Biogas Opportunities Roadmap

Voluntary Actions to Reduce Methane Emissions
and Increase Energy Independence

U.S. Department of Agriculture, U.S. Environmental Protection Agency, U.S. Department of Energy

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Executive Summary

Methane is both a potent greenhouse gas and a valuable source of energy. In the Climate Action Plan, President Obama directed the Administration to develop a comprehensive, interagency strategy to reduce methane emissions. In March 2014, the White House released the *Climate Action Plan - Strategy to Reduce Methane Emissions*. As part of the Strategy, the U.S. Department of Agriculture (USDA), the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) committed to work with industry leaders to formulate a biogas roadmap.

This *Biogas Opportunities Roadmap* builds on progress made to date to identify voluntary actions that can be taken to reduce methane emissions through the use of biogas systems and outlines strategies to overcome barriers to a robust biogas industry in the United States. It supports the U.S. dairy industry's voluntary 2008 goal to reduce its greenhouse gas emissions by 25% by 2020. This goal was a driver behind a partnership forged between the Dairy Industry and USDA in December 2009 and renewed in May 2013. As part of the 2013 renewal, the dairy industry also requested that USDA create a voluntary biogas roadmap to support this goal.

Biogas is a proven source of energy used in the United States and around the world for decades. The United States currently has more than 2,000 sites producing biogas. The Roadmap found that with the proper support, more than 11,000 additional biogas systems could be deployed in the United States. If fully realized, these biogas systems could produce enough energy to power more than 3 million American homes and reduce methane emissions equivalent to 4 to 54 million metric tons of greenhouse gas emissions in 2030, the annual emissions of between 800,000 and 11 million passenger vehicles.

In order to realize these opportunities, the Roadmap identifies actions the Federal government will take to increase the use of biogas to meet our renewable energy goals, strengthen the economy, and reduce methane emissions exclusively through voluntary actions. These include:

- **Promoting Biogas Utilization through Existing Agency Programs**: USDA, DOE, and EPA will use their existing programs as a vehicle to enhance the utilization of biogas systems in the U.S by ensuring that existing criteria for technical and financial assistance considers the benefits of biogas systems, leveraging over $10 million in research funding to enhance the economic viability and benefits of biogas systems and co-products, and strengthening programs that support the use of biogas for clean energy, transportation fuel, renewable chemicals and biobased products.

- **Fostering Investment in Biogas Systems**: To help overcome financial barriers to the widespread investment in biogas systems, USDA will lead efforts to improve the collection and analysis of industry financial and technical data needed to track the performance of anaerobic digesters, evaluate current loan and grant programs for opportunities to broaden the financing options available for biogas systems, and review Federal procurement guidelines to ensure that products of biogas systems are eligible for and promoted by applicable government procurement programs.

- **<u>Strengthening Markets for Biogas Systems and System Products</u>:** To strengthen U.S. markets for renewable energy and value-added non-energy products from biogas systems, USDA, DOE, and EPA will review opportunities to overcome barriers to integrating biogas into electricity and renewable natural gas markets, for example, though modernizing existing Federal incentives provided for renewable energy generation. USDA, EPA, and DOE will also drive the creation of tools to help industry broaden the market development for energy and non-energy biogas systems products.

- **<u>Improving Communication and Coordination</u>:** In order to implement the strategies laid out in this document and promote strong coordination and messaging across Federal agencies, USDA will establish a Biogas Opportunities Roadmap Working Group that will include participation from DOE and EPA, as well as the dairy and biogas industries. The Working Group will collaborate with industry to publish a progress report in August 2015, which identifies and prioritizes policies and technology opportunities to expand the biogas industry and reduce greenhouse gas emissions.

The emissions intensity of the production of meat and milk in the United States is already much lower today than it was even a few decades ago[i]. Due to improvements in production efficiency, it's amongst the lowest in the world[ii]. Enhancing the deployment of cost-effective technology to utilize biogas can increase revenues and reduce emissions, providing another "win-win" for farmers, communities, and the nation.

I. Biogas and Biogas Systems

Biogas is primarily a mixture of methane and carbon dioxide produced by the bacterial decomposition of organic materials in the absence of oxygen. Depending on the source of organic matter, biogas typically contains 50-70% methane, 30-40% carbon dioxide, and trace amounts of other constituents, such as hydrogen sulfide, hydrogen, nitrogen, and siloxanes.

Today, methane accounts for nearly 9% of domestic greenhouse gas emissions. Thirty six percent of these emissions come from the agricultural sector, equivalent to over 200 million tons of carbon pollution. While methane's lifetime in the atmosphere is much shorter than carbon dioxide, it is more efficient at trapping radiation. Pound for pound, the comparative impact of methane on climate change is over 20 times greater than carbon dioxide over a 100-year period. Although U.S. methane emissions have decreased by 11 percent since 1990, they are projected to increase through 2030 if additional action is not taken.

Biogas systems have the potential to capture methane that would escape into the atmosphere and utilize it to create energy (e.g., electricity, heat, vehicle fuel). Other byproducts of biogas systems include non-energy products such as nutrient rich soil amendments, pelletized and pumpable fertilizers, and even feedstock for plastics and chemicals. Successful biogas systems capture and use gas from landfills and/or the anaerobic digestion of wastewater biosolids, animal manure, and other organics for energy. Each system includes both the infrastructure to manage the organic wastes as well as the equipment to generate energy from the resulting biogas. These systems have been used on a commercial scale in the United States since the late 1970s, when concerns over energy prices and U.S. dependence on oil spurred interest in the use of recovered biogas as a source of energy.

While the landfill gas energy industry has matured over the last 40 years due to third-party private investment, a strong project development community, and federal incentives, the biogas industry as a whole has not advanced at the same rate. There are currently more than 630 landfill gas energy projects in place across the United States, with more than 2,000 MW of installed capacity for electricity generation and more than 310 million cubic feet per day of gas delivered for industrial purposes.[iii] Meanwhile, only 239 manure-based digesters are in operation across the United States. The landfill gas energy sector offers many lessons that could be applied to the biogas industry as a whole due to the similarities in project development and the technologies for processing and using the resultant biogas.

Differences between landfills and anaerobic digesters are clear; however, divisions based on feedstock sources are becoming blurred. While older biogas systems typically were designed to process one feedstock, new systems usually can accept a variety of organic materials. Traditional waste management systems and recycling or alternative processing options are now converging. Lines drawn between landfills, water resource recovery facilities, manure management, source-separated organics, and industrial waste streams are becoming harder to discern. Anaerobic digesters and biogas systems have become a hot topic for many local, state, and national discussions as policymakers recognize organic waste as a resource to use rather than a problem to manage.

