure swing adsorption (PSA), and mixing with higher quality gases.

Biomass – Sources of organic materials used to create biogas, e.g. dairy manure, landfill waste, forestry and agricultural processing byproducts, the organic fraction of municipal solid waste, food processing byproducts, etc.

Biomethane – Biogas which has been upgraded or "sweetened" via a process to remove the bulk of the carbon dioxide, water, hydrogen sulfide and other impurities from raw biogas (digester gas). The primary purpose of upgrading biogas to biomethane is to use the biomethane as an energy source in applications that require pipeline quality or vehicle-fuel quality gas, such as transportation. From a functional point of view, biomethane is extremely similar to NG except that it comes from renewable sources. (Note that the term "biomethane" has not yet come into popular usage; thus the term "biogas" is often used when referring to both the raw and upgraded forms of biogas/biomethane.)

Compressed Biomethane – Compressed biomethane is basically equivalent to CNG. The main difference is that CNG is made by compressing NG (a fossil fuel) whereas compressed biomethane is made by compressing biomethane (a renewable fuel).

Compressed Natural Gas (CNG) – CNG is NG that has been compressed to 3000 - 3600 psig for purposes of fuel storage on-board natural gas vehicles. (While technically incorrect, CNG is sometimes also used to refer to compressed biomethane.)

Digester Gas – The raw biogas produced by an anaerobic digester. Digester gas must normally be at least partially "cleaned up" to remove some of the hydrogen sulfide and water content before it can be used as low-quality fuel in burners or gen-sets for heat and/or power applications.

Fischer-Tropsch (FT) – FT is a gas-to-liquid (GTL) process which can produce a high quality diesel fuel from a variety of sources including NG, coal and biogas. The output of this process is a low-sulphur fuel referred to as a "middle distillate" which can either be used directly as fuel (e.g. synthetic diesel) or for blending with conventional diesel (in approximately a 1:4 ratio) to produce a "cleaner" diesel fuel.

Landfill Gas (LFG) – LFG is biogas produced as a result of natural organic decomposition at landfills. LFG is typically composed of approximately 50% methane, 50% air (due to air introduced into the underground LFG collection pipe system), and smaller amounts of siloxanes, sulfur compounds, various trace hydrocarbons and other impurities.

Liquefied Biomethane – Liquefied biomethane is basically equivalent to LNG. The main difference is that LNG is made using NG (a fossil fuel) as a feedstock whereas liquefied biomethane is made using biomethane (a renewable fuel) as a feedstock.

Liquefied Natural Gas (LNG) – LNG is NG in its liquid phase. LNG is a cryogenic liquid formed by cooling NG to approximately - 260ºF at atmospheric pressure. In practice, LNG is typically stored at somewhat elevated pressures (e.g. 50 – 75 psig) to reduce cooling requirements and allow for pressure increases due to LNG vapor “boil off”. LNG is stored in double-insulated, vacuum-jacketed cryogenic tanks (pressure vessels) to minimize warming from the external environment. LNG is typically >99% methane.

Liquefied Petroleum Gas (LPG) – LPG is a mixture of propane (typically 70%) and butane (typically 30%). It is obtained as a by-product during petroleum and natural gas refining operations and is liquefied via compression (typically around 75 psig). LPG is used chiefly as a domestic fuel in rural areas, as well as for industrial and motor fuel applications. Also referred to as “bottled gas”, “compressed petroleum gas” and “LP gas”.

Methane – Methane is the main component of natural gas and biogas. It is a natural hydrocarbon consisting of one carbon molecule and four hydrogen molecules (CH_4).

Natural Gas (NG) – NG is a combination of methane (>90%), propane, and butane. NG is generally found either above crude oil deposits or in “stranded” natural gas fields. In the past NG was often burned off (i.e. flared) as a low-value byproduct during the oil pumping process.

Natural Gas Vehicle (NGV) – A vehicle which operates on either CNG or LNG fuel.

Propane – Propane is a colorless gaseous hydrocarbon occurring naturally as a component of natural gas, as a dissolved gas in crude petroleum and also made artificially. It consists of three carbon molecules and eight hydrogen molecules (C_3H_8). Propane is widely used as a fuel for stationary and transportation applications.

Thermal Gasification – A chemical process whereby biomass is converted to synthetic gas (“syngas”) by mixing with reactants at very high temperatures. The resulting syngas can be similar to biogas produced via anaerobic digestion.

2 Biogas Production

Biogas can be produced from various types of biomass feedstock via either anaerobic digestion or thermal gasification, the latter process often using coal rather than biomass as a feedstock.

2.1 Potential Biomass Feedstocks

Almost any organic (carbon-based) material is a potential source of biomass feedstock to produce biogas. Organic waste excreted by animals (e.g. manure) and the industrial waste streams generated by agricultural, animal and other food processing activities are examples of historically low value waste products which have potentially increased value when viewed as renewable biomass feedstock sources. The following is a brief list of some of the most common biomass feedstocks used to produce biogas:

- Sewage
- Organic fraction of municipal solid waste (e.g. in landfills)
- Manure (e.g. dairy, pig, cattle)
- Forestry wastes
- Agricultural wastes
- "Energy crops" (e.g. clover grass, corn)
- Industrial food processing wastes

Note that biomass sources are sometimes blended to optimize the feedstock for a particular biomass-to-biogas conversion process. *Co-digestion* refers to anaerobic digestion of two or more biomass sources simultaneously, e.g. to improve overall biogas yield.

2.2 Anaerobic Digestion

Anaerobic digestion is a biochemical process whereby organic biomass sources are broken down via microorganisms in a low-oxygen environment, thus producing biogas as a natural byproduct of the reaction. Since the microorganisms are already present in all organic material (such as animal manure), the process is triggered once the biomass is placed in a low-oxygen environment, such as underwater in a manure lagoon. Anaerobic digestion (both naturally occurring and artificially induced) is typically used in connection with wastewater treatment plants (WWTPs), landfills, cleaning of industrial waste streams, and production of biogas from dairy and pig manure for on-farm generation of heat and electricity. These kinds of facilities are natural candidates for implementation of biogas recovery systems. The composition of the biogas produced is highly dependent on the biomass feedstock and anaerobic digestion technology used; therefore there is no standard composition of biogas, rather a range of compositions.

2.2.1 Types of Anaerobic Digesters

The following is a brief description of the major types of anaerobic digesters currently used:

- Covered Lagoon – This is the simplest and least expensive type of anaerobic digester. It is intended to be used on large volume, liquid manure lagoons with less than 2% solids, typically on a dairy or swine farm. It consists of a non-porous, plastic cover over a manure lagoon with a built-in biogas collection system. The cover traps gas produced during the decomposition of the manure. Covered lagoons are sometimes installed for odor control purposes (in which case the captured biogas may be flared) but with additional equipment, the recovered biogas can be used to provide heat and electric power to the farm.

- Complete Mix – This type of anaerobic digester is more expensive than a covered lagoon and is intended for manure with 2 – 10% solids. It consists of either above- or below-ground tanks with a built-in mixing and biogas collection system. The mixing system, which may be either mechanical or gas-based, helps to increase the efficiency of the digestion process as well as accelerate it. Likewise a built-in heating system also increases the efficiency of the digestion process. Typically 10 – 15% of the biogas output is used to provide heating for the digester and electricity for other biogas plant processes.

