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Case Study: Production of Fuels and Petrochemicals

Microchannel Fischer-Tropsch Synthesis

Enabling Biofuels and Associated Gas Monetization

Presented by Velocys, Inc. (subsidiary of Oxford Catalysts Group)

14th New Industrial Chemistry and Engineering (NIChE) Conference

September 2009

Presentation Roadmap

- Who we are
- Microchannel Fischer-Tropsch Technology
- Comparison to Conventional
- Biofuels Opportunity
- Associated Gas Opportunity
- Other Applications Under Development

Who we are

Oxford Catalysts Group PLC

Oxford Catalysts Ltd.

- Commercialising >20 yrs' research at university Chemistry Department
- Largest Chemistry Department in Western World
- Company founded by Head of Inorganic Chemistry
- Listed company (LSE: OCG); well capitalised
- Developing and commercialising catalysts for production of **clean fuels**
- Based near Oxford, UK

Velocys, Inc.

- Commercialising 15 yrs' research originating in US DoE National Laboratory (PNNL)
- Conducted by Battelle – world's largest independent science & technology organisation ($4bn R&D p.a. / 20,000 staff / 130 locations)
- **Over $160m** invested in technology to date, primarily by commercial partners
- **Global leader** – largest microchannel process technology IP portfolio in world
- Acquired by Oxford Catalysts in Nov-08
- Based near Columbus, Ohio, USA

Critical mass: some 90 employees

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US Facilities: Microchannel Development

Primarily chemical & mechanical engineers

Team: 62

Core competencies:

- **Microchannel design** (microfluidics – reaction engineering, CFD, heat transfer, predictive design; testing; prototype design and fabrication)
- **Catalyst application** (into and out of microchannels)

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UK Facilities: Catalyst Development

Chemists (catalysis) Team: 30

High-throughput experimentation capability

Access to University characterisation equip.

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Group Vision and Strategy

- The reason we exist is to help the world produce chemicals, fuels and energy more sustainably
- We are concentrated on what we do better than anything else
  - development of novel and 'super active' catalysts
  - process intensification (mainly microchannel technology)
  - technology transfer from research organisations to industry
- We work with key partners for
  - market introduction and growth
  - plant design and support
  - manufacturing of our products
- Primary revenues from licences / royalties

TEC
MODEC
ptt Group

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Microchannel Fischer-Tropsch

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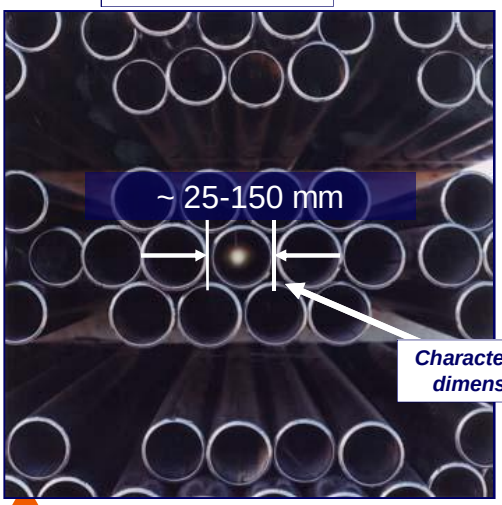
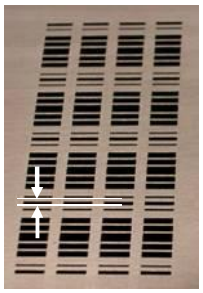
Microchannel Technology

Conventional



Accelerate heat and mass transfer resistance with short path lengths

Microchannel



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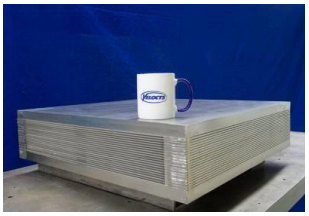
Microchannel Fischer-Tropsch

- Microchannel Fischer-Tropsch work began prior to formation of Velocys and has been supported a number of key industrial partners including Total S.A.
- Current sponsors include Toyo Engineering, MODEC and a dedicated biofuels developer
- Expected key benefits include
  - Reduction in size and capital cost
  - Improved catalyst stability
  - Modularity
  - Economic at small scales (300-5,000 bpd)
- Field demonstration early 2010 at Güssing
- Technology could be adapted for production of methanol or higher alcohols