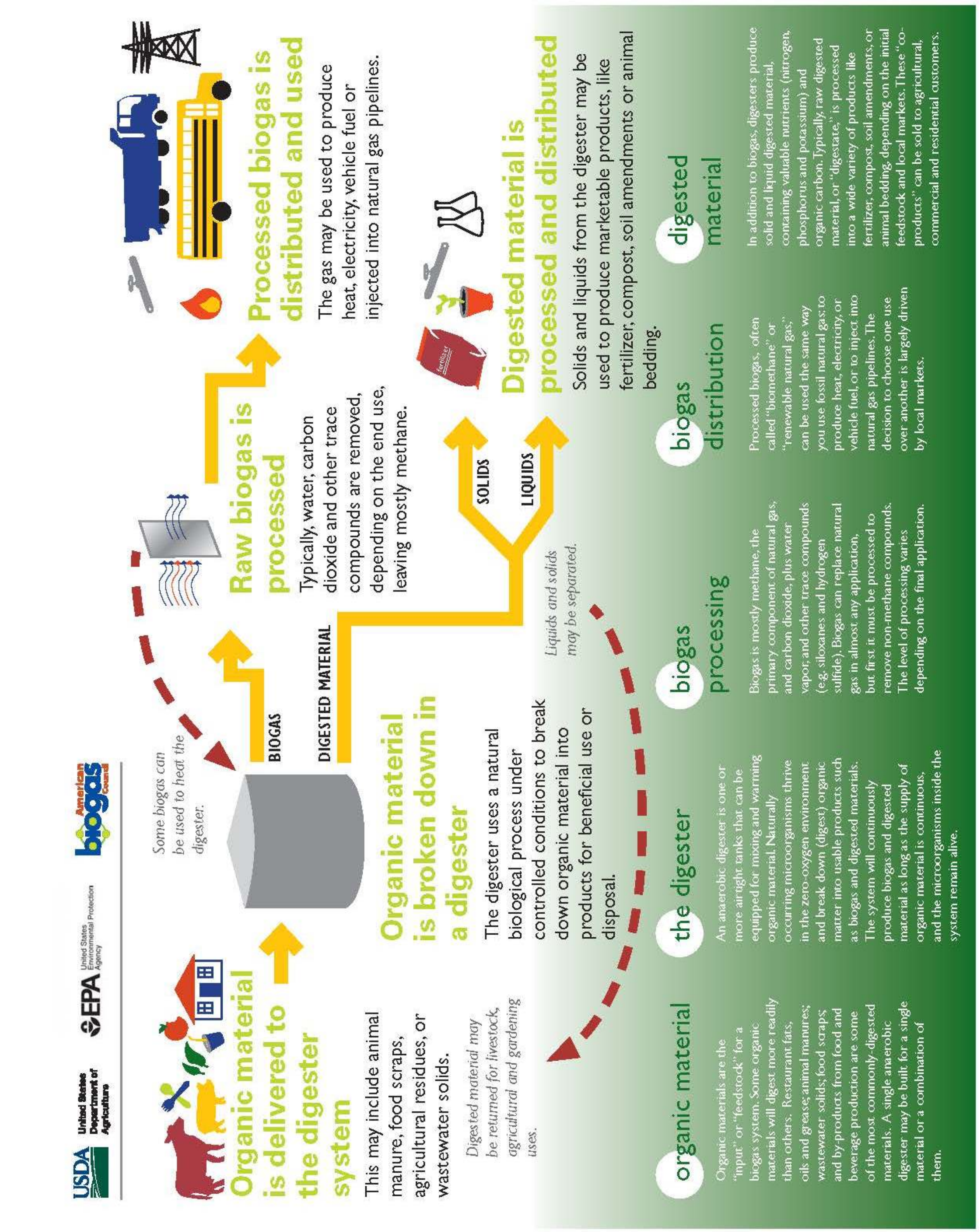

Figure 1 - Overview of Anaerobic Digester Systems

Biogas Feedstocks

A growing awareness of the resource potential of organic material discarded each day in the U.S. is inspiring interest in using organic waste as biogas system feedstocks. Historically, the feedstocks for most biogas systems have been livestock manure, wastewater sludge and, in the case of landfills, municipal solid waste. While new projects continue to use these traditional feedstocks, many projects are also using source-separated and industrial organics as either a primary or supplemental feedstock. The primary biogas system feedstocks include:

- Livestock manure – dairy, swine, poultry, and beef.
- Municipal solid waste – mixed MSW delivered to landfill (~30% organics).
- Wastewater biosolids and primary sludge – by-product of water recovery treatment process.
- Food loss and waste – the amount of edible food, postharvest, that is available for human consumption but is not consumed for any reason.
- Food production residuals – by-products of the food production and processing industry.

Blending Feedstock for Biogas Systems: A Growing Trend in America

A growing number of existing and planned projects combine multiple feedstocks within a given biogas system. Some examples of this exciting new trend include:

- In Ithaca, New York, the local municipal water resource recovery facility is co-digesting food waste with wastewater biosolids to provide an alternate waste management option and boost biogas production.
- In Rutland, Massachusetts, a digester accepts manure from 300 cows as well as residuals from ice cream and salad dressing production to increase tipping fee revenue and biogas output.
- In Arlington, Texas, a biogas system blends landfill gas and wastewater digester gas to fuel an energy plant that powers the facility and supplies energy to the grid.
- In Janesville, Wisconsin, the local wastewater treatment facility digests biosolids and food wastes, using the biogas to both power microturbines for electricity production and a unit to produce vehicle fuel.

Figure 2 - Harvest Energy Garden

- At the Harvest Energy Garden in Lake Buena Vista, Florida, wastewater biosolids, fats, oils, grease, and food waste from Walt Disney World and surrounding communities are fed into the digester to recover energy and nutrients, manage odors, process biosolids, and produce a high-quality organic fertilizer.

As the biogas industry deploys more digester facilities across the country, the potential for blending feedstocks from various sources will increase due primarily to decreased hauling distances.

II. Benefits of Biogas Systems

Biogas systems provide economic, energy, and environmental benefits for farms, businesses, and communities. These systems enable the capture and use of methane while also addressing waste management and nutrient recovery needs.

Biogas system products vary from energy (electricity, heat, fuel) to nutrient-rich soil amendments, pelletized and pumpable fertilizers, a renewable replacement for natural gas, and even feedstocks for renewable chemicals and bioplastics. The energy products typically come from the biogas, while the other products are made from the digested solid and liquid materials a biogas system produces.

Provide a Renewable Source of Energy
There are several different options for converting biogas to energy. Numerous factors such as project goals, local energy policies, infrastructure availability, and markets for renewable energy products will dictate what end use best fits the project. Unlike intermittent renewable energy alternatives such as wind and solar power, biogas delivers a continuous source of energy with a very high capacity factor. The flexibility and reliability of biogas systems are very important assets. Currently 37 states recognize biogas in their state renewable energy goals, and the U.S. government has set a target for 20 percent of the electricity consumed by Federal agencies to be from renewable energy by 2020. Biogas can assist in achieving these goals and provide many energy benefits. Specific commercially proven energy uses for biogas include:

Figure 3 - The Los Angeles County Sanitation District (LACSD) in California has operated a 50 megawatt (MW) landfill gas energy project at its Puente Hills Landfill since 1985, producing electricity for customers throughout Los Angeles.

Thermal applications: Biogas is used directly on-site to heat digesters and buildings/maintenance shops, to fuel boilers or kilns, and to generate heat or steam.

Power generation: Electricity is produced through an internal combustion engine, gas turbine, or microturbine technologies for on-site use or sale to the electric grid. Combined heat and power (CHP) systems increase overall energy efficiency of electricity systems by producing heat and electricity at the same time, which can be used for heating, cooling, dehumidification or other process applications. Unlike intermittent renewable energy sources, biogas systems are providing continuous dispatchable electricity onto the grid.

Industrial applications: Biogas can be used in industrial applications to offset use of natural gas, propane, fuel oil, or other fossil fuels. Many industries such as sugar refineries, distilleries, dairies, and paper mills generate processing and waste water that can be digested directly on site. The resulting biogas can then be used for fuel in equipment such as boilers, kilns (e.g., cement, pottery, brick), sludge dryers, infrared heaters, paint shop oven burners, tunnel furnaces, process heaters, and blacksmithing forges or for other direct thermal applications.