- Plug-Flow – This type of anaerobic digester is intended for ruminant animal manure (cows) with 11 – 14% solids and is therefore not appropriate for manure collected via a flush system. The design is similar to the complete mix digester but without the mixing system. Plug-flow digesters are cheaper to construct and operate than complete mix digesters but are also less efficient.

- Multiple-Tank (2-Stage) – This type of anaerobic digester is similar to the complete mix digester design except that digestion occurs sequentially in two phases. The first phase is a higher temperature (thermophilic) phase at 55ºC followed by a second, lower temperature (mesophilic) phase at 35ºC. While laboratory tests of this design show promise for increased digester efficiency, there is very little data on field-scale systems yet.

2.3 Thermal Gasification

Thermal gasification is a chemical process whereby coal or biomass sources may be converted to syngas (similar to biogas) by mixing with reactants at very high temperatures. The composition of the syngas is highly dependent on the feedstock, specific gasification process, and the reactants used. *Due to current technological impediments to near-term commercialization of this technology, thermal gasification is not considered a near-term option for commercial biogas production.*

3 Biomethane Production

Biogas is a low quality (i.e. low calorific or heating value) gas with limited uses. It is typically used as a fuel source for local heat and electrical power generation. The boilers and engine-generator sets ("gen-sets") used to produce heat and/or electric power from biogas are specifically designed or modified to operate with biogas. For example, biogas typically has a heating value of around 550 – 600 BTUs whereas natural gas (a high quality gas) typically has a heating value of around 1,000 BTUs/cubic foot. This directly affects the amount of air that must be mixed with the fuel in order to combust the fuel efficiently.

In practice, some "clean up" of the raw biogas may be performed prior to using raw biogas in biogas gen-sets and boilers. This "clean up" typically consists of removing enough of the hydrogen sulfide (H_2S), water vapor (H_2O) and particulates from the biogas to prevent mechanical damage from occurring to the engine or burner jets provided appropriate maintenance schedules are followed. However biogas may also be combusted directly (i.e. without prior "clean up") if minor necessary engine modifications are made and a more frequent oil change schedule is implemented.

Gas-fueled consumer appliances (such as gas ranges) and most gas-fueled industrial equipment are designed to operate with "pipeline quality" natural gas, i.e. high quality gas meeting natural gas industry standards. Similarly natural gas vehicle (NGV) engines are designed to use natural gas meeting vehicle fuel quality standards. Generally speaking, biogas must be "upgraded" in order to be used as a fuel source for consumer appliances, industrial equipment or vehicle fuel for NGVs.

In addition to increasing the energy content (i.e. the relative methane content) of the gas, the biogas upgrading process also removes trace components in the raw biogas which are harmful to the natural gas grid, appliances, engines, other equipment or end-users. These trace components include H_2S, H_2O, nitrogen, oxygen, particles, halogenated hydrocarbons, ammonia and organic silicon compounds.

The primary tasks in the biogas upgrading process (also referred to as "sweetening") are:

- Hydrogen sulfide (H_2S) removal
- Carbon dioxide (CO_2) removal
- Water (H_2O) removal
- Removal of other contaminants
- Odorization (not applicable to liquefied biomethane)

The output of the biogas upgrading process is biomethane. Depending on the technology used, some of the biogas upgrading tasks may be performed simultaneously or as separate steps in the process. In addition, there may be further processing required depending on the composition of the raw biogas, the final form of the biomethane (e.g. low pressure gas, compressed, liquefied) and its intended usage.

3.1 H_2S Removal

Depending on the biomass feedstock and biogas production process, the H_2S content of the raw biogas may vary from 50 to 3000 ppm or higher. Pipeline gas and vehicle fuel standards require an H_2S content of less than approximately 16 ppm. Some of the technologies used to reduce the H_2S content to acceptable levels are:

- In-situ reduction of H_2S within the digester vessel by adding metal ions (e.g. iron chloride) to form insoluble metal sulfides or creation of elementary sulfur through oxidation
- Removal of H_2S with metal oxides (e.g. iron oxide and zinc oxide) such as SulfaTreat™ and hydroxides (e.g. iron hydroxide)
- Oxidation with air
- Adsorption of H_2S on activated carbon

If the H_2S content of the raw biogas is high, the operational costs associated with in-situ reduction of H_2S by adding metal ions such as iron chloride can be prohibitively expensive. Removal of H_2S with metal oxides such as SulfaTreat™ is a popular method within the biogas industry due to its efficiency and reasonable operational costs. Removal of H_2S via oxidation with air is cheaper than chemical cleaning and has gained popularity in Danish biogas plants. Unfortunately the addition of air into the biogas often necessitates additional aftertreatment to obtain pipeline quality or vehicle fuel quality biomethane. Removal of H_2S via adsorption by activated carbon requires periodic regeneration or replacement of the activated carbon as it becomes "used up" by the H_2S adsorption process. Typically the activated carbon is replaced rather than regenerated.

3.2 CO_2 Removal

Reducing the relative amount of carbon dioxide (CO_2) in the biogas is the main task of the biogas upgrading process. Raw biogas is typically 60 – 70% methane and 30 – 40% CO_2. Depending on its intended usage (e.g. pipeline vs. vehicle fuel), biomethane is typically 97 – 99% methane and 1 – 3% CO_2. (Note that typical natural gas pipeline specifications require a CO_2 content of less than 3% whereas vehicle fuel specifications require a combined $CO_2 + N_2$ content of 1.5 – 4.5%.) Since the methane content of the gas is directly proportional to its energy content, increasing the relative methane content by removing CO_2 results in gas with a higher heating (calorific) value.

The following list identifies the most common methods used to decrease the CO_2 content and increase the methane content of biogas:

- Membrane separation
- Pressure Swing Adsorption (PSA)
- Water scrubbing (with and without regeneration)
- Removal of CO_2 using Selexol™

- Removal of CO_2 using Low Pressure COOAB™

In membrane separation, the biogas is directed to a very thin (<1 mm) physical membrane where the rates of CO_2 and H_2S diffusion through the membrane are very high relative to the rate of methane diffusion. As a result, most of the methane is retained on one side of the membrane and most of the CO_2 and H_2S passes through to the other side. By placing several membranes in series, the relative percentage of methane in the biomethane can be increased although there is a corresponding penalty in methane losses (although this can be partially offset by recirculation of some of the permeated CO_2-enriched gas).

PSA is a method for separating CO_2 from methane via adsorption/desorption of CO_2 on zeolites or activated carbon at different pressure levels. The system consists of multiple vessels filled with adsorption material. During the adsorption phase, biogas is fed into the bottom of a vessel. As it travels to the top of the vessel, CO_2, O_2 and N_2 are adsorbed on the surface of the adsorption material, resulting in pressure buildup and >97% methane content of the gas leaving the top of the vessel. Before the adsorbent material becomes completely saturated, the vessel is disconnected from the biogas input and the adsorbent material is regenerated via depressurization of the vessel. Simultaneously the biogas is diverted to a regenerated vessel such that the flow of input and output gases is continuous.

