Biogas Upgrading: Renewable Natural Gas (RNG)
Biogas to RNG

bi·o·gas, ˈbīōˌgas/, noun, gaseous fuel, especially methane, produced by the fermentation of organic matter.

- Methane, CH₄
- Carbon Dioxide, CO₂
- Nitrogen, N₂
- Oxygen, O₂
- Hydrogen Sulfide, H₂S
- Moisture
- Particulates
- Siloxanes
- Volatile Organic Compounds
Reducing Capital and Maintenance Costs - H₂S Removal

- Digester or Landfill
- Hydrogen Sulfide Removal
- Gas Compression/Moisture Removal
- Siloxane Removal

- Micro Turbine
- IC Engine-Generator
- Boiler
Hydrogen Sulfide Removal Systems

Ferric Oxide, Fe$_2$O$_3$ coated (reaction)
- Wood based
- Clay based

Ferric hydroxide pellet (adsorption)

Wausau WWTP, WI
Hydrogen Sulfide Removal Media

- Ferric Hydroxide, FeO(OH)
  - Used on saturated gas
  - Conditioning step – Ca to CaCO₃
  - Tolerant of variable or low moisture content
  - Sulfur is pulled into pores and media remains granular

- \[ 2 \text{Fe(OH)}_3 + 3 \text{H}_2\text{S} \rightarrow \text{Fe}_2\text{S}_3 + 6 \text{H}_2\text{O} \]

- Exothermic reaction when exposed to oxygen
Persigo WWTP, Grand Junction, CO

### Persigo WWTP Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Up Date</td>
<td>April 6, 2015</td>
</tr>
<tr>
<td>System Flow</td>
<td>100 scfm</td>
</tr>
<tr>
<td>Inlet H₂S:</td>
<td>3,000 ppmv</td>
</tr>
<tr>
<td>Oxygen:</td>
<td>0.229%</td>
</tr>
<tr>
<td>Moisture:</td>
<td>4-20 mg/l* (*25 mg/l = 100% saturation)</td>
</tr>
<tr>
<td>Vessels:</td>
<td>(2) 8’ Ø x 12’ ss</td>
</tr>
</tbody>
</table>

**Media Type**  

<table>
<thead>
<tr>
<th>Media Type</th>
<th>Cost/Change out</th>
<th>*Estimated days before change out with saturated gas</th>
<th>Actual days before change out (50 ppmv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SulfaTreat</td>
<td>$31,394</td>
<td>102</td>
<td>41</td>
</tr>
<tr>
<td>Iron Sponge</td>
<td>$17,442</td>
<td>90</td>
<td>60</td>
</tr>
<tr>
<td>UNI-H₂S</td>
<td>$30,500</td>
<td>150</td>
<td>104</td>
</tr>
</tbody>
</table>

Sulfatreat and iron sponge both require 100% saturated gas to operate at their optimum.

*Based on percent by weight removal capacity, assuming optimum conditions*
What is a Siloxane?

- Silica and organic compounds are combined (Organosilicon)
- Used in many industrial products and consumer products
  - Deicing fluid
  - Windshield Cleaning Products
  - Silicone caulks
  - Food additives
  - Commercial products for washing fruits and vegetables
  - Shampoo/conditioner
  - Laundry detergents
  - Furniture polish

- Siloxanes break down in landfills and digesters, and combine with the methane gas

https://hpd.nlm.nih.gov/cgi-bin/household/brands?tbl=chem&id=1784
Volatile Organic Compounds (Commonly Found)

- Acetone
- Benzene
- Chlorobenzene
- Decane
- Ethylbenzene
- Heptane
- Hexane
- Isopropyl Alcohol
- Octane
- Xylene
- Toluene

Suitability Factors for Media Systems: Inlet Biogas Quality – Siloxanes, Hydrocarbons and VOC’s

**Siloxanes**
Organic Compounds with Silica

- Tetramethyl silane
- Trimethyl silanol
- Hexamethyldisiloxane (L2)
- Hexamethycyclotrisiloxane (D3)
- Octamethyltrisiloxane (L3)
- Octamethycyclotetrasiloxane (D4)
- Decamethyltetrasiloxane (L4)
- Decamethyleneptasiloxane (D5)
- Dodecamethylpentasiloxane (L5)
- Dodecamethycyclohexasiloxane (D6)

22-35 compounds typically reported
When methane gas is used as a fuel, the siloxanes form $\text{SiO}_2$ Silicon Dioxide, and precipitate to a hard deposit on surfaces.

