Opportunities and Challenges in Anaerobic Digestion: Maryland and the NE Experience

"Use of Biogas: Scrubbing, RNG, Gen-sets, Reclaimed Heat"

Curt Gooch
Dairy Environmental Systems Engineer
Team Leader - Dairy Environmental System Program
Cornell University

www.manuremanagement.cornell.edu
On-Farm AD: Linking Agriculture, Community and Industry toward a Sustainable Future

7.1M lbs of solids from dairy manure

Food waste and other biomass 0-50% weight of manure

Anaerobic Digester

Electricity 3.5M kWh/day

Biogas 78M ft³/day

OR

Nutrient-rich organic fertilizer

OR

Gas clean-up

OR

Heating 42,000 mmBtu’s

OR

Pipeline Distribution 40,000 mmBtu’s

Potential NYS Biogas Estimates
AD: Heat Production

- As much as 75% of the produced heat is wasted
- Excess heat is typically dumped to the ambient using large radiators

- Some (few) farms use recovered heat in a beneficial manner...
- Waste heat usage represents a valuable opportunity for farms
Coupling Dairy Manure Anaerobic Digesters with Commercial Greenhouses: An Assessment of Technical and Economic Feasibility
Phase I - Project Goals:

- Develop user friendly computer programs to:
  - Predict the surplus heat and electricity available from digesters of user specified size, design and operational characteristics. *Cornell Anaerobic Digester Simulation Tool*
    - Predict the required heat and electricity for a greenhouse of user specified size, design and operational characteristics. *Cornell Greenhouse Simulation Tool*
    - Use the output from the AD computer program, and determine the size of greenhouse that could be supported by the specified digester, or the portion of the energy usage of a specified greenhouse that could be digester supported. *Cornell AD/GH Synergy Simulation Tool*
Monitoring Surplus Heat Of Digesters
Thanks to:

- **Dairies**
  - Synergy Dairy (Covington, NY)
  - Stonyvale Farm (Exeter, ME)
  - Sunnyside Dairy (Venice, NY)
  - Willet Dairy (Locke, NY)

- **Commercial Greenhouses**
  - Challenge Industries (Ithaca, NY)
  - Durham Foods (Port Perry, ON)
Anaerobic Digester Surplus Heat

Average Daily Vented (Net) Heat

Heat Flow (MMBtu/day)

- January
- February
- March
- April
- May
- June
- July
- August
- September
- October
- November
- December

- Sunnyside
- Stonyvale
- Willet
Out of Sync Heat Production and Consumption

Digester Supply (3,200 Cows)

Greenhouse Demand (1,000 heads of lettuce daily)

Surplus
New York Freestall Barn
Dairy Monthly Electricity Use

Source: Adapted from Peterson, Northeast Agriculture Technology Corporation 2014
NY Greenhouse Yearly Electricity Usage

- Monthly Purchased Electricity (kWhr)
- X-axis: Months from January to December
- Y-axis: Monthly Purchased Electricity (kWhr)
- Two categories: Totals and Supplemental Lighting

Graph showing the electricity usage for each month, with higher usage in January, February, and December for both Totals and Supplemental Lighting.
Complementary Electricity Use

![Graph showing monthly electricity usage (kWh) for Greenhouse and Digester from January to December. The usage is highest in July and lowest in February.]
Digester Simulation Computer Program
Greenhouse Simulation Computer Program
<table>
<thead>
<tr>
<th>Farm Size (LCE)</th>
<th>Co Digestion²</th>
<th>Greenhouse Size (ft²)</th>
<th>Value of Heat³ ($/year)</th>
<th>Value of Electricity⁴ ($/year)</th>
<th>Benefit⁵ ($/year)</th>
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</table>
Food Hub Operations Model

- Transport seedlings to finish their growth at smaller, distributed operations, located to take advantage of inexpensive heat and power.
Dairy Manure Derived Biogas: Raw Composition