Biomethane injection: Upgraded and refined biogas, also called renewable natural gas (RNG), can be injected into existing natural gas networks.

Vehicle fuels: Upgraded biogas can be converted to various vehicle fuels including compressed natural gas, liquefied natural gas, hydrogen, and liquid transportation fuels.

Benefits of Combined Heat and Power:
Vander Haak Dairy was the first Washington State dairy to install an anaerobic digester. The dairy utilizes on-farm waste and manure from two neighboring operations. Biogas generated is burned in a reciprocating engine. Thirty to sixty percent of the engine heat is used to heat the digester and the rest is used to dry bedding fiber and heat a house. Excess heat is available to meet additional needs of the dairy.

Biogas may also be used for fuel cells, which, with appropriate cleanup to remove trace contaminants, chemically convert biogas directly into electricity. Like engine systems, fuel cell systems can be configured to produce heat as well as power. Certain fuel cell systems can also be configured to produce pure hydrogen, in addition to heat and power, known as trigeneration.

Currently in the United States, biogas fuels milk and recycling trucks, produces electricity for on-site and grid use, chills milk, heats greenhouses, produces steam, fires pottery and brick kilns, supplies pipeline quality gas, and provides fuel to local industrial plants. Projects range from small scale farm or community driven initiatives to multimillion-dollar private investments. Nearly 11,000 additional projects like these could be developed with the sources of biogas currently available in the United States.

Biogas Systems as 'BioRefineries'

There is a growing trend towards integrated biorefineries (biogas systems as sophisticated manufacturing centers) that are built to produce energy and high-value products as opposed to constructed as an add-on waste management process. These can involve a suite of technologies and processes to more efficiently and effectively process approved feedstocks to produce renewable fuels as well as marketable and valuable commodities and products, while potentially reducing environmental impacts. Primarily being developed by third-party private investors, these systems can be municipally owned, offering a good opportunity for public-private partnerships, or privately owned. As project developers look to more comprehensive solutions related to organic feedstocks, additional opportunities for biogas and co-product use are emerging. Some examples include:

- Biogas that is used to produce renewable hydrogen fuel for use in fuel cell applications.
- Biogas that is used as a feedstock for biodegradable plastics and intermediates for other bio-based product manufacturing.

- -Anaerobic digester systems that enable algal biomass and advanced biofuel production. This could include biogas to generate electrical power to run algae production and biorefinery systems; excess heat offtake to stabilize and regulate water temperature systems for open raceway pond and photobioreactors; generator set exhaust that serves as the necessary CO_2 source for algae production; and recycled digester effluent that provides a needed nutrient source to promote algae biomass and lipid production.

Using Food Waste for Energy

USDA estimates that in 2010, approximately 133 billion pounds of food from U.S. retail food stores, restaurants, and homes went uneaten. This represents 31% of the 430 billion pounds of the available food supply at the retail and consumer levels in 2010, with retail-level losses accounting for 10% (43 billion pounds) and consumer-level losses for 21% (90 billion pounds) of the available food supply.

With the U.S. Food Waste Challenge, the U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (EPA) have joined efforts to:

- Reduce food loss and waste,
- Recover wholesome food for human consumption, and
- Recycle food waste to other uses including animal feed, composting, and energy generation.

One objective of the U.S. Food Waste Challenge is to reduce the amount of food discarded to landfills. The EPA estimates that food waste is the single largest component of municipal solid waste going to landfills and that landfills are the third largest source of methane in the United States.

States, counties, and municipalities are helping to lead the way in reducing the amount of food waste discarded into landfills. Some are starting to mandate diversion of primarily commercial organics from landfills. Thus, more source-separated organics (SSO) are becoming available as feedstocks for biogas systems. Food production plants, universities, restaurants, hotels, and hospitals generate considerable volumes of organic wastes. Biogas systems can be designed and built specifically to process organic wastes on-site at these commercial facilities, or wastes from these sites can be transferred to serve as the feedstock for digesters at agricultural sites for improved food system resiliency. Some generators produce waste streams that are an economic liability to their operations but would be welcome financial additions to a biogas project, such as whey, residuals from bakery/brewery/winery, fats, oils and greases (FOG), due to the fact that these wastes produce high amounts of biogas.

The community digester at Sensenig Dairy in Kirkwood, Pennsylvania is fed six times a day with manure from cows, hogs and chickens, and community food waste. The project has reduced emissions and operational costs, while creating additional revenue from the sale of carbon credits, fertilizer, and bedding.

Drive Economic Growth

Biogas systems offer a wide range of potential revenue streams, growing jobs and boosting economic development in the community. These systems can also improve rural infrastructure for waste management and distributed energy delivery improving community health, resiliency, and viability. Biogas systems can produce high-quality, concentrated liquid organic fertilizer for improved land management and increased crop yield, building and maintaining healthy and productive soils needed for sustainable food production. Along with generating revenues from the sale of renewable energy products, outputs from biogas systems can offer avoided costs of on-site electricity, heat, and transportation fuel. Renewable electricity can be sold into the power grid, and is often the primary driver for many biogas project investments. However, energy off-take contracts are often insufficient to fully finance a biogas system, and to be feasible many projects must realize the broader value of co-products, such as separated nutrients, marketable fertilizers and soil amendments. Separated fibers from the effluent stream can also reduce operational expenses or increase revenue through the production and sale of animal bedding. While niche markets exist for these products locally, developing more reliable national markets would reduce time for system payback, making project financing more attractive.

Low-Emission Fuel for Vehicles

On a well-to-wheel (WTW) basis, a truck fueled with fossil natural gas (NG) produces only slightly less CO_2 equivalent (CO_2e) emissions per mile traveled than one fueled with gasoline (Argonne National Lab, GREET 2013, http://GREET.es.anl.gov). If that same compressed natural gas vehicle (CNGV) were fueled with RNG produced from the anaerobic digestion of manure or at a wastewater treatment plant (WWTP), there would also be a significant reduction in CO_2e emissions from currently uncaptured and/or flared biogas, thereby resulting in negative CO_2e emissions.

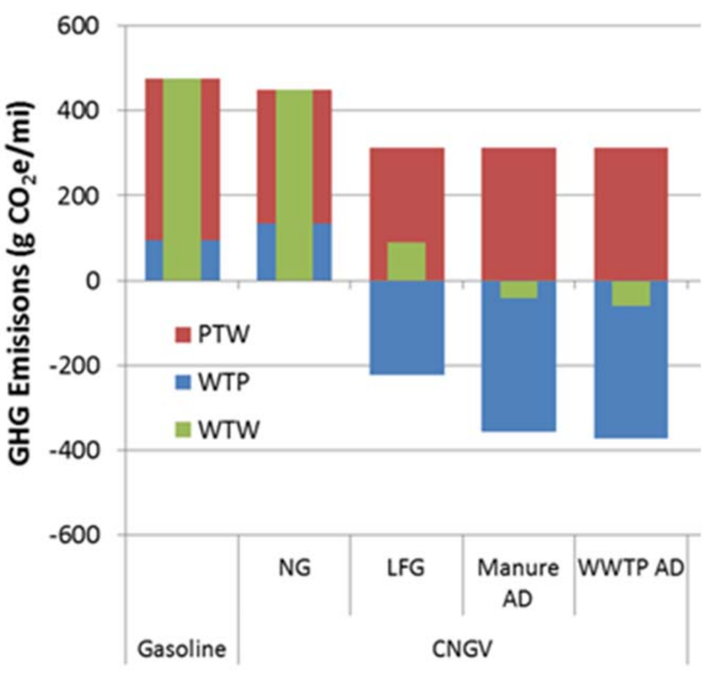

Figure 4 -Well to Wheel Emissions, Biogas v. Fossil Fuel Sources (PTW- Pump to Wheels, WTP- Well to Pump, LFG-

