VII.5 Biogas Resources Characterization

Ali A. Jalalzadeh-Azar (Primary Contact), Genevieve Saur, and Anthony Lopez
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3305
Phone: (303) 384-7562
E-mail: Ali.Jalalzadeh@nrel.gov

DOE Technology Development Manager:
Fred Joseck
Phone: (202) 586-7932
E-mail: Fred.Joseck@ee.doe.gov

Project Start Date: August 15, 2009
Project End Date: September 30, 2010

Objectives

- Develop a cost-analysis tool for biomethane production from biogas and delivery of biomethane based on the H2A Production and H2A Delivery models, respectively.
- Collect Geographical Information System (GIS) data on select biogas resources–dairy farms, landfills, and sewage treatment plants–in California and cost data on biogas upgrading systems.
- Perform techno-economic analyses for scenarios involving production of biomethane from dairy digester biogas and delivery of the product gas to natural gas pipeline or another end-use site.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section (4.0) of the Fuel Cells Technologies Program's Multi-Year Research, Development and Demonstration Plan [1]:

(B) Stove-piped/Siloed Analytical Capability
(C) Inconsistent Data, Assumptions and Guidelines
(D) Suite of Models and Tools

Contribution to Achievement of DOE Systems Analysis Milestones

This project contributed to achievement of the following DOE milestones from the Systems Analysis section (4.0) of the DOE Fuel Cell Technologies Program's Multi-Year Research, Development and Demonstration Plan:

- Milestone 5: Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for various hydrogen scenarios. (4Q, 2009)
- Milestone 8: Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for technology readiness. (4Q, 2014)
- Milestone 11: Complete environmental analysis of the technology environmental impacts for the hydrogen scenarios and technology readiness. (2Q, 2015)
- Milestone 26: Annual model update and validation. (4Q, 2010)
- Milestone 39: Annual update of Analysis Portfolio. (4Q, 2010; 4Q, 2011)
- Milestone 41: Annual Analysis Conference for the hydrogen community. (4Q, 2010; 4Q, 2011)

Accomplishments

- Based on the H2A Production and H2A Delivery models, developed the H2A Biomethane, cost analysis model for biomethane production and delivery. The model determines the levelized cost of biomethane at the production site and point of delivery. It also estimates the energy consumption and emissions for the biogas upgrading system, the upstream processes, and downstream pressure-boosting compressors.
- Using GIS analysis tools, collected and evaluated geo-spatial data for biogas potential from landfills, dairy farms, and sewage treatment plants in the state of California.
- Performed a techno-economic analysis to (1) address the impact of biogas feed capacity (flow rate) on unit cost of biomethane, (2) evaluate economic feasibility of transporting the biomethane product to a natural gas pipeline, and (3) determine the critical cost components and identify opportunities for cost reduction.
- Determined that (1) the levelized cost of biomethane is greatly influenced by the wide variations in the costs of biogas and biomethane transport to a natural gas pipeline, and (2) biomethane produced from dairy-farm biogas can be economically competitive with natural gas for large-scale systems.

✧ ✧ ✧ ✧ ✧

Introduction

Production of biomethane (predominantly methane) from biogas presents an opportunity to reduce emissions and augment the natural gas supply. Along with these attributes, the evolving requirements of renewable portfolio standards, environmental regulations, and the available incentives are among the drivers for biomethane production and utilization. To determine the energy, economic, and environmental potential of biomethane, analysis tools, GIS data, and cost data are required, forming the premise of this project. Although biogas can be extracted from a variety of bio wastes and energy crops, stranded biogas from dairy farms, landfills, and sewage treatment plants is the primary focus here.

As a primary objective of this project, a cost-analysis model, H2A Biomethane, was developed to help perform technoeconomic analyses of scenarios involving production of biomethane from biogas and pipeline connection to the natural gas network or another demand site. Inclusion of the grid-connection feature was based on the realization that export of biomethane to the natural gas grid can expand the market for the potential biogas producers and consumers. Geo-spatial data on biogas resources (dairy farms, landfills, and sewage treatment plants) were collected for the state of California and analyzed using GIS mapping to evaluate the biogas potential in conjunction with the current natural gas consumption. Using the H2A Biomethane model, along with the GIS and cost data, "what-if" analyses were performed for scenarios focusing on biomethane production from biogas and its transport for injection into the natural pipeline.

