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March 30, 2015

Commercializing Velocys Fischer-Tropsch synthesis technology  
Syngas Convention 2
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 (>7,600 granted GTL patent claims)

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

• **Commercial roll-out underway**

• **Well capitalised** with **strong resources**
  — Commercial center in Houston, Texas; technical centers near Columbus, Ohio and Oxford, UK
  — Permanent pilot plant in operation
Microchannel reactors
Backbone of Velocys FT technology

• Microchannels enhance heat and mass transfer rates
• Alternating process & coolant layers allow close coupling of exothermic reaction with steam generation aiding the robust performance
• Particulate catalyst in small process channels
• Cross-flow orientation of coolant with syngas downflow
**Superior catalysts**
Enabled by organic matrix combustion methodology

- Organic Matrix Combustion (OMX)
  - Novel synthesis method
  - Yields highly active and stable catalysts

- Apparent TOF for **commercially manufactured** catalyst 3-6 times higher than typical Co FT catalysts\(^1\)

- FT catalyst\(^2\)
  - Activity depends on small (optimal) sizes of Co\(_3\)O\(_4\) particles
  - Stability depends on a narrow particle size distribution

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\(^1\)Robota et.al., Catal. Surv. Asia, 18, p177, 2014
Velocys FT technology
Compact, robust, efficient and economic

- Isothermal behavior – thermally stable
- High per-pass CO conversion (>70%)
- Extremely high volumetric productivity
- Robust to upsets
- Ease of modularization
- Strong economy of mass manufacturing
- Installed spares relatively cheap
- High on-stream factor

Commercial FT reactor
Process performance
**Single channel reactor**  
Laboratory testing tool

- 1 process channel
  - No catalyst dilution
  - Coolant channels with hot oil circulation

- During scale-up, number of channels increases (size does not) without any change in performance#

- Validate commercialization requirements
  - Stability
  - Regenerability
  - Catalyst life
  - Predictive models
  - Tolerance to feed contaminants, upsets

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Stable operation at high per pass (>70-75%) conversion with high C5+ selectivity
Low deactivation rate maintained after >2 years of operation

LeViness, Deshmukh et.al., Top. Catal., 57, p518, 2014
Excellent regenerability
>90% activity of fresh catalyst after 13 regenerations
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 $\text{H}_2$:$\text{CO}$ 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 $\text{H}_2$:$\text{CO}$ ratio: 1.4 – 4.5
Temperatures: 175 – 235 °C
Pilot plant and training facility

- Integrated GTL pilot plant in Ohio
- Provides
  - Performance data to support differing client designs
  - Product for client studies
  - Permanent training facility for plant operators
- Platform for
  - Developing our own field support staff
  - Demonstrating future product generations
Stable pilot plant operation with commercial catalyst
High per-pass CO conversion
High alpha product from pilot plant
Path to commercialization
Catalyst scale-up

• Identify and address issues related to commercial manufacturing
  — Formula optimization to establish acceptable range for each component
  — Identify potential contaminants from shared equipment and establish allowable limits
  — Quality assurance protocols to control physical and chemical characteristics
  — Validate performance

• Charging technology developed for integration with microchannel reactor
  — Service partner trained and certified
Full composition specification is established using a “formulation optimization” experimental design

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<th>Support</th>
<th>Co wt%</th>
<th>Prom. 1</th>
<th>Prom. 2</th>
<th>Mod. 1</th>
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‘1’ represents nominal value

Determine process response to each composition variable

Identify interactions among variables

Verify that “limiting compositions” fall well within allowable performance thresholds

Validate measurement methods for composition and physical characteristics
Limits on manufacturing-related foreign elements also set using experimental design

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<th>Catalyst N</th>
<th>Impurity level (ppm)</th>
<th>Test results</th>
<th>XCO</th>
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A two part process:
- Initial screening
- A refined evaluation (the most damaging impurities)
Reactor manufacturing scale-up
Supply chain development

**Prototype process development**
- Engage process technology leaders
- Focus on quality & repeatability
- Process validation & qualification
- Test protocol development

**Integrator & sub-supplier selection**
- Finalist evaluation:
  - Capacity planning
  - Quality control planning
  - Risk planning
  - Cost planning

**Partner qualification**
- Engage world class suppliers
- Prototype approval
- Design for manufacturing
- Mass production feasibility
- Test protocol refinement

**Mass production**
- Equipment Install
- Supplier audits
- Mass pro
- Certification
Manufacturing partnership
Cost-effective quality mass production

• Shiloh Industries
  — N. America’s leading supplier of engineered metal products to automotive industry
  — Working together since 2012

• Production cell is replicable and scalable
  — Several $ million in manufacturing resources
  — Dedicated team of engineers

• Initial manufacturing capacity supports **10,000 bpd/yr** of orders; plans in place to grow to **40,000 bpd/yr**
Mechanical integrity testing
Reactor approved as *fit for deployment*

- FT reactor designed to ASME, boiler and pressure vessel code, section VIII, division 1
- FEED review
  - Design criteria, material selection, operating conditions, fabrication process
- FMEA
  - Reactor manufacture, FT process impact, equipment operation, corrosion/life
- Reactor testing
  - Weld inspection, temperature cycles, pressure cycles, reactor autopsy
JV with Waste Management, NRG Energy and Ventech
Oklahoma City GTL project

• Project description
  — First GTL plant that will use a combination of renewable biogas and natural gas

• Enabling factors
  — Low cost landfill gas as feedstock
  — RIN credits under the Renewable Fuel Standards
  — WM’s existing experience of operating GTL technology using landfill gas as feedstock

• Status
  — Final investment decision taken July 2014
  — Detailed engineering and procurement underway
Ashtabula GTL

- Project description
  - 4,200 bpd GTL plant in Ashtabula, Ohio, USA

- Enabling factors
  - Reduction in capex from integration with substantial existing infrastructure viz. waste water treatment; power plant; cooling water pumping; air separation; gas pipeline; rail and barge; local customers for by-products

- Status
  - Velocys acquired the Ashtabula GTL project, and its project developer, in June 2014
  - Initial engineering completed by Ventech (EPC), Haldor Topsoe & Velocys
GreenSky London

- Project description
  - Commercial **2,500 bpd** waste-biomass-to-jet fuel plant being developed by Solena Fuels in Development with **British Airways**
- Enabling factors
  - Negative feedstock cost (tipping fees)
  - Regulatory incentives for aviation biofuels
  - Support of a major air-line that takes its environmental performance very seriously
- Status
  - Pre-Front End Engineering completed
  - **Site selection** announced April 2014
Red Rock Biofuels

• Project description
  – 1,100 bpd forestry waste to liquids plant in Oregon, USA

• Enabling factors
  – Supported by US DoD and US DoE
    • Received $4.1m phase 1 grant for engineering
    • Received $70m phase 2 construction grant September 2014

• Status
  – FEED study complete
  – Southwest Airlines to offtake 3 million gal/yr of aviation fuel from the plant
Summary

• Velocys, the company at the forefront of smaller scale GTL technology
  — 15 years and >$300 million invested in its unique innovative technology
  — Exhaustive global patent protection (>7,600 granted GTL claims)
  — Broad & deep in-house capabilities.
  — With first class partners will deliver a complete GTL solution

• Superior catalyst and advanced reactor design leading to exceptional process performance

• Financial commitment secured for construction of first commercial plant
Thank you

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