Renewable Natural Gas (RNG)
CASE STUDY: SATS

Dr. Joshua Rapport, M.S., Ph.D.
Vice President of Research and Development
About CleanWorld

- Founded in 2009
- CEO, Michele Wong
- VP of R&D, Josh Rapport
- Convert organic waste streams into
  - **Renewable electricity**
  - Heat
  - Natural gas
  - Nutrient-rich fertilizers
Sacramento BioDigester Facility at SATS

Initially commissioned in 2013

- First of its kind facility
- 10,000 TPY, **scaled-up** to 40,000 TPY
- **Redevelopment partnership** with Atlas Waste Hauling
- 100% **source-separated organics**
- 200 kW IC Engine
- 300 scfm **BioCNG** making **200 mmBTU/d RNG**
  - **BioCNG 100 & BioCNG 200** installed separately
- On-site filling station with **natural gas** and **RNG**
- Purchased by Insight Clean Energy in 2017
CleanWorld Technology: How it Works

Sacramento Biodigester Flow Diagram

1. **Feedstock Receiving**: Incoming feedstock is dumped from the truck into a pit where it is immediately conveyed into the top of the pre-processing unit.

2. **Feedstock Pre-Processing**: The pre-processing unit removes contaminants from the feedstock and grinds the organic material into a slurry that is pumped directly into the hydrolysis tank.

3. **Hydrolysis Tank**: Slurried feedstock is consumed by bacteria and converted biologically to organic acids and nutrients that become feedstocks for methanogenic microorganisms.

4. **Methanogenesis Tank**: The organic acids are converted to methane and carbon dioxide biogas, and the residual solids are further liquefied.

5. **Polishing Tank**: The liquid from the methanogenesis tank is transferred to the polishing tank where any remaining acids are digested to maximize biogas production.

6. **Fertilizer Production**: Undigested solids are separated and converted to solid soil amendments, while the liquid fraction is fortified and processed to create liquid fertilizers.

7. **Electrical Generation**: A small portion of the biogas is diverted to an engine generator to produce enough renewable electricity to run the digester and fueling station.

8. **Biogas Refining**: Biogas is piped from the headspace of the tanks to the biogas refining system where hydrogen sulfide, water vapor and carbon dioxide are removed to create transportation-quality renewable natural gas.

9. **Fueling Station**: The renewable natural gas is compressed and stored in high pressure vessels until it is pumped into CNG vehicles through either fast-fill or slow-fill fueling terminals.
SATS Facility Layout
Preprocessing & Feedstocks

- Multiple preprocessing options
- Ability to handle both liquid and solid feedstock
- Contamination removal
Sacramento BioDigester Facility at SATS

- Phase I: 10,000 TPY, Commissioned Jan 2013
- Phase II: 40,000 TPY, Commissioned Jun 2015
SATS Biogas Processing System
Overview
SATS Biogas Processing System
H2S Scrubbing
SATS Biogas Processing System
Biogas Processing (BioCNG)
SATS Biogas Processing System
RNG Storage and Compression
SATS Biogas Processing System

Fueling Station
## RNG Vehicle Fuel Specs and Concentrations Seen

<table>
<thead>
<tr>
<th>Compound</th>
<th>Limit (SAE J1616)</th>
<th>Pipeline</th>
<th>Min</th>
<th>Avg (n &gt; 30)</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>N2 + CO2</td>
<td>4.5% max</td>
<td>3% max</td>
<td>0.5%</td>
<td>4.5%</td>
<td>11.9%</td>
</tr>
<tr>
<td>O2</td>
<td>1% max</td>
<td>0.2% max</td>
<td>0%</td>
<td>0.07%</td>
<td>0.5%</td>
</tr>
<tr>
<td>H2</td>
<td>0.1% max</td>
<td>NA</td>
<td>0%</td>
<td>0%</td>
<td>0.02%</td>
</tr>
<tr>
<td>Ethane</td>
<td>6% max</td>
<td>NA</td>
<td>0%</td>
<td>1.2%</td>
<td>4.3%</td>
</tr>
<tr>
<td>CH4</td>
<td>88% min</td>
<td>97% min</td>
<td>87.8%</td>
<td>94.5%</td>
<td>99.5%</td>
</tr>
<tr>
<td>H2S</td>
<td>10 ppm (ARB)</td>
<td>4 ppm</td>
<td>0 ppm</td>
<td>0.5 ppm</td>
<td>7.5 ppm</td>
</tr>
<tr>
<td>Total sulfur</td>
<td>16 ppm max</td>
<td>?</td>
<td>0.9 ppm</td>
<td>15.9 ppm</td>
<td>72.5 ppm</td>
</tr>
<tr>
<td>Acetone</td>
<td>NA</td>
<td>NA</td>
<td>35 ppb</td>
<td>1,941 ppb</td>
<td>10,700 ppb</td>
</tr>
<tr>
<td>MEK</td>
<td>NA</td>
<td>NA</td>
<td>38 ppb</td>
<td>5,416 ppb</td>
<td>52,600 ppb</td>
</tr>
<tr>
<td>Siloxane</td>
<td>3,000 ppb</td>
<td>?</td>
<td>0 ppb</td>
<td>0 ppb</td>
<td>290 ppb</td>
</tr>
</tbody>
</table>
Biogas and RNG Analytes Found in Our Samples

**Primary**
- CO2
- CH4

**Secondary**
- N2
- O2
- H2
- Ethane

**Sulfur Compounds**
- H2S
- Carbonyl Sulfide
- Methyl Mercaptan
- Ethyl Mercaptan
- Dimethyl Sulfide
- Carbon disulfide
- Isopropyl Mercaptan
- tert-Butyl Mercaptan
- n-Propyl Mercaptan

