Screening Tools to Evaluate Waste Biomass to Energy Opportunities

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MWEA Sustainable Energy Seminar, East Lansing, MI
October 19, 2017
Anaerobic Digestion of Biosolids

From the quasar energy group, water reclamation facility electrical requirement compared to the estimated energy that can be produce from anaerobically digesting only biosolids, flows from 4.0 to 120 MGD.

- Range from 11 to 61%
- Averaged about 50%
- Payback period 10 – 20 years


**Water reclamation facilities that use co-digestion can be energy positive.**
Co-Digestion

- Excess nutrients and buffering capacity in biosolids supports the addition of carbon that can produce more biogas.
- High strength wastes, such as food processing and service wastes, contain large amounts of BOD that require expensive oxygen and activated sludge systems.
- Diverting such wastes from the sewer reduces wastewater treatment plant energy needs and increase biogas production, compounding the benefits.

- Anaerobic conditions
- Multiple microbial communities
- Multiple pathways
- Nutrients

- $K_2HPO_4$
- $NH_4Cl$
- $CaCl_2 \cdot 2H_2O$
- $MgCl_2 \cdot 6H_2O$
- $FeCl_2 \cdot 4H_2O$
- $MnCl_2 \cdot 4H_2O$
- $H_3BO_3$
- $ZnCl_2$
- $CuCl_2$
- $Na_2MoO_4 \cdot 2H_2O$
- $CoCl_2 \cdot 6H_2O$
- $NiCl_2 \cdot 6H_2O$
- $Na_2SeO$
- $NaHCO_3$

**C:N:P**

100/4.3/0.9*
## Co-Digestion

<table>
<thead>
<tr>
<th>Source</th>
<th>Biogas Yield (ft³ biogas/lb VS)</th>
<th>CH₄ Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WWTP biosolids</td>
<td>6.57</td>
<td>55</td>
</tr>
<tr>
<td>Cafeteria Waste</td>
<td>8.81</td>
<td>60</td>
</tr>
<tr>
<td>Beef</td>
<td>4.00</td>
<td>55</td>
</tr>
<tr>
<td>Dairy</td>
<td>4.00</td>
<td>55</td>
</tr>
<tr>
<td>Sheep</td>
<td>4.00</td>
<td>55</td>
</tr>
<tr>
<td>Swine</td>
<td>6.09</td>
<td>55</td>
</tr>
<tr>
<td>Turkey</td>
<td>7.69</td>
<td>55</td>
</tr>
<tr>
<td>Chicken</td>
<td>7.69</td>
<td>55</td>
</tr>
<tr>
<td>Corn Stover</td>
<td>6.41</td>
<td>60</td>
</tr>
<tr>
<td>Wheat Straw</td>
<td>6.41</td>
<td>60</td>
</tr>
<tr>
<td>Bakery</td>
<td>8.81</td>
<td>60</td>
</tr>
<tr>
<td>Beverage</td>
<td>8.81</td>
<td>60</td>
</tr>
<tr>
<td>Confection</td>
<td>8.81</td>
<td>60</td>
</tr>
<tr>
<td>Dairy processing</td>
<td>8.81</td>
<td>60</td>
</tr>
<tr>
<td>Fruit &amp; vegetable processing</td>
<td>8.81</td>
<td>60</td>
</tr>
<tr>
<td>Meat processing</td>
<td>8.81</td>
<td>60</td>
</tr>
<tr>
<td>FOG</td>
<td>13.60</td>
<td>60</td>
</tr>
</tbody>
</table>

Co-Digestion

Delhi Charter Township Wastewater Treatment Plant, Holt, MI

- Wastewater solids are mixed with food scraps.
- Food collection program at schools within the township
- Students sort out food waste from their trash at lunch.
- Other food collected from nearby facilities.

Photo Credit: Delhi Charter Township.
Co-Digestion

Waste Management COR®

Prepares Engineered Bioslurry (EBS®) from pre- and post-consumer food waste that can serve as a co-feed that is directly added to the municipal anaerobic digester.

