An Overview of the MSU Anaerobic Digestion Research and Education Center & Anaerobic Digestion in Michigan

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January, 2015
Anaerobic Digestion

• Is the biological conversion of organic material into biogas and a stabilized slurry (digester) in a warm (>100°F), oxygen (<2%) deprived atmosphere

• Biogas contains approximately 60% Methane (CH₄), 40% Carbon Dioxide (CO₂) and other trace gases including Hydrogen Sulfide (H₂S)

• Digestate is a mix of water, undigested solids, nutrient, minerals & other stuff

• Anaerobic digestion is best suited for liquid or slurries containing less than 20% total solids
Anaerobic Digestion Benefits

- Odor control
- Emission control
- Waste stabilization (treatment)
- Carbon recycling
- Nutrient availability/recovery
- Renewable energy (revenue)
  - Energy offset / sale
  - Renewable energy certificates (REC’s)
  - Carbon offset credits
  - Tipping fee for non-farm organic waste
  - Fence line business opportunities
- Landfill/WWTP organics diversion
Anaerobic Digestion Benefits!
OBJECTIVES

- Research and develop novel waste-to-resource technologies capable to convert organic wastes into value-added fuel and chemical products
- Fulfill commercialization and technology transfer of new waste-to-resource concepts
- Educate the next generation of engineers, scientists and policymakers on waste utilization design and practice
Lab-scale Facilities and Equipment

- Culture room
- Small anaerobic bioreactors
- Serum bottles
- Anaerobic chamber
Microbial Community Analysis

- **Primers for PCR amplification 16S rRNA gene:**
  Universal bacterial primers 357f (5’-CCTACGGGAGGCAGCAG-3’) and 926r (5’-CCGTCATTTCMTTTRAGT-3’)

- **Primers for 454 sequencing:**
  Human Microbiome Project (HMP) primers targeting the V3-V5 region of 16S rRNA gene

- **GT 454 FLX sequencer**

- **Readings from the sequencer**

- **Abundance of bacterial community**

- **Cultures under 35C**

- **Cultures under 50C**
(a). the inoculum consisting of six algal genera, *Scenedesmus*, *Limnothrix*, *Chlorella*, *Pseudanabaena*, *Synechocystis*, and *Phormidium*; (b). *Chlorella*, a dominant alga after 5 months culture; (c). *Scenedesmus*, another dominant alga after 5 months culture; (d). *Synechocystis*, another dominant alga after 5 months culture.
Integrated Farm-based Biorefining (IFBBR) Concept

1. Solar energy
   - Solar energy collection

2. Anaerobic digestion
   - Organic residues
     - Methane
   - Effluent (N,P)
     - Combined heat & power
       - Heat
       - Electricity

3. Microbial processes
   - Cellulose enzymes
     - Sugars
       - Advanced biofuel conversion
         - Other fermentations
           - Other value-added products
             - Fresh water
               - Algal assemblage
                 - Pure culture
                 - Fertilizer
                 - Bioenergy
                 - Value-added products

4. Algal culture
   - CO₂

5. Water reclamation
System Integration

MSU Campus digester and algal cultivation facility

- MSU anaerobic digestion and algal cultivation facility
- MSU Dairy Farm
- MSU ADREC
- Solar panels
- 600,000 Btu/hr Boiler

- CSTR system (2000 m³, 0.5 MW)
- Algal pond No. 1 (LxWxD = 250x50x3 ft)
- Anaerobic digester (250,000 gallon)
System Integration

Solar-biopower generation system (Central America)

Solar powered bioreactor

Sand filter

Engines

Surface wetland
1. Feedstock evaluation for anaerobic digestion and other biofuels/chemicals production
2. Evaluation of biogas production
3. Biogas utilization of electricity and fuel production
4. Nutrient management of agricultural wastes
5. Organic wastewater reclamation
6. Feasibility studies for anaerobic digestion and biorefining processes
7. Testing anaerobic digestion and algal cultivation processes at various scales
8. System modeling and design for waste utilization facility
International Projects – Costa Rica, Nicaragua, Panama, Ghana, China & India
Improving Access to Clean Energy in Rural Central America Using On-site Solar-Biopower Generation

Support from:

United States Department of State
Bureau of Western Hemisphere Affairs
Energy & Climate Partnership of the Americas
Develop and deploy an integrated small-scale self-sustained waste-to-clean energy generation system co-producing value-added by-products such as fertilizers for local farming applications and reclaiming water.
Integrating wastes utilization with solar and biological technologies will create a novel self-sustainable clean energy generations system for small-medium scale operations.
DOS WHA Objectives

- Optimize local thermophilic anaerobic microbial consortia on mixed waste streams
- Design and implement the integrated portable solar-biopower generation system on mixed waste streams at UCR
- Evaluate technical and economic performance of the system for various rural scenarios in Central America
- Establish an outreach program in Central America to include technology transfer, business development, and workforce training
Effects of location, feedstock composition and temperature on digestion stabilization *