- Significant impact on electrical generation systems
  - Increased down time for maintaining equipment
  - Increased costs for components, i.e. spark plugs, valve seats
  - Engine rebuild time is more frequent
Siloxane/VOC Removal

- Coal
- Coconut shell
- Wood
- Extruded pellets
- Silica gel - spheres
- Silica gel – irregular shaped
- 4 x 8 mesh chips
Media After Activation

- External surface
- Internal surface
- Submicropores ($r < 0.4 \text{ nm}$)
- Micropores ($0.4 \text{ nm} < r < 1 \text{ nm}$)
- Mesopores ($1 \text{ nm} < r < 25 \text{ nm}$)
- Macropores ($r > 25 \text{ nm}$)

Porous structure (schematically)
Siloxane Removal Systems

Akron, OH

Evansville, IN
Driving Factors for RNG

Current operations:

- High fuel costs
- Rising utility costs
- Dependence on grid

Renewable fuel with a low carbon content:

- Revenue from D3 and D5 RIN’s
- LCFS Credits
- Reduce fossil fuel usage
- Lower greenhouse gas emissions
# Fuel Quality Specification

<table>
<thead>
<tr>
<th>Biogas Constituents</th>
<th>Raw Biogas</th>
<th>SAE J1616 CNG Fuel Quality Specification</th>
<th>Natural Gas Pipeline Fuel Quality*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>50-80%</td>
<td>88% or greater</td>
<td></td>
</tr>
<tr>
<td>BTU</td>
<td></td>
<td></td>
<td>950-990 BTU/ft³</td>
</tr>
<tr>
<td>Carbon Dioxide (CO₂) and Nitrogen (N₂)</td>
<td>20-50%</td>
<td>&lt;4.5%</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td>0-1%</td>
<td>&lt;1%</td>
<td>6 ppm to 0.2%</td>
</tr>
<tr>
<td>Hydrogen Sulfide (H₂S)</td>
<td>&lt;1,000 ppm</td>
<td>&lt;16 ppm</td>
<td>&lt;4 ppm</td>
</tr>
<tr>
<td>Water Content</td>
<td></td>
<td>7#/MMcf</td>
<td>3-7#/MMcf</td>
</tr>
<tr>
<td>Siloxanes and Volatile Organic Compounds</td>
<td>&lt;2,000 ppm</td>
<td>ND</td>
<td>ND to 1 ppm</td>
</tr>
<tr>
<td>Pressure</td>
<td>0-2 psig</td>
<td>3,000-3,600 psig</td>
<td>50 to 900+ psig</td>
</tr>
</tbody>
</table>

*Varies depending on the utility
# Small Scale Systems

Biogas Inlet Flow (scfm) | Fuel Production (GGE/day) | Fuel Production (DGE/day)
--- | --- | ---
50 | 185 - 300 | 160 - 260
100 | 370 - 600 | 320 - 520
200 | 740 - 1,200 | 640 - 1,040
400 | 1,480 - 2,400 | 1,280 - 2,080
Membrane Separation Schematic

Hollow fiber bundle
0.5 – 1.2 million fibers per 12-inch bundle
Laid end to end, contains 750 miles (1,200 km)
of fiber

Bore Feed Separator
200 psi (13.8 bar) pressure limitation
N2, CO2 separations

Epoxy tube sheet
(fibers open on both ends)
Methods to Deliver RNG

- Digester or Landfill
- Biogas Upgrading System
- CNG for Vehicles
  - Fast fill stations
  - Time fill stations
  - Dedicated Pipeline
  - Virtual Pipeline
  - Natural Gas Pipeline

