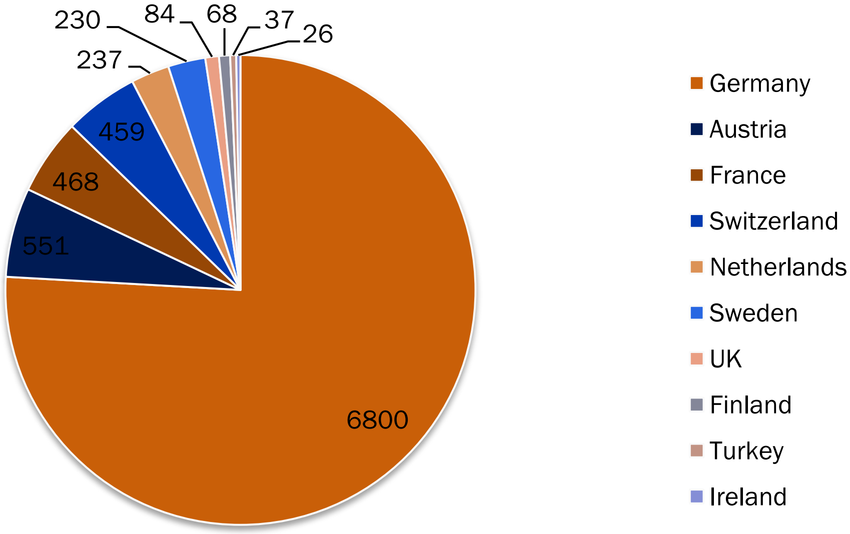
Anaerobic Digesters

Quick Facts

- Anaerobic digesters provide a variety of environmental and public health benefits including: greenhouse gas abatement, organic waste reduction, odor reduction, and pathogen destruction.
- Anaerobic digestion is a carbon-neutral technology to produce biogas that can be used for heating, generating electricity, mechanical energy, or for supplementing the natural gas supply.
- In 2010, 162 anaerobic digesters generated 453 million kWh of energy in the United States in agricultural operations, enough to power 25,000 average-sized homes.[1]
- In Europe, anaerobic digesters are used to convert agricultural, industrial, and municipal wastes into biogases that can be upgraded to 97 percent pure methane as a natural gas substitute or to generate electricity. Germany leads the European nations with 6,800 large-scale anaerobic digesters, followed by Austria with 551.[2]
- In developing countries, small-scale anaerobic digesters are used to meet the heating and cooking needs of individual rural communities. China has an estimated 8 million anaerobic digesters while Nepal has 50,000.[3]

Figure 1: Number of operating anaerobic digesters in select European countries.



Source: [Country Report of Member Countries, Istanbul, April 2011](). IEA Bioenergy Task 37.

Background

Anaerobic digestion is a natural process in which bacteria break down organic matter in an oxygen-free environment to form biogas and digestate. A broad range of organic inputs can be used including manure, food waste, and sewage, although the composition is determined by the industry, whether it is agriculture, industrial, wastewater treatment, or others. Anaerobic digesters can be designed for either mesophilic or thermophilic operation – at 35°C (95°F) or 55°C (131°F), respectively.[4] Temperatures are carefully regulated during the digestion process to keep the mesophilic or thermophilic bacteria alive. The resulting biogas is combustible and can be used for heating and electricity generation, or can be upgraded to renewable natural gas and used to power vehicles or supplement the natural gas supply. Digestate can be used as fertilizer.

Description

Anaerobic digestion has a defined process flow that consists of four distinct phases: *pre-treatment, digestion, biogas processing and utilization, and disposal or reuse of solid waste*.

1. In pre-treatment, wastes may be processed, separated, or mixed to ensure that they will decompose in the digester;
2. During digestion, waste products are broken down by bacteria and biogas is produced;
3. Biogas produced is either combusted or upgraded and then used to displace fossil fuels. During upgrading, scrubbers, membranes, or other means are used to remove impurities and carbon dioxide (CO_2) from biogas; and
4. Reuse or disposal of solid digested waste. Digested waste has a high nutrient content and can be used as fertilizer so long as it is free of pathogens or toxics, or it can be composted to further enhance nutrient content.[5]

Digestion process

Digestion, or decomposition, occurs in three stages. The first stage consists of hydrolysis and acidogenesis, where enzyme secreting bacteria convert polymers into monomers like glucose and amino acids and then these monomers are transformed into higher volatile fatty acids. The second stage is acetogenesis, in which bacteria called acetogens convert these fatty acids into hydrogen (H_2), CO_2, and acetic acid. The final stage is methanogenesis, where bacteria called methanogens use H_2, CO_2, and acetate to produce biogas, which is around 55-70 percent methane (CH_4) and 30-45 percent CO_2.[6]

Types of anaerobic digesters

Though there are many different types of digesters that can be used for agricultural, industrial, and wastewater treatment facility wastes, digesters can be broadly grouped based on their ability to process liquid or solid waste types (Table 1).

