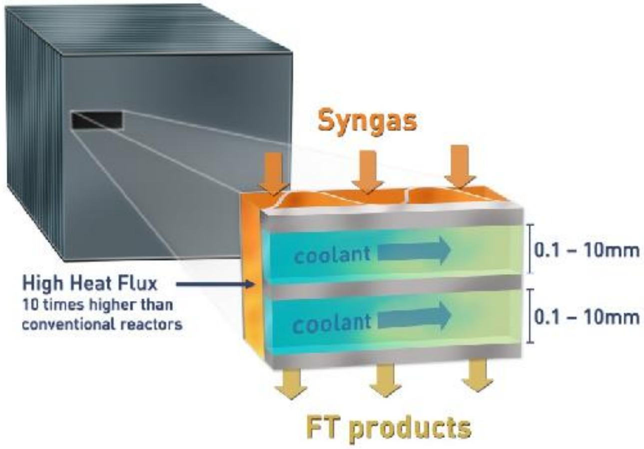
Laura Barrio
PIN-24, Newcastle, 21st June 2016

Intensified smaller scale GTL process

VELOCYS

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

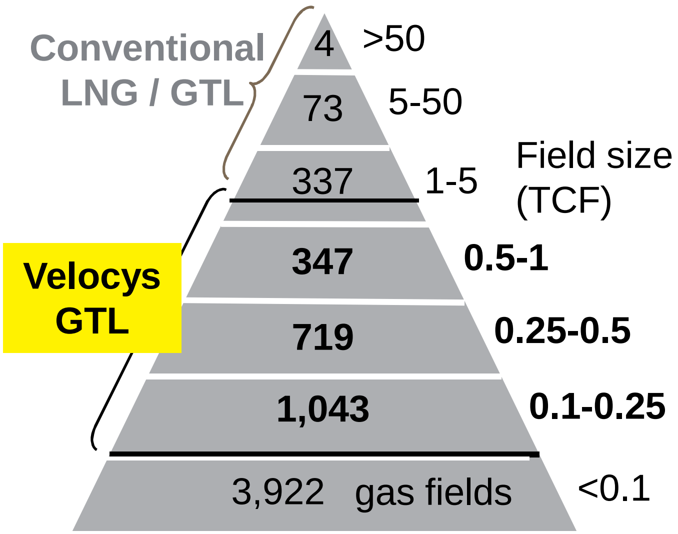
- **International presence**
  - Commercial center in Houston, Texas; technical centers near Columbus, Ohio and Oxford, UK
  - Permanent pilot plant in Ohio

Our business: the gas-to-liquids (GTL) process

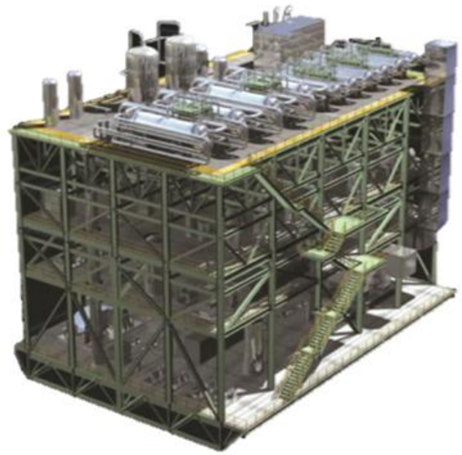
Chemical conversion of natural gas to refined products

Reforming → Fischer-Tropsch (FT) → Hydro-processing

Natural gas → **Syngas** (carbon monoxide + hydrogen) → **Syncrude** (synthetic crude oil) → **Clean synthetic fuels & chemicals** (diesel, jet fuel, Lubricants, waxes etc.)



