GTL TECHNOLOGY UPDATE

Presented by:
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Managing Director
Muse, Stancil & Co.

February 11, 2015
MUSE, STANCIL & CO.

- Independent energy consulting firm founded in 1984, providing industry expertise from wellhead to end-user; www.musestancil.com

- Energy Sectors Served
  - Natural Gas Processing
  - Refining and Refined Products
  - Pipelines
  - Crude Oil
  - Natural Gas Liquids
  - Petrochemicals
  - Biofuels

- Representative Assignments
  - Market Studies
  - Asset Valuation
  - Project Development
  - Transactional Due Diligence
  - New Technology Assessment
  - Insurance Claims (Property & Business Interruption)
  - Litigation Support
  - Royalty Negotiation/Auditing
  - Contract Negotiation/Dispute Resolution
GTL TECHNOLOGY UPDATE

- Available gas “liquefaction” pathways

- Why GTL?

- Gas-To-Liquids Pathways

- Fischer Tropsch
  - R&D work ongoing worldwide to increase efficiency in reaction pathway
  - Engineering design leading to more cost effective process design

- New market entrants
GAS LIQUEFACTION PATHWAYS

- Variety of technology pathways exist for conversion of commercial natural gas to various liquid products
  - Natural Gas Liquefaction (LNG)
  - Natural Gas Conversion
    - Natural Gas to Methanol (GTM)
    - GTM integrated with Methanol to Gasoline (MTG) or other products such as dimethylether (DME)

- Comparison of Netback Prices, Basis: 2014 Averages and Henry Hub

<table>
<thead>
<tr>
<th>Product Sales Price</th>
<th>LNG to Europe (U.S. Dollars Per MMBTU)</th>
<th>LNG to Asia (U.S. Dollars Per MMBTU)</th>
<th>Methanol (MT)</th>
<th>GTL (BBL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>8.73</td>
<td>14.21</td>
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<td>Shipping</td>
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<td>U.S. Dollars Per MMBTU gas processed</td>
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**WHY GTL?**

- **“Stranded” Gas**
  - Geographically isolated gas deposits
  - Gas reserves with limited economic market accessibility
  - Gas flaring

- **Diesel Markets**
  - Strong diesel demand worldwide
  - Emphasis on increasingly “cleaner” diesel fuel worldwide
  - Significant change in the gasoline/diesel price relationship since 2008
Why GTL?

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**Small-scale, compact and mini-GTL enable project development in a wide variety of locations both onshore and offshore**
WORLDWIDE GAS RESERVES

- Large-scale GTL already in service in Qatar
- LNG projects dominate Asia & Oceania
Worldwide Gas Reserves

- Large-scale GTL already in service in Qatar
- LNG projects dominate Asia & Oceania

But...many opportunities exist to deploy smaller-scale GTL worldwide
## GTL Products Exceed Stringent Quality Requirements

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<th><strong>GTL</strong></th>
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<th><strong>CARB</strong></th>
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<td></td>
<td><strong>Diesel</strong></td>
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*Note: ULSD and Jet specifications based on Colonial Pipeline 12/2011 specifications. CARB Diesel specification based on Kinder Morgan Pipeline specification.*
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CARB Diesel specification based on Kinder Morgan Pipeline specification

GTL produces a perfectly fungible fuel and, therefore, GTL products can be supplied into almost any market
DEMAND GROWTH FOR HIGHEST QUALITY PRODUCT

- Air quality concerns have driven global diesel requirements toward very low sulfur, low aromatic product specifications.
- The U.S. demand for diesel is growing and U.S. refiners are also exporting huge volumes of higher quality diesel fuels.
- These trends are expected to continue.

U.S. Distillate Demand

- Note: Data for 2014 is January-November.
- Source: Energy Information Administration

U.S. Diesel Product Quality

- Source: Energy Information Administration
NATURAL GAS TO DIESEL (GTL) – WELL ESTABLISHED AND PROVEN

History

Franz Fischer
1918 – “Father” of GTL

Visit www.fischer-tropsch.org for complete history of GTL

Advances in catalyst development and process design are fueling expansion in small-scale GTL sector
NUMEROUS COMPANIES DEVELOPING MINI-GTL TECHNOLOGY
## NEW ENTRANTS IN THE MARKET FOR MINI-GTL

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<th>Technology</th>
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<td>INFRA</td>
<td>FT</td>
<td>100 BPD plant (2015)</td>
</tr>
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<td>Greyrock</td>
<td>FT</td>
<td>1000 BPD plant (2015)</td>
</tr>
<tr>
<td>Emerging Fuel Tech. (EFT)</td>
<td>FT</td>
<td>1 BPD pilot plant</td>
</tr>
<tr>
<td>Gas2</td>
<td>FT</td>
<td>3 BPD pilot</td>
</tr>
<tr>
<td>Marcellus GTL</td>
<td>MTG</td>
<td>2000 BPD (2016)</td>
</tr>
<tr>
<td>TIGAS</td>
<td>MTG</td>
<td>Demo plant in Houston</td>
</tr>
<tr>
<td>Primus GE</td>
<td>MTG</td>
<td>6.5 BPD plant in operation</td>
</tr>
<tr>
<td>TU Freiberg</td>
<td>MTG</td>
<td>15 BPD plant</td>
</tr>
<tr>
<td>Siluria</td>
<td>OCM</td>
<td>1 TPD ethylene pilot plant being constructed</td>
</tr>
<tr>
<td>Proton Ventures</td>
<td>Small scale Ammonia</td>
<td>0.2 MMcfid feed rate (3 TPD Ammonia)</td>
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POSITIVE ATTRIBUTES

