Digester Gas Combustion

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INTRODUCTION

Anaerobic digesters have become an increasingly popular method of manure handling throughout the U.S. One of the advantages of digesters is the ability to capture and beneficially use the methane generated by anaerobic digestion of manure. Once captured from a digester, biogas can be upgraded to pipeline quality and injected into a natural gas pipeline, or it can be used onsite or at a nearby facility as fuel. The many benefits associated with this practice include reduced methane emissions (a powerful greenhouse gas), potential to recoup capital costs through biogas or power sales, and ability to replace natural gas usage with biogas. However, combusting biogas can also result in issues different from those encountered when combusting natural gas, among them changes in emissions, difficulties meeting required emission standards, and capital costs required to comply with regulations. This discussion will focus on expected emissions and environmental impacts, regulations and cost of compliance, and future trends in control technologies and regulations associated with the combustion of biogas.

DIGESTER GAS GENERATION AND COMBUSTION

Anaerobic Digestion

During anaerobic digestion, microorganisms decompose organic matter in an oxygen-free environment, producing methane (CH_4) and carbon dioxide (CO_2) (Madigan et al., 2003). In fact, anaerobic manure storage vessels (e.g., digesters) are designed to maximize the production of digester gas, or biogas. By collecting the produced gas, the overall release of CH_4 from the manure storage can be reduced, depending on the end use of the gas.

There are multiple potential end uses for the gas. The first potential end use (which is more accurately a disposal method) consists of combusting the digester gas in a flare. This converts the CH_4 to CO_2; although this reduces the total global warming potential of the GHGs emitted by over 95%, it is not a beneficial use of the gas. The second potential option is the injection of processed biogas into an existing natural gas pipeline. In order for this option to be feasible, the dairy needs to be located near an existing pipeline, in an area served by a utility that accepts biogas, and purchase and operate the required gas cleanup equipment. The third potential option, which will be the focus of this paper, is the onsite production of energy. This option involves routing the digester gas to energy generation equipment such as an internal combustion engine

(ICE), microturbines, or fuel cells.

Emissions

Digester gas is primarily CH_4. However, unlike natural gas, there are additional trace gases in digester gas. Digester gas is approximately 60% CH_4 and 35% carbon dioxide (CO_2), with the remainder consisting of other components such as oxygen, nitrogen, and hydrogen sulfide (H_2S). Similar to natural gas and other fuels, combusting digester gas results in emissions of criteria pollutants (oxides of nitrogen, NO_x; carbon monoxide, CO; volatile organic compounds, VOC; particulate matter, PM; and oxides of sulfur, SO_x) as well as greenhouse gases (CO_2, CH_4, and nitrous oxide, N_2O). Emissions of these pollutants from combusting digester gas vary depending on the type of combustion device, the presence of air pollution control equipment, and the composition of the gas; fewer impurities will result in emissions similar to natural gas while more impurities result in a different emissions profile as illustrated in Table 1 and Table 2.

Table 2 shows that emissions from digester gas combustion in ICEs can vary widely. These data were obtained from farms located in California. These farms used different digester configurations (i.e., plug flow, covered lagoons) and had different electric generating capacities (75 kw to 563 kW). One of the parameters that varied the most was the concentration of H_2S in the biogas. The H_2S concentrations ranged from 4 ppm to 1,586 ppm, leading to widely varying SO_x emissions as H_2S converts to SO_x at a very high rate in combustion devices.

Table 1. Criteria pollutant emissions from stationary turbines fired with natural gas and digester gas.

Fuel	**Emission Factor (lb/MMscf)**				
	NO_x [a]	**CO[a]**	**VOC[b]**	**PM[b],[c]**	**SO_x[b]**
Digester gas (uncontrolled)[d]	96.0	10.2	3.48	NA	3.9
Natural gas (uncontrolled)[e]	336.0	86.1	2.21	6.9	3.6

[a] Obtained from AP-42, Chapter 3.1. Stationary Gas Turbines, Table 3.1-1.
[b] Obtained from AP-42, Chapter 3.1. Stationary Gas Turbines, Table 3.1-2a (natural gas) and Table 3.1-2b(digester gas).
[c] Total particulate matter.
[d] Emission factors in AP-42 were given in lb/MMBtu. A heating value of 600 MMBtu/MMscf was used to convert to lb/MMscf.
[e] Emission factors in AP-42 were given in lb/MMBtu. A heating value of 1,050 MMBtu/MMscf was used to convert to lb/MMscf.

Table 2. Criteria pollutant emissions from engines fired with natural gas and digester gas.