¼ scale FT reactor
Device: 24" x 24" x 6"
Capacity if operated:
~7-12 barrels/day

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R&D 100

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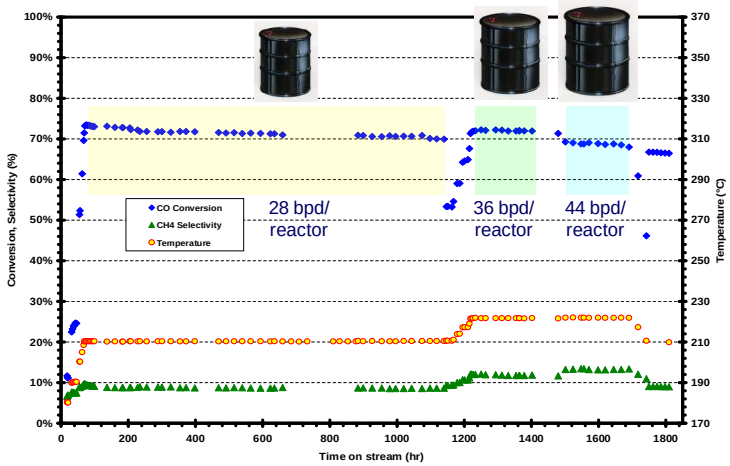
Fischer-Tropsch Reactor Performance



Demonstrated capacity of 40+ bpd/reactor

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Pilot Reactor Products

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Comparison to Conventional

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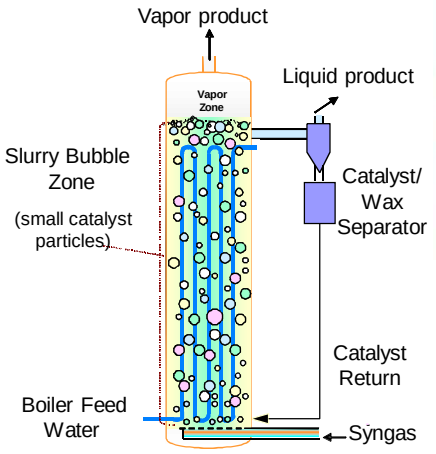
FT Technology Today – Slurry Bed



FT Reactor during shipping

Capacity = 15,000 bpd
Weight = 2,200 tons
Height = 60 m
Outer Diameter = 10m

Slurry bubble FT Reactors among largest in the world

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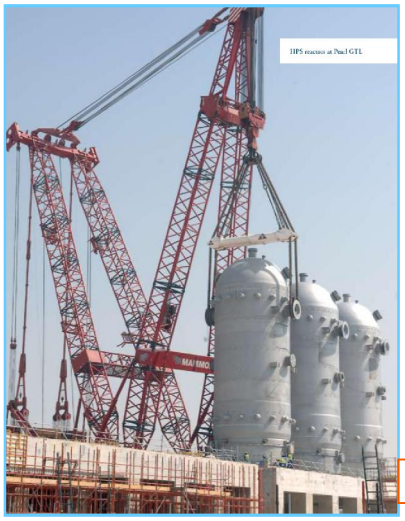
FT Technology Today – Fixed Bed



- Key Reactor Stats:
  - Weight: 1,200 tonnes
  - Capacity: 5,800 bpd
  - Diameter: 7m
  - Height: 20m
  - Reactor tubes: 29,000
  - Tube diameter: 2.5cm

Fixed Bed FT Reactors are also massive

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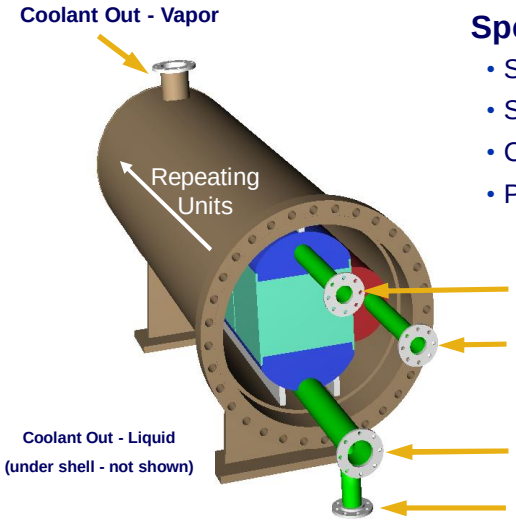
Microchannel FT Reactor Assembly