In water scrubbing systems, biogas is fed into the bottom of a tall vertical column and water is fed into the top of the column, thereby creating a gas-liquid counter flow. Under pressure, CO_2 is dissolved in the water flowing through the column. Thus the gas leaving the top of the column has a high methane content and the water leaving the bottom of the column has a high dissolved CO_2 content. The water may be regenerated via depressurization in a "flash tank" to remove the CO_2 before being recirculated back into the system. Alternatively a continuous stream of new water may be used.

Selexol™ is a polyglycol ether liquid which readily absorbs CO_2, H_2O and H_2S. The process is extremely similar to water scrubbing with the water replaced by recirculating Selexol™. Regeneration of the Selexol™ is performed via depressurization in a "flash tank" although additional processing is necessary to remove the H_2S absorbed by the Selexol™. Since the Selexol™ absorbs H_2O, further drying of the output gas is normally not necessary.

Low Pressure COOAB™ is a CO_2 absorption technology based on an amine absorption liquid called COOAB™ which efficiently absorbs CO_2 at low pressure. The process is extremely similar to Selexol™ with the Selexol™ replaced by recirculating COOAB™. Regeneration of the COOAB™ is performed via steam heating in a "CO_2 stripper" unit. Heat exchangers are used to recover and transfer heat between the COOAB™ in the CO_2 removal (low temperature) and CO_2 stripper (high temperature) stages, thereby minimizing process energy requirements. The Low Pressure COOAB™ technology is relatively new and has the advantage of producing methane at >99% purity without the need for compression at the input stage of the process (unlike the water scrubbing and Selexol™ systems). Note that COOAB™ does not absorb H_2O or H_2S.

3.3 H_2O Removal

Raw biogas is saturated with water vapor (H_2O). Depending on the biogas upgrading technology used, later stages in the biogas upgrading process may also be fully or partially saturated with H_2O. Since H_2O is potentially damaging to natural gas pipeline equipment and engines, pipeline and vehicle fuel requirements regarding H_2O content and dewpoint are very strict. Pipeline quality gas standards require a maximum H_2O content of 7 lbs/million standard cubic feet (approximately 0.5% by weight) and compressed natural gas (CNG) vehicle fuel standards require a dewpoint of at least 10º below the 99% winter design temperature for the local geographic area. (Dewpoint is the temperature at which water liquefies in a gas at a given pressure.)

The removal of H_2O can be performed via a number of different methods at varying points in the biogas upgrading process. H_2O is typically removed before any compression of the biogas takes place since increased pressure at constant temperature raises the dewpoint of the gas. The following list identifies some of the most common methods used for removing the H_2O from biogas (sometimes referred to as drying the biogas):

- Refrigeration
- Adsorption
- Absorption

Refrigeration is a common method used in many systems. Adsorption drying requires regeneration of the adsorbing (drying) agent. H_2O can also be absorbed, e.g. with glycol, triethylene glycol or hygroscopic salts. Hygroscopic salts cannot be regenerated and must be replaced as they absorb H_2O from the gas.

3.4 Removal of Other Contaminants

In addition to H_2S, H_2O and CO_2, there may be other trace contaminants present in the biogas which are potentially harmful to equipment and/or people and must therefore be removed or reduced to acceptable levels. The presence and amount of undesired trace components is highly dependent on the biomass feedstock as well as the anaerobic digester and biogas upgrading technologies employed. These additional contaminants include particles, halogenated hydrocarbons, ammonia, nitrogen, oxygen and organic silicon compounds (e.g. siloxanes). A number of effective, commercially available technologies exist to reduce or eliminate these contaminants including filters, membranes, activated carbon and other absorption media.

3.5 Odorization

Upgraded biogas must be odorized in order to ensure that gas leaks will be detected. This applies to cases where the biomethane will be injected into dedicated biogas pipelines, the natural gas pipeline network or used as a vehicle fuel for CNG vehicles. When biomethane is liquefied for use with liquefied natural gas (LNG) vehicles, odorization is not practical and therefore not required. (Note that vehicles using LNG fuel are required to have methane gas detectors for the fuel system.)

Odorization is normally accomplished by introducing tetrahydrotiophen (THT) or mercaptans into the gas via a controlled dosing process. Concentrations are typically in the range of 5 – 30 mg/m^3.

3.6 Supplementary Mixing with Propane or Liquefied Petroleum Gas (LPG)

The addition of propane or LPG (which is gaseous at ambient pressure) is sometimes used to increase the calorific (heating) value of biomethane in order to meet pipeline quality specifications. Since this method does not increase the overall methane content of the gas, it is not by itself sufficient for upgrading biogas to biomethane. Note that additions of large amounts of propane or LPG is costly and hence the percentage of any propane or LPG mixed in with biomethane tends to be small (e.g. <8%).

4 Biogas Usage

In its raw state, biogas has a relatively low calorific (heating) value (directly proportional to the methane vs. CO_2 content of the biogas) and a moderate level of potentially damaging contaminants. The primary usage of biogas is as a fuel for burners and generator-sets (“gen-sets”) specifically designed or modified to operate with biogas. Note that in some cases, a limited amount of “clean up” is performed on the biogas to reduce H_2S, H_2O and particulates to acceptable levels prior to combustion.

4.1 Production of Heat, Power and Mechanical Work

Burners to produce heat and gen-sets which produce electrical power and heat (often referred to as combined heat and power or CHP) are the most common uses for biogas. Gen-sets are commercially available in sizes ranging from approximately 75 KW – 1.5 MW. In addition, biogas can be used as a fuel for similarly modified engines to perform mechanical work. In most cases, the heat, electricity, and/or mechanical work performed by burning biogas is consumed locally, for example, to operate lighting and other electrical equipment on a large farm.

4.2 Emerging Opportunities for Biogas as a Feedstock for Fischer-Tropsch Fuels

There is an emerging opportunity to use raw biogas as a feedstock for a Fischer-Tropsch (FT) Gas-to-Liquid (GTL) conversion process which converts low quality gas to high quality liquid fuel. FT fuels can be used either directly as a vehicle fuel or blended with other fuels, such as diesel, to produce a cleaner burning vehicle fuel. *While GTL processes are currently very expensive and not well-suited to small-scale production, future technological improvements and cost reductions in this area may provide commercial opportunities for direct conversion of biogas to a liquid transportation fuel.*

5 Biomethane Usage

The potential uses for biogas are expanded significantly if the biogas is upgraded to biomethane. Since biomethane is essentially equivalent to natural gas, biomethane can be used for any application where natural gas is used. This includes domestic gas appliances, commercial/industrial/agricultural gas equipment, and as fuel for natural gas vehicles (NGVs). In Sweden, upgraded biogas is injected into the natural gas pipeline network for general use and compressed for use as a vehicle fuel.