Approach

The new analysis tool, H2A Biomethane, was developed based on the vetted H2A Production and Delivery models [2,3] that are intended to be transparent with respect to the key assumptions and procedures for calculation of the costs, energy consumption, and emissions. The methodology described in reference [4] was applied for estimating the energy requirements and emissions associated with dairy digester biogas. Reference [5] was also consulted in developing a data set for biomethane (natural gas) pipeline construction. The new model offers versatility in characterizing the upgrading process and the pipeline for transportation of the product biomethane to the natural gas grid or to another end-use site. To determine reasonable default values for the input variables/parameters of the model, cost data were collected from vender, literature, and real-world projects involving biomethatne production from biogas. Use of these sources of data helped develop validated default values with reasonable accuracy.

The preliminary techno-economic analyses conducted in this project are intended to demonstrate the capabilities of the new cost-analysis tool and to provide an insight on the cost structure for biomethane production and delivery. These analyses focus on the relative significance of the various cost components (e.g., costs of feed biogas, upgrading/cleanup process, and delivery pipeline) and explore their variation with the feed biogas capacity. Efforts are made to maintain consistency between the delivery component of this model and the H2A Delivery model in handling the pipeline extension and compression. The results of these and future analyses can lend themselves to stakeholders, including dairy farm owners, municipalities, and policy makers. This notion, coupled with the need for realistic data and practical considerations, prompted formation of a panel discussion with the stakeholders at an early stage of the project.

Results

GIS Analysis

Figure 1 presents the GIS map for the three biogas resources–dairy farms, landfills, and sewage treatment plants–in the state of California. The estimates for the total biomethane potential of these resources and the corresponding stranded gas are provided in Figure 2. At about 73% of the total potential, the aggregated

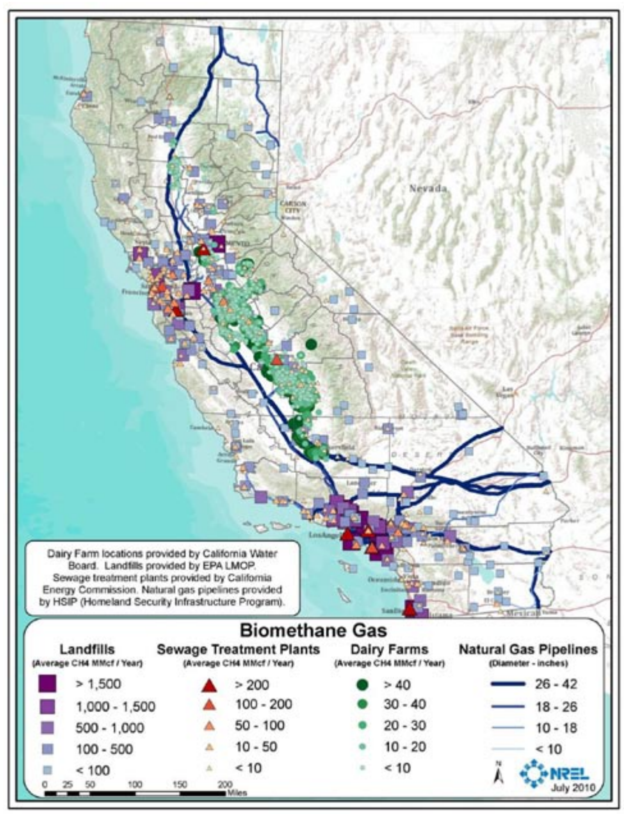

FIGURE 1. GIS Map for Select Biogas Resources and Natural Gas Transmission Lines in California

landfills have the dominant share followed by the dairy farms at approximately 22%. However, considering that only about 50% of the biomethane potential from the landfills in that state is stranded compared to nearly 100% for the dairy farms, the dominance of the landfills lessens for future implementation. (Another potentially limiting factor for landfill gas may have to do with the lack of protocols/guidelines for permitting injection of biomethane produced from landfill gas into natural gas network.) The total biomethane potential comprises about 5% of the natural gas consumption in California.