• Methane (CH₄); 55 to 68 percent → 60%

• Carbon Dioxide (CO₂); 32 to 45 percent → 40%

• Hydrogen Sulfide (H₂S); 1,500 – 5,000 ppm

• Ammonia (NH₃); 0 – 300 ppm

• Water Vapor (H₂O); saturated gas: ~4%
Biogas Yields for Sizing Clean-up System

• Cow manure only anaerobic digester systems: 60 to 100 ft$^3$ biogas per lactating cow equivalent on a volatile solids basis (LCE$_{vs}$ basis)

• Co-digestion anaerobic digester systems: 2 – 3x cow manure only systems on a LCE$_{vs}$ basis or more

• For existing systems, use gas meter data to size
Landfill Biogas: Raw Composition

Dairy Manure Derived Biogas Components plus various other contaminants such as:

- Siloxanes
- CFCs
- S-compounds
- Oxygen
- Nitrogen
Important Considerations

- End use of biogas/rng and its requirements
- Requirements can drive clean up system method selected
- Clean up systems require energy: electricity and sometimes heat
- CAPEX and OPEX
Important Considerations

- Sometimes no cleanup is cheapest option
- Some methods need redundancy
- Most appropriate solution may include multiple methods arranged in series
Biogas clean-up/upgrading

– Level 1 of 3: Moisture removal
– Level 2 of 3: Hydrogen sulfide removal
– Level 3 of 3: Carbon dioxide removal
Biogas Cleanup – Level 1 of 3

Moisture removal for local use/pipeline transport
Level 1 - Moisture Removal: *Passive Condensation*
Level 1 - Moisture Removal: 

Refrigeration

- Heat exchangers used to cool biogas to desired dew point
- Biogas pressurized to increase further dryness
- Condensate removed from system and disposed of as wastewater
Level 1 - Moisture Removal: *Adsorption*

- Adsorption agents used to capture moisture
- Silica gel or aluminum oxide used when biogas used for vehicle fuel
- Two vessels are used for continuous treatment
Biogas Cleanup – Level 2 of 3

$\text{H}_2\text{S}$ and moisture (sometimes) reduction for on-site combustion
Level 2 - Hydrogen Sulfide

Sources of Sulfur on Farms Not Importing Food Waste for Co-digestion

Source: Ludington and Weeks, 2009
Level 2 - Hydrogen Sulfide

Sources of Sulfur on Farms Importing Food Waste for Co-digestion

Source: Ludington and Weeks, 2009
# Level 2 - Hydrogen Sulfide

Max. Concentration for Various Biogas End Uses

<table>
<thead>
<tr>
<th>Designated End Use</th>
<th>Max. $[\text{H}_2\text{S}]$, ppm</th>
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<tbody>
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<td>Boiler</td>
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<tr>
<td>Engine-Generator</td>
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<td>Vehicle Fuel</td>
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<td>Pipeline Injection</td>
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<td>Fuel Cell</td>
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Source: Electrigaz Report, 2008
Level 2 - Biogas Hydrogen Sulfide Reduction Options

• Digester Influent Additives
  – Iron Chloride Dosing
  – Ferric Hydroxide Dosing

• Biogas: Physical/Chemical
  – Iron Sponge
  – Activated Carbon

• Biogas: Microbial
  – Biological Fixation
Digester Influent Additive: *Iron Chloride (FeCl₂)*

- Liquid form - Injected directly into digester by an automated dosing unit
- Good for high initial $[\text{H}_2\text{S}]$ as a first stage of a multistage $\text{H}_2\text{S}$ removal process
- Comparatively low CAPEX
- Comparatively high OPEX due to chemical cost
Digester Influent Additive: *Ferric Hydroxide* - Fe (OH)$_3$