Specifications

- Shell Diameter = 4'
- Shell Length = 12'
- Coolant flow length = ~24"
- Process flow length = ~18"

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FT Reactor Comparison

Technology Characteristics	Fixed Bed (Shell)	Slurry (Sasol)	MPT (Velocys)	Velocys advantage
Pore diffusion	–	✓	✓	Small catalyst particles (~300 µm)
Catalyst loading in process channel	✓	–	✓	Fixed bed enables high catalyst loading
Gas-liquid mass transfer	✓	–	✓	Avoid CO mass transfer limitation through wax
Isothermal behavior	–	✓	✓	High heat transfer performance
Catalyst exchange	–	~	–	Slurry reactors enable continuous catalyst change-out, but require fine filters
Catalyst attrition	✓	–	✓	Catalyst held stationary
Need for liquid-solid separation	✓	–	✓	Catalyst maintained in reactor
Scale-up	✓	–	✓	"Numbering up" approach
Reactor costs for BTL	–	–	✓	Able to scale down cost effectively

Ref – Reactors for FT Synthesis, Guettel et al, Chem. Eng. Tech., 2008

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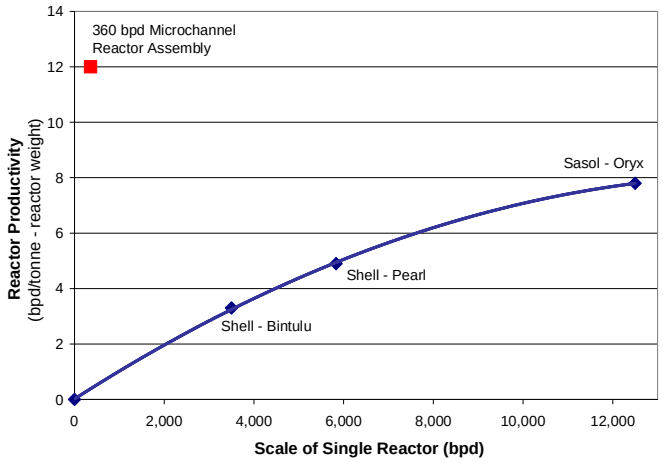
FT Reactor Productivity Comparison



Microchannel FT matches capacity requirements of biomass and flared gas resources

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Biofuels Opportunity

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Biofuels Today

Feedstock → Process → Distribute → Use

- Corn
- Soybeans
- Other Food Crops

- Blending
- Dedicated supply

- Compromised performance

- Fermentation
- Distillation

Corn ethanol and biodiesel do not fully meet requirements

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First Generation vs. Second Generation Biofuels

Generation	First Generation		
Feedstock	Corn	Sugar	Soy Oil
Biofuel	Ethanol	Ethanol	Biodiesel
Commercial Technology?	✓	✓	✓
Low Production Costs?	?	✓	X
Non-Food?	X	X	X
High Energy Density?	X	X	✓
Low Shipping Costs?	X	X	X
Good Engine Performance?	X	X	✓
Significant CO_2 Reductions?	X	?	?
Fuel Type	**Gasoline**	**Gasoline**	**Diesel**

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First Generation vs. Second Generation Biofuels