Fuel	Emissions (lb/MMscf)[a]		
	NO_x[b]	CO[b]	SO_x[b]
Digester gas[c]	324 (18 to 918)	546 (222 to 948)	870 (6 to 3,180)
Natural gas[d],[e]	588	892.5	0.6

[a] Reported average emissions are shown with the range in parentheses.
[b] Emissions were obtained from CEC (2006) in units of lb/MMBtu.
[c] Emissions were converted to lb/MMscf by assuming an average heating value of digester gas of 600 MMBtu/MMscf.
[d] Emissions were converted to lb/MMscf by assuming an average heating value of natural gas of 1,050 MMBtu/MMscf.
[e] CEC (2006) cites AP-42 as the source for natural gas emissions.

There are both human health and environmental impacts of these emissions. The US Environmental Protection Agency (US EPA) regulates the criteria pollutants because these pollutants have negative human health and welfare effects.

Table 3 describes some health effects associated with five of the six criteria pollutants (lead is not included as digesters are not a significant source of lead emissions). There is only a small population that is likely to be directly harmed by emissions from digester gas combustion (i.e., the people who live in close proximity to the farm, farm workers, etc.). However, the emissions from digester gas combustion contribute to the concentration of these pollutants in the ambient air. Because of this, the USEPA, as well as state agencies (e.g., Cal/EPA) establishes ambient air quality standards that dictate the permissible level of these pollutants in the air. These permissible levels are established to limit and prevent health effects due to cumulative concentrations of the criteria pollutants. For example, smog (ozone) is caused by a reaction of sunlight, nitrogen oxides, and VOCs. The health effects of smog have been well-documented and can include decreased lung capacity, shortness of breath, and wheezing, among others.

Table 3. Criteria pollutants, their precursors, and related health effects.[a]

Pollutant	Health Effects
Particulate Matter[b]	Respirable particulates ($PM_{2.5}$ and PM_{10}) pose a serious health hazard, alone or in combination with other pollutants. More than half of the smallest particles inhaled get deposited in the lungs and can cause permanent lung damage. Respirable particles have been found to increase morbidity and mortality via the following adverse health effects: decreased lung function, aggravated asthma, exacerbation of lung and heart disease symptoms, chronic bronchitis and irregular heartbeats. In addition, respirable particles can act as a carrier of absorbed toxic substance.[c]
Ozone[d]	Elevated ozone concentrations have been shown to induce airway irritation, cause airway inflammation, induce wheezing and difficulty breathing, aggravate preexisting respiratory conditions such as asthma, and can lead to permanent lung damage after repeated exposure to elevated concentrations.[e]
Carbon Monoxide (CO)	Carbon monoxide is a colorless and odorless gas that is known to cause aggravation of various aspects of coronary heart disease, dizziness, fatigue, impairment to central nervous system functions, and possible increased risk to fetuses.
Sulfur Dioxide (SO_2)	Sulfur dioxide is known to cause irritation in the respiratory tract, shortness of breath, and can injure lung tissue when combined with fine PM. It also reduces visibility and the level of sunlight.
Nitrogen Dioxide (NO_2)	Long-term exposure to nitrogen dioxide has the potential to decrease lung function and worsen chronic respiratory symptoms and diseases in sensitive population. It has also been associated with cardiopulmonary mortality and emergency room asthma visits. USEPA recently adopted a 1-hour federal standard to address short-term exposure impacts (e.g., adverse respiratory effects), particularly near major roadways.

[a] SCAQMD Final 2007 Air Quality Management Plan, June 2007, http://www.aqmd.gov/aqmp/07aqmp/aqmp/Complete_Document.pdf.
[b] Particulate matter ($PM_{2.5}$ and PM_{10}) can be directly emitted. In addition, oxides of nitrogen (NO_x) and oxides of sulfur (SO_x) are precursors of $PM_{2.5}$ and PM_{10}.
[c] USEPA National Center for Environmental Assessment, particle pollution health affects http://www.epa.gov/air/particlepollution/health.html.
[d] Ozone is not a directly emitted pollutant from emission sources. Instead, volatile organic compounds (VOCs) and NO_x are precursors of ozone.
[e] USEPA National Center for Environmental Assessment, ground level ozone health affects http://www.epa.gov/air/ozonepollution/health.html.