Opportunities

- Approximately 68 million dry tons of waste biomass is produced annually in the U.S.\(^1\)
- Americans waste approximately 40% of all food produced.\(^2\)
- “Just in the United States, $218 billion a year is spent growing, processing, transporting and disposing of food that is never eaten.” \(^3\)
- “Fourteen percent of materials in our trash is food.” \(^3\)
- If all of the waste biomass in Michigan is treated in an anaerobic digester, 6,351,418 MBtu/yr of electrical energy can be produced.\(^4\)

Opportunities

In the United States, number of water reclamation
• facilities: ~16,000
• facilities producing biogas: ~2,000
• facilities that can support the production of biogas: ~11,000

In Michigan, number of water reclamation
• facilities: 246
• facilities producing biogas: 65

What’s Really Possible?

Biomass feedstocks are very diverse and the energy and economical costs for transportation are substantial (unlike energy production from solar and wind energy).

Non-optimized facilities may
- result in an economic loss and
- net negative environmental and health impacts.

Holistic cost/benefit tools are crucial to determine the best location and sources of biomass for co-digestion and must include
- siting consideration,
- life-cycle costs,
- public and private policy concerns, and
- environmental and socioeconomic considerations.
Anaerobic Digestion Design Tools

Michigan Waste Biomass Inventory to Support Renewable Energy Production (Inventory)

Screening level insights on biomass feedstock formulations and energy production potentials.

• Determines if further study at a specific location with a specific feedstock is warranted.
• Provides regional and state-wide renewable biomass energy potential estimates.

http://mibiomass.rsgis.msu.edu/
Inventory
### Inventory

<table>
<thead>
<tr>
<th>Name</th>
<th>Miles</th>
<th>Net Energy</th>
<th>Address</th>
<th>City</th>
<th>State</th>
<th>Zipcode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berlyn Acres-CAFO</td>
<td>0</td>
<td>2,628</td>
<td>2356 Thelen Road</td>
<td>Fowler</td>
<td>MI</td>
<td>48835</td>
</tr>
<tr>
<td>Cary Dairy Farm Inc-CAFO</td>
<td>0</td>
<td>1,462</td>
<td>6625 Poorman Rd.</td>
<td>Battle Creek</td>
<td>MI</td>
<td>49017</td>
</tr>
<tr>
<td>Clover Family Farms-CAFO</td>
<td>0</td>
<td>1,512</td>
<td>2412 N. Stage Road, Ionia 48846</td>
<td>-</td>
<td>-</td>
<td>48846</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>902</td>
<td>7540 Clintonia Rd.</td>
<td>Westphalia</td>
<td>MI</td>
<td>48894</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1,883</td>
<td>86 141st Street, Wayland 49348</td>
<td>-</td>
<td>-</td>
<td>49348</td>
</tr>
</tbody>
</table>

### Feature Properties

- **Feature Name**: Beaver Creek Dairy-CAFO
- **Net Energy**: 2,452 (MBtu/Year)
- **Miles**: 0

**Property**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Tonage (tons)</td>
<td>20735</td>
</tr>
<tr>
<td>Moisture %</td>
<td>91.5</td>
</tr>
<tr>
<td>Volatile Solid %</td>
<td>80</td>
</tr>
<tr>
<td>Biogas Yield (mol biogas/ton VS)</td>
<td>10128</td>
</tr>
<tr>
<td>Methane Percentage of Biogas</td>
<td>55</td>
</tr>
</tbody>
</table>
Inventory

Michigan Biomass Inventory

Biomass Analysis Site Information

County: Clinton
Local Unit: Bingham
Longitude: -84.6012223417624
Latitude: 43.0267624321684

Final Results

Biomass Site Evaluation Summary

Net Energy: 218,668.72 (MBtu/Year)*

Site Inputs

County: Clinton
Local Unit: Bingham
Latitude: 43.0267624321684
Longitude: -84.6012223417624

Site Assessment Values
Combustion Technology: AD

Change Layer Transparency:
Biomass Sources

Cancel

Previous

Next
Anaerobic Digestion Design Tools
Anaerobic Digestion Development Iterative Tool (ADDIT)

Publically available resource that enables a comparative analysis of feedstocks and includes the costs/benefits of diverting high strength wastes from the sewer directly into the anaerobic digestion.

www.egr.msu.edu/~SteveS/
Conclusions

Screening Protocol

1. Find feedstocks – Inventory
2. Predict best theoretical potential - ADDIT -
3. Conduct laboratory experimentation - Biogas Assays -
4. Conduct pilot-scale studies
5. Interpret results - Sankey Diagrams -