- Unison Solutions
Persigo WWTP, Grand Junction, CO

Dedicated Pipeline

- Population – Approximately 80,000, Grand Junction and Mesa County
- Located on the Colorado River
- 12.5 MGD municipal plant (Avg. flow 8 MGD)
- 100 scfm of biogas produced
City of Grand Junction RNG Pipeline

- Dedicated 5.8 mile pipeline
- Located on the Colorado River
- Extends from WWTP to existing fueling stations
Persigo WWTP
Grand Junction, CO

- April 2015 – Startup

Gas Conditioning Equipment

- Hydrogen sulfide removal
- Gas compression/Moisture removal
- Siloxane removal
- Carbon dioxide removal
2017 - 62 city and county vehicles total being used
Saved $179,000 on gasoline

- Time Fill for CNG-Fueled collection trucks and city buses
- Fast Fill for emergency fill ups
- Dedicated 5.8 mile pipeline
- 142,000 gallons of gasoline diverted
- CO₂ Reduction of 3 million pounds/year
- 2017 - 62 city and county vehicles total being used
- Saved $179,000 on gasoline
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- Particulates
- Siloxanes
- Volatile Organic Compounds
Regulated Natural Gas Utilities

[Map of Ohio showing the regulated natural gas utilities]

Legend:

1. Arlington
2. Beinard
3. Cincinnati Gas
4. Columbia
5. Constitution
6. East Ohio
7. Eastern
8. Forsker
9. Gasco
10. KNG
11. MED
12. Northeast
13. Ohio Cumberland
14. Ohio Gas
15. Ohio Valley
16. Orell
17. Oxford
18. Piedmont
19. Pia
20. Sheldon
21. Southeast
22. Suburban
23. Brickland
24. Vreden
25. Verona
26. Waterville

Public Utilities Commission of Ohio, 2002
http://www.PUCO.ohio.gov
Weighing the Options

BIOSECURITY
EFFICIENCY
SCALE / SIZE

On-Farm Digesters

DEWATERING
TRUCKING
BIOSECURITY

Centralized Digesters
Optima KV – Key Points

- 80,000 MMBtu/y (11,000 MWh)
- 15-Year Agreement with Duke Energy
- Biogas upgraded to natural gas
- Injected into existing pipeline, Piedmont Gas
- Used to fuel
  - H.F. Lee Power Plant, near Goldsboro
  - Sutton Power Plant in Wilmington
    - <1% of total fuel
How it Works

In-ground Anaerobic Digester: x5

Centralized Biogas Refinery
(Gas Upgrading Skid)

Injection into Existing NG Pipeline

Biogas Drying Skid x 5
Dedicated pipeline to central processing

- 3 Farms, 5 In Ground Digesters ≈ 60,000 Hogs
- (4) 60 scfm Compression/Moisture Removal
- (1) 140 scfm Compression/Moisture Removal
- (2) Injection Compressors (1,050 psig)
Unison Solutions, Inc. and Puregas Solutions are bringing a new Biogas Upgrading Technology to the U.S. market.
99.9% Methane Efficiency

- Less than 0.1% methane slip
  - Protecting our environment

- No hidden additional cost or energy requirement associated with treating the tail gas

- 99.9% of the methane in the biogas can be sold
  - Always the highest revenue
Integrated Biogas Upgrading Solutions

- Lüderode, Germany since 2013
- 440 scfm
- Agricultural waste from crops
- Biogas to natural gas pipeline grid
Riverside Biogas - Scotland

- 1,060 scfm biogas from spent malt
- 99.9% methane efficiency
- Heat supplied from CHP
- Back up biogas boiler
- Injects 690 scfm biomethane direct to the gas grid
- Propane enrichment and gas network entry facility
Q & A

Biogas

Electricity, Heat, Fuel for Vehicles, Grid Injection