Additional opportunities exist for revenue generation from environmental attributes of the system, such as Renewable Energy Certificates (RECs) for electricity generation or Renewable Identification Number (RIN) credits under the Renewable Fuel Standard for the generation and use of biogas as vehicle fuel. There are also developing markets for carbon emission and nutrient offset credits, like that in California and the Chesapeake Bay watershed[iv], which provide opportunities to offset regulatory compliance costs with voluntary installation of biogas systems

All these potential financial returns can benefit project stakeholders and others involved in the biogas system. In addition, the federal government can provide environmental incentives to help defray infrastructure costs for systems which support conservation. For example, if a dairy farm installs a biogas system for enhanced manure management and renewable energy generation, cost-share funding from USDA's Environmental Quality Incentives Program (EQIP) could be combined with grant funding under USDA's Rural Energy for America Program (REAP) to help offset the investment.

Businesses and other organizations, such as universities and government facilities, can save on energy costs and achieve sustainability goals by choosing biogas as a direct fuel source in place of fossil fuels. Some end-users have saved millions of dollars over the duration of their biogas energy projects. Farmers and other companies who are recognized as leaders in sustainability and use of renewable energy may achieve indirect economic benefits through publicity of these accomplishments.

As with development of any energy project, biogas projects can benefit the local economy. Temporary jobs are created for the construction phase, while design and operation of the collection and energy recovery systems produce long-term jobs. Biogas energy projects involve engineers, construction firms, equipment vendors, and utilities or end users of the power produced. Some materials for the overall project may be purchased locally, and often local firms handle construction, electrical, plumbing, and other services.

Create Additional Revenue from Non-Energy Digester Products

In addition to energy, other potential revenue streams include nutrient recovery and management, tipping fees, thermal usage, bedding savings for farms, and carbon offsets, where available. Digestate liquids and solids (what remains after digestion) can produce additional economic benefits. The digestate has soil enhancement qualities and can be applied to growing crops, making it a marketable and valuable soil amendment. Reducing the need for synthetic fertilizers, the digestate delivers nutrients in a form that is more consistent, more readily absorbed, and more concentrated than raw manure. The use of digestate could provide a cost-savings to the farmer when compared to the purchase of synthetic fertilizers. Storage, mixing, pumping, and spreading digestate are easier than handling undigested organic materials, which can reduce energy demand and handling costs. Biogas production facilities designed to process landfill gas or source-separated organics (SSOs) provide economic benefits to the municipalities or waste management companies that own these facilities, as well as the broader community. Direct revenue sources include commercial tipping fees for SSOs.

An emerging benefit associated with biogas systems that use anaerobic digesters is the extraction of valuable nutrients, which supports environmentally and economically sound waste management. A number of systems, technologies, and procedures are available for nutrient recovery. The degree to which nutrients are removed depends on the value of the recovered nutrients, the need to produce clean water, and the economics of the technology used. Recovered nutrients offer an opportunity to create a "value-added" product that can be sold off-site as an organic amendment or as an organic fertilizer.

Cut Methane Emissions

Methane emissions in agricultural systems primarily come from three sources: livestock enteric fermentation, livestock manure waste, and rice cultivation. Manure management from dairy cattle, swine, and beef cattle operations in the United States accounts for 26% of all greenhouse gas emissions related to livestock sources.

Biogas systems can be used to capture methane that would escape into the atmosphere and contribute to climate change, and use it to create energy instead. The 239 livestock biogas systems currently operating in the U.S, reduce methane emissions by approximately 2 million metric tons of carbon dioxide equivalent annually. These projects provide enough renewable energy to power the equivalent of almost 70,000 average American homes.

The diversion of organics from landfills, collection of landfill gas and anaerobic digestion at waste water treatment plants can also decreases methane production and release.

Anaerobic digestion of livestock manure has been adopted by the State of California as an eligible project type for the generation of offsets under its statewide cap-and-trade program. This means that there is potentially a developing market demand for offsets from dairy and swine manure digester projects.

Protect the Environment
In addition to reducing methane emissions, some of the many environmental benefits of biogas systems include:

- Stabilization of nutrients for reduced water contamination risks, including substantial reduction of pathogens in manures and food wastes.
- Nutrient recovery and recycling.
- Reduction of odors during storage and decomposition.
- Providing a natural waste treatment process.
- Smaller physical footprint for organics waste processing versus composting.
- Reduced volume of waste for transport and land application.
- Efficient organic decomposition.

Digester systems protect America's waters by providing a step in broader biosolids treatment and nutrient management programs. The anaerobic digestion of manure and biosolids plays an important role in cost-effective wastewater treatment at thousands of facilities. Anaerobic digestion concentrates nutrients such as nitrogen and phosphorus, which can then be managed and diverted from water bodies to beneficial uses. With proper post-digestion nutrient management, biogas systems can thus improve water quality. Using an anaerobic digester to process organic wastes can help protect water quality. Pathogen levels can be reduced up to 99% compared to undigested manure. Anaerobic digestion is also an essential precursor to many advanced phosphorus and nitrogen separation technologies.

Biogas systems can offer significant improvements over traditional waste practices for organic material. While most organics other than manure find their way into landfills, companies and municipalities are looking to digesters for numerous environmental improvements.

Biogas systems must be properly designed and managed to operate effectively and avoid creating new environmental problems. Anaerobic digestion systems do not reduce the total amount of nutrients in the system or eliminate all organic wastes. For example, some of the organic nitrogen in the waste streams is converted to ammonium salts, which is easier for crops to utilize when incorporated into farmland. However, if not incorporated into the soil, ammonium salts can be converted to ammonia gas which is released, potentially at two to three times the rate of ammonia emissions from aerobic storage of organic waste streams. Similarly, some combustion equipment used to generate energy from biogas can increase air emissions as well. Therefore, it is important to evaluate the entire system holistically to determine impacts from pollutants of concern, including particulate matter, volatile organic compounds, nitrogen oxides (NO_x), ammonia, hydrogen sulfide, and greenhouse gases. In some instances the installation of a biogas system can necessitate additional controls and permitting requirements, which the project developers and stakeholders must be aware of and able to meet.

Overall, employing innovative digester systems with appropriate control of the nutrients, digestate solids and liquids, and air emissions could be a "win-win" for farmers, communities, the environment, and project investors. These efforts may lead to voluntary reductions in greenhouse gases and other air pollutants, pathogen load in runoff from farms, and the amount of organic wastes going to landfills. Communities that take appropriate actions to improve environmental quality, including the installation of biogas systems, can lower pollution control costs and extend the life of landfills. Economies of scale can be achieved by combining wastes from several sources.

Enhance Resilient Communities

Biogas systems can support sustainable communities by reducing methane emissions, improving water quality, producing a local source of renewable heat, electricity and fuel, and strengthening the local economy by reducing energy costs and generating revenue. They can also play a vital role in helping communities adapt and become more resilient to the effects of climate change. For example, the distributed nature of the biogas systems can increase the reliability of critical services – food, energy, waste management, wastewater treatment, and transportation – during and after disasters. Biogas systems are potentially less vulnerable to grid failures that can halt vital services. For example, a wastewater treatment or food production that is powered by onsite biogas could continue operation during a grid-wide power outage. Biogas system products could also be used to produce a renewable transportation fuel for routine use or should traditional sources be temporarily cut off.

