Problem/Opportunity

- 2,450 Landfills in US
- 20% of Human Source of Methane
- Requirement to Capture and Mitigate
- RFS Increase in RVO
- Waste Industry Consumes ~ 4% US Diesel consumption
- Ag Industry Consumes ~3% US Diesel Consumption
- AD Technology Advancements (~1,500 projects operating in US)
Current Issues

Total US Biogas Generation Rate ~ 800,000 SCFM

Landfill LFG Collection Rate

- < 4k SCFM: 85.6%
- 4k-8k SCFM: 10.8%
- 8k-16k SCFM: 3.2%
- > 16k SCFM: 0.4%

What’s the best use of this energy resource?
- Electricity generation
- Biomethane
- Gas to Liquids

Key Factors
- Economics
- Infrastructure
- Location
- Efficiency
- Policy
Focus and Technology

Demonstrate small scale GTL in economical and profitable manner
Tri-reforming:
• Minimize cleanup and pretreatment process
• Less energy consumption
• Produce high quality syngas (H₂:CO ~ 2)

Endothermic CH₄ reforming
• CH₄ + CO₂ → 2CO + 2H₂
  • ΔH^o<sub>298</sub> = 247.3 kJ/mol

Steam reforming
• CH₄ + H₂O → CO + 3H₂
  • ΔH^o<sub>298</sub> = 206.3 kJ/mol

Exothermic oxidation of CH₄
• CH₄ + ½ O₂ → CO + 2H₂
  • ΔH^o<sub>298</sub> = -35.6 kJ/mol
• CH₄ + 2O₂ → CO₂ + 2H₂O
  • ΔH^o<sub>298</sub> = -880.3 kJ/mol

Utilize 100% of biogas as feedstock
Control H₂ and CO selectivity
Generate heat in-situ
Project Overview

Tri-reforming of LFG

<table>
<thead>
<tr>
<th>Catalyst Bed temp. (°C)</th>
<th>GHSV (h⁻¹)</th>
<th>CH₄ conv. (%)</th>
<th>CO₂ conv. (%)</th>
<th>H₂:CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>770-810</td>
<td>30,000</td>
<td>92-99</td>
<td>52-72</td>
<td>1.70-2.23</td>
</tr>
</tbody>
</table>

Catalyst Optimization

Thermally Stable
High Surface Area
Coke Resistant
High OSC
Excellent Redox Properties
High Dispersion
Excellent Selectivity
High Activity
Economical
Low Pressure Drop
Project Overview

FTS Eggshell Catalyst

- Overcome mass and heat transfer limitations
- Selective product distribution in middle distillate region
- Avoid wax production

<table>
<thead>
<tr>
<th>CO % Conv</th>
<th>LFG Energy Recovery In Liq Fuel (%)</th>
<th>Selectivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C1-4</td>
</tr>
<tr>
<td>71</td>
<td></td>
<td>43.7</td>
</tr>
</tbody>
</table>
Project Overview

Benchscale TRIFTS Unit

- Optimize process conditions
- Facilitate Pilot/Demonstration Design
- Plug bench data into ASPEN
- Update full scale techno-economic analysis
Project Overview

Fuel Analysis

- Low aromatics improve net heat of combustion and reduce soot
- Isomers improve cold temp properties
- Further reduce olefin content w/ addition of catalyst promoters
- Excellent middle distillate boiling point distribution
- Control phase separation temp to fractionate light ends
- Final boiling point aligns with commercial diesel

### Fuel Analysis

<table>
<thead>
<tr>
<th>Hydrocarbon Family</th>
<th>T2C-E (H2:CO=1.7)</th>
<th>Commercial Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraffins</td>
<td>67.164</td>
<td>19.95</td>
</tr>
<tr>
<td>Isomers</td>
<td>28.243</td>
<td>31.6</td>
</tr>
<tr>
<td>Olefins</td>
<td>4.323</td>
<td>0.92</td>
</tr>
<tr>
<td>Aromatics</td>
<td>0.02</td>
<td>39.48</td>
</tr>
<tr>
<td>Cyclics</td>
<td>0.25</td>
<td>8.05</td>
</tr>
</tbody>
</table>

**Fuel Analysis**

- Low aromatics improve net heat of combustion and reduce soot
- Isomers improve cold temp properties
- Further reduce olefin content w/ addition of catalyst promoters
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- Control phase separation temp to fractionate light ends
- Final boiling point aligns with commercial diesel
### Fuel Analysis Results