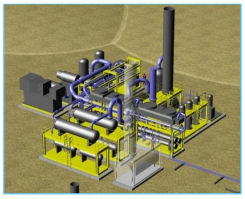
Generation	First Generation			Second Generation			
Feedstock	Corn	Sugar	Soy Oil	Cellulosic	Multiple	Algae	Cellulosic
Biofuel	Ethanol	Ethanol	Biodiesel	Ethanol	Butanol	Biodiesel	FT
Commercial Technology?	✓	✓	✓	X	X	X	X
Low Production Costs?	?	✓	X	?	?	?	?
Non-Food?	X	X	X	✓	✓	✓	✓
High Energy Density?	X	X	✓	X	✓	✓	✓
Low Shipping Costs?	X	X	X	X	✓	X	✓
Good Engine Performance?	X	X	✓	X	✓	✓	✓
Significant CO_2 Reductions?	X	?	?	✓	?	✓	✓
Fuel Type	**Gasoline**	**Gasoline**	**Diesel**	**Gasoline**	**Gasoline**	**Diesel**	**Jet or Diesel**

Microchannel FT Enables a Better Biofuel

Feedstock → Process → Distribute → Use

- Wood waste
- Municipal Solid Waste

- Modular technology
- Distributed processing



- Compatible with existing infrastructure
- Geographically widespread available feedstocks

- Superior diesel and jet fuels

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Associated Gas Opportunity

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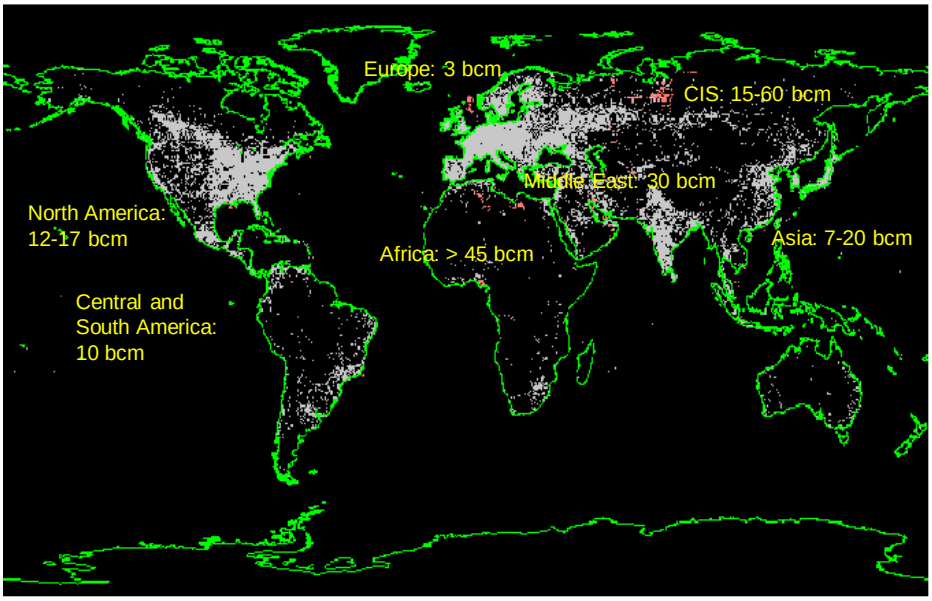
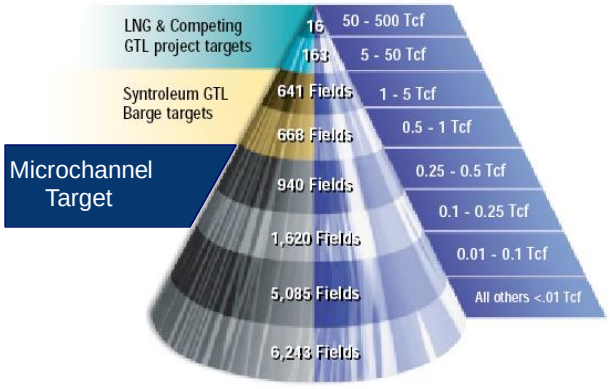
Associated Gas Flares



Resource Requirements



World's Gas Fields by Size (Outside North America)