Today's clean water agencies are increasingly considering how they can improve environmental performance, benefit their communities and improve their financial picture. The Water Resources Utility of the Future (UOTF) initiative encourages water utility leaders who are using innovative technologies and cutting-edge practices to focus on resource recovery including energy production, water reuse, green infrastructure or watershed-based approaches. The National Association of Clean Water Agencies, the Water Environment Research Foundation (WERF), and the Water Environment Federation (WEF) released the *Water Resources Utility of the Future . . . Blueprint for Action* to define relevant issues, analyze key data, and offer recommendations for critical actions for the future. Currently more than 1,200 water resource recovery facilities have anaerobic digester systems, and more than 2,400 additional facilities could install an anaerobic digester on site. Working closely with the water resource utilities is one important way to help grow the biogas industry and enhance wastewater resiliency.[v]

Furthermore, putting food waste in digesters helps close the food system loop. Connecting food waste and nutrients back to the farm creates synergies and resiliency for agriculture's adaptation needs.

The Columbus, Ohio, Merchant Digester produces biogas from municipal wastewater biosolids, food and beverage wastes, and fats-oils-and greases. The biogas is converted to CNG and electricity to supply community needs for transportation, fuel, and power. The effluent is a high-value liquid fertilizer for use on farms and community landscapes.

As an example, public and private partners in Columbus, Ohio added anaerobic digesters to the municipal wastewater treatment plant to process 300 tons per day of organic waste. The plant now produces enough biogas to generate one megawatt (MW) of electricity and 1,200 gasoline gallon equivalents (GGE) per day of CNG transportation fuel plus 90,000 gallons per day of nutrient-rich fertilizer for agricultural and landscape uses.

III. Biogas Potential in the United States

There are vast organic resources available to feed biogas systems in the United States, with the primary feedstock sources being livestock manure, food waste, landfill gas, water resource recovery facility biosolids, and food production residuals. The decomposition of these organic materials can release methane, a potent greenhouse gas that has an effect on global temperatures that is over 20 times greater than carbon dioxide over a 100-year period. Already:

- Thirty-six percent of human-related methane emissions come from the agricultural sector in the United States, equivalent to more than 200 million tons of carbon dioxide pollution.[vi]
- Municipal solid waste landfills account for approximately 100 million metric tons of carbon dioxide equivalent pollution.[vii] While more than 600 landfills currently capture and use landfill gas for energy, hundreds of additional landfills are capturing their gas for compliance and safety but flare it without producing energy.
- In 2010, more than 130 billion pounds of food meant for human consumption at the retail and consumer levels was not consumed; this is the equivalent of approximately $160 billion worth of food.[viii]
- In 2011, more than 34 million tons of food waste was landfilled or otherwise disposed of in ways that do not allow for nutrient recovery.
- More than 1,200 water resource recovery facilities across the United States use anaerobic digestion for biosolids management, thereby producing biogas that could be captured[ix]
- Food production and processing facilities (e.g., milk processing, breweries, wineries, juice plants) produce large volumes of industrial organics as a by-product of their processes. While a number of these facilities have installed on-site digesters to manage these wastes, many more processors could produce biogas by installing digesters.

If captured and managed in a biogas system, these resources could yield substantial energy and bio-based product resources while providing environmentally sound management. According to U.S. Federal government and industry sources, the United States has more than 2,000 operational biogas systems out of more than 13,000 potential sites that could host a biogas system with manure, landfill gas and water recovery facility biosolids as feedstocks[x]. The potential for these systems to generate energy and reduce greenhouse gases is summarized in the following tables.

Currently Operational and Potential Biogas Systems in the United States				
	Livestock Manure	Landfill Gas	Water Resource Recovery Facilities	Total
Currently Operational Biogas Systems	239[xi]	636[xii]	1,241[xiii]	2,116
Total Potential Number of Biogas Systems	8,241[xiv]	1,086[xv]	3,681[xvi]	13,008

Figure 5 - Currently Operational and Potential Biogas Systems in the United States
Creating Energy

If the potential projects outlined in Figure 5 were fully realized, biogas could become a significant reliable renewable energy source. When taken together, these biogas sources could provide 41 billion kWh/year of electricity from 654 billion cubic feet of biogas/year. This is enough energy to power more than 3 million U.S. homes for one year or to produce the equivalent of 2.5 billion gallons of gasoline for vehicles.

Estimated Energy Potential from Biogas Sources in the United States[xvii]				
	Livestock Manure	Landfill Gas	Water Resource Recovery Facilities	Total
Biogas Production Potential (billion cubic feet/year)	257[xviii]	284[xix]	113[xx]	654
Annual Energy Production Potential (MMBTU/year)	142,000,000[xxi]	142,000,000[xxii]	67,000,000[xxiii]	351,000,000
Annual Electricity Potential (billion kWh/year)	13.1[xxiv]	22.5[xxv]	5.6[xxvi]	41.2
Equivalent Residential Electricity Use (1000 homes/year)[xxvii]	1,089	1,864	539	3,492
Potential Vehicle Fuel Gallons Displaced (million GGE)[xxviii]	1,031	1,028	441	2,499

Figure 6 - Energy Potential from Biogas Sources in the United States

Cutting Carbon Pollution

Biogas capture from landfills, livestock operations and water resource recovery facilities can lead to significant reductions in U.S. greenhouse gas emissions. According to the *Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030*, annual methane reductions from the landfill, livestock and wastewater sectors could range from almost 4 to 54 million metric tons of greenhouse gas emissions in 2030, depending on the cost-effectiveness of various abatement options[xxix]. These reductions are equivalent to the annual greenhouse gas emissions of between 800,000 and 11 million passenger vehicles.

Boosting the Economy

In estimating the market potential for full deployment, a lack of consolidated financial and technical data for the biogas industry limited analysis which could be done by federal agencies. Based on a survey with the industry and project developers reflecting current deployment, building those 11,000 potential systems would result in an estimated $33 billion in capital deployment for construction activity which would result in approximately 275,000 short-term construction jobs and 18,000 permanent jobs to build and run the digesters.[xxx] This number does not reflect the full market impact of biogas, which would also include energy and product sales and potential environmental credits. A complete economic analysis of the benefits of expanding biogas systems is not available; however, a study[xxxi] examining the market potential from installing digesters on 2,647 dairy operations provides insight into the potential value.