Distr. of conv. gas fields outside US



Smaller scale GTL:
1,500 – 15,000 bpd

Distributed scale GTL opportunity size (mmbpd)	
Unconventional gas*	18
Associated gas	2.7
Stranded gas*	4.8
Total	**> 25**

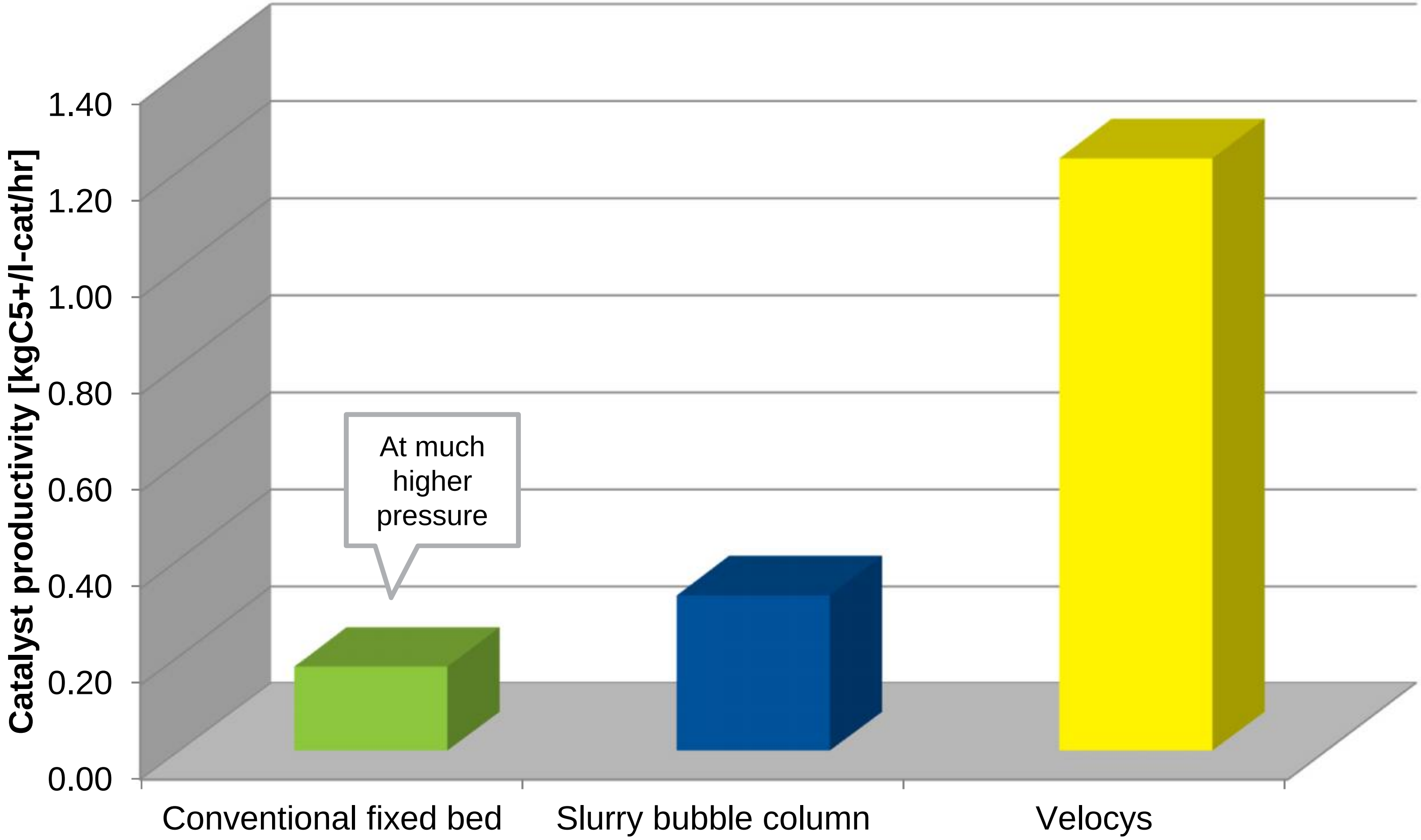
* *Assumes monetisation over 100 yrs*

Velocys' technology at a glance

Super-active catalyst & microchannel reactors