Source: IHS Energy Group, 1998

Microchannel FT matches capacity requirements of flared gas opportunities

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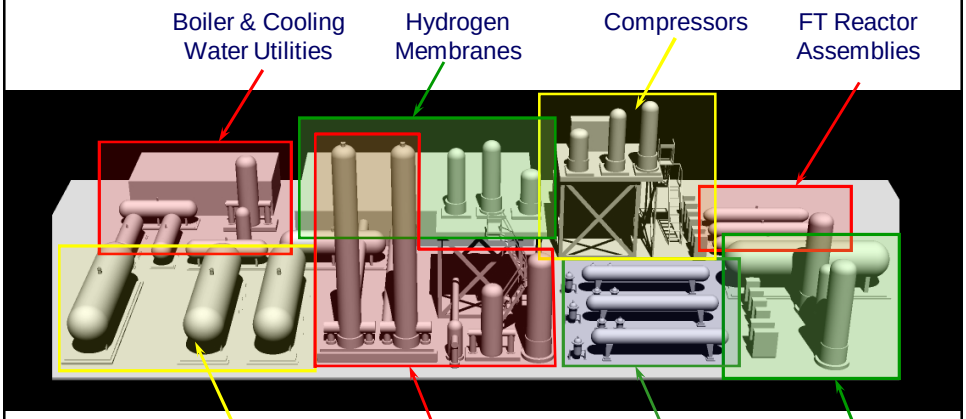
Gas-to-Liquids (GTL) Process Layout



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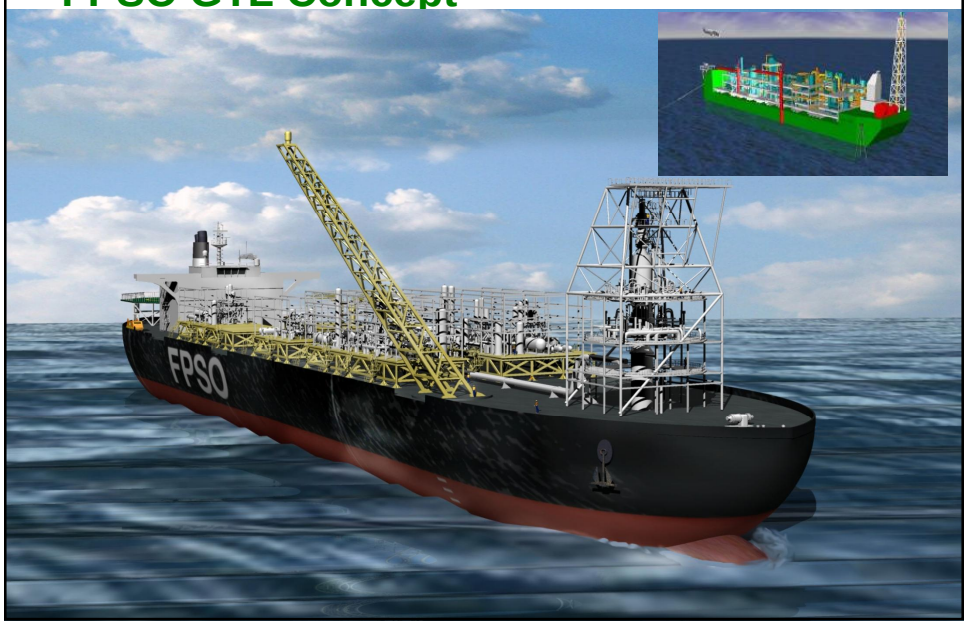
FPSO GTL Concept



Offshore GTL Alliance

Global Toyo

- Founded in 1961
- Based in Chiba, Japan; over 1,000 employees
- Provider of R&D, design, engineering, equipment procurement, construction, test operations, and technical guidance
- Plant design experience spans over 45 years and more than 1,400 projects

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MODEC

- Founded in 1968
- Turnkey supplier of FPSO vessels, Tension Leg Platforms and semi-submersibles
- Operates 10 FPSOs worldwide; has four under construction
- Recognized by the Offshore Technology Conference for its MOSES Self Stable Integrated Platform (SSIP) TLP.