5.1 Domestic Gas Appliances

If the biogas is upgraded to pipeline quality biomethane and distributed via the natural gas pipeline network, it can be used as a fuel for domestic gas appliances. Examples of domestic gas appliances that could operate on biomethane are:

- Gas cooking appliances
- Gas water heaters
- Gas space heaters

5.2 Commercial/Industrial/Agricultural Gas Equipment

If the biogas is upgraded to pipeline quality biomethane and distributed via either the natural gas pipeline network or dedicated biomethane pipelines to the intended consumer, it can be used as a fuel for commercial, industrial or agricultural equipment. Examples of gas equipment that could operate on biomethane in commercial, industrial and agricultural applications are:

- Gas water heaters
- Gas space heaters
- Gas refrigeration equipment
    - Absorption chillers
    - Adsorption chillers
- Gas agricultural (irrigation) pumps
- Other gas-powered industrial equipment

5.3 Natural Gas Vehicles (NGVs)

If the biogas is upgraded to vehicle fuel quality biomethane, it can be used as a fuel for NGVs provided that the biomethane is either compressed or liquefied according to the needs of the vehicle. Examples of NGVs that could operate on biomethane are:

- CNG vehicles (requires compressed biomethane fuel)
- LNG vehicles (requires liquefied biomethane fuel)

- Bi-fuel NGVs (requires compressed biomethane fuel)
- Dual-fuel NGVs (requires liquefied biomethane fuel)

CNG vehicles include light-, medium- and heavy-duty vehicles that use CNG as their only fuel source. LNG vehicles are predominantly heavy-duty vehicles. These vehicles use LNG as their only fuel source. Bi-fuel NGVs have two separate fuel systems. They operate on CNG as their primary fuel source and have a secondary fuel source (typically gasoline) as a backup in case the CNG fuel runs out. Bi-fuel NGVs are predominantly light-duty vehicles. Dual-fuel NGVs have two separate fuel systems and blend the two fuels onboard the vehicle (e.g. 85% LNG or CNG, 15% diesel) to increase combustion efficiency and engine performance. The majority of dual-fuel NGVs are medium- and heavy-duty vehicles operating on LNG/diesel or CNG/diesel however there have been demonstrations of light-duty vehicles operating on CNG/gasoline.

5.3.1 NGV Market

An estimate of the California NGV market and CNG/LNG fuel consumption as of 2004 is summarized in Table 1 below. Note that these estimates include dedicated and dual-fuel NGVs only. Bi-fuel NGVs are assumed to represent a negligible portion of the NGV market and have not been included.

CNG Vehicles	2004	Comments
Light-Duty	15,500	Shuttles, taxis, municipal fleet vehicles
Medium- and Heavy-Duty	4,850	Transit buses, school buses, refuse trucks
Total CNG Vehicles	*20,350*	
Total CNG Consumption	*69 Million GGEs*	1 Gasoline Gallon Equivalent (GGE) = 125 standard cubic feet of natural gas
LNG Vehicles		
Light-Duty	0	
Medium-Duty	0	
Heavy-Duty	1,200	Transit buses, refuse trucks, class 8 urban delivery
Total LNG Vehicles	*1,200*	
Total LNG Consumption	*11 Million GGEs*	1 Gasoline Gallon Equivalent (GGE) = 1.52 gallons of LNG
Total NGVs (CNG + LNG)	***21,550***	
Total (CNG + LNG) Fuel Consumption	***80 Million GGEs***	

Table 1 - Summary of California NGV Market & Fuel Consumption

While there is a modest established base of NGVs in California, these vehicles tend to be clumped in urban fleets and few are located in agricultural areas where dairy biogas, for example, would be produced. Hence "matching" vehicle quality biomethane production to vehicle consumption as well as distribution of biomethane from the point of production to the point of consumption are major issues associated with the usage of biomethane for transportation applications.

There are conflicting indications regarding future growth of the NGV market in California and the U.S. Ford and General Motors have both recently abandoned or severely limited their NGV production efforts. Small Vehicle Manufacturers (SVMs), such as Baytech Corporation, BAF, and DRV Energy, performing natural gas conversions of light- and medium-duty vehicles have attempted to fill the resulting gap between NGV supply and demand. However their overall capacity is limited. In addition, in 2004 the U.S. Supreme Court disallowed a portion of the South Coast Air Quality Management District (SCAQMD) fleet rules (specifically the part affecting private fleet purchases of certain kinds of heavy-duty vehicles) due to a legal issue regarding SCAQMD jurisdiction. While there is a strong effort underway to effectively reinstate the rules via a state mechanism, the Supreme Court action has at least temporarily removed one of the primary drivers for sales of certain kinds of heavy-duty NGVs in California. Given the potential instability of the current situation, it is difficult to predict the overall effect on the California NGV market.

6 Biomethane Distribution

Depending on the biomethane production location, there may be several options for distribution to the ultimate point of consumption. These options include:

- Distribution via dedicated biomethane pipelines
- Distribution via the natural gas pipeline network
- Over-the-road transportation of compressed biomethane
- Over-the-road transportation of liquefied biomethane

6.1 Distribution via Dedicated Biomethane Pipelines

If the point of consumption is relatively close to the point of production (e.g. <1 mile), the biomethane would typically be distributed via dedicated biogas pipelines (buried or above ground). For example, biomethane intended to be used as CNG vehicle fuel could be transported via dedicated pipelines to a CNG refueling station co-located with the biomethane production facility. For short distances over privately owned property where easements are not required, this is usually the most cost-effective method. Installed costs for dedicated biomethane pipelines can vary greatly but normally range between about $100,000 – $200,000 per mile according to industry sources in California. Note that biomethane distributed via dedicated biomethane pipelines need generally only compete with the retail price of natural gas.

6.2 Distribution via the Natural Gas Pipeline Network

The natural gas pipeline network offers a potentially unlimited storage and distribution system for biomethane. Since the natural gas pipelines are typically owned by either private or municipal gas utilities, the biomethane producer must negotiate an agreement with the pipeline owner (i.e. the local gas utility) to supply biomethane into the natural gas pipelines. One of the prerequisites for such an agreement would be that any biomethane injected into the natural gas pipeline network must meet the local gas utility's pipeline gas quality (i.e. composition) standards. Once the biomethane is injected into the natural gas pipeline network, it can be used as a direct substitute for natural gas by any piece of equipment connected to the natural gas grid, including domestic gas appliances, commercial/industrial gas equipment, and CNG refueling stations.

In reality, there is likely to be significant resistance by the local gas utility towards attempts to distribute biomethane via the natural gas pipeline network. The local gas utility's concern is justified in that poor gas quality can have potentially devastating effects on gas equipment. For this reason, there are likely to be severe requirements for gas quality monitoring and fail-safe disconnection of the biomethane supply from the natural gas pipeline network which may lead to prohibitively high costs for biomethane producers. In addition, biomethane distributed via the natural gas pipeline network would be sold to the local gas utility and therefore must compete with the wholesale price of natural gas offered by other natural gas suppliers. This is generally assumed to require relatively large scale biomethane production (e.g. much larger than a typical dairy) in order to keep costs sufficiently low.