Table 1: Types of Anaerobic Digesters

Type of waste	*Liquid waste*	*Slurry waste*	*Semi-solid waste*
Appropriate digester	Covered lagoon digester/Upflow anaerobic sludge blanket/Fixed Film	Complete mix digester	Plug flow digester
Description	Covered lagoon or sludge blanket type digesters are used with wastes discharged into water.	Complete mix digesters work best with slurry manure or wastes that are semi-liquid (generally,	Plug flow digesters are used for solid manure or waste (generally, when the waste's solids

	The decomposition of waste in water creates a naturally anaerobic environment.	when the waste's solids composition is less than 10 percent). These wastes are deposited in a heated tank and periodically mixed. Biogas that is produced remains in the tank until use or flaring.	composition is 11 percent or greater). Wastes are deposited in a long, heated tank that is typically situated below ground. Biogas remains in the tank until use or flaring.

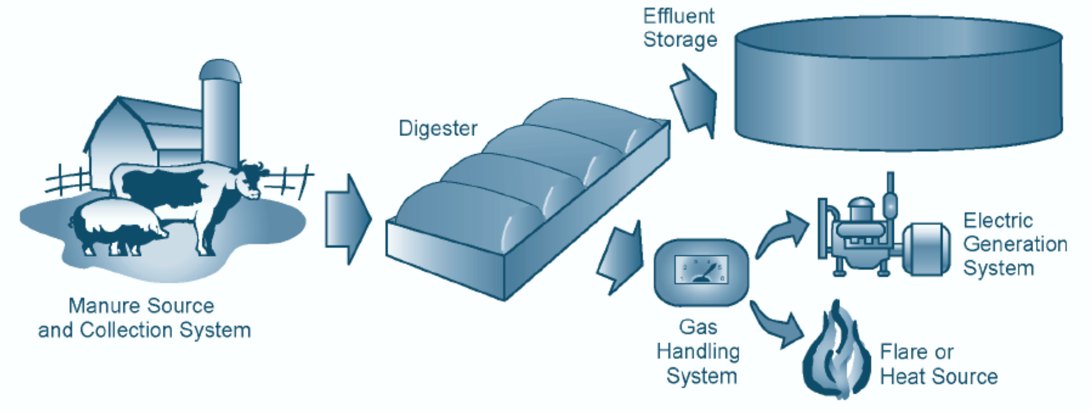
Uses of Anaerobic Digesters

Anaerobic digesters are utilized in many situations where industrial or agricultural operations produce a significant organic waste stream. In addition, municipal solid waste (MSW) landfills produce landfill gas from natural decomposition of organic material in the waste that can be captured for use as an energy source. Many MSW sites now have wells to capture biogas produced from waste decomposition.[7] Wastewater treatment plants (WWTPs) can also be converted to operate anaerobically, and they can be used to produce biogas from a variety of wastes.

Agriculture

In agriculture, animal and crop wastes are typically used as a feedstock for anaerobic digesters. Domestically, there are about 162 agricultural anaerobic digester systems. They collectively produced approximately 453,000 megawatt-hours (MWh) of energy in 2010, enough to power 25,000 average U.S. homes.[8] Different types of digesters are used depending on the existing waste management system for a given farm.

Figure 2: Components and Products of a Biogas Recovery System.



Source: Managing Manure with Biogas Recovery Systems: Improved Performance at Competitive Costs. EPA AgSTAR

Industrial

Organic waste generated by industrial processes, particularly waste from the food processing industry, can be used as a feedstock for an anaerobic digester. Food waste makes an excellent feedstock, as it has as much as 15 times the methane production potential that dairy cattle manure does.[9] Food waste substrates may also be combined with manure to improve methane generation in a process known as co-digestion. Much like agriculture, different digesters are used depending on the moisture content of the waste feedstock. Biogas is typically used for heat or other energy production when produced from industrial wastes.