- Proven chemistry

- Years of bench-scale testing, industry has “fine tuned” catalyst and commercialized catalyst manufacturing

- Scale-up of most of the process components already proven
  - Production of syngas, front end
  - Hydrocracking of wax and distillation of products, back end

- GTL-FT diesel product has been tested in many commercial applications
  - Commercial Aircraft
  - Trucking Industry
  - Military, B52 Bomber

- Commercial plants have operated in South Africa for many years
**CHALLENGES**

- Capital cost for fixed-bed reactor processing configuration historically dictated larger projects to capture economies of scale; largest world-scale project completed to date far exceeded budget estimate

- Margin risk associated with uncorrelated feedstock and product price volatility

- Catalyst selectivity for wax production versus direct conversion to diesel or gasoline

- Scale-up of high efficiency, fluidized bed reactors not proven thus complicating process technology guarantees and project finance
  - Physical design, wax separation from catalyst particles
  - Heat balance, highly exothermic reaction requires active control of heat balance to avoid “hot spots”
CHALLENGE – CAPITAL COST

- Number of companies developing modular process design
- Minimize “custom” aspects of project design
- Provide for shop fabrication to improve quality control and compress projection execution timeline
- With modular approach, smaller projects become economically feasible
- In addition, developer are seeking brownfield sites or have partnered with integrated producers to integrate smaller-scale commercial units into existing facilities
CHALLENGE — MARGIN RISK

- AGE OLD QUESTIONS – What will oil and gas prices be next week? Next month? Next year? In 5 years? In 10 years?

- Commercial viability of small-scale units requires venture capital support; technical advances in reactor design are enabling such projects

- Project finance will require positive economic margin outlook in the medium to long term

- **Opportunities enabled by new reactor design technologies include:**
  - Offshore or floating installations
  - Focus on “portable” nature of the process
  - Remote locations where liquid takeaway infrastructure is available or can be installed at lower cost than can gas infrastructure
  - In many locations worldwide where gas flaring is being severely limited
CHALLENGE — CATALYST DEVELOPMENT

- All GTL catalysts are proprietary although most GTL companies have one or two catalyst manufacturers who are licensed to produce

- Most recent leap forward is catalyst for direct conversion of natural gas to diesel, thus eliminating the wax step
  - Will likely result in reduced capital cost for less complex “back end” of the process
  - May also have implications for reactor design and ultimate reactor scale up, yet to be determined

- INFRA
  - Announced investment decision on 100 BPD plant in June
  - Pilot Plant launch in July
  - Will test additional catalysts and plant configurations

- Greyrock
  - Direct-to-Diesel™ Catalyst
  - Modular construction of a 1,000 BPD plant
  - Capacity can be increased by adding additional modules
  - “Drop in” fuel which has been tested in heavy duty engines
**NON-FT PROCESSES - GAS TO CHEMICALS AND GASOLINE**

- **Primus Green Energy**
  - 6.5 BPD pilot plant was commissioned in 2013
  - Currently in third continuous run
  - Producing 93 octane gasoline

- **TIGAS**
  - Conversion to gasoline in a single synthesis loop with no need for methanol storage

- **Proton Ventures**
  - Gas2Ammonia process

- **Siluria**
  - Conversion of methane and ethane into gasoline and ethylene
**CHALLENGE — REACTOR SCALE-UP**

- Process developers have been mindful of the need for measured scale-up with respect to fluidized-bed reactors.

- Some demonstration scale units have been built and operated to prove aspects of reactor engineering design.

- To address the issue of clean wax separation from catalyst particles, new catalysts are being developed to eliminate the wax production and directly produce diesel; development work continues and the industry awaits commercially-available data on these new catalysts.

- Other developers have focused on innovative changes in fixed bed reactor design developing modular, micro channel reactors.

- Pilot plant and demonstration-scale plants employing micro-channel reactor technology have operated and larger scale commercial projects are being developed:
  - Velocycs
  - Compact GTL
CONCLUSIONS

- A wide variety of options exist for GTL projects

- Large increase in gas supply in North America has increased the attractiveness of these projects

- While LNG and large scale GTL projects continue, the newer technology is aimed at mini GTL plants that can be built with smaller gas reserves

- The smaller units provides good economics by being modular and skid mounted, so they can be constructed in areas that provide market opportunities

- New technologies are in various stages of commercialization, and there are several very promising start-ups competing for investment funds