In addition to the human health impacts, there are environmental impacts as well. In addition to criteria pollutants, digester gas combustion also results in emissions of GHGs. In its most recent assessment report in 2007, the Intergovernmental Panel on Climate Change (IPCC, 2007b) reported that it is "extremely likely" (i.e., representing a 95% confidence level or higher) that anthropogenic emissions of GHGs are causing a change in the global climate. Although there is a scientific consensus that anthropogenic emissions of GHGs are impacting the global climate, there is still debate as to the magnitude of this impact. However, potential environmental impacts that can result from increased concentrations of GHG in the atmosphere include the following:

- Decreased crop yields – Increased temperatures can reduce the potential benefit of increased CO_2 concentrations. However, hotter temperatures create a need for additional irrigation, which may be difficult to achieve if precipitation is also impacted by the changing climate. Also, more extreme weather events are likely to occur (IPCC, 2007a).
- Human health – Evidence indicates that global climate change will change the distribution of allergenic pollen species, increase malnutrition, increase morbidity and mortality associated with ground-level ozone, and change the range of some infectious disease vectors (IPCC, 2007a).
- Freshwater resources – Climate change is expected to decrease the water resources in semi-arid and arid regions of the world, including the western US. Extreme weather events are likely to lead to increased water pollution. For example, increased precipitation intensity will cause more runoff, which will contribute more sediment, pesticides, nutrients, and other pollutants into the receiving water body (IPCC, 2007a).

REGULATORY FRAMEWORK

Criteria Pollutants

Because of the risks to the environment and human health, emissions of these pollutants are regulated. The USEPA regulates criteria pollutants by establishing permissible levels, or National Ambient Air Quality Standards (NAAQS), based on human health standards or environmental criteria. The Clean Air Act (CAA) allows states to adopt more stringent ambient air quality standards as appropriate (Table 4). State and local agencies are required under the CAA to develop a State Implementation Plans (SIP), a general plan indicating how to attain and/or maintain the NAAQS. State and local regulations are developed as part of SIPs, with the goal of achieving NAAQS or state standards.

Table 4. Ambient air quality standards.

Pollutant	Averaging Period	Federal Standard[a]	California Standard[b]
Ozone (O_3)	1 hour	Revoked	0.09 ppm (180 μg/m^3)
	8 hour	0.075 ppm (147 μg/m^3)	0.07 ppm (137 μg/m^3)
Respirable Particulate Matter (PM_{10})	24 hour	150 μg/m^3	50 μg/m^3
	Annual	Revoked	20 μg/m^3
Fine Particulate Matter ($PM_{2.5}$)	24 hour	35 μg/m^3	---
	Annual	15 μg/m^3	12 μg/m^3
Carbon Monoxide (CO)	1 hour	35 ppm (40 mg/m^3)	20 ppm (23 mg/m^3)
	8 hour	9 ppm (10 mg/m^3)	9.0 ppm (10 mg/m^3)
Nitrogen Dioxide (NO_2)	1 hour	0.100 ppm	0.18 ppm (339 μg/m^3)
	Annual	0.053 ppm (100 μg/m^3)	0.030 ppm (57 μg/m^3)
Sulfur Dioxide (SO_2)	1 hour	0.075 ppm (197 μg/m^3)	0.25 ppm (655 μg/m^3)
	3 hour [c]	0.5 ppm (1310 μg/m^3)	---
	24 hour	--	0.04 ppm (105 μg/m^3)
Sulfates	24 hour	---	25 μg/m^3

[a] Federal Standards as listed on USEPA website (http://epa.gov/air/criteria.html).
[b] California standards as listed on CARB website (http://www.arb.ca.gov/research/aaqs/caaqs/caaqs.htm).
[c] This is a secondary standard.

These regulations often include permitting requirements for sources of air emissions. Among these requirements is the need to use Best Available Control Technology (BACT). BACT requires that a process meet emissions limits or utilize control technologies that, for a similar source, (1) are in an EPA-approved SIP, (2) have been achieved in practice, or (3) are economically and technologically feasible (USEPA, 2012). The USEPA, as well as various regional and state agencies, have BACT clearinghouses based on what has been required as BACT in air permits.

California has the most dairy cows of any State in the U.S. In addition, California generally has the strictest air emissions regulations. Although agricultural sources previously were exempt from many permitting requirements, California Senate Bill 700 (SB 700) was signed into law in 2003, removing this exemption. Now, agricultural sources in California are subject to many of the same permitting requirements as industrial sources.

These requirements present a unique challenge for farmers seeking to beneficially use digester gas. Currently, the BACT limit for NO_x in San Joaquin Valley is 9 ppmv (SJVAPCD 2012). Control devices, such as selective catalytic reduction (SCR), are available to reduce NO_x emissions from combustion equipment. However, the additional trace gases in the digester gas, namely H_2S, cause fouling of the catalyst in the SCR.