### Conclusions  Top Potential Energy Generation

<table>
<thead>
<tr>
<th>Rank based on “At Facility”</th>
<th>WWTP Facility Name</th>
<th>County</th>
<th>Net Electrical Estimation (10^3 MBtu/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 Mile Radius</td>
</tr>
<tr>
<td>1</td>
<td>Detroit</td>
<td>Wayne</td>
<td>718</td>
</tr>
<tr>
<td>2</td>
<td>Kalamazoo</td>
<td>Kalamazoo</td>
<td>75.2</td>
</tr>
<tr>
<td>3</td>
<td>Grand Rapids</td>
<td>Kent</td>
<td>70.2</td>
</tr>
<tr>
<td>4</td>
<td>Wayne Co-Downriver</td>
<td>Wayne</td>
<td>54.5</td>
</tr>
<tr>
<td>5</td>
<td>Muskegon Co</td>
<td>Muskegon</td>
<td>54.2</td>
</tr>
<tr>
<td>6</td>
<td>Genesee Co-Ragnone</td>
<td>Genesee</td>
<td>39.9</td>
</tr>
<tr>
<td>7</td>
<td>Wyoming</td>
<td>Kent</td>
<td>35.4</td>
</tr>
<tr>
<td>8</td>
<td>YCUA Regional</td>
<td>Washtenaw</td>
<td>35.1</td>
</tr>
<tr>
<td>9</td>
<td>Lansing</td>
<td>Ingham</td>
<td>26.3</td>
</tr>
<tr>
<td>10</td>
<td>Battle Creek</td>
<td>Calhoun</td>
<td>25.2</td>
</tr>
</tbody>
</table>

*Development Tools for Sustainable Waste Biomass to Energy in Michigan, Saferman et al., Project Final Report, Michigan Economic Development Corp., Grant No. MEO-12-28, Submitted on September 20, 2012*
Flint Biogas Plant:
Success with co-digestion
• Originally developed by Swedish Biogas in 2010
• 21 year operations contract with City of Flint
• Fully integrated with City of Flint Water Pollution Control Facility
• $5.5 million CAPEX
• Provides cost savings and revenue to the City
• Biogas plant consists of:
  • Two 1.1 million gallon digesters
  • One 1.1 million gallon feedstock storage tank
  • Electricity production from biogas (600 kw)
  • Ability to generate Class B biosolids
Typical Process Flow

1. **Sewage Sludge/Food Processing Waste** (as needed)
2. **Digesters**
3. **Digestate/Biogas Storage**
4. **Back up Boiler**
5. **CHP**
6. **BIOGAS**
7. **NAT GAS Replacement**
8. **RNG FUEL**
9. **Land Application**
10. **Compost**
11. **Other disposal methods**

- **DIGESTATE**
- **DIGESTATE RECYCLE STREAMS TO SEWER OR LIQUID BIOFERTILIZER**
- **THICKENED SLUDGE**
- **FILTRATE**
- **DECANT**
- **ENERGY UTILIZATION ALTERNATIVES**
Flint Biogas Site

- Feedstock Storage
- Digester #1
- Digester #2
- Biogas and digested sludge storage
- Flare
<table>
<thead>
<tr>
<th>Asset/Capability</th>
<th>Flint Biogas</th>
<th>Fremont Community Digester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Digesters</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Digester Capacity (total), gallons</td>
<td>2,200,000</td>
<td>2,600,000</td>
</tr>
<tr>
<td>Feedstock storage, gallons</td>
<td>1,100,000</td>
<td>450,000</td>
</tr>
<tr>
<td>Processing of liquid feedstocks</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Processing of semi solid feedstocks</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Electrical Generation</td>
<td>600 kW</td>
<td>2.8 MW</td>
</tr>
<tr>
<td>Electrical generation potential</td>
<td>2 MW</td>
<td>2.8 MW</td>
</tr>
<tr>
<td>Limitations</td>
<td>Low PPA price</td>
<td>No digestate storage</td>
</tr>
<tr>
<td>CAPEX invested</td>
<td>$5.5 Mio</td>
<td>$28 Mio</td>
</tr>
</tbody>
</table>
System Automation
Flint Biogas feedstocks utilized include:

- Sewage sludge –
- Food processing wastes
- Grease trap waste
- Industrial byproducts with agricultural ingredients

BioWorks Energy provides complete procurement of feedstocks - no middle man.