- Granular, powder, and liquid forms
- Application rate – nonlinear, depends on [H$_2$S] and digester size
- Use started (2013) by NE farm with very good results (3.5 bags/day)
- Google Search reveals price $600 - $1,500/tonne
Ferric Hydroxide
NE Dairy Farm AD
Ferric Hydroxide - Results
Chemical Removal of H$_2$S: *Iron Sponge*

- Chemical reaction bonds sulfur to iron oxide
- Reaction occurs at ambient temperatures
- Must be in alkaline conditions, pH > 7.5 w/ 8-10 preferred; caustic soda added as needed
- Temperature < 110F
Chemical Removal of H$_2$S:

*Iron Sponge* (con’t)

- Each pound of Fe$_2$O$_3$ can remove 0.56 lbs. sulfide
- Iron oxide is impregnate in wood bark: 15 lbs. Fe$_2$O$_3$ per bushel of bark (1 bushel in-place = 1 cu. ft.)

$$3\text{H}_2\text{S} + \text{Fe}_2\text{O}_3 + \text{H}_2\text{O} \rightarrow 4\text{H}_2\text{O} + \text{Fe}_2\text{O}_3$$
\[ [H_2S]_{in} = 1k \text{ to } 4k \text{ ppm} \]

\[ [H_2S]_{out} = 50 \text{ ppm} \]

\[ \Delta p: \]

2 - 3" wc initially
8 - 10" over time
Iron Sponge – MSU AD System
Two Tank System for Biogas Clean-up
Iron Sponge Scrubbers – Janesville WWTP, Janesville, WI
Chemical Removal of H$_2$S: *Activated Carbon*

- Activated carbon impregnated with potassium iodine or sulfuric acid

- Air injected into biogas to promote carbon adsorption of H$_2$S

- Carbon also regenerated with injected air

- H$_2$S $\rightarrow$ elemental S
Microbial Removal of Biogas $\text{H}_2\text{S}$

**Biological Fixation**

- 2 to 4% air injected into biogas
- Operative microbes grow on surfaces
- Reductions to 60 - 200 ppm
- Reduces $\text{NH}_3$ as well
- Final $[\text{O}_2]$ 0.5 to 1.8% by volume with also Some N due to the injection process
Microbial Removal of H$_2$S

*Biological Fixation*

H$_2$S + 0.5 O$_2$ $\rightarrow$ S + H$_2$O  
(Partial Oxidation)

H$_2$S + 2O$_2$ + 2OH $\rightarrow$ SO$_4$ + 2H$_2$O  
(Total Oxidation)

*Thiobacillus* sp.
Microbial Removal of Biogas H$_2$S

*Biological Fixation*

Two Possible Locations:

- Digester Biogas Head Space
- Separate Vessel
Microbiological Scrubber – Synergy Farm, Covington, NY
Total Annual Cost or Benefit

\[ \sum \text{Total Annual Costs} - (\sum \text{Annual Cost Savings} + \sum \text{Annual Revenues}) \]

If a positive No., then the system is an economic cost to the farm

If a negative No., then the system is likely an economic benefit to the farm
Biogas Cleanup – Level 3 of 3

$\text{H}_2\text{S}$, $\text{H}_2\text{O}$, $\text{CO}_2$, & $\text{NH}_3$ removal for pipeline injection or transportation fuel → “biomethane” or often called “Renewable Natural Gas (RNG)”
Carbon Dioxide (CO$_2$) Removal – Options

1. Regenerative Water Wash
2. Regenerative Amine Wash (Amine)
3. Pressure Swing Adsorption (PSA)
4. Membrane Separation
5. Cryogenic Distillation
Physical Removal of CO$_2$: 
*Pressure Swing Adsorption (PSA)*

- CO$_2$ is absorbed by means of adsorption materials (molecular sieve)
- This system is used extensively in Germany and Sweeden
Biogas Clean Up - PSA

Gas molecules:
- CH₄
- N₂/O₂
- H₂O/H₂S
- CO₂

Carbon molecular sieve

Pressure Swing Adsorption ("PSA")