**Primary**
- Methylethylsulfide
- sec-Butyl Mercaptan
- iso-Butyl Mercaptan
- Diethyl Sulfide
- n-Butyl Mercaptan
- Dimethyl Disulfide (DMDS)

**Volatile Organic Compounds**
- Tetrahydrothiophene
- Propene
- Methanol
- Ethanol
- Acetone
- 2-Propanol
- MEK (2-Butanone)
- Hexanone
- Hexane
- Chloroform
- Ethyl Acetate

**Tetrahydrofuran**
- 1,2-Dichloroethane
- Benzene
- Cyclohexane
- TCE
- Trimethylpentane
- Heptane
- MiBK
- Toluene
- MBK
- Ethylbenzene
- m&p-Xylenes
- Styrene
- o-Xylene
- Trimethylbenzene

**Siloxanes**
Technology Selection

Initial analysis done in 2011 – 2012

• California Energy Commission funded feasibility grant

Selection Criteria:
1. Small scale: 50 – 100 scfm initially
2. Scalable (80 scfm -> 320 scfm)
3. Variable input feed rate
4. Reliable (meets SAE J 1616 fuel and engine specs)
5. Cost effective at small and large scale
## Technologies Considered

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pros</th>
<th>Cons</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amine Scrubbing</td>
<td>High removal rates</td>
<td>High power for regen Multiple steps Not cost effective for small scale</td>
<td>No</td>
</tr>
<tr>
<td>Pressure Swing Adsorption</td>
<td>Low power Compact skid Upstream heat recovery</td>
<td>Carbon sieve replacement Not cost effective for small scale</td>
<td>No</td>
</tr>
<tr>
<td>Water Scrubbing</td>
<td>Removes H2S also Can recover CO₂ Low opex (water)</td>
<td>Water consumption pH monitoring Not cost effective for small scale</td>
<td>Maybe</td>
</tr>
<tr>
<td>Selexol Scrubbing</td>
<td>High absorbance</td>
<td>Novel chemistry EH&amp;S concerns</td>
<td>No</td>
</tr>
<tr>
<td>Membrane</td>
<td>Simple skid Low power Very reliable Least costly</td>
<td>New technology Requires upstream processing</td>
<td>Yes</td>
</tr>
</tbody>
</table>
BioCNG Issues and Lessons Learned

1. Controls and integration
2. Flare issues
3. Gas quality monitoring
4. VOC toxicity (especially ketones: i.e. MEK and Acetone)
Brightmark Energy is developing greenfield swine and cow manure projects, partnering with dairy and swine farmers to house a digester on their property and economically utilize excess manure.

Project Details:
- **Locations:** Midwest, New York, North Carolina
- **Size:** 300 mmtbu/day and up combined system
- **Technology:** Digesters, Gas Upgrade equipment, virtual pipeline.
- **Payments:** Upfront joining payment as well as yearly payments based on gas production.

Project Benefits from:
- Existing lagoons
- Existing digestors

Project Economics
- Varies based on
  - Condition of existing digester
  - Distance to an interconnection gas pipeline
How it works

1. Co-locate on largest facility

2. Truck manure in from local basket to augment on site production

3. Virtual pipeline to transport the RNG to a natural gas pipeline

4. Obligated RIN purchasers

Theoretical gas particle pathway to California for LCFS credits and use in transportation vehicles.

Point of Interconnection
1. **RINS**
   - **Federal** Renewable Fuel Standard (RFS)
   - Obligations (RVO): fraction of fuel from renewable resources
   - To comply, **oil companies purchase** RINs
   - Prices reflect scarcity of RIN (D3 cellulosic > D5 advanced) set by government via RVOs

2. **LCFS Credits**
   - **CA** Low Carbon Fuel Standard
   - Every fuel given a carbon intensity (CI) score = gCO2 equivalent per MJ (Well-to-Wheels Lifecycle Assessment, GREET Model)
   - **Fuel users incentivized to purchase** low carbon fuels due to limits on total carbon emissions
   - Prices reflect carbon intensity of fuel and efficiency of end user
   - Available to out-of-state producers
Market Analysis

- Senate bill No.1383 The RFS Program was created under the Energy Policy ACT (EPAct) of 2005, and established the first renewable fuel volume mandate in the US.
- Energy Independence and Security Act “EISA” (Dec 2007) expanded the RFS program.
- RFS2 – Cellulosic Biofuel:D3
  - 16 bil gal by 2022,
  - Cellulose, Hemicellulose, Lignin
  - Must meet 60% lifecycle GHG threshold

The LCFS program was created under the AB 32 Scoping Plan (Executive Order S-1-07) in 2007, and established the nation’s first performance-based, fuel neutral standard in the United States.

Low Carbon Fuel Standard Credit- LCFS policy unit used demonstrate compliance with the standard. Based on a Metric Ton of CO2 Equivalent

RFS2 Post 2022+ & Sunset Misconception – EISA specifies that the EPA administrator is to establish applicable volumes for years after 2022, and specifies analysis to be taken into considering when setting those volumes. It is clear from EISA that the RFS continues beyond 2022 and that the law requires the EPA to set volumes for years after 2022.
## Potential Economics

<table>
<thead>
<tr>
<th>Sizing of Facilities</th>
<th>500 MMbtu</th>
<th>750 MMbtu</th>
<th>1000 MMbtu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment by BME</td>
<td>$12.5M</td>
<td>$18M</td>
<td>$24M</td>
</tr>
<tr>
<td>Payback period (yrs)</td>
<td>5</td>
<td>4.5</td>
<td>4</td>
</tr>
<tr>
<td>Tons of waste/yr</td>
<td>86,400</td>
<td>130,000</td>
<td>173,000</td>
</tr>
</tbody>
</table>