BioWorks has full scale laboratory in Flint to qualify feedstock potential and to determine overall value (setting of tip fees).
• BioWorks uses lab scale digesters to model Flint “mix” of feedstocks to predict performance and anticipate potential upsets
• Flint facility currently handles over 100,000 tons per annum of organic wastes
• Has capacity to take high volumes (+100,000 gallons) of waste at any given day
• Is not “bottlenecked” by front storage or back end disposal
• Can process both liquid and “solid” wastes
Flint Biogas Plant

Biogas quality as a function of Methane content

Ave Flint Biogas Quality = 69.2%
~10% higher than Muni Digester
~25% higher than Ag Digester

Impact of high sugar substrate load

Typical municipal digester gas
Typical agricultural digester gas

Flint Biogas Metrics
BioWorks Energy provides complete knowledge of the process:

- Engineering/design
- Operations management
- Process troubleshooting
- Substrate procurement and qualification
- Offtake development for residuals
- Power Purchase Agreements
- Carbon Credits
- Biogas utilization – electricity, combined heat and power, vehicle fuel, gas conditioning
- Gas quality analysis
“Beyond Biogas”
THANK YOU

BioWorks Energy LLC
Advanced organics processing

Chad L. Antle, P.E.
Cell (740) 972-2499
chad.ante@bioworksenergy.com
The Joys of Anaerobic Digestion

Dana Kirk, Ph.D., P.E.
Michigan State University
Biosystems and Agricultural Engineering Department
Anaerobic Digestion Research and Education Center
MSU South Campus Anaerobic Digester
Generalized Process Flow for MSU Anaerobic Digester

- FOOD & FOG RECEIVING
- MANURE RECEIVING
- MIX TANK
- GRINDER
- MIXED ANAEROBIC DIGESTER
- SOLID-LIQUID SEPARATION
- POST DIGESTER STORAGE
- H2S REMOVAL
- ELECTRICAL GENERATION
- COMPOST
- LAND APPLICATION
• Digester tank
  • 52’ * 26’ plus cover (400,000 gallons)

• Digestate storage tank
  • 101’ * 42’ plus cover (2.1 million gallons)

• CHP system
  • 380 kW electrical production & 400+ kW of thermal energy recovery
  • Offset power at 8 to 10 south campus facilities
  • Thermal energy used to sustain the process, heat support building and separator area

• Digestate
  • Separated solids to compost
  • Separated liquid to storage and land application
## MSU South Campus Digester Feedstock

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>TS (%)</th>
<th>Planned (2012)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy manure</td>
<td>12</td>
<td>7,000</td>
<td>43</td>
</tr>
<tr>
<td>Fruit &amp; vegetable</td>
<td>11</td>
<td>3,900</td>
<td>24</td>
</tr>
<tr>
<td>FOG</td>
<td>20</td>
<td>5,000</td>
<td>30</td>
</tr>
<tr>
<td>Cafeteria food waste</td>
<td>10</td>
<td>750</td>
<td>3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>16,650</strong></td>
<td></td>
</tr>
</tbody>
</table>
### MSU South Campus Digester Feedstock

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>TS (%)</th>
<th>Planned (ton)</th>
<th>Planned (%)</th>
<th>2014 (ton)</th>
<th>2014 (%)</th>
<th>2015 (ton)</th>
<th>2015 (%)</th>
<th>2016 (ton)</th>
<th>2016 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy manure</td>
<td>12</td>
<td>7,000</td>
<td>43</td>
<td>16,000</td>
<td>67</td>
<td>9,525</td>
<td>43</td>
<td>10,554</td>
<td>52</td>
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<tr>
<td>Fruit &amp; vegetable</td>
<td>11</td>
<td>3,900</td>
<td>24</td>
<td>2,900</td>
<td>12</td>
<td>2,900</td>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>FOG</td>
<td>20</td>
<td>5,000</td>
<td>30</td>
<td>4,400</td>
<td>19</td>
<td>3,730</td>
<td>17</td>
<td>4,747</td>
<td>23</td>
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<tr>
<td>Cafeteria food waste</td>
<td>10</td>
<td>750</td>
<td>3</td>
<td>430</td>
<td>2</td>
<td>440</td>
<td>2</td>
<td>513</td>
<td>3</td>
</tr>
<tr>
<td>Milk processing waste</td>
<td>12</td>
<td></td>
<td></td>
<td>430</td>
<td>2</td>
<td>440</td>
<td>2</td>
<td>513</td>
<td>3</td>
</tr>
<tr>
<td>Packing material</td>
<td>90</td>
<td></td>
<td></td>
<td>60</td>
<td>2</td>
<td>60</td>
<td>3</td>
<td>34</td>
<td>0.2</td>
</tr>
<tr>
<td>Glycerin</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>88</td>
<td>0.4</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>16,650</strong></td>
<td><strong>23,730</strong></td>
<td><strong>22,070</strong></td>
<td><strong>20,380</strong></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