As of 2005, there is only one example in the US of biomethane being sold to a gas utility as a supplemental equivalent for natural gas. The Seattle Metro Renton Water Reclamation Plant includes an anaerobic digester and water scrubbing unit which produces pipeline quality biomethane. The biomethane is then sold to the local gas utility, Puget Sound Energy, which in turn resells the biomethane to its natural gas customers. The biomethane produced by the Renton plant is more valuable than the electric power that could have been produced by the biogas because electric power is extremely cheap in the Seattle area (2.5 – 3 cents/KWH). In California where electric power costs are much higher (e.g. 8 – 10 cents/KWH), it would have been more valuable to generate electric power from the biogas rather than upgrade it to biomethane.

6.3 Over-the-Road Transportation of Compressed Biomethane

In cases where distribution of biomethane via dedicated pipelines or the natural gas grid is impractical or prohibitively expense, over-the-road transportation of compressed biomethane may be an option. Since the energy density of biomethane is extremely low at ambient pressure, it must be compressed to relatively high pressures (e.g. 3,000 – 3,600 psi) to transport economically in over-the-road vehicles.

CNG bulk transport vehicles, often referred to as "tube trailers", are used in those cases where over-the-road transportation of CNG or compressed biomethane is required. U.S. Department of Transportation (DOT) regulations classify CNG as a Class 2 (gas), Division 2.1 (flammable) hazardous material and over-the-road transportation of compressed biomethane is assumed to be held to the same requirements. Major requirements include:

- Transportation in DOT-approved tanks (e.g. DOT-3AAX seamless steel cylinders) not exceeding the rated tank pressure
- Less than 0.5 lbs. water vapor/million standard cubic feet (i.e. < 10 ppm H_2O)
- Minimum 98% methane
- Appropriate Hazardous Materials markings

Given the transportation and capital equipment costs associated with over-the-road transportation of compressed biomethane as well as the probable need for additional compression at the point of consumption, this method of biomethane distribution is generally not considered a long-term, cost-effective solution. Rather it is used as a temporary solution in certain situations, for example, as a means of expanding the use of compressed biomethane vehicle fuel into a new market prior to the installation of permanent refueling infrastructure.

6.4 Over-the-Road Transportation of Liquefied Biomethane

Over-the-road transportation of liquefied biomethane is a potential way of addressing many of the infrastructure issues associated with biomethane distribution, however this method presents additional technical challenges. Bulk LNG is transported in LNG tankers. These are typically class 8 vehicles consisting of a tractor towing a 10,000 gallon tanker. LNG is transported at relatively low pressures (e.g. 20 – 150 psi) however it is a cryogenic liquid (e.g. -260ºF/-160ºC) and therefore requires special handling U.S. DOT regulations classify LNG as a Class 2 (gas), Division 2.1 (flammable) hazardous material and over-the-road transportation of liquefied biomethane is assumed to be held to the same requirements. Major requirements include:

- Transportation in DOT-approved tanks (e.g. double-walled insulated steel tanks)
- Two independent pressure relief systems
- Maximum One Way Travel Time (OWTT) marking
- Appropriate Hazardous Materials markings

One of the most attractive features of over-the-road transportation of liquefied biomethane is that an infrastructure and market already exist. (Note that in addition to acting as a fuel for LNG vehicles, liquefied biomethane can also be used to provide fuel for CNG vehicles via LCNG refueling stations which turn LNG into CNG.) In California where almost all LNG is currently imported from other states, in-state production of liquefied biomethane would gain a competitive advantage over LNG with respect to transportation costs. While liquefaction of landfill gas (LFG) has been demonstrated at a number of locations throughout the U.S., this technology has never been applied to biomethane produced from dairy manure or similar feedstocks.

One of the main disadvantages of liquefied biomethane is that it must be used fairly quickly after it is produced (typically within one week) in order to avoid significant fuel losses from thermal evaporation. Since standard LNG tankers carry about 10,000 gallons, a small-scale LNG liquefaction facility should produce at least about 3,000 gallons of liquefied biomethane/day. This would allow a full LNG tanker to be loaded approximately every four days for cost-effective distribution to the ultimate point of consumption. The production of 3,000 gallons of liquefied biomethane/day would require an extremely large dairy farm with approximately 10,000 cows or a centralized digester facility processing the biomethane output equivalent of 10,000 cows.

Due to the relative immaturity of small-scale liquefaction technology as well as suspected large energy requirements during the liquefaction process, further research is required to determine whether a business case exists for production of liquefied biomethane in California.

7 Biomethane Gas Quality Standards

The gas quality standards applicable to biomethane depend on the physical form of the biomethane (e.g. low pressure gas, compressed, liquefied) as well as its intended usage.

7.1 Natural Gas Pipeline Quality Standards

Any gas (including biomethane) transported via the natural gas pipeline network is required to meet the local gas company gas quality standards set by the owner of the natural gas pipeline network. In California, the two major private NG pipeline distribution networks are owned by Pacific Gas and Electric Company (PG&E) and Southern California Gas Company (SoCalGas) which provide natural gas for most of northern and southern California respectively. In addition to PG&E and SoCalGas, there are a number of municipal gas utilities throughout the state which own and operate their own natural gas pipeline distribution networks. Default gas quality and interchangeability requirements for PG&E and SoCalGas are set forth in PG&E's Rule 21 and SoCalGas's Rule 30 respectively (although these requirements may be superseded by specific agreements). Key default requirements are summarized below.

Gas Quality	*PG&E*	*SoCalGas*
CO_2	≤ 1%	≤ 3%
O_2	≤ 0.1%	≤ 0.2%
H_2S	≤ 0.25 grains/100 scf	≤ 0.25 grains/100 scf
Mercaptan sulfur	≤ 0.5 grains/100 scf	≤ 0.3 grains/100 scf
Total sulfur	≤ 1 grain/100 scf	≤ 0.75 grains/100 scf
H_2O	≤ 7 lbs/million scf	≤ 7 lbs/million scf
Total inerts	No requirement	≤ 4%
Heating value	Specific to receipt point	970 – 1150 BTUs/scf
Landfill gas	Not allowed	No requirement
Temperature	60 - 100ºF	50 - 105ºF
Gas Interchangeability	*Per AGA Bulletin 36*[1]	*Per AGA Bulletin 36*[1]
Wobbe Number	Specific to receipt point	Specific to receipt point
Lifting Index	Specific to receipt point	Specific to receipt point
Flashback Index	Specific to receipt point	Specific to receipt point

7.2 Vehicle Fuel Gas Quality Standards

Biomethane may be stored on-board vehicles for use as a transportation fuel in either compressed or liquefied form.

[1] American Gas Association, Research Bulletin 36, Interchangeability of Other Fuel Gases with Natural Gases.

7.2.1 Compressed Biomethane vs. Liquefied Biomethane

Since biomethane has an extremely low energy density at ambient pressure and temperature, it must be either compressed or liquefied to increase its energy density sufficiently for transportation fuel applications. In this respect, biomethane is similar to natural gas which must also be either compressed to CNG or liquefied to LNG for use as a transportation fuel.