Wastewater treatment plants (WWTP)

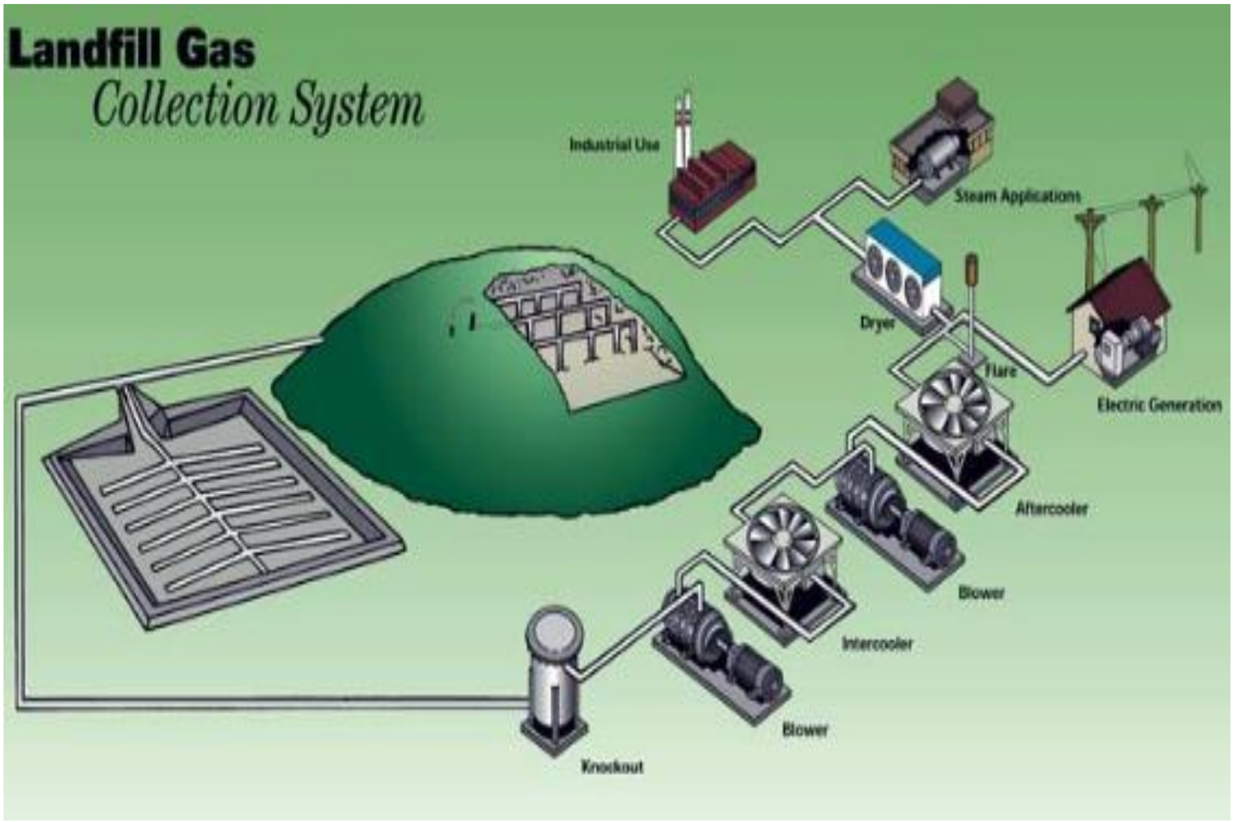
Wastewater treatment facilities employ anaerobic digesters to break down sewage sludge and eliminate pathogens in wastewater. Often, biogas is captured from digesters and used to heat nearby facilities. Some municipalities have even begun to divert food waste from landfills to WWTPs; this relieves waste burdens placed on local landfills and allows for energy production.[10]

Municipal solid waste (MSW)

The compaction and burial of trash at MSW facilities creates an anaerobic environment for decomposition. As a result, landfills naturally produce large amounts of methane. Gas emitted from MSW facilities is typically called landfill gas, as opposed to biogas. The primary difference between the two is the lower methane content of landfill gas relative to biogas – approximately 45-60 percent compared to 55-70 percent. There are 510 MSW facilities in the U.S. that utilize landfill gas capture to reclaim naturally emitted methane, which generate enough energy to power 433,000 homes. [11]

In a landfill gas collection system, gas is directed from various points of origin in waste facilities to a central processing area using a system of wells, blowers, flares, and fans. It is then upgraded and either flared to reduce odor and greenhouse gas (GHG) emissions or combusted to produce energy or heat. Since it has lower methane content than biogas, it requires greater upgrading in order to become a substitute for natural gas. The figure below depicts a MSW landfill gas system.