Technoeconomic Analysis

An analysis was conducted to determine the levelized cost of biomethane production and pipeline delivery to the natural gas grid for a range of feed biogas capacity based on the following assumptions.

- Biomethane production site is about 16 km (10 miles) from the natural gas transmission line whose operating pressure is 40 bar (600 psia).
- Biogas containing 60% methane (by volume) enters the upgrading/cleanup system at the atmospheric pressure.
- Pipeline-quality biomethane leaves the upgrading system with 97% methane (by volume) at about 7 bar (105 psia) and compressed for injection into the transmission line.
- The life span for the entire system (upgrading system and extension pipeline) is 20 years.
- The investment rate of return is 10% and the inflation rate is 1.9%.
- Biogas cost is $5/GJ of the biomethane product. This cost is closer to the lower limit of the range reported in a United States Department of Agriculture report [6].

Presented in Figure 3 are the total levelized cost of biomethane and its constituents as functions of the feed biogas capacity. Considering that the biogas output capacity of the largest dairy farms rarely exceeds 400 Nm^3/h (based on the GIS analysis), potential local/regional clustering of the farms is the basis for the range of the feed biogas capacities covered in this analysis. Examination of these results (Figure 3) leads to the following observations.

- The total levelized cost of biomethane delivered to the natural gas grid is about $35/GJ and $11/GJ corresponding to feed biogas capacities of 250 Nm^3/h and 3,000 Nm^3/h, respectively. These results are indicative of strong dependency of the biomethane cost on the system size.
- For feed biogas capacities below 2,000 Nm^3/h, the pipeline transport cost is the dominant cost component. At higher capacities, the contributions of the biogas upgrading and transporting costs are about equal.
- At the assumed cost of $5/GJ, the feed biogas takes on a greater significance than the upgrading and pipeline transport constituents for biogas capacities exceeding 2,000 Nm^3/h.

Although all of the cost results are subject to uncertainties, the pipeline transport cost is additionally influenced by the proximity of the production site to the natural gas pipeline, a variability that is not captured in Figure 3. For example, if injection of biomethane into a distribution pipeline is permissible, a shorter extension line and less pressure-boosting compression for grid connection can ensue, resulting in a markedly