For CNG vehicles, biomethane is compressed to either 3,000 or 3,600 psi for storage in CNG tanks on the vehicle. For LNG vehicles, the biomethane must undergo a liquefaction process which converts the biomethane to a cryogenic liquid at approximately -260ºF (-160 ºC) and 50 – 150 psi. Natural gas vehicle engines can usually operate with both CNG and LNG fuel, however the on-vehicle storage tanks and fuel delivery systems for CNG and LNG are necessarily different to accommodate the unique properties of each fuel type.

Note that biomethane liquefaction is an additional step beyond biogas upgrading and therefore has additional costs. In addition, the technology for small-scale liquefaction is expensive and not yet commercially mature.

7.2.2 CNG Vehicle Fuel Quality Standards

National CNG fuel quality standards (non-binding) are specified in SAE J1616, "Recommended Practice for CNG Vehicle Fuel". California standards for CNG fuel quality (legal requirements) have been specified by the California Air Resources Board (CARB) and are found in the California Code of Regulations (CCR), title 13, section 2292.5. In addition, all natural gas engine manufacturers have issued their own natural gas quality standards for compatibility of natural gas fuel with their engines. While the various gas quality standards have not been harmonized, the CARB standard is a legal requirement in California and is therefore generally viewed as the overriding standard. The key requirements from the CARB CNG fuel specification are:

- Methane: 88% Min.
- Ethane: 6% Max.
- Propane: 3% Min.
- Oxygen: 1% Max.
- Inert Gases (CO_2 + N_2): 1.5 – 4.5%
- Total Sulfur: 16 ppm
- Dewpoint: ≥10ºF below 99% applicable local winter design temperature

7.2.3 LNG Vehicle Fuel Quality Standards

There are currently no LNG fuel quality standards that parallel the standards for CNG fuel quality. This is generally not perceived as a problem because the liquefaction process tends to inherently eliminate potential variability in the final fuel composition regardless of the feedstock. In particular, LNG contains no oil, particulates, H_2S or H_2O and is typically > 99% pure methane.

8 Benefits of Biogas and Biomethane

Usage of biogas and biomethane provides benefits in several areas including energy, greenhouse gas reductions, air quality, water quality, waste disposal, soil nutrient management and other environmental benefits and potential economic benefits. The actual extent of these benefits for a particular application will vary by industry, feedstocks, technology, applicable incentives and the end usage of the biogas or biomethane.

8.1 Energy

Biogas and biomethane are renewable energy sources. Unlike non-renewable fossil fuels, biogas and biomethane are derived from a variety of renewable biomass sources such as manure, organic refuse, and industrial food processing by-products. It therefore presents a potential opportunity to turn marginal and zero-value waste products into feedstocks for a source of renewable energy. In addition, the business case is strengthened when tipping fees can be collected in connection with the co-digestion of certain types of organic wastes such as waste from slaughterhouses and rendering operations.

The most common usage of biogas is as a low-quality fuel for burners that create heat and gen-sets that create heat and electrical power (primarily for local consumption, e.g. to operate farm lighting and equipment or to power industrial equipment). In some cases, excess energy can be sold to the local electric power utility or a nearby industrial customer.

Biomethane may be used as a substitute for natural gas in a variety of applications including as a fuel for NGVs. Biomethane usage as a vehicle fuel results in increased energy independence due to a decreased need for oil imports. This also has the benefit of reducing the U.S. trade deficit which is due in large part to the U.S.'s reliance on importing foreign oil to satisfy its energy needs.

8.2 Reduction of Greenhouse Gases (GHGs)

Biogas occurs naturally whenever organic materials decompose in a low-oxygen environment, such as at landfills and manure lagoons. If this gas is not captured, the high methane content in the gas is released directly into the atmosphere. Methane is 21 times more powerful as a greenhouse gas (GHG) than carbon dioxide and is a major contributor to global warming. The US Department of Energy (DOE) estimates that methane is responsible for 15% of the greenhouse gas buildup in the atmosphere. Capturing biogas that would ordinarily have been released to the atmosphere results in a reduction of GHGs and consequently contributes to a reduction in global warming.

When biomethane is used as a fuel for NGVs, there is a 100% reduction (i.e. zero net increase) in GHGs because the CO_2 released when the biomethane is combusted is part of the natural carbon cycle. When natural (uncaptured) methane gas emissions from anaerobic decomposition of organic feedstocks (such as dairy manure) are taken into account, biomethane usage can result in a net decrease of systemic GHG emissions.

8.3 Air Quality

For agricultural applications, levels of ammonia and volatile organic compounds (VOCs), which normally evaporate into the air from livestock manure and urine, will be reduced significantly as a result of timely use of livestock waste as biogas feedstock. Note that VOCs are a precursor to the formation of ground level ozone and smog.

Since biomethane and natural gas are extremely similar in chemical composition, the use of biomethane as a vehicle fuel results in emissions reductions similar to natural gas. While comparative engine emissions are highly dependent on the emissions standards in effect for a particular model year, typical biomethane emissions compared to gasoline and diesel engines are:

- 90/75% reduction in nitrogen oxides (NOx) compared to gasoline/diesel
- 95/60% reduction in non-methane hydrocarbons (NMHC) compared to gasoline/diesel
- 60/85% reduction in particulate matter (PM) compared to gasoline/diesel

A real but often overlooked local benefit of biogas production from animal manure is the reduction of offensive odors (e.g. around dairy farms) due to covering of manure lagoons as part of the biogas recovery system. This benefit is particularly appreciated by nearby residents and helps foster a “good neighbor” relationship between farmers and local residents.

8.4 Water Quality

Improved manure management practices reduce the potential for contamination of surface waters from stormwater runoff. Anaerobic digestion greatly reduces both the pathogen content and the biological oxygen demand (BOD) of manure, thus making the manure inherently less dangerous to aquatic life should it eventually enter a water course.

8.5 Waste Disposal

Producing biogas and biomethane from organic waste such as animal manure contributes to a sustainable society. Many types of organic waste are currently either buried in landfills or destroyed by incineration. Thus external sources of raw materials and energy are constantly required to produce food and other goods for society. Converting organic waste into biogas and biomethane (along with other agricultural products such as biofertilizer) allows the waste outputs of agriculture to become the energy inputs (in the form of heat, electrical power and transportation fuel) for the agriculture industry and other parts of society.

8.6 Soil Nutrient Management

In the agriculture industry, nutrients in the soil are consumed to grow plants which are in turn consumed by animals. The manure excreted by these animals (e.g. dairy cows) is rich in the three main components of soil fertilizers: nitrogen (N), phosphorus (P) and potassium (K). While soil nutrient management is an extremely complex issue, there is some evidence to indicate that there are benefits to using the biodigestate output of anaerobic digesters as fertilizer rather than simply field-spreading the manure. The primary benefits are thought to be:

- Pathogen reduction (primarily applicable to heated digesters) in field runoff water
- Potential less losses of N due to evaporation (depending on frequency of manure collection)
- Greater conversion of organic nitrogen in manure to ammonium (NH_4) in biodigestate which is easier for plants to absorb directly
- Liquid biodigestate is an easier working material for farmers to field-apply as fertilizer compared to solid manure

8.7 Other Environmental Benefits

Unlike underground fuel sources such as oil, natural gas and coal, the biomass sources from which biogas is created are readily available above ground and do not require drilling or other environmentally destructive methods to obtain them.