Adsorption: gas pressure high
Regeneration: gas pressure low

Biogas: CH₄/CO₂/N₂/O₂/H₂O/H₂S
Waste gas: CO₂/N₂/O₂/H₂O/H₂S

Source: Carbotech, 2008
Biogas Clean Up - PSA

Source: Carbotech, 2008
PSA

- No process water
- No wastewater treatment
- No chemicals
- Removal of $\text{H}_2\text{O}$ to dew point -90°C
• $N_2$ and $O_2$ removal

• Hydrocarbon, VOC, and Silicon Compounds removed

• Flexible system, containerized
PSA

- Efficient; 97% CH$_4$ capture
- Off-the-self components
- Very low maintenance
Biogas Clean Up - PSA

(culmination sewage slurry/organic waste)
Biomethane Energy Content

100% CH₄
- LHV = 896 Btu’s/scf
- HHV = 960 Btu’s/scf

Wobbe Index:
- Used to compare the combustion energy output of different composition fuel gases in an appliance
- An indicator of the interchangeability of gaseous fuels

\[ WI = \frac{\text{higher heating value}}{\sqrt{\text{gas SG}}} \]
## Average Cost of Biogas Upgrading

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Biogas Flow (cfm)</th>
<th>Year</th>
<th>Cost ($/MMBtu)</th>
<th>Technology</th>
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Source: Electrigaz Report, 2008
Biogas as Liquid Fuel Replacement

Source: Mike McCloskey, 2012
# Biogas Thermal Energy Value and Diesel Volume Equivalents

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<thead>
<tr>
<th>Farm</th>
<th>CH$_4$ (%)</th>
<th>CH$_4$ (lbs./day)</th>
<th>Annual Heating Value (mmBtu/yr.)</th>
<th>Diesel Eq. (gal/yr.)</th>
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2007 – Dairy Manure Derived Biogas Injection to Natural Gas Pipelines in US

- Few locations attempting this; ID, WI
- Natural gas companies (NGC) very interested
- 17 NGC project investors funded a project in 2007 to develop a US guideline for dairy-based biogas injection
US Guideline for Dairy-Based Biogas Injection (continued)

Biogas testing for:

✓ Basic composition
✓ Dissolved metals
✓ Dust
✓ Microbes – MIC
✓ Others
US Guideline for Dairy-Based Biogas Injection (continued)

Biogas testing for:

- Basic composition
- Dissolved metals
- Dust
- Microbes – MIC
- Others

Guideline Completed 8/2008
2005-2010 Cayuga Renewable Energy, LLC
AD/Pipeline/End Use Project
Dairyville 2020: A Vision for Bio-Energy Communities in New York State

2020 Goal!
- 40% of manure goes to digesters.
- Powers 32,000 homes
- Maintains 13,000 jobs
- 100,000 cars off the road in carbon emissions

Perfect Goal!
- 100% of food & farm waste goes to renewable energy

Vision:
Strengthening the role of farms as the heart of the community

Habitat Protection
Community as an eco-system
Industrial ecology
Water quality
Significant community involvement

Dairyville Welcome!
1 befahrbare Waage
2 befahrbare Siloplatten
3 Güllevorgrube
4 Vorratscontainer für Fermenter
5 Fermenter
6 Nachgärbehälter
7 Blockheizkraftwerk-Container
8 Holzhackschnitzelhalle

9 Container mit Holzhackschnitzelofen und Wärmeverteilung
10 Ölkesselcontainer
11 Wärmepufferspeicher für das Nahwärmennetz
12 Transformatorhaus für Stromeinspeisung
13 Feuerlöschteich
14 Überlaufbecken
15 Warte
16 Nahwärmennetz in der Straße nach Jühnde

Luftbild der Bioenergieanlage in Jühnde
Why are you here?
Perhaps...

- For networking opportunities
- To share knowledge
- Looking for new opportunities
- Representing products/services for sale
- To learn
- Seeking a business opportunity