Intensified smaller scale GTL process
Overview

- Our business
- Our technology at a glance
  — Catalyst
  — Microchannel technology
- Commercialising our offer
  — Development tools & scale-up methodology
- Current & future projects
Velocys
The company at the forefront of smaller scale GTL

- **Leader** in smaller scale gas-to-liquids technology
  - 15 years and >$300 million invested in product development
  - Exhaustive global patent protection
  - Robust technology
    - >1.3 million hours of laboratory scale tests
    - >26,000 hours testing at the pilot/demonstration scale

- First class **partners** offering a **complete GTL solution**: Haldor Topsøe, Ventech, Hatch, Mourik, SGS, Shiloh

- **Commercial roll-out underway**
  - ENVIA Energy project under construction
  - Ashtabula GTL
  - Red Rock Biofuels

- **International presence**
  - Commercial center in Houston, Texas; technical centers near Columbus, Ohio and Oxford, UK
  - Permanent pilot plant in Ohio
Our business: the gas-to-liquids (GTL) process
Chemical conversion of natural gas to refined products

Reforming  Fischer-Tropsch (FT)  Hydro-processing

Natural gas  \[\rightarrow\]  Syngas  \[\rightarrow\]  Syncrude  \[\rightarrow\]  Clean synthetic fuels & chemicals
(carbon monoxide + hydrogen)  (synthetic crude oil)

Clean synthetic fuels & chemicals (diesel, jet fuel, Lubricants, waxes etc.)

<table>
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<tr>
<th>Field size (TCF)</th>
<th>Distributed scale GTL opportunity size (mmbpd)</th>
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<td>Unconventional gas* 18</td>
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<tr>
<td>73</td>
<td>Associated gas 2.7</td>
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<td>Stranded gas* 4.8</td>
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<td>347</td>
<td>Total &gt; 25</td>
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<td>719</td>
<td>* Assumes monetisation over 100 yrs</td>
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<td>1,043</td>
<td>Smaller scale GTL: 1,500 – 15,000 bpd</td>
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<td>3,922</td>
<td>Distributed scale GTL opportunity size (mmbpd)</td>
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<td>Gas fields</td>
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Velocys’ technology at a glance
Super-active catalyst & microchannel reactors
Key catalyst criterion: super-active catalyst
Velocys catalyst is an order of magnitude more productive than competitive FT catalysts

Catalyst productivity [kgC5+/l-cat/hr]

0.00  0.20  0.40  0.60  0.80  1.00  1.20  1.40

Conventional fixed bed  Slurry bubble column  Velocys

At much higher pressure
Origin of exceptional catalyst performance
Patented organic matrix combustion (OMX) method

- **Traditional catalyst manufacturing**
  - Produces broad distribution of cobalt particle sizes

- **OMX catalyst manufacturing**
  - Produces optimized and more uniform cobalt particle sizes
  - **Higher activity** from smaller particles
  - **Greater stability** from narrower particle size distribution
Key reactor criterion: reaction intensification
Microchannels intensify chemical processes

- Conventional FT reactor
  Tube length 30+ feet (9+ meters)

- Velocys FT reactor
  Tube length 2 feet (0.6 meters)

Enhanced mass and heat transfer

~ 25-37 mm

~ 0.1-10 mm
Key reactor criterion: exceptional heat removal
Microchannels keep the catalyst bed more isothermal

- **Microchannel** coolant and process channels more effectively transfer heat out of the catalyst bed giving better control and performance

- **Tubular reactors** operate with a greater temperature gradient from the center of the tube to the tube wall, risking thermal instability
Thinking smaller is bringing GTL to the mainstream
Large-scale economics at smaller scales

Conventional Fischer-Tropsch reactor

Note: Reactor capacities differ considerably

Velocys Fischer-Tropsch reactor
Commercialising our offer
Development tools & scale-up methodology
Commercial catalyst manufacturing

Ensure performance is maintained at commercial scale

1. Lab scale
   - Gram quantities produced multiple runs

2. Developmental scale
   - Kg quantities produced multiple runs

3. Pilot scale
   - Multiple runs yielding a combined 1.5 MT

4. Commercial scale
   - Full commercial lot sized produced by 2 manufacturers. QA/QC established

4-year commercialisation program
From lab-scale to commercial reality

**Laboratory**

- Multiple tests and experiments to determine
  - Impact of catalyst composition on performance (optimal formulation and QA/QC)
  - Parameters used in statistical and flow modelling
  - Procedure for regenerating the catalyst and discharge
  - Impact of deviations from normal operation

**Pilot Plant**

- A pilot plant reactor was operated for a complete run, prepared for discharge, discharged, re-loaded and restarted successfully – **all within commercially acceptable time constraints**
  - Measured performance and validated models
  - Demonstrated efficacy of our procedures and methods for loading and discharge

**Commercial**

- Commercially produced cores are used for extensive long term life cycle tests
- Demonstration plants include Gussing and Petrobrass
- A full scale (3-core) commercial unit was used to develop catalyst loading procedures
- A single core commercial variant is used to improve and innovate new catalyst handling techniques
Developing tools for engineering studies
Process model development

- Designed experiments to cover wide range of FT operations
- Independent variation of parameters: e.g. $P_{\text{CO}}, P_{\text{H}_2}$
- >60 data points
  - Close monitoring of outlet $\text{H}_2$:CO ratio and CO conversion
  - Product sample at each point
- Assessment of ageing and regeneration on process response
- Field demonstration unit data in agreement with model prediction

Inlet pressure: 200 – 450 psig
Inerts: 10% – 70%
Contact time: 150 – 500 ms
Feed $\text{H}_2$:CO ratio: 1.4 – 4.5
Temperatures: 175 – 235 °C
Verified performance and scale up methodology

Modeling

Multiple regenerations

Catalyst testing

Laboratory
Verified performance and scale up methodology

Field model demonstration

Sustained stable operation

Pilot Plant
Laboratory

VELOCYS
Verified performance and scale up methodology
Verified performance and scale up methodology

Duplicate reactors and trains for commercial facilities
FT performance
Performance of the microchannel reactor and catalyst demonstrated in the Velocys Pilot Plant (VPP)
Pilot plant runs in the 18 months to November 2015
Process intensification

- Successful piloting of commercially produced catalysts
- Continuous improvement without changing our technology basis
- Process intensification results in significant capital cost improvement
Pilot plant runs in the 18 months to November 2015
Reduced start-up time: minimising reactor downtime

Run 10: 156 hrs to reach target
Run 11: 76 hrs to reach target
Run 12: 36 hrs
<24 hrs
Run 14
Run 12
Run 11
Run 10

CO conversion (%)

Time on stream (hrs)
Commercial roll-out underway
ENVIA Energy’s plant being built
Adjacent to WM East Oak landfill in Oklahoma City, USA
ENVIA Energy - Oklahoma City project
Significance and progress

• **Landmark for GTL**
  • Landfill gas & natural gas as feedstock
  • Major companies committing to smaller scale GTL

• **Construction underway**
  — Manufacture of FT catalyst and reactors completed in 2015
  — Fabrication of modules complete
  — All modules, including those incorporating Velocys’ reactors, set in place on site

• Will be our commercial reference plant – a **major milestone**
  — Demonstrate parallel operation of full-scale Velocys reactors
Some of the FT modules
ENVIA Energy’s Oklahoma City GTL plant
All major process units on site

View of GTL plant from landfill site

Landfill gas inlet

Steam methane reformer

Syngas compression

LFTL and HFTL columns

CO₂ wash column
Thank you

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Think Smaller

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