Figure 3: Diagram of a Landfill Gas Collection System.



Source: [Landfill Gas](). City of Ann Arbor, MI.

Environmental Benefit/Emission Reduction Potential

Anaerobic digesters make several contributions to climate change mitigation. First, in many cases, digesters capture biogas or landfill gas that would have been emitted anyway because of the nature of organic waste management at the facility where the digester is in operation. By capturing and combusting biogas or landfill gas, anaerobic digesters are preventing fugitive methane emissions. Methane is a potent GHG with a global warming potential 25 times that of CO_2. When the captured biogas or landfill gas is combusted, methane is converted into CO_2 and water, resulting in a net GHG emissions reduction. Some digesters simply incorporate flares designed to burn the biogas they capture instead of using it for heat or energy applications. This is usually done when it is not cost-effective to install heat or energy generation equipment in addition to the digester.

Another benefit of anaerobic digesters is the displacement of fossil fuel-based energy that occurs when biogas is used to produce heat or electricity. Biogas is generally considered to be a carbon-neutral source of energy because the carbon emitted during combustion was atmospheric carbon that was recently fixed by plants or other organisms, as opposed to the combustion of fossil fuels where carbon sequestered for millions of years is emitted into the atmosphere. As such, substituting energy from biogas for energy from fossil fuels cuts down on GHG emissions associated with energy production.

GHG emissions are also reduced when the nutrient-rich digestate created from anaerobic digestion is used to displace fossil-fuel based fertilizers used in crop production. This digestate makes a natural fertilizer that is produced with renewable energy as opposed to fossil fuels.

Additional environmental benefits outside of GHG reduction stem from the use of anaerobic digesters. For one, the process of anaerobic digestion reduces waste quantities by decomposing organic material. This alleviates the disposal burden on municipal landfills and cuts down on environmental problems associated with landfilling or stockpiling large amounts waste, including problems such as water supply contamination, eutrophication—where oxygen levels in surrounding bodies of water may decrease due to algal blooms brought on by nutrient loading— and land resource constraints. Anaerobic digesters and the combustion of biogas also eliminate noisome odors created by organic decomposition. For MSWs, landfill gas capture facilities prevent hazards associated with the accumulation and subsurface migration of flammable landfill gas.[12] Finally, anaerobic digesters reduce the number of pathogens present in many types of waste.[13]

Cost

The net-cost of anaerobic digesters and the production of biogas depend on a number of factors, including the following:

- the methane production potential of the feedstock used;
- digester type;
- volume of waste and intended hydraulic retention time;
- the amount of waste available as a feedstock;
- the capital and operating costs of the digester type needed for a particular application;
- the intended use of the biogas produced; and
- the value of the fertilizer produced as a byproduct of digestion.

The type and size of the digester used will have a large impact on cost, as some digesters are more costly to construct and operate. The use of biogas will also have an effect on the net-cost of an anaerobic digester. Depending on the project and the region in which it is being developed, the type of fuel a digester is displacing will have an effect on its net-cost. For instance, substituting upgraded biogas for natural gas—as opposed to using it to produce electricity—in an area where electricity is a less expensive energy source will make a project more cost-effective. In some cases, the use of a digester will have external benefits that may not be reflected in its cost. For example, anaerobic digestion may cut down on municipal waste disposal costs by decreasing the amount of waste deposited in landfills. It may also decrease environmental regulation compliance costs, such as those associated with water protection or odor control.

