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April 29, 2016

In 2015, Southern California Gas Company (SCG) commissioned Black & Veatch to perform a characterization and evaluation of current biogas upgrading technologies that would allow the injection of upgraded biogas into SCG natural gas pipelines, with a focus on technology availability, performance, cost, and future R&D recommendations. This paper provides a high level overview of the analysis performed and key findings.

Introduction

In order to inject biomethane into the existing natural gas infrastructure, the gas must meet standards as defined by SCG Rule 30 and AB 1900. The main compositional modifications that must occur in order to meet pipeline specifications are the removal of water, hydrogen sulfide (H_2S), siloxanes, nitrogen (N_2), oxygen (O_2), and carbon dioxide (CO_2). From a technological perspective, processes are well established to remove each of these contaminants to typically acceptable levels; there are a number of commercially operating systems in North America and Europe. While it was assumed that removal of other AB1900 "constituents of concern" not outlined above (typically trace constituents such as vinyl chloride and metals) can be achieved, there is currently insufficient data to determine the extent to which additional biogas cleaning processes will be required to comply with AB 1900 requirements. Regarding these low concentration materials, the CPUC Decision regarding AB 1900 notes that the Joint Report of the California Air Resources Board (CARB) and the California Office of Environmental Health Hazard Assessment (OEHHA) states "for most compounds, the maximum values found [in analyzed biogas samples] are well below the trigger levels."[1]

Beyond the removal of these components, there are other considerations that should be taken into account when developing a biogas upgrading system. A high BTU value gas (such as propane) may need to be injected to raise the heating value and Wobbe Index to compliant levels when using some technologies. Additionally, the gas leaving the biogas upgrading process is likely to be at relatively low pressure and will require further compression for pipeline injection.

[1] California Public Utilities Commission (CPUC). "Decision regarding the Biomethane Implementation Tasks in Assembly Bill 1900." Issued January 22, 2014.

Cases and Technologies

Full designs were prepared for cleaning raw biogas to pipeline quality renewable natural gas, using the following flowrates and compositions as a starting point, which reflect typical raw biogas compositions in Southern California:

Dry Gas Composition for Biogas Upgrading Cases

CASE	BIOGAS	FLOW RATE (SCFM)	CH_4 (%)	CO_2 (%)	N_2 (%)	O_2 (%)	H_2S (PPM)	SILOX-ANES (PPM)
A	Landfill Gas	3,000	56.9	30.3	10.6	2.1	100	100
B	Digester Gas	1,050	65.2	34.8	~0	~0	100	100
C	Digester Gas	400	63.4	33.9	2.1	0.5	1,500	6

A range of technology providers were surveyed to determine the appropriate designs for each case. While preferred technologies for removal of H_2S, N_2, O_2, and siloxanes did not vary considerably, a number of options are available for CO_2 removal including the following:

- Pressure Swing Adsorption
- Membrane Separation
- Water Scrubbing
- Amine Scrubbing

From past work performed by the team, it is clear that the technologies available for biogas cleaning have improved. Key findings in the initial analysis were:

- Rather than integrating components from separate equipment suppliers, several biogas upgrading suppliers now provide full upgrading solutions. These full solution providers are considered commercial.
- The consensus of biogas technology upgrading suppliers is that the commercially available upgrading systems are technologically capable of meeting all of the requirements of SCG Rule 30 and AB 1900. The areas of greatest concern expressed by developers were in regard to meeting requirements for BTU content of the gas (990 BTU/scf) and the analytical techniques needed to properly detect the appropriate trigger level concentrations for siloxanes.

Economics

Black & Veatch developed preliminary estimates of the capital and operating cost required for the installation of biogas upgrading systems and interconnection to the SCG system. These cost estimates are based on current market pricing and reference recent and ongoing cost estimating experience for similar projects. An economic model was used to provide an estimate of the 20 year levelized cost of biomethane. The economic model considers all-in capital costs, financing parameters, O&M costs, and biogas technical considerations (such as methane losses from the upgrading processes) associated with the project.

Based on the technologies considered in the analysis, the range of results for cost and levelized gas prices at different flowrates can be seen below. Note that these costs are solely for biogas cleaning, and do not include any costs for gas production.

