Cool GTL
A New Biogas Conversion Process from GTI

Presented by Terry Marker, Senior Institute Engineer, Bioenergy Initiatives Manager, Gas Technology Institute
78 Year History of Turning Raw Technology into Practical Energy Solutions

FOR A BETTER ECONOMY AND A BETTER ENVIRONMENT

- SUPPLY
- CONVERSION
- DELIVERY
- UTILIZATION

World-class piloting facilities headquartered in Chicago area
Cool GTL Goal

"It is always the simple that produces the marvelous." - Amelia Barr

- Simple modular design
- Utilize the CO₂ present in biogas as well as methane
- Low cost
- Skid mounted/Cookie Cutter
- Commercially Attractive
- How do you turn a complicated – expensive process into something commercially viable at small scale? - SIMPLIFY

1. "That's been one of my mantras - focus and simplicity. Simple can be harder than complex: You have to work hard to get your thinking clean to make it simple. But it's worth it in the end because once you get there, you can move mountains." - Steve Jobs
2. "Truth is ever to be found in simplicity, and not in the multiplicity and confusion of things." - Isaac Newton
Cool GTL

- Converts CO₂-rich methane, ethane and propane to high-quality gasoline, diesel and jet fuel
- Works well for any gas containing CO₂ or CO
- Uses unique CO₂/steam reforming catalyst to directly make 2:1 -2.4:1 H₂/CO synthesis gas
- Uses unique combined Fischer-Tropsch and wax-cracking reactor
- Simple and compact with unique catalysts in each stage
What’s Unique and Different about Cool GTL?

- **Unique Catalyst in Cool Reforming Step**
  - Robust with long life - minimal coking
  - Directly makes 2/1 H₂/CO synthesis gas by adjusting amount of steam added
  - Simple and direct, mild temperatures, steady performance

- **Unique Catalyst in Fischer-Tropsch Step**
  - No wax produced
  - Drop in gasoline, diesel and jet
  - Integrated Trailing reactor to totally convert all wax
  - High Conversion per pass

Low cost, simplified version of a traditional process.
Why Combine Fischer Tropsch with Wax Cracking/Isomerization?

- NO wax!
- High per pass conversion
- Simplified product slate
- Low cost reactor
- Easy scale up and scale down
- Follow on polishing wax cracking/isomerization reactor to insure complete wax conversion
Cool GTL Products are High Quality

Cool GTL Product Distillation Curve

Freeze Point = -2°C
Laboratory Scale Cool GTL – Reformer and Fischer Tropsch
### Cool GTL Reactions

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Equation</th>
<th>Conditions</th>
<th>Reactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I)</td>
<td>H$_2$O + CH$_4$ → CO + 3H$_2$</td>
<td>CO and H$_2$ formation (800°C)</td>
<td>Reactor 1</td>
</tr>
<tr>
<td>(II)</td>
<td>CO$_2$ + CH$_4$ → 2CO + 2H$_2$</td>
<td>CO and H$_2$ formation (800°C)</td>
<td>Reactor 1</td>
</tr>
<tr>
<td>(III)</td>
<td>CO$_2$ + H$_2$ → H$_2$O + CO</td>
<td>Water-gas shift to equilibrium</td>
<td>Reactor 1</td>
</tr>
<tr>
<td>(IV)</td>
<td>CO + 2H$_2$ → -[CH$_2$]- + H$_2$O</td>
<td>Hydro/oligomerization (200°C)</td>
<td>Reactor 2</td>
</tr>
<tr>
<td>(V)</td>
<td>H$_2$ + -[CH$_2$]- → -[CH$_2$]- + H$_2$</td>
<td>Isomerization (200°C)</td>
<td>Reactor 2</td>
</tr>
</tbody>
</table>
Many Biogas Locations in United States
Cool GTL for Biogas Conversion

Biomass Digester

Cool GTL

Cool GTL Utilizes the CH$_4$ + CO$_2$ present in biogas
• Use electrolysis to make H₂ from water use biogenic gas to make more biogenic liquids.
• LCA shows IH² + Cool GTL liquids still provide >60% GHG reduction.
U-Gas® Gasifier + Cool GTL

Best Integration under Review
Cool GTL Applications & Markets

- Biogas to GTL → Direct utilization of CO₂ methane, ethane, propane
- Integration with Gasifier – wood to drop in gasoline jet and diesel
- High CO₂ content natural gas → utilize some shut-in natural gas
- Flare gas mitigation → any CO₂ containing natural gas, offshore, Africa
Cool GTL was Designed from the Beginning for Modular Deployment

Applications typically small in size (such as biogas plants, associated gas, and individual oil wells), and locations with limited takeaway infrastructure call for:

› Simplified process
› Compact equipment
› Small footprint
Liquid fuels are easy to transport and valuable.
# Cool GTL Preliminary Economics *

<table>
<thead>
<tr>
<th></th>
<th>Cool GTL for IH² Application</th>
<th>Cool GTL for Digester Biogas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid product made (bbl/d)</td>
<td>434</td>
<td>200</td>
</tr>
<tr>
<td>Value of product ($/gal)</td>
<td>$2.50 (as refined biogenic liquid)</td>
<td>$2.50</td>
</tr>
<tr>
<td>Product value/year ($)</td>
<td>15,960,000</td>
<td>$6,930,000</td>
</tr>
<tr>
<td>Value of feed gas ($/MMBtu)</td>
<td>$3.00</td>
<td>$3.00</td>
</tr>
<tr>
<td>Overall incentive ($ million/year)</td>
<td>12.9</td>
<td>5.94</td>
</tr>
<tr>
<td>Modular capital estimate ($ million)</td>
<td>29.9</td>
<td>18.6</td>
</tr>
<tr>
<td>Additional OSBL* costs ($ million)</td>
<td>6.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Estimated erected costs ($ million)</td>
<td>35.4</td>
<td>21.3</td>
</tr>
<tr>
<td>Years to simple payback (years)</td>
<td>2.7</td>
<td>3.1</td>
</tr>
</tbody>
</table>

* Base on modeling and lab tests

*OSBL = outside battery limits
Cool GTL Status

- Three patent applications filed
- Requires longer-term tests
  - Validate catalyst life
- Requires larger-scale, skid-mounted modular testing
  - Validate at larger scale
- Three years from commercialization
- Requires a commercialization partner
- New DOE Project Biogas to Jet Fuel kicked off Sept 2019
New DOE Cool GTL Project Kicks off

• Scale up the Cool GTL and demonstrate at a larger scale
• Make 100 gallons of high quality jet fuel from biogas
• Use a real biogas feed for Cool GTL feed
• Show high conversion per pass for FT
• Show Cool GTL Process and Stability
• Fully integrated and fully automated-round the clock operation

Cool GTL Project Team

- GTI Experimental testing
- PSRI FT-Modeling
- Hatch Engineering Technoeconomics
- Veolia Commercialization
- Synsel Energy Commercialization
- MTU LCA

Additional Subcontractors:
- Forest Concepts - IH2 wood preparation
- Intertek/SGS – Jet Product Work up and Testing
Larger Scale Cool GTL Pilot Plant
GTI-Turning Ideas into Practical Solutions
Acknowledgements

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