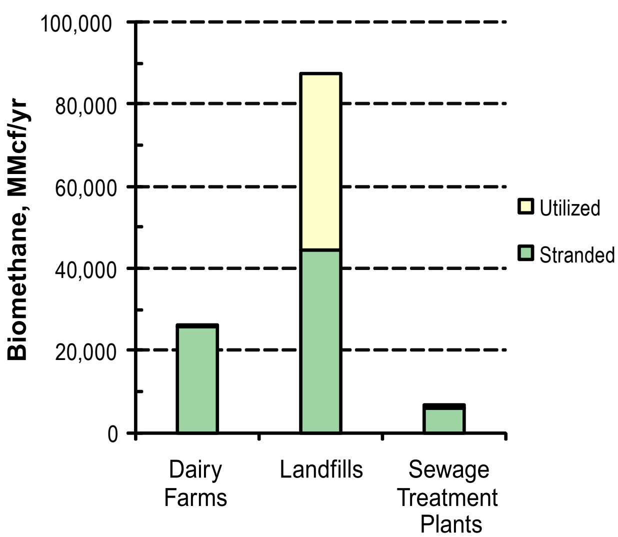

FIGURE 2. Estimates of Total Biomethane Potentials and Stranded Amounts

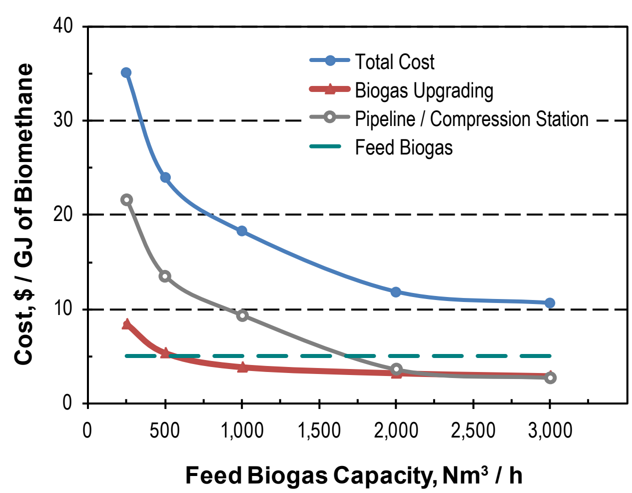

FIGURE 3. Cost Analysis of Biomthane Production and Delivery

lower transport cost. Consequently, the ranking of the transport and upgrading costs may even be reversed at low biogas capacities.

The cost of biogas also has a critical role, particularly in larger systems, given its wide range stemming from the availability of various anaerobic digestion types implemented in dairy farms [6]. The total biomethane cost trend in Figure 3, coupled with the notion that the price of natural gas (residential) is approximately $9.5/GJ for the state of California and $11.7/GJ for the U.S. average [7], the biomethane production for on-site utilization (not involving transport) can be economically competitive for biogas capacities (greater than 500 Nm^3/h) evaluated in Figure 2. More favorable economics can be expected when less costly biogas becomes available (e.g., biogas from covered lagoons in mild climates or from landfills). However, the cost of grid connection limits the economic competitiveness of the delivered product gas to large systems only (not accounting for any available state/federal incentives for renewables).

The results shown in Figure 3 do not include storage or any other unforeseen ancillary costs (e.g., sequestration and/or faring of the waste stream from the biogas upgrading process). Based on a report by Krich et al. [8], inclusion of a storage system for two day's worth biomethane production can increase the cost by about $1.3 to $3 per GJ. For the case of clustered farms, the additional cost of transporting biogas (or bio waste) from the individual farms to a central location for upgrading is not addressed in this analysis either. A comprehensive and more accurate cost analysis requires details that are specific to each given project/scenario.

For cases where biomethane is produced for on- or near-site utilization and the feed biogas cost is available at low prices, the pipeline transport cost vanishes and, consequently, the upgrading cost takes on greater significance. In such scenarios, knowledge of the cost breakdown for the upgrading system can be valuable in identifying opportunities for cost reduction. Figure 4 illustrates the variation of the relative contributions of the key cost components with the feed biogas capacity. This figure suggests an increasing role of the variable costs (primarily utilities) as larger systems are considered.

Based on the emissions results of the H2A Biomethane model, the greenhouse gas emissions arising from the biogas upgrading and the upstream processes are approximately 1.84 kg/kg biomethane and -1.75 kg/kg, respectively, resulting in a net amount of 0.092 kg/kg biomethane. The emission for the biogas upgrading system is a function of the system energy efficiency and the biomethane recovery rate, which is assumed to be 99%.

The newly developed tool, along with analyses similar to the preceding, can assist the DOE Fuel Cell Technologies Program with evaluation of the economic and environmental benefits of using renewable biogas for on-site power generation with fuel cell systems. Other stakeholders, including biogas producers, can also benefit from these in the case-by-case decision making process.