<table>
<thead>
<tr>
<th>Fuel Analysis, ASTM Standard</th>
<th>Spec (No. 2 Diesel)</th>
<th>Commercial Diesel</th>
<th>TRIFTS LFG</th>
<th>TRIFTS LFG (Dist 55°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity, ASTM D4052 (g/cc)</td>
<td>≥ 0.8215</td>
<td>0.7386</td>
<td>0.7489</td>
<td></td>
</tr>
<tr>
<td>Cetane Index, ASTM D976</td>
<td>≥ 40</td>
<td>57.6</td>
<td>84.5</td>
<td>72.7</td>
</tr>
<tr>
<td>Cetane Index, ASTM D4737</td>
<td>≥ 40</td>
<td>59.7</td>
<td>92.3</td>
<td>83.4</td>
</tr>
<tr>
<td>Flash Point, ASTM D93 (°C)</td>
<td>≥ 52</td>
<td>87</td>
<td>49</td>
<td>57</td>
</tr>
<tr>
<td>Cloud Point, ASTM D2500 (°C)</td>
<td>-6</td>
<td>-6</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>Pour Point, ASTM D97 (°C)</td>
<td>-9</td>
<td>-9</td>
<td>-6</td>
<td></td>
</tr>
<tr>
<td>Distillation, ASTM D86 (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IBP: 0.5wt%</td>
<td>203</td>
<td>143</td>
<td>142</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>220</td>
<td>164</td>
<td>154</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>269</td>
<td>234</td>
<td>216</td>
<td></td>
</tr>
<tr>
<td>90%</td>
<td>282-338</td>
<td>329</td>
<td>327</td>
<td>314</td>
</tr>
<tr>
<td>FBP: 99.5%</td>
<td>378</td>
<td>388</td>
<td>378</td>
<td></td>
</tr>
<tr>
<td>Net Heat Comb., ASTM D3338 (MJ/kg)</td>
<td>43.164</td>
<td>44.520</td>
<td>44.355</td>
<td></td>
</tr>
</tbody>
</table>
Pilot/Demonstration Scale Up

35 SCFM LFG Feed → 111 Gal/Day Diesel

Example of skid mounted unit
Key Challenges and Approach
Key Challenges and Approach

- Reformer energy requirement met by FTS fuel gas
- Efficient heat integration
- Utility requirements provided by process itself
- Overall self sufficient process
- Minimize any outside fossil fuel derived energy inputs

<table>
<thead>
<tr>
<th>Energy Requirements and Generation from 1500 scfm LFG Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Reformer requires</td>
</tr>
<tr>
<td>Fuel Gas Energy Content</td>
</tr>
<tr>
<td>Boiler</td>
</tr>
<tr>
<td>LFG cooler</td>
</tr>
<tr>
<td>Reformer HX</td>
</tr>
<tr>
<td>Syngas cooler</td>
</tr>
<tr>
<td>FTS cooler</td>
</tr>
<tr>
<td>FT reactor</td>
</tr>
<tr>
<td>Compressor 1</td>
</tr>
<tr>
<td>Air Compressor</td>
</tr>
<tr>
<td>Compressor 2</td>
</tr>
<tr>
<td>Compressor 3</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
</tr>
<tr>
<td>Equip/RXN Required</td>
</tr>
<tr>
<td>Energy Produced</td>
</tr>
<tr>
<td>Net Energy Produced</td>
</tr>
<tr>
<td>Additional Electric Power Generation</td>
</tr>
</tbody>
</table>
Financials (1,500 SCFM Biogas)
118 bpd (5k gal/day) Diesel Facility

- At current pump price of 2.47 NPV = $40.6MM
- Initial Construction Capital $7MM
- RIN = $4.47/gal diesel (D3 ~ $2.63/RIN)
- Breakeven No RIN credit at 435 SCFM biogas production rate
Unique Aspect Summary

- Utilize 100% of Biogas Feedstock (CO$_2$ Utilization)
- Significant Reduction of Unit Operations
- Compatible with Current Infrastructure
- High Quality Value Add Product (Drop-In Diesel)
- Self Sufficient Process
- Vastly Improved Economics and Profitability
Management Team

Devin Walker
CEO

Dr. John Kuhn
President

Dr. Babu Joseph
VP

Timothy Roberge
CFO

Dr. Ali Gardezi
CTO

- 40+ Years in Biofuel Industry
- Recognized Industry Leaders
- Proven Track Record in Technology Scale Up
- Partnered with US Cleantech and Renovare Fuels as part of US and Global Business Strategy
Sustainable Solutions for The Waste To Energy Sector