The EPA has issued some cost estimates for digesters in livestock operations. These estimates, based on farm and animal size, are expressed in animal units (AUs) equal to 1,000 pounds of live animal weight. Costs estimates are as follows:

- Covered lagoon digester: $150-400 per AU
- Complete mix or plug flow digester: $200-400 per AU

These estimates are based solely on the upfront capital costs associated with installing a digester and do not include operating costs or costs of installing energy generation equipment like turbines.[14]

Current Status of Anaerobic Digesters

Experimentation with controlled, industrialized anaerobic digesters began in the middle of the 19th century. In 1895, Exeter, England used biogas from a sewage treatment facility to power street lamps. While the relatively low cost of fossil fuels has stymied anaerobic digester development in industrialized nations since then, small-scale digesters have been employed by developing nations to provide heat and energy.[15] For example, in China it is estimated that 8 million small-scale digester systems are in operation today, mostly providing biogas for cooking and lighting in households.[16] U.S. farms first began using digesters in the 1970's. Around 120 agricultural digesters existed by the 1980's because of federal incentives, but costs and performance issues inhibited further development.[17] A new series of incentives and policies has helped to motivate new growth in agricultural digesters. For example, incentives in the form of grants and loan guarantees offered through the EPA's AgStar program, and policies in the form of renewable electricity portfolio standards, have helped to catalyze digester installation. Today, there are around 162 agricultural anaerobic digester systems, many of which are new. They collectively produced around 453,000 megawatt hours (MWh) of energy in 2010.[18] Average figures for industrial digesters do not exist, but new digester technology has made it easier to process waste and incentives have made the use of industrial digesters more cost effective.

Many MSW facilities have begun to utilize landfill bioreactors to produce electricity, eliminate odors, and prevent hazards. Currently, the EPA estimates that around 510 MSW facilities combust landfill gas to generate electricity and heat and an additional 510 MSW facilities could be converted for electricity generation cost-effectively.[19]

WWTPs have also begun to employ digesters in greater numbers because of their waste reduction and energy benefits. The EPA estimates that 544 large WWTPs (those that process more than five million gallons of wastewater per day) currently utilize anaerobic digesters to produce biogas. This represents around half of the WWTPs of this size nationally.[20]

Several European nations have ambitious targets for biogas usage in vehicles. Germany and Austria have mandates requiring that 20 percent biogas be used in natural gas vehicles. Feed-in tariffs established for biogas in Germany have also catalyzed the development of anaerobic digesters. Currently, 6,800 agricultural digesters exist in Germany, an increase from 4,000 in 2009.[21] Sweden, which has nearly 11,500 natural gas vehicles, estimates that biogas meets half of its fuel needs, and continues to support the use of biogas as a vehicle fuel. Globally, it is estimated that 70,000 vehicles will be powered with biogas by 2010.[22]

Obstacles to Further Development or Deployment of Anaerobic Digesters

Reliability

Controlled anaerobic digestion requires sustaining somewhat delicate microbial ecosystems. Digesters must be kept at certain temperatures to produce biogas, and the introduction of inorganic or non-digestible waste can damage systems. Performance issues with agricultural digesters in the 1980's stalled their development and damaged their reputation amongst farmers.[23] Improvements have been made to the current generation of digesters, but questions about long-term reliability still remain.

Investment uncertainty

Installation, siting, and the operation of digesters remain costly. When biogas is utilized for energy, agricultural digesters have a payback period of around 3 to 7 years[24]; WWTP digesters have a payback period of less than 3 years, and less if food wastes are also accepted as co-digestion fuel.[25] Financial incentives have helped to catalyze the development of digesters with longer payback periods, but uncertainty about long-term support for digester projects, in the form of tax incentives or subsidies, has impeded development.

Interconnection with the electricity grid

While the Energy Policy Act of 2005 required net metering (the ability for electricity consumers to sell electricity generated on-site back to a utility) to be offered to consumers upon request in every state, disparate policy implementation and electricity rates have hindered wide-scale adoption of anaerobic digesters for electricity generation from agricultural sources. California, for example, does not allow utility providers to apply standby charges, minimum monthly charges, or interconnection fees,[26] but utility providers do not buy back excess electricity, leading many farmers to burn-off excess gas rather than to provide the utilities with free energy to the grid.[27] Further hindering adoption are varying limits on the amount of electricity that may be sold back to the grid under net metering rules.[28] The situation should improve as electricity providers gain experience in incorporating anaerobic digesters into the electrical grid.

Policy Options to Help Promote Anaerobic Digesters

Price on carbon

A price on carbon, such as that which would exist under a GHG cap-and-trade program, would raise the cost of coal and natural gas power, making anaerobic digesters more cost competitive.