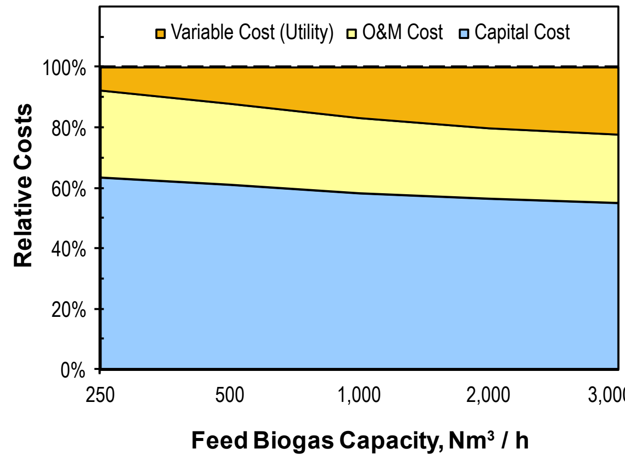

FIGURE 4. Relative Contributions of Biogas Upgrading Cost Components

Conclusions and Future Direction

- The newly developed H2A Biomethane model can lend itself to cost analysis of producing biomethane from biogas for on-site utilization or export to natural gas grid or another end-use application site. The model also allows calculation of the energy consumption and emissions for the biogas upgrading system and the upstream processes.
- Price of biogas, feed biogas capacity, distance between the production site and point of delivery, and the delivery pressure influence the levelized cost of biomethane.
- By taking advantage of the economy of scale for biogas upgrading process (biogas capacity greater than about 2,000 Nm^3/h) and assuming purchase of dairy digester gas at $5/GJ, the levelized cost of biomethane production for on- or near-site utilization can be as low as $7/GJ. Therefore, biomethane produced from dairy digester biogas can be economically competitive with natural gas in certain circumstances even without applying any financial incentives.
- Achieving economy of scale for biomethane production from dairy digester biogas can be challenging because dairy farms offer relatively small feed biogas capacities (compared to landfills). Therefore, participation of near-by dairy farms in implementing a central system may be imperative if cost reductions are to be realized from the economy of scale.

Based on the predefined scope of the project, dissemination of the results at a conference or workshop is the only remaining activity. The following list outlines additional activities recommended for future work.

- Addressing oxidization and/or sequestration of the waste streams from the biogas upgrading process.
- Investigating the impact of biogas impurity level on the cost of the upgrading process.
- Performing analyses for nascent and existing installations/field studies.

FY 2010 Publications/Presentations

1. Jalalzadeh-Azar, Ali. 2009. Overview of an Analysis Project for Renewable Biogas / Fuel Cell Technologies. A Panel Discussion at 2009 Fuel Cell Seminar, Palm Springs, CA, November 19, 2009.

2. Jalalzadeh-Azar, A.; Saur, G.; and Lopez, A. 2010. DOE Hydrogen Program Annual Merit Review and Peer Evaluation. Washington, D.C., June 7–11, 2010.

References

1. U.S. Department of Energy. Hydrogen, Fuel Cells & Infrastructure Technologies Program, Multi-Year Research, Development and Demonstration Plan: Planned Program Activities for 2005-2015, http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html.

2. U.S. Department of Energy. DOE Hydrogen Program, DOE H2A Analysis, H2A Production Model, Version 2.1, 2008. http://www.hydrogen.energy.gov/h2a_production.html.

3. U.S. Department of Energy. DOE Hydrogen Program, DOE H2A Analysis, H2A Delivery Components Model Version 1.1. 2007. http://www.hydrogen.energy.gov/h2a_delivery.html.

4. California Air Resources Board, *Detailed California-Modified GREET Pathway for Compressed Natural Gas (CNG) from Dairy Digester Biogas Version 1.0*. 2009, California Environmental Protection Agency.

5. Parker, N.C. "Using Natural Gas Transmission Pipeline Costs to Estimate Hydrogen Pipeline Costs." Report UCD-ITS-RR-04-35. 2005, Institute of Transportation Studies, University of California Davis, CA.

6. An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities, Technical Note No. 1, Natural Resources Conservation Service, USDA, October 2007.

7. U.S. Energy Information Administration Independent Statistics and Analysis, http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=CA.

8. Krich, K.; Augenstein, D.; Batmale, JP; Benemann, J.; Rtledge, B.; and Salour, D. "Bio-methane from Dairy Waste–A Sourcebook for the Production and Use of Renewable Natural Gas in California." July 2005.