Effects of Climate Region, Reaction Temperature and Feed Composition on Microbial Community and Anaerobic Digestion Performance
Rui Chen\textsuperscript{a}, Mariana Murillo\textsuperscript{b}, Yuan Zhong\textsuperscript{a}, Terry Marsh\textsuperscript{a}, Lorena Uribe Lorio\textsuperscript{b}, Lidieth Uribe Lorio\textsuperscript{b}, Dana Kirk\textsuperscript{b}, Wei Liao\textsuperscript{a*}
2014 ASABE International Annual Meeting

*: Digestion stability is based on pH
2. Pilot-scale Digestion in Central America

Effects of location, feedstock composition and temperature on digestion performance

- Biogas productivity (mL/gTS reduced/L digestion)

<table>
<thead>
<tr>
<th>Location</th>
<th>Temperature</th>
<th>Test Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCR</td>
<td>35 °C</td>
<td>100:0, 90:10, 80:20</td>
</tr>
<tr>
<td>MSU</td>
<td>50 °C</td>
<td>100:0, 90:10, 80:20</td>
</tr>
</tbody>
</table>
2. Pilot-scale Digestion in Central America

Effects of location, feedstock composition and temperature on digestion performance

- Biogas production (mL/L-digestion/day)
- TS reduction (%)

<table>
<thead>
<tr>
<th>Location</th>
<th>Feedstock Composition</th>
<th>Temperature</th>
<th>Biogas Production</th>
<th>TS Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCR</td>
<td>100:0</td>
<td>35 °C</td>
<td>2500</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>90:10</td>
<td>35 °C</td>
<td>2000</td>
<td>20</td>
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<tr>
<td></td>
<td>80:20</td>
<td>35 °C</td>
<td>1500</td>
<td>40</td>
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<td></td>
<td>80:20</td>
<td>50 °C</td>
<td>1500</td>
<td>40</td>
</tr>
</tbody>
</table>

- MSU

- 100:0 35 °C 1500 0
- 90:10 35 °C 1000 20
- 80:20 35 °C 500 40
- 100:0 50 °C 2500 0
- 90:10 50 °C 2000 20
- 80:20 50 °C 1500 40
2. Pilot-scale Digestion in Central America

Abundance of dominant bacteria

<table>
<thead>
<tr>
<th></th>
<th>Dairy</th>
<th>Chicken</th>
<th>Dairy</th>
<th>UCR</th>
<th>MSU</th>
<th>UCR</th>
<th>MSU</th>
<th>UCR</th>
<th>MSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original manure samples</td>
<td>UCR</td>
<td>MSU</td>
<td>100 : 0</td>
<td>90 : 10</td>
<td>80 : 20</td>
<td>100 : 0</td>
<td>90 : 10</td>
<td>80 : 20</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>35 C</td>
<td>50 C</td>
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<td></td>
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</tr>
</tbody>
</table>

- Firmicutes (phylum)
- Bacteroidetes (phylum)
- Chloroflexi (phylum)
- Proteobacteria (phylum)
- Actinobacteria (phylum)
- Synergistetes (phylum)
- Spirochaetes (phylum)
- Thermotogae (phylum)
- Unclassified Bacteroidetes
- Bacteroides
- Petrimonas
- Clostridia
2. Pilot-scale Digestion in Central America

Pilot bioreactor system at the UCR Fabio Agricultural Experiment Station

- Feeding unit
- Bioreactor (20 m³)
- Biogas storage (60 m³)
- Flare
- Engines (16 kw x 2)
2. Pilot-scale Digestion in Central America

Mass balance for the pilot scale digester

Mass balance for the solar-bio system on 1,000 kg of mixed chicken, dairy manure and food wastes

- Generating 25 kWh electricity per day
- Producing 2 gasoline gallon equivalent (GGE) renewable fuel per day
2. Pilot-scale Digestion in Central America

Performance comparison between lab- and pilot-scale *

![Bar chart showing biogas production comparison between lab-scale and pilot-scale digesters. Lab-scale digester produces 1000 ml/g TS reduction, while pilot-scale digester produces 866 ml/g TS reduction.]