Renewable Portfolio Standards

A renewable portfolio standard (sometimes called a renewable or alternative energy standard) requires that a certain percentage or absolute amount of a utility's power plant capacity or generation (or sales) come from renewable sources by a given date. As of June 2011, 30 U.S. states and the District of Columbia had adopted a mandatory renewable or alternative energy portfolio standard and an additional seven states had set renewable energy goals. Renewable portfolio standards encourage investment in new renewable generation and can guarantee a market for this generation.

Tax credits and other subsidies

Ensuring that current incentives, such as the Federal Production Tax Credit, remain in place in the long term will sustain investment and growth in biogas production. Other forms of assistance, like grant programs and loan guarantees to anaerobic digester project developers, will also catalyze the development of digester projects.

Feed-in Tariffs

Feed-in tariffs require that utilities purchase energy from certain generation facilities at a favorable rate. As demonstrated in Germany, a feed-in tariff that mandates the purchase of biogas energy from anaerobic digesters and provides a financial return to digester projects could catalyze their development.

Related Business Environmental Leadership Council (BELC) Company Activities

- Johnson Controls, Inc.
- Deutsche Telekom

Related Pew Center Resources

- *Agriculture's Role in Greenhouse Gas Mitigation*, 2006
- *U.S. Agriculture & Climate Change Legislation: Markets, Myths & Opportunities*, 2010

Further Reading/Additional Resources

International Energy Agency Bioenergy: Biogas Production and Utilization, 2005

California Integrated Waste Management Board: Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste, 2008

U.S. Environmental Protection Agency (EPA)

- The Benefits of Anaerobic Digestion of Food Waste at Wastewater Treatment Facilities
- Managing Manure with Biogas Recovery Systems: Improved Performance at Competitive Costs

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[1] The Agstar Program. U.S. Farm Anaerobic Digestion Systems: A 2010 Snapshot. *U.S. EPA.* U.S. EPA. Accessed June 2, 2011.

[2] IEA Bioenergy Task 37. Country Reports of Member Countries, Istanbul, April 2011. International Energy Agency. Accessed June 3, 2011.

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[4] Lukehurst, C. T., Frost, P., Al Seadi, T. Utilisation of digestate from biogas plants as biofertiliser. IEA Bioenergy. June 2010. Accessed June 3, 2011.

[5] Fabien, Monnet. An Introduction to the Anaerobic Digestion of Organic Waste. Biogas Max. Remade Scotland, November 2003. Accessed June 13, 2011.

[6] Ibid.

[7] Oregon Department of Energy. Biogas Technology. Oregon Department of Energy. Accessed June 3, 2011.

[8] Supra note 1.

[9] The Benefits of Anaerobic Digestion of Food Waste At Wastewater Treatment Facilities. *U.S. EPA.* U.S. EPA. Accessed June 3, 2011.

[10] Ibid.

[11] Landfill Methane Outreach Program. Frequently Asked Questions. *U.S. EPA.* U.S. EPA. Accessed June 6, 2011.

[12] Landfill Methane Outreach Program. Basic Information. *U.S. EPA.* U.S. EPA. Accessed June 6, 2011.

[13] Supra note 7.

[14] The Agstar Program. Managing Manure with Biogas Recovery Systems. Improved Performance at Competitive Costs. *U.S. EPA.* U.S. EPA, Winter 2002. Accessed June 13, 2011.

[15] Supra note 5.

[16] Supra note 3.

[17] Supra note 7.

[18] Supra note 1.

[19] Supra note 12.

[20] U.S. EPA Combined Heat and Power Partnership. Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities. *U.S. EPA.* U.S. EPA, April 2007. Accessed June 6, 2011.

[21] Supra note 2.

[22] Alternative and Advanced Fuels. What is biogas? *U.S. DOE.* U.S. DOE. Accessed June 13, 2011.

[23] Supra note 7.

[24] Supra note 14.

[25] Supra note 9.

[26] DSIRE. California – Net Metering. Accessed June 13, 2011.

[27] Mullins P. A., Tikalsky S. M. Anaerobic Digester Implementation Issues. Phase II – A Survey of California Farmers (Dairy Power Production Program). California Energy Commission. December 2006. Accessed June 13 2011.

[28] DSIRE. Net Metering Map. June 2011. Accessed June 13, 2011.