Because of the catalyst poisoning, a dairy would need to install a scrubber (e.g., Iron Sponge) on the engine inlet side to reduce the H_2S concentration in the digester gas. This would clean the gas in an attempt to prevent catalyst poisoning in the SCR unit, as well as reduce SO_x emissions. However, this places another economic burden on the farmer. In addition to the costs of the digester (which are not included here), a farmer would thus need to install the engine as well as the associated control and backup equipment. Capital costs for these pieces of equipment are estimated to be approximately $275,000 ($90,000 for the engine; $65,000 for the gas scrubber; and $120,000 for the SCR unit (Ramon Norman personal communication; CEC, 2006). There would also be annual operation and maintenance costs. These annual costs could vary widely but, at a minimum, would include replacement of the iron sponge media, which is estimated to cost $45,500 each year (CEC, 2006). Some regulatory agencies are encouraging the use of microturbines or fuel cells rather than ICEs. However, these equipment are more expensive and can be impacted by the H_2S concentration in digester gas as well.

Greenhouse Gases

In addition to limitations on criteria pollutant emissions, several pieces of legislation have been passed limiting emissions of GHGs to prevent further impacts on the global climate. These regulations include EPA's Mandatory GHG Reporting Rule, the GHG Tailoring Rule, and California's Assembly Bill 32 (AB32).

The Mandatory Reporting Rule requires monitoring and reporting of GHGs from facilities subject to the rule. The affected facilities include a) facilities that contain any of the listed source categories (e.g., cement production, adipic acid production); b) facilities that emit greater than 25,000 metric tons (MT) of CO_2 equivalents (CO_2eq) per year from stationary source combustion and the source categories listed in the proposed rule; or c) facilities that have an aggregate maximum heat input capacity of 20 million British Thermal Units per hour (MMBtu/hr) and emit greater than 25,000 MT CO_2eq per year from stationary source combustion.

EPA's GHG Tailoring Rule tailors the permitting requirements for emissions of GHGs only under the existing Prevention of Significant Deterioration (PSD) and New Source Review (NSR) programs. Without the tailoring rule, the thresholds would be 100 ton per year (tpy) or 250 tpy depending on the source for attainment areas (i.e., PSD), or 10 tpy to 100 tpy depending on the source and location for nonattainment areas (i.e., Nonattainment NSR). With the Tailoring Rule, the thresholds are 100,000 tpy CO_2eq for new sources and 75,000 tpy CO_2eq for modifications to existing facilities.

AB32 requires California to reduce GHG emissions to 1990 levels by 2020. The Scoping Plan required under AB32 identifies a plan for California to reach this goal. As part of AB32, facilities are required to report emissions of GHG. Also, a cap-and-trade program was established to help meet these restrictions. The program covers major emitters of GHGs (e.g., refineries, power plants, transportation fuels) and establishes an enforceable GHG emissions limit that will decline over time (CARB, 2012).

IMPLEMENTATION

All of these regulations are aimed at restricting levels of criteria pollutants and GHGs to avoid the health and environmental impacts associated with emissions. Because of these, and other, regulations, emissions resulting from combustion of digester gas must be controlled. As discussed above, it is difficult to predict the emissions expected from combustion equipment, even with controls, burning digester gas. One method for quantifying emissions is to perform source tests on the combustion equipment. A source test will tell the operator the emissions they can expect when running the combustion equipment under the same conditions as occurred during the test. However, because of the differences in digester gas, results from source tests cannot always be extrapolated to another farm. Although source tests from one farm are not always applicable for another farm, results from previous source tests likely provide the most reasonable option for a farmer who wants to quantify what expected emissions would be. In the absence of source tests, emission factors or modeling can be used to predict emissions. But, like extrapolating source tests, these methods will likely not provide the most accurate results.

FUTURE TRENDS

In the future, new control technologies may be developed that are better suited for controlling emissions from digester gas combustion. In addition, improvements in engine technology may result in lower NO_x emissions from engines. Most importantly, permitting agencies need to work with farmers to come to technically feasible and cost-effective requirements that allow the federal and state standards to be achieved while allowing farmers to reduce greenhouse gases and generate useful electricity. One example of a potential path forward is flexible permits that would require control technologies but would allow emissions above limitations if the limits are not met with the controls (Warner, 2009).

CONCLUSION

Anaerobic digesters can provide environmental benefits through reduced emissions as well as economic benefits through reduced electricity costs or added income. However, there are challenges to beneficially using the digester gas produced. Namely, compliance with permitting requirements that were initially set for industrial facilities can be challenging for agricultural sources. However, with mutual agreement between farmers and regulatory agencies, anaerobic digesters can continue to provide benefits for public health and the environment.

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