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Microchannel FT Demonstration

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Location – Güssing, Austria

- Operating since 2002
  - 8 MW Capacity
  - Gasification process – Fast Internal Circulating Fluidized Bed
- Slipstream to be cleaned and fed to microchannel FT skid
  - See next slide

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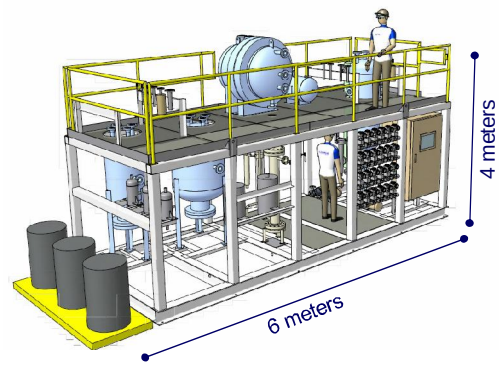
FT Field Demonstration Skid



- 25 gallon/day capacity

Operation to commence in early 2010

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Other Applications

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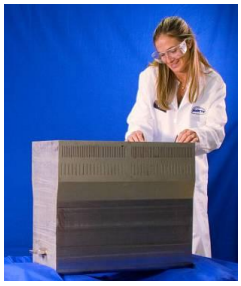
Steam Methane Reforming

- SMR was genesis of Velocys, expertise dates back to PNNL in 1990s
- Development of the technology has been supported by many major partners over the years, including Total S.A. and others
- Key benefits include:
  - Reduction in size and capital cost
  - Higher efficiency and reduced emissions
  - Economic at smaller scales of application
- Commercial demonstration in 2010/2011
- Technology could be adapted/optimised for:
  - Production of hydrogen
  - Reforming of other hydrocarbons
  - Biogas reforming



⅓ scale SMR reactor
Device: 22" x 12" x 24"
Capacity if operated:
0.33 million ft^3/day of H_2

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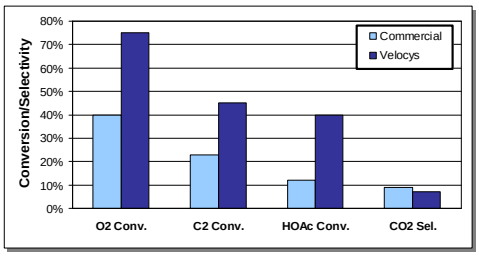
Selective Oxidations

- Microchannel platform offers many advantages
  - Precise mixing of reactants on microscale
  - Tailored catalyst form – packed bed, engineered, coated
  - Heat removal limits maximum temperature
  - Rapid quenching preserves metastable products
  - High surface/volume ratio – favors heterogeneous reactions
  - Potential for higher pressure partial oxidation
- *Example: Vinyl Acetate Monomer (VAM)*



- Higher oxygen conversion without sacrificing VAM selectivity
- More active catalyst utilization
- Higher throughput, space time yield
- Higher ethylene conversion
- Lower recycle
- Microchannels can provide advantage for reactions with a particulate catalyst

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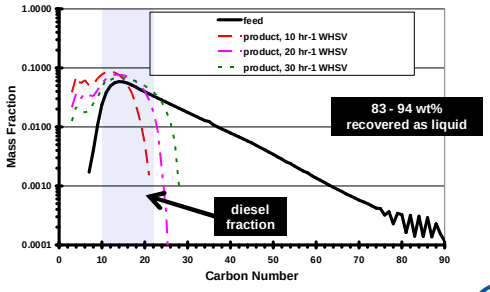
Hydroprocessing

- Microchannel hydroprocessing improves:
  - Kinetics – use of high activity catalyst
  - Pressure Drop – short bed lengths
  - Heat Transfer – improves catalyst life
  - Mass Transfer – enhanced catalyst-liquid-gas interface
- Demonstrated 30X productivity for hydrocracking FT wax



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Summary

- Velocys & Oxford Catalyst are focused on large-scale microchannel applications
- Microchannel FT offers substantive improvements over conventional reactors
  - 10-15X productivity, temperature control, economic at small-scale
- Market pull for Microchannel FT
  - Enables production of 2nd generation biofuels
  - Enables monetization of associate gas
- Demonstration at Güssing will begin in early 2010
- Other large-scale applications in development
  - Steam methane reforming, selective oxidations, hydroprocessing

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Thank You

- Contact

Laura Silva

Director, IP and Licensing
Velocys, Inc.
7950 Corporate Blvd.
Plain City, OH 43064
614-733-3300
silva@velocys.com
www.velocys.com

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