*: Under the same operational conditions
Anaerobic Digester Industry in Michigan

Crude Oil, 01/13/15
45.67 USD -0.22 (-0.48%)

Michigan CAFO’s & Food Processors with Operation ADs

- CAFO
- Food Processor
- WWTP
Lowell Energy Anaerobic Digester (LEAD)

- Public private partnership – Lowell Light and Power & Spart
- UDR System (fixed film/CSTR)
- 800 kW of generation capacity
- Feedstocks
  - 80% waste cooking oil & grease
  - 15% dairy manure
  - 5% local food processing waste
• Consumers Energy – Experimental Advanced Renewable Program (EARP) – Anaerobic Digestion
  • Option 1
    • Fixed rate program for 20 years
    • Standard offer of $86 MWh
  • Option 2
    • 10 to 20 year contract with escalating rates
    • 2015 ($76.39) to 2038 ($106.39)
  • Four farms accepted
    • Beaver Creek Farms (new), Coopersville
    • Brook View Dairy (existing), Freeport
    • Green Meadow Farms (existing), Elsie
    • Scenic View Dairy (existing), Fennville
Anaerobic Digester at Michigan State University
• Plug flow
• Capacity of 250,000 gallons
• Variable HRT
• Biogas destroyed for heat
• Heating
  • Hot water to sludge
  • In wall & floor heat
• Mechanical solid liquid separation
• Algal raceway system
• Operational September, 2011
• Digester tank
  • 52’ * 26’ plus cover (400,000 gallons)
• Digestate storage tank
  • 101’ * 42’ plus cover (2.1 million gallons)
• CHP system
  • 400 kW electrical production & 450 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
Combined Heat & Power Unit (CHP)
Digester Challenges Experience at MSU

• Process design (plumbing – size and restrictions)
• Operational time (process design philosophy)
• Mechanical failures (digester mixer)
• Undersized feedstock receiving tanks
• Frozen sensors – false alarms
• Control system & feedback
  • Excessive alarms, not categorized
  • Alarm lockout
• Debris in feedstock
• Feedstock characteristics and quantities
PLANNED

Dairy Manure (43%)
- Quantity: 7,000 ton/yr
- Total Solids: 12%

Fruit & Vegetable Waste (24%)
- Quantity: 3,900 ton/yr
- Total Solids: 11%

Fat, Oil & Grease (FOG) (30%)
- Quantity: 5,000 ton/yr
- Total Solids: 20%

Campus Food waste (3%)
- Quantity: 500 - 1,000 ton/yr
- Total solids: 8 – 12%
• Electrical energy – 3,000 MW/yr
  • 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
• Greenhouse gas reduction (carbon credits)
  • Dairy manure – 400 mton CO$_2$/yr$^1$
  • Landfill diversion – 4,000 mton CO$_2$/yr (est.)
  • FOG – ?
• Landfill & wastewater diversion (≈10,000 ton/yr)
• Recycling of carbon and nutrients
  • Emission & odor control
  • Pathogen & weed seed reduction
• Education, outreach & research opportunities
### PLANNED

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<th>Quantity</th>
<th>Total Solids</th>
</tr>
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<tbody>
<tr>
<td>Dairy Manure (43%)</td>
<td>7,000 ton/yr</td>
<td>12%</td>
</tr>
<tr>
<td>Fruit &amp; Vegetable Waste (24%)</td>
<td>3,900 ton/yr</td>
<td>11%</td>
</tr>
<tr>
<td>Fat, Oil &amp; Grease (FOG) (30%)</td>
<td>5,000 ton/yr</td>
<td>20%</td>
</tr>
<tr>
<td>Campus Food waste (3%)</td>
<td>500 - 1,000 ton/yr</td>
<td>8 - 12%</td>
</tr>
</tbody>
</table>

### 2014 ACTUAL

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Quantity</th>
<th>Total Solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure (64%)</td>
<td>16,000 ton/yr</td>
<td>12%</td>
</tr>
<tr>
<td>Fruit &amp; Vegetable Waste (11%)</td>
<td>2,900 ton/yr</td>
<td>11%</td>
</tr>
<tr>
<td>Fat, Oil &amp; Grease (FOG) (17%)</td>
<td>4,400 ton/yr</td>
<td>2%</td>
</tr>
<tr>
<td>Campus Food waste (2%)</td>
<td>430 ton/yr</td>
<td>8 - 12%</td>
</tr>
</tbody>
</table>
Energy Potential of Digester Feedstock

![Bar chart showing biogas potential (ft³/ton as is) for various substrates.](chart.png)

- Liquid dairy manure
- Cheese Whey
- Fish offal
- FOG/food grease
- Mixed food waste
- Food processing waste
- Fruit & Vegetable waste
- Glycerin
- Switchgrass, fresh
- Waste Potatoes

Substrate
Graph showing the relationship between Feedstock Deliveries (ton/month) and Electrical Output (kWh/month) over the period from 1/1/2014 to 11/30/2014. The graph includes data points for each month, with some months showing higher feedstock deliveries and lower electrical output compared to other months. The graph also includes target lines for both feedstock and electrical output, indicating the expected performance levels. The chart indicates that the actual performance has generally tracked below the target levels, particularly in the later months of the period.
Digester Performance Indicators – OLR & Electrical Production

OLR (g VS/L-d)

Electrical Production (kWh)

7 Day OLR
30 Day OLR
Questions?

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