8.8 Economic Benefits

Biogas feedstocks such as animal manure, municipal organic waste and agricultural industry by-products are low value waste products which are available in abundant quantities. Producers of these types of waste products typically pay to have contractors (such as waste-hauling and disposal companies) remove the material from where it was produced to places where it can be processed. As feedstocks for anaerobic digestion, these waste products represent a potential income stream for biogas/biomethane producers via either “tipping fees” or avoided costs. Selective collection and transportation of these feedstocks to a digester facility, however, can present a significant financial obstacle in a business case analysis.

For biogas producers, biogas represents a potential source of income provided that it can be captured and converted to useable forms of energy (e.g. heat and electrical power) in a cost-effective manner. Income for the biogas producer comes primarily in the form of avoided electrical power costs as well as potential sales of excess power to the electric utility. In California, a net metering law allows independent power producers (such as dairy farmers using biogas to generate electrical power) the opportunity to offset and potentially eliminate electrical power costs by generating their own power. Within certain restrictions, the dairy farmers may also "tie in" to the electrical grid and sell their excess power to the electric utility. In reality, however, the process of "tying in" to the electrical grid is difficult and expensive and the returns so little that this option has not been widely exercised by dairy farmers.

Biomethane represents a potentially more valuable product than biogas because biomethane may be used as a substitute for natural gas in both stationary and transportation applications. While biomethane is more valuable, it is also more expensive to produce than biogas. Natural gas is currently selling at a historically high commercial retail price of approximately $10/MMBTU (where 1 MMBTU is equal to 1,000,000 BTUs or about 1,000 standard cubic feet). Wholesale prices are currently approximately $7/MMBTU. In order for biomethane to compete with natural gas, it would have to at least be produced for less than or equal to the appropriate selling price (wholesale vs. retail) of natural gas. (Note also that the natural gas market has historically had a high degree of variability.)

Based on examples of large scale centralized digester and biogas upgrading plants in Sweden, the cost to produce biomethane can be as low as $8 - $9/MMBTU. While this is potentially cost-competitive with retail natural gas prices in the U.S., there are additional factors such as biomethane distribution and regulatory obstacles which must be taken into account before a realistic business case can be developed.

The distribution of biomethane plays a major role in the overall business case. Distribution of biomethane via dedicated biomethane pipelines is very expensive (e.g. $100,000 - $200,000/mile) and has limited flexibility. Distribution of biomethane via the natural gas pipeline network would be ideal however due to concerns about gas quality monitoring, this has currently been implemented at only one location in the U.S. Distribution of liquefied biomethane has advantages in terms of flexibility and reduced transportation costs (especially in California), however it requires an additional liquefaction stage which is both expensive and energy intensive.

The solid and liquid components of the biodigestate output from the anaerobic digester also represent a potential source of income. These products may be sold as biofertilizer, compost and soil amendments to the agricultural and other industries.

The economic benefits of biogas and biomethane production for a particular application can vary significantly depending on local and market factors and scale of operation. For this reason, it is difficult if not impossible to generalize, especially regarding biomethane production, since biogas upgrading technology has only been used in limited applications in the U.S. Economically successful biomethane projects (such as in Sweden) have generally benefited from preferential tax treatment, co-digestion of multiple waste sources (often involving "tipping fees"), economies of scale, relative proximity to biomethane consumers and involvement by municipal governments and local utilities. *Recommended areas for further research are 1) to generate a complete economic framework for evaluation of proposed biomethane production projects, and 2) to apply* *this framework to several promising potential applications including centralized digester facilities which can potentially take advantage of economies of scale.*

9 Current Status of Biomethane Industry

9.1 U.S. Biomethane Industry

While there are existing niche applications for biogas production at wastewater treatment plants (WWTPs), landfills and certain types of farms, the current U.S. biomethane industry is extremely limited. One of the reasons for this is that there are currently no direct, high value economic incentives or legislation in California or the U.S. to specifically encourage the production and usage of biomethane. There are indirect, lower value incentives related to natural gas vehicles and renewable energy sources that could be applied to biomethane production but nothing significant enough to stimulate serious growth or development of this industry. *As a result, current market economic conditions indictate that, in general, the most cost-effective usage for biogas is as a low-quality fuel for gen-sets producing heat and power.* While technically feasible, upgrading biogas to biomethane as a substitute for natural gas in pipeline and vehicle fuel applications does not appear to be generally economically viable in California and the U.S. under prevailing market conditions.

There is currently one example in the U.S. (at the Renton Water Reclamation Plant near Seattle, Washington) where upgrading biogas to biomethane has been shown to be economically profitable, primarily due to extremely low costs for electric power in that region. In this case, pipeline quality biomethane is being sold to the local gas utility (Puget Sound Energy). There may be additional cases where the right combinations of circumstances exist to make upgrading biogas to biomethane economically attractive, however these have yet to be identified. Due to economies of scale, it is likely that any future successful biomethane facilities would involve significantly larger biogas and biomethane production capacity than a typical dairy could support. *For this reason, municipal wastewater treatment plants, landfills, and centralized digester facilities are viewed as significantly better candidates for biomethane production facilities than individual dairies.* Even with better economies of scale, however, the additional costs of biogas upgrading and biomethane distribution present a significant economic obstacle to overcome compared to directly using the biogas for on-site generation of heat and electrical power.

The trend towards higher natural gas prices in recent years will help improve the potential business case for biomethane production although the volatility of the natural gas market may tend to discourage investment in biomethane facilities, especially in cases where small profit margins are expected. Government support of biomethane production and usage, e.g. funding to offset capital equipment expenses, favorable tax incentives, etc., would seem to be a natural role for the government in this market, especially considering the general social benefits of biogas and biomethane usage. *Given the existing market conditions in the U.S., it is unlikely that the biomethane industry will develop significantly without additional government support.*

9.2 Swedish Biomethane Industry

Sweden is a world leader in the production and usage of biomethane for transportation applications. During a tour of the Swedish biogas industry organized by WestStart in June 2004, the primary reasons for the success of the Swedish program were identified:

- Government Support – Defrayment of capital expenses for biogas plants and refueling station infrastructure, support for public education efforts regarding biomethane, incentives for municipalities, businesses and individuals to use renewable fuels, support for purchases of CNG and bi-fuel vehicles, general commitment to reducing GHGs and increased usage of non-fossil fuels.

- High Level of Cross-Industry Cooperation – Cooperation between multiple organizations covering entire chain from biogas production to biomethane consumption, e.g. agriculture, waste hauling, biogas technology, national and municipal government agencies, biogas distribution, transit providers, energy providers, vehicle manufacturers, etc.

- Co-digestion of Multiple Waste Streams – Simultaneous co-digestion of multiple biomass feedstocks which increases the efficiency of the anaerobic digestion process and improves the business cases by capturing tipping fees for certain types of waste such as animal slaughterhouse and rendering operations waste, organic waste by-products from food processing operations, etc.