*Other materials include waste feed, eggs and one-offs*
2016 MSU SCAD Feedstock

Volume (gal/month)

Month

FOG 1  FOG 2  MSU FOG  Lactose  Milk Process  Starch  Render Oil
Feedstock Value

- Methane potential
  - Based on BMP
- Nutrients
  - Market lacking
- Application
  - Minimal volume change
  - Savings $0.001
- Environmental
  - No considered
  - Odor
  - Well head

### Table: Feedstock Value

<table>
<thead>
<tr>
<th>Description</th>
<th>Feedstock Source</th>
<th>MSU Dairy</th>
<th>MSU FOG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivered quantity, gal/load</td>
<td></td>
<td>10,000</td>
<td>2,770</td>
</tr>
<tr>
<td>Methane potential, ft³/gal</td>
<td></td>
<td>1.7</td>
<td>5.9</td>
</tr>
</tbody>
</table>

### Revenue

- Energy, $/gal
  - MSU Dairy: $0.015
  - MSU FOG: $0.053
- Nutrient, $/gal
  - MSU Dairy: $0.00
  - MSU FOG: $0.00
- Tip fee, $/gal
  - MSU Dairy: $0.00
  - MSU FOG: $0.10

### Cost

- Application, $/gal delivered
  - MSU Dairy: $0.039
  - MSU FOG: $0.038
- Handling, $/gal

<table>
<thead>
<tr>
<th>Value, $/gal</th>
<th></th>
<th>MSU Dairy</th>
<th>MSU FOG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value, $/load</td>
<td></td>
<td>-$244</td>
<td>$318</td>
</tr>
</tbody>
</table>
## Operational Summary

<table>
<thead>
<tr>
<th>Year</th>
<th>Temp (°F)</th>
<th>pH</th>
<th>OLR (g VS/L-d)</th>
<th>Biogas (scfm)</th>
<th>Methane (%)</th>
<th>Ave. Electrical Output (kW/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>103.0</td>
<td>7.9</td>
<td>3.14</td>
<td>54</td>
<td>63.4</td>
<td>199</td>
</tr>
<tr>
<td>2015¹</td>
<td>103.7</td>
<td>7.4</td>
<td>3.52</td>
<td>82</td>
<td>61.3</td>
<td>260</td>
</tr>
<tr>
<td>2016¹,²</td>
<td>101.8</td>
<td>7.5</td>
<td>4.72</td>
<td>84</td>
<td>62.4</td>
<td>306</td>
</tr>
<tr>
<td>2017²</td>
<td>102.6</td>
<td>7.7</td>
<td>4.08</td>
<td>76</td>
<td>65.2</td>
<td>253/306</td>
</tr>
</tbody>
</table>

¹Engine failure Dec 2015 – May 2016
²Engine failure Nov 2016 – Feb 2017
2017 MSU SCAD – Daily Biogas Flow

Day

1/1/17 2/1/17 3/1/17 4/1/17 5/1/17 6/1/17 7/1/17 8/1/17 9/1/17 10/1/17

Biogas Flow Rate (SCF/d)

0 20,000 40,000 60,000 80,000 100,000 120,000 140,000 160,000 180,000 200,000

CHP Flare Boiler

Property of Michigan State University
Animal feed study –
palmitic, stearic & oleic acid
Digester Contribution to Campus Sustainability

- Electrical energy – 2,800 MW/yr
  - 10% of energy produce needed to operate system
  - 7.3% of the 2015 energy transition goal (based on 08-09)
  - Renewable energy certificates – 3,000 MW/yr
- Thermal energy – +3,000 MW/yr
  - <50% of the thermal energy needed to maintain temperature
- Greenhouse gas reduction (carbon credits)
- Landfill & wastewater diversion (≈8,000+ ton/yr)
- Recycling of carbon and nutrients
Questions

Dana Kirk
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517.432.6530