Gas Cleaning Economics

CASE	BIOGAS	FLOW RATE (SCFM)	CAPITAL COST ($000)	OPERATING COST ($000/YR)	LEVELIZED $/MMBTU
A	Landfill Gas	3,000	20,000 to 25,000	1,000 to 1,500	7 to 9
B	Digester Gas	1,050	7,000 to 10,000	400 to 700	8 to 10
C	Digester Gas	400	5,000 to 8,000	300 to 500	14 to 15

To examine the variations in biomethane costs as certain project parameters are modified, sensitivity analysis was performed. These analyses considered the effects of:

- Potential reductions in interconnection costs.
- Incentives that may be applicable to biomethane projects in California.
- The elimination of energy recovery systems.
- Biogas upgrading systems for streams with limited nitrogen content.

Economic Sensitivity Analysis Summary

SENSITIVITY	TEST	IMPACT
Pipeline interconnection costs	Reduce interconnection cost by 50 percent	3 to 10 percent reduction in biomethane costs. Greater impact on smaller cases.
Incentives	Determine 10-year incentive levels to be breakeven with natural gas	Would require an incentive of $3 to $5/MMBTU
Elimination of energy recovery systems	Send tail gas to thermal oxidizer instead of engines	Raises costs by $1-1.50/MMBTU
No air upgrading cases	Eliminate nitrogen rejection	Lowers cost by 20 to 25 percent for large scale cases

Key findings from the economic analysis include the following:

- Costs appear to flatten at project sizes above 1.4 MMSCFD (1,000 SCFM), particularly if nitrogen rejection systems are not required. If costs of nitrogen removal and pipeline interconnection are reduced and incentives are available, the minimum size likely to be economic may be 1 MMSCFD or lower.
- Based on the conceptual design and estimates of capital and O&M costs developed in this study, the levelized cost of biomethane (excluding potential incentives) is estimated to be in the range of approximately $7/MMBtu to $9/MMBtu for large scale systems. This cost increases significantly for small systems; 400 SCFM units with nitrogen rejection are estimated to have a levelized cost of biomethane of approximately $14/MMBtu to $15/MMBtu.

Research and Development for Biogas Upgrading

An assessment of current and ongoing research and development (R&D) for biogas upgrading was performed to provide SCG with guidelines and recommendations with regard to R&D of biomethane technologies and their application.

Through our technology review and outreach with suppliers, operators, advocates, and other stakeholders, key barriers to biogas project development were identified. These barriers are outlined below:

- Gas Monitoring Practices – Gas specifications and monitoring requirements will have significant implications to operating costs and procedures. There is currently question within the biogas industry as to whether the levels specified by AB1900 and Rule 30 can be continuously and reliably measured when employing currently available methods.
- Interconnection Costs – One of the high project startup costs associated with biogas upgrading for pipeline injection is the cost to interconnect to the pipeline. These costs are often uncertain in early stages of development and can comprise a very large portion of the overall project costs, and, in some cases, can be prohibitive for smaller projects.
- Unfavorable Economies of Scale – Smaller biogas projects are disadvantaged due to higher equipment and interconnection costs, in terms of $/SCFM of processing capacity. Since many biogas opportunities are at the small scale, greater investigation into technology improvements at the small scale would be beneficial.
- Lack of Biogas-Specific R&D Drivers – While there is significant R&D occurring in the biogas industry, the level of R&D directed toward biogas applications, including upgrading for pipeline injection, is limited.

About Black & Veatch

Black & Veatch Corporation is a leading global engineering, consulting and construction company with the mission of *Building a World of Difference*®. Founded in 1915, Black & Veatch now has over 10,000 employees worldwide with its headquarters in Overland Park, KS and regional offices in almost all 50 U.S. states.

Black & Veatch is recognized as one of the most diverse providers of biomass (solid biomass, biogas, and waste-to-energy) systems and services in the world. From initial technology research and project development, through turnkey design and construction, Black & Veatch has worked exclusively with project developers, utilities, lenders, and Government agencies on biomass projects utilizing over 40 different biomass fuels throughout the world.

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