- Biogas Upgrading Technology – Proven, commercially available technology for biogas upgrading is available in Sweden but has not been introduced into the U.S. market yet.

- Biogas Distribution Systems – Unlike the U.S., biomethane producers have legally protected access to distribution via the natural gas pipeline system in the European Union. In addition, processes for permitting dedicated biogas pipelines have been streamlined and generally do not compete with the natural gas pipeline network due to the limited coverage of the natural gas pipeline network in Sweden.

- Bi-fuel Vehicles – Light-duty vehicles using CNG/compressed biomethane with gasoline as a backup are available from major auto manufacturers such as Volvo and, unlike the U.S., receive preferential tax and incentive treatment from the government.

- Transit Buses as "Anchor Customers" for Biomethane Plants – Transit agencies have shown great interest in operating CNG transit bus fleets with biomethane and have established long-term fuel contracts with local biomethane producers in Sweden.

While the Swedish biomethane industry provides a model for how a biomethane industry could be established in California and the U.S., it is clear that there are major political, social and economic obstacles to overcome before the U.S. would be in a position to follow Sweden's lead in this industry. *(A complete trip report of WestStart's tour of the Swedish biogas industry is available on-line at www.weststart.org/info/publications.)*

10 Conclusions

10.1 General Conclusions

The California biogas industry is currently oriented primarily towards generation of heat and electrical power from biogas for stationary applications. The primary sources of biogas production are WWTPs, landfills (which produce LFG), and a limited number of dairies and swine farms. In most cases, the heat and electrical power is consumed by on-site processes or by co-located industrial facilities. In some cases, excess electrical power is sold to the local electric utility.

There is currently no significant biomethane industry in California. The only known case is a single LFG project at the Puente Hills Landfill in Los Angeles County where compressed biomethane is produced for refuse trucks that dump their loads at the landfill and fill up afterwards at an on-site CNG refueling station. This is considered a technology demonstration project and is believed to be heavily subsidized.

The business case for upgrading biogas to biomethane is currently very challenging, especially for transportation applications. Biogas upgrading (potentially followed by liquefaction) adds considerable cost to the price of biomethane. In addition, distribution of biomethane from the point of production to the point of consumption involves both complex regulatory issues and expenses. Costs can vary significantly depending on the availability and type of biomass feedstocks, anaerobic digester and biogas upgrading technologies used, form of biomethane and distribution system, proximity of biomethane consumption and economies of scale. As a result, it is extremely difficult to generalize about the business case for biomethane. Rather, promising biomethane projects need to be evaluated individually based on local conditions to determine if there is a viable business case.

One of the likely roles for transit in establishing a potential business case for biomethane in transportation applications is as a long-term “anchor” customer for vehicle fuel quality biomethane, similar to transit’s role in the Swedish biogas industry. High fuel consumption, centralized refueling and government subsidies of vehicle capital expenses make transit buses an excellent candidate for early adoption of compressed or liquefied biomethane usage.

10.2 Recommendations

It is clear that biomethane production and usage is technically feasible, as evidenced by examples in numerous European countries, most notably Sweden. Why then hasn’t this technology been applied on a commercial scale in the U.S.? Why have U.S. efforts been focused on small-scale local biogas production and consumption (e.g. on dairy farms) whereas European efforts have been focused on large-scale biomethane production at centralized facilities (e.g. municipal biogas plants)? Chapter 8 of this report briefly reviews some of the differences between the U.S. and other countries with successful biomethane industries to begin answering these questions. While economics is the major issue, it is clear that political will and social attitudes towards energy and the environment are also important factors.

To clearly define the necessary conditions to create a successful biomethane industry in California and elsewhere in the U.S., WestStart recommends the following course of action:

- Develop a general economic framework to evaluate proposed biomethane projects.
- Identify several promising potential biomethane projects including the key stakeholders for each project.
- Perform a detailed investigation of the potential business case for each of the identified biomethane project proposals in coordination with key stakeholders.
- Specifically identify those areas where additional support (government, financial, or otherwise) is necessary to overcome regulatory, economic or other obstacles.
- Based on the above investigations, generate a set of key recommendations designed to stimulate development of a California and U.S. biomethane industry.

Appendix A – California and U.S. Biogas and Biomethane Projects

IEUA Centralized Digester (Biogas) Pilot Project

The Inland Empire Utilities Agency (IEUA) in cooperation with various industry and government partners has demonstrated a successful pilot project at their Regional Plant No. 5 (RP5) in the Chino Basin for conversion of dairy cow manure to biogas and subsequent utilization of the biogas for heat and electrical power cogeneration. The IEUA pilot project is an integrated system whereby "wet" manure (approximately 12% solids content) from 6,250 cows on surrounding dairy farms is collected daily and processed by an anaerobic digester. Approximately 30% of the "cleaned" biogas output (to reduce the corrosive H_2S and H_2O content) is compressed and supplied directly to four Capstone microturbines which generate the electrical power necessary to run the digester facility equipment. The remainder of the "cleaned" biogas is sent to power electrical generators at the Chino 1 Desalter Facility which provides clean drinking water to 20,000 local households. The total electrical output of RP5 is approximately 500 KW/day. A preliminary analysis by IEUA indicates a reduction in GHGs of approximately 15,000 tons of CO_2-equivalent annually.

Farm-Based Biogas and Biomethane Projects

There are currently 15 - 20 biogas projects either existing or planned for dairies and swine farms in California. In all cases, the biogas is used to generate heat and electrical power for on-farm use. In some cases, excess electrical power is sold to the local power utility. Other dairy and livestock states such as Wisconsin and New York also have similar numbers of farm-based biogas projects.

There are currently no farm-based biomethane projects planned for farms in California. There have been a number of press releases about planned biomethane projects for large scale farming and livestock operations in various parts of the U.S. in recent years but none of these projects appear to have made it past the design stage yet.

Landfill Gas (LFG) Biogas and Biomethane Projects

There are a significant number of LFG projects in operation and/or planned for landfills in California and elsewhere in the U.S. In most cases, the "cleaned" LFG is used to generate heat and electrical power which may be partially used by landfill operations with the excess sold to the local power utility.

There have been a small number of biomethane technology demonstration projects at landfills to generate both CNG (e.g. Los Angeles County Sanitation District Landfill in Puente Hills, California) and LNG (e.g. Burlington County Landfill in Columbus, New

Jersey) for refuse trucks. While this technology shows promise, current applications are limited.

Wastewater Treatment Plant (WWTP) Biogas and Biomethane Projects

There are numberous instances of biogas projects at wastewater treatment plants (WWTPs) in California and elsewhere in the U.S. Biogas is a natural by-product of commonly used anaerobic treatment processes for wastewater. In most cases, the "cleaned" biogas is used to generate heat and electrical power which is totally or partially used by the WWTP with any excess sold to the local power utility.

There is currently only one case in the U.S. (at the Renton Water Reclamation Plant near Seattle, Washington) where upgrading biogas to pipeline quality biomethane has been shown to be economically profitable, primarily due to extremely low costs for electric power in that region. Due to significantly higher electric power costs in California, it would generally be more cost-effective to produce heat and electric power from biogas at WWTPs in California.