Biogas Utilization

Part 1: Overview of options with CHP comparison

November 2021

Introduction

Biogas produced from anaerobic digestion at a dairy farm can be utilized in several ways. To date in New York State, biogas has been predominantly utilized to fuel combined heat and power (CHP) systems to produce electricity and digester heating energy. The commercially available CHP technology options are compared in Table 1. Other biogas utilization options include fueling a boiler and producing renewable natural gas (RNG) that is suitable for either vehicle fueling or natural gas pipeline injection. This fact sheet series will describe each of the four primary CHP technology options with information on dairy farm applications, biogas conditioning requirements, capital and operating cost, and emissions. In addition, the series will describe the options of utilizing a boiler and producing RNG. This fact sheet (Part 1) contains an overview of the CHP options.

Table 1. Combined heat and power (CHP) technology comparison.

	Reciprocating Internal Combustion (IC) Engine[a]	Microturbine (small gas turbine)	Fuel Cell	Gas Turbine
Single Package Size Range (multiples possible)	1 kW – 10 MW	30 kW – 1 MW	200 kW – 2.8 MW	500 kW – 300 MW
Electric Efficiency (HHV)	27 – 37%	24 – 30%	30 – 63%	24 – 36%
Heat Recovery Efficiency from Cooling System (MMBTU/hr)	12 – 36%	No cooling system	10 – 16%	No cooling system
Heat Recovery Efficiency from Exhaust (MMBTU/hr)	17 – 24%	36 – 48%	10 – 20%	33 – 42%
Capital Cost as CHP[b] ($/kW)	$2,360 – $2,900	$2,500 – $4,300[c]	$4,600 – $10,000	$1,250 - $3,280[c]
O&M Cost as CHP[b] ($/kWh)	$0.019 – $0.030	$0.009 – $0.016	$0.036 – $0.045	$0.009 - $0.013
Gas Compression (inlet fuel pressure in psig)	No (1 – 5)	Yes (55 – 90)	No (10 – 20)	Yes (167 – 500+)
H_2S Removal Target (ppmv)	< 200 – 545[d]	< 5,000 – 6,500	< 1 – 2[d,e]	< 10,000[d]
Other Biogas Cleaning?[f]	moisture removal	moisture removal	fuel reformer[g]	moisture removal
NOx Emission (lb./MWh) *not including selective catalytic reduction (SCR)*	1.5 – 6 (lean burn) 0.07 with SCR	0.14 – 0.46	0.0017 – 0.016	0.52 – 1.31
Uptime/Availability	96 – 98%	98 – 99%	95%+	93 – 96%

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[a] All table values except single package size are given for the typically used unit size range of 100 kW – 1.1 MW.
[b] Capital cost range is for installed combined heat and power (CHP) system and does not include biogas cleaning system. Operation and maintenance (O&M) cost range is for CHP system and does not include biogas cleaning component maintenance.
[c] Includes gas compressor subsystem.
[d] Riley, D.M. et al. 2020. https://doi.org/10.3390/environments7100074.
[e] National Renewable Energy Lab (NREL). 2013. Biogas and Fuel Cells Workshop Summary Report.
[f] It is assumed that siloxanes are not present in the manure-based anaerobic digester gas, even with organics co-digestion. Siloxanes need to be removed to trace levels if they are present.
[g] Solid oxide fuel cells (SOFCs) do not need to remove moisture or CO_2 from the biogas; however other types do.

CHP technology use on farms and with biogas

According to the U.S. Department of Energy CHP database[1], most of the anaerobic digester gas fueled CHP systems utilize a reciprocating IC engine prime mover (i.e., the electricity generator component of the CHP system). This is particularly true in agriculture applications. The next most common prime mover used is the microturbine, with many applications at wastewater treatment plant (WWTP) digesters. While there are a few gas turbine CHP installations operating on biogas in the country, their application is limited primarily due to the large size that is not a fit for most dairy or WWTP biogas production. Finally, fuel cells operating on biogas are extremely limited, with two known agriculture applications[2,3] and 16 known WWTP applications (four of those are at New York City plants). In California, there are several fuel cell installations at buildings that utilize RNG produced originally by dairy farms and injected into the natural gas pipelines.

Heat recovery from CHP technologies

Heat recovered from the prime mover can be used to maintain the operating temperature of the anaerobic digester if the quantity and quality are sufficient. Gas turbines (including microturbines) generate heat only in the form of exhaust and produce large amounts of heat, while reciprocating IC engines produce heat primarily from the jacket cooling system and in the exhaust. SOFCs and molten carbonate fuel cells (MCFCs) operate at higher temperatures than the other fuel cell types, thereby capable of producing higher quality heat. However, the hot exhaust from these fuel cells is primarily used in the internal reforming of the inlet process hydrocarbon gas to produce a hydrogen-rich stream and the excess heat may be insufficient for digester heating year-round.

Biogas conditioning for CHP systems

As indicated in Table 1, the CHP technologies have a wide range of biogas conditioning requirements. Firstly, microturbines and gas turbines can accept very high levels of hydrogen sulfide (H_2S) in the biogas. This is principally because they do not require the lubricating oil system that an engine does, which is quickly contaminated by H_2S levels over a few hundred parts per million (ppm) in the biogas. Dairy farms typically have H_2S levels in the ADG stream that exceed 1,000 ppmv and so H_2S removal is required for engine CHP systems but is most likely not required for microturbine CHP systems. H_2S contaminates the fuel cell anode even at very low levels and must be completely removed from the biogas to maintain a suitable lifespan.

Biogas exits a digester at low pressure (typically 1 – 3 psi) and must be boosted in the gas conditioning system for all CHP technologies. Engines and fuel cells require relatively low-pressure gas, and a blower is typically adequate to boost the biogas pressure. Microturbines and gas turbines require pressurized gas at their fuel inlet, and a gas compressor is used. As an example, 5% of the rated power from a 200 kW microturbine is needed to power the compressor and this should be accounted for when estimating the total system savings. Except for SOFC technology that can accommodate both the moisture and the CO_2 in the biogas, all other CHP technologies benefit from or require some level moisture removal to meet their fuel specification.

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[1] US DOE CHP Database, https://doe.icfwebservices.com/chpdb/.
[2] https://www.manuremanager.com/fuel-cell-power-plant-installed-on-ca-egg-farm-3245/.
[3] https://bioenergyinternational.com/heat-power/bloom-energy-deploys-bar-20-dairy-farms-biogas-power-project

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