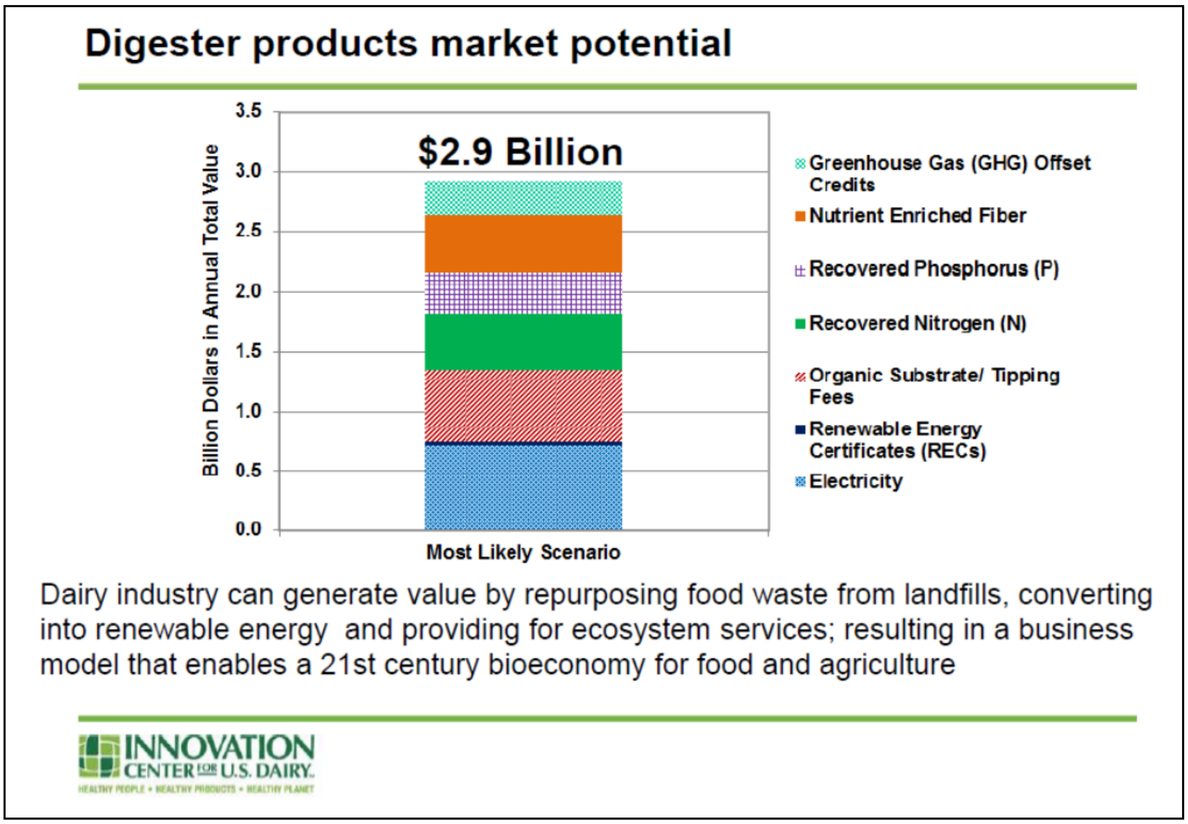

Figure 7 – Dairy digester products market potential based on Informa Economics analysis

Realizing the Potential of Biogas Systems

Fully realizing the market potential of biogas systems will take significant investment by livestock producers, municipalities, food producers, the private waste sector, and project developers. An integrated approach will be necessary to overcome the barriers limiting growth of the biogas industry. Critical efforts to promote development of biogas include:

- Support from federal agencies, including modifications or expansions of programs that advance biogas systems.
- Greater private investment in biogas systems.
- Development of broader markets for biogas and biogas system products.
- Increased emphasis on research and development to optimize systems.

IV. Primary Barriers to Realizing the Full Potential of a U.S. Biogas Industry

While there is a growing understanding among investors, policymakers, and the public of the value of investing in renewable energy systems, there remain significant barriers toward achieving a robust U.S. biogas industry.

- **Lack of Awareness of Biogas Benefits.** Investors, policy makers, and the public could benefit from gaining a deeper understanding of the value of investing in biogas systems and a biogas industry in the United States. Greater public support for the adoption of biogas systems could result in more opportunity for biogas development.

- **Unpredictable Biogas Market Conditions**. Market unpredictability is a prime barrier toward greater investment in biogas systems. Unpredictability arises from multiple factors, including uncertainty and inconsistency in state and national energy policy, which restricts access to financial markets. Further market uncertainty arises when consumers perceive inconsistency in the quality or quantity of biogas systems or in the safety and quality of solid and liquid end products from digesters.

- **Lack of Market Maturity.** Underdeveloped markets for greenhouse gas reduction benefits pose a significant barrier toward biogas systems adoption. Additionally, immature markets for non-energy products– such as nutrient rich soil amendments, pelletized and pumpable fertilizers and feedstock for plastics – also reduce incentives to invest. Additionally,there is a need for a classification system for the use of digested solid and liquid residuals to encourage consumer confidence in product safety and consistency.

- **Lack of Full Valuation.** It is difficult for small generators to interconnect to the grid and to receive a fair market price that reflects the full environmental value provided. Overall, the high project costs without financial recognition of the non-energy servicescreate a barrier toward widespread investment in biogas systems.

- **Inconsistencies across Federal, State, and Local Governments.** Fragmentation of existing resources, regulatory authorities, and jurisdictions at the Federal, State, and local levels affect biogas system implementation. Additionally, fragmented efforts within and among Federal agencies to inform stakeholders, State and Tribal governments, and the public of the regulations, policies, practices, and potential funding of biogas systems create additional barriers.

- **Lack of Technical and Applied Research & Development**. The United States currently lacks adequate environmental, technical, and economic performance data related to biogas-system production of energy, co-products, greenhouse gas and other emissions, and water quality benefits. Consolidation of this data could help market analysis and underwriting**.** There is also a need for more advanced research in the United States related to renewable energy and biogas co-product benefits, including a better understanding of barriers by sector that prevent full utilization of anaerobic digester capacity and digestion of feedstocks.

V. Solutions to Enhance Biogas Potential

In order to help the private sector voluntarily realize the full potential of biogas systems, the Roadmap identifies near terms voluntary actions the government will take to promote biogas utilization through existing programs, foster investment and strengthen markets for biogas systems and products, and improve coordination and communication. Together, these actions will increase the use of biogas to meet our renewable energy goals, strengthen the economy, and reduce methane emissions.

Promote Biogas Utilization through Existing Agency Programs

A number of programs at USDA, DOE, and EPA are driving the development of biogas systems. AgSTAR and the Landfill Methane Outreach Program (LMOP) are dedicated to promoting biogas utilization from the livestock and landfill sectors in order to reduce greenhouse gas emissions. The Rural Energy for America Program, Environmental Quality Incentives Program, Bioenergy Program for Advanced Biofuel, Biorefinery Assistance Program, and Conservation Innovation Grants provide funding for biogas systems and components. USDA, DOE, and EPA will use existing programs as a vehicle to enhance the utilization of biogas systems in the U.S through:

Promoting Biogas Systems in Federal Tools

- EPA recently released a National Agricultural Anaerobic Digestion Mapping Tool that allows users to view and analyze information about the current status and potential for biogas recovery systems in the agriculture sector.
- EPA is currently updating its Waste Reduction Model, which helps solid waste planners and organizations track and voluntarily report GHG emissions from several different waste management practices, to include anaerobic digestion.
- EPA is preparing updates to the Pacific Southwest region Co-Digestion Economic Analysis Tool, which assesses the initial validity of food waste co-digestion at wastewater treatment plants for the purposes of biogas production.

Technical and Financial Assistance: USDA's Natural Resources Conservation Service (NRCS) provides technical and financial assistance to farmers and ranchers for voluntary conservation practices. The NRCS will conduct a full review of the standards used to determine which conservation practices are eligible to receive technical and financial assistance through the Environmental Quality Incentives Program (EQIP) and other programs to ensure that they recognize the full environmental benefits of modern anaerobic digesters. Accounting for these conservation benefits (e.g., methane destruction, manure separation and nutrient recovery, manure pipelines, and manure application) will enhance the amount of financial and technical assistance available to farmers and ranchers using biogas systems.

Research and New Technology: USDA's Agricultural Research Service and National Institute of Food and Agriculture will leverage over $10 million in research funding for anaerobic digesters to improve research for nutrient recovery, particularly nitrogen and phosphorus, from biodigester effluent and solids and investigate agronomic and economic viability of using captured nutrients as commercial fertilizers and soil amendments. USDA will also continue evaluating the carbon sequestration and soil productivity potential of biochar production from biodigester solids. These results will be communicated to stakeholders (e.g. industry, regulatory agencies, and private carbon market entities) to accelerate the adoption of anaerobic digester systems. In addition, DOE will further integrate biogas and biosolids systems into the Bioenergy

Technologies Office program and develop a research plan to implement the recommendations of the Biomass Research & Development Technical Advisory Committee to accelerate development of bio-based products from biogas systems.

Partnerships: EPA will continue to engage stakeholders to address barriers to deploying biogas systems through existing programs, such as AgSTAR, the Landfill Methane Outreach Program, the Combined Heat and Power Partnership, and the Sustainable Materials Management program, including increasing outreach to state and regional partners on the benefits of biogas systems.

Transportation Fuel: DOE will include renewable natural gas from biogas as a clean energy option for research and development in the Vehicle Technology Office's Fuel and Lubricant Technologies Program to drive additional research on the utilization on biogas as a transportation fuel. DOE will also strengthen programs that support the use of renewable natural gas from biogas to compressed or liquid vehicle fuel directly; as feedstock to develop other renewable vehicle fuels (e.g., hydrogen, DME, etc.) and generate renewable liquid fuels (e.g., gasoline, diesel, jet fuel); and as a tool to increase fuel efficiency of vehicles. DOE will also increase the visibility of their existing commitment to support the use of renewable natural gas as a part of the Clean Cities Program's.

Renewable Energy: DOE will analyze the impact that biogas energy can have on electricity generation and fuel production in the U.S and its potential role as a drop-in biofuel and explore and map ways to integrate biogas with wind and solar for distributed renewable energy.

<u>Biogas under the Renewable Fuel Standard</u>

EPA has recognized the benefits of promoting net low-carbon fuels derived from biogas, and in a recent rulemaking EPA classified many sources of biogas as cellulosic feedstock for transportation fuels as part of the Renewable Fuel Standard (RFS). Cellulosic biofuels are the highest level of advanced biofuels specified in the RFS and achieve greater than 60% greenhouse gas (GHG) reductions as compared to the fossil fuels they replace. Use of biogas derived fuels in the transportation sector can substantially reduce GHG emissions and can serve to promote effective organic waste management, as well as efficient biogas production, recovery and utilization. Further, use of biogas under the RFS can improve anaerobic digester economics by allowing biogas producers to generate Renewable Identification Numbers (RINs).

http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm

<u>Fostering Investment in Biogas Systems</u>

High initial project costs create a barrier for the widespread investment in biogas systems. To begin to overcome this challenge, USDA, DOE, and EPA will take the following actions:

Propose NAICS Codes for Biogas Systems: The lack of NAICS codes for biogas systems has prevented the collection and analysis of industry financial and technical data needed to track the performance of anaerobic digesters. To address this, the Administration will assess the efficacy of developing NAICS codes for biogas systems, and if appropriate, submit a proposal for the development of a NAICS classification for biogas systems for consideration by the Economic Classification Policy Committee and the Office of Management and Budget.

Enhance Federal Financing: USDA and DOE will review applicable current loan and grant programs to enhance the financing options available for biogas systems. This includes exploring unique funding strategies for which biogas could qualify, including the Rural Utility Service's

Energy Efficiency Conservation Loan Program along with the traditional Electric Loan Program, and improving access to capital under the Rural Energy for America Program. USDA will also work with the financial community through its partnership with the dairy industry to help them better understand the risks of biogas projects to encourage additional investment.

Lead by Example: To further the development and deployment of biogas systems, within 90 days, the USDA and partners will review federal procurement guidelines for alternative fuel use and renewable energy procurement and provide recommendations to CEQ and OMB, including the Office of Federal Procurement Policy, for ensuring that products of biogas systems are eligible for and promoted by applicable government procurement programs.

Strengthening Markets for Biogas Systems and Products

According to investors, market unpredictability is a prime barrier to greater investment in biogas systems. Immature markets for biogas energy and products are also limiting development of this technology. To strengthen U.S. markets for biogas systems energy and their value-added, non-energy products, such as recovered nutrients, fiber, and soil amendments, USDA, DOE, and EPA will take the following actions:

Accelerate the Use of Biogas in Clean Energy Markets: Already, 37 states consider biogas a renewable source of energy in their renewable energy targets. USDA, DOE, and EPA will continue to work with the appropriate state and local agencies to recognize biogas' role in supporting local and state environmental and renewable energy goals and ensure that biogas systems' contribution to greenhouse gas reductions, renewable energy generation, environmental improvements and energy security are recognized. USDA, DOE, and EPA will also review opportunities to overcome barriers to integrating biogas into electricity and renewable natural gas markets through the following mechanisms:

- Electric utility and natural gas interconnection standards;
- Interconnection fee structures;
- Natural gas pipeline injection standards;
- Fair market access and right to wheel provisions;
- Net-metering; and
- Current federal incentives provided for renewable energy generation.

Promote Products of Biogas Systems: USDA, EPA, and DOE will drive the creation of tools to broaden the market for non-energy biogas system products. These tools could include best management practices for digestate use and land application, particularly in targeted watersheds with nutrient trading potential.USDA, DOE, and EPA will also provide information on the ability of biogas system products to participate in markets that provide environmental benefits. This includes working to inform decisions that could increase the degree to which biogas receives credit related to renewable electricity, fuel, carbon reductions, and water quality improvements (e.g., RECs, RINs, carbon offsets, nutrient trading credits). USDA, DOE, and EPA will analyze markets for energy and non-energy products of biogas systems and the benefits these will generate. The energy and value-added products include:

- Electricity, heat, renewable natural gas, vehicle fuels.
- Nutrients, fertilizer, fiber, soil amendments.
- Liquid biofuels, renewable chemicals, intermediaries and bio-based products.

Improving Coordination & Communication

Strengthening communication across Federal agencies, state and local levels of government will be imperative to increase the adoption of biogas systems. To overcome this barrier, USDA, DOE, and EPA will:

Establish a Biogas Opportunities Roadmap Working Group: In order to implement the strategies laid out in this document and promote strong coordination and messaging across Federal agencies, USDA will establish a Biogas Opportunities Roadmap Working Group that will include participation from DOE and EPA, as well as the dairy and biogas industry. The working group will commit to collaborating with industry to publish a progress report in August 2015 that identifies and prioritizes policies and technology opportunities to expand the biogas industry and reduce greenhouse gas emissions. A key component of this effort will be to assess existing and potential interagency cooperative structures, specifically EPA's and USDA's AgSTAR Program; DOE's and USDA's Biomass Research & Development Initiative; the EPA, USDA, and DOE "Biodigesters and Biogas" Workgroup; and the EPA, USDA, and USGS integrated nutrient management strategy.

Improve Information Sharing: USDA, DOE, and EPA will work together to improve existing information on biogas systems within government programs. This will include updating biogas data and links to resources that describe the benefits of biogas to reflect current knowledge and state of the industry on Federal websites. The Agencies will also provide guidance on incorporating biogas systems within existing technical assistance and market programs, including anaerobic digestion as a component of relevant project development tools. Agencies will also review current information related to renewable energy and other relevant initiatives to identify where additional coverage of biogas systems can help accelerate biogas system deployment.

Research and Development: USDA, DOE, and EPA will also continue to improve communication and coordination of research and development among government agencies, industry groups, and the public. Better communication of research results will aid industry's efforts to continue making advancements in the biogas sector. To initiate this process, the Biogas Opportunities Roadmap Working Group will identify research gaps in biogas and anaerobic digestion technology, including environmental benefits, market assessment, and performance standards. Examples for possible investigation could include:

- Nutrient capture technology and markets;
- U.S. biogas feedstock and biogas energy markets;
- Advanced biogas technology applications such as biochemical and algae production, carbon black, nano-fibers, biochar, fuel cell, and bio-plastic;
- Potential impact of biogas energy as first mover for other distributed renewable energy resources;
- Standards and testing for digester performance and solid and liquid residuals quality control;
- Biogas systems as infrastructure resiliency in municipal, natural disaster, and military applications;

- Logistics and infrastructure requirements for organic materials diverted from landfills to farms and community waste water treatment; and
- Biogas systems to improve rural and urban water resource recovery and treatment.

USDA, DOE, EPA Programs for Biogas Utilization

USDA, EPA, and DOE have targeted programs aimed at facilitating better communication and coordination. As the actions in the Roadmap are implemented, the agencies will utilize these programs to effectively disseminate new information to interested parties. For example, USDA and EPA will use the Food Waste Challenge to educate target audiences, especially organic waste generators, on the benefits of organics recycling using biogas systems. Additional examples of existing programs include:

USDA has programs from applied research to end use markets and financial and technical assistance programs to assist in deployment and assistance on biogas systems and, since 2009, has worked closely with the Dairy Industry to capture triple-bottom-line benefits with biogas systems. USDA's primary programs for funding biogas systems are the Rural Energy for America Program, the Environmental Quality Incentives Program, Bioenergy Program for Advanced Biofuel, Biorefinery Assistance Program, and Conservation Innovation Grant, among others. Information on these programs, past investments and other tools for project development can be found at www.USDA.gov/Energy.

EPA currently provides a wide range of information related to biogas systems, including educational materials describing biogas systems and their benefits, profiles of biogas facilities, and technical information and tools to help stakeholders evaluate the feasibility of potential biogas projects. More information on these tools can be found at www.epa.gov/agstar.

DOE is developing advanced "drop-in" biofuels, which take advantage of existing infrastructure by providing nearly identical biobased substitutes for derived intermediates gasoline, diesel fuel, jet fuel, and chemicals and other products from crude oil. DOE has also made pioneering advances to reduce costs and establish best practices for harvesting, handling, and preprocessing a variety of crops for energy production. DOE's Bioenergy Technologies Office is focused on forming cost-share partnerships with key stakeholders to develop and demonstrate technologies for advanced biofuels production from lignocellulosic and algal biomass and waste streams. Additional information can be found at:

http://energy.gov/eere/transportation/bioenergy
http://www1.eere.energy.gov/financing/current_opportunities.html

VI. Conclusion

Developing a viable biogas industry in the United States can boost the economy and provide a reliable, distributed source of renewable energy while reducing greenhouse gas emissions. Increasing production of biogas not only supports President Obama's Climate Action Plan goal of cutting methane emissions, but it also increases energy independence and security.

Biogas systems are currently installed primarily to manage wastes, but can also improve profitability for operations through energy and co-product sales, nutrient recovery and avoided energy costs. These new revenue streams come along with the added benefits of reducing greenhouse gas emissions, improving water quality, and limiting odors. Although 2,000 sites operate today, more than 11,000 additional biogas systems could be employed to handle organic waste and produce energy and biogas system co-products. Biogas can play a critical role in the sustainability and viability of communities throughout the U.S.

Realizing the full potential for the biogas industry will require support from federal agencies, greater investment, expanded markets for biogas and biogas products, and increased research and development. The benefits of biogas systems are clear. The task ahead is to reduce barriers and promote financial opportunities to move forward in developing a robust biogas industry.

Endnotes

[i] Capper, J.L., Cady, R.A., Bauman, D.E. 2009. The environmental impact of dairy production: 1944 compared with 2007. Journal of animal science, 87 (6), 2160-2167

[ii] Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., & Tempio, G. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

[iii] USEPA Landfill Methane Outreach Program

[iv] http://www.wri.org/publication/comparison-tables-state-nutrient-trading-programs-chesapeake-bay-watershed

[v] http://www.nacwa.org/index.php?option=com_content&view=article&id=1604&Itemid=250

[vi] Climate Action Plan: Strategy to Reduce Methane Emissions, March 2014

[vii] ibid

[viii] The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States, USDA Economic Research Service, February 2014

[ix] Water Environment Federation

[x] More biogas systems based on dedicated food production and processing facilities could also be built, although it is more difficult to estimate the full market potential due to a lack of industry data in those sectors.

[xi] http://epa.gov/agstar/projects/index.html

[xii] http://www.epa.gov/lmop/projects-candidates/index.html

[xiii] http://www.wrrfdata.org/biogas/biogasdata.php

[xiv] http://epa.gov/agstar/documents/biogas_recovery_systems_screenres.pdf

[xv] http://www.epa.gov/lmop/projects-candidates/index.html (Added current + potential)

[xvi] Assuming facilities with an average flow > 1 million gallons per day are potential sites. http://www.wrrfdata.org/biogas/ and EPA 2008 Clean Watershed Needs Survey

[xvii] The energy production potential and methane estimates were calculated using two difference mythologies. For further information on the methodology refer to the sources cited in each section.

[xviii] Assuming biogas from livestock manure is 60% methane; http://epa.gov/agstar/documents/biogas_recovery_systems_screenres.pdf

[xix] Adding current + potential biogas production potential from http://www.epa.gov/lmop/projects-candidates/index.html (460 +317 mmscfd * 365 days/year = 283.605 billion ft3/year)

[xx] Utilities of the Future Energy Findings, Steve Tarallo, et. al published by WERF under ENER6C13 estimate fall 2014

[xxi] http://epa.gov/agstar/documents/biogas_recovery_systems_screenres.pdf

[xxii] Using potential biogas production above and a biogas energy content of 500Btu/scf. http://www.epa.gov/lmop/faq/landfill-gas.html

[xxiii] Utilities of the Future Energy Findings, Steve Tarallo, et. al published by WERF under ENER6C13 estimate fall 2014

[xxiv] http://epa.gov/agstar/documents/biogas_recovery_systems_screenres.pdf

[xxv] Used current + potential electricity potential from: http://www.epa.gov/lmop/projects-candidates/index.html and converted MW to kWh/year using (MW*24 hrs/day * 365 days/year *.9 time online)

[xxvi] http://www.werf.org/c/_FinalReportPDFs/OWSO/OWSO11C10.aspx

[xxvii] Calculated based on 12,069 kWh/home/year (EIA2013a) - http://www.epa.gov/cleanenergy/energy-resources/refs.html

[xxviii] Calculated using HHV of gasoline from: http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf and a 90% system efficiency.

[xxix] Global Mitigation of Non-CO2 Greenhouse Gases: 2010-2030, EPA Report 430R13011, September 2013

[xxx] based on industry survey of current project developers and assumes $3M capital cost, 25 construction job, 1.66 permanent job per project

[xxxi] National Market Value of Anaerobic Digester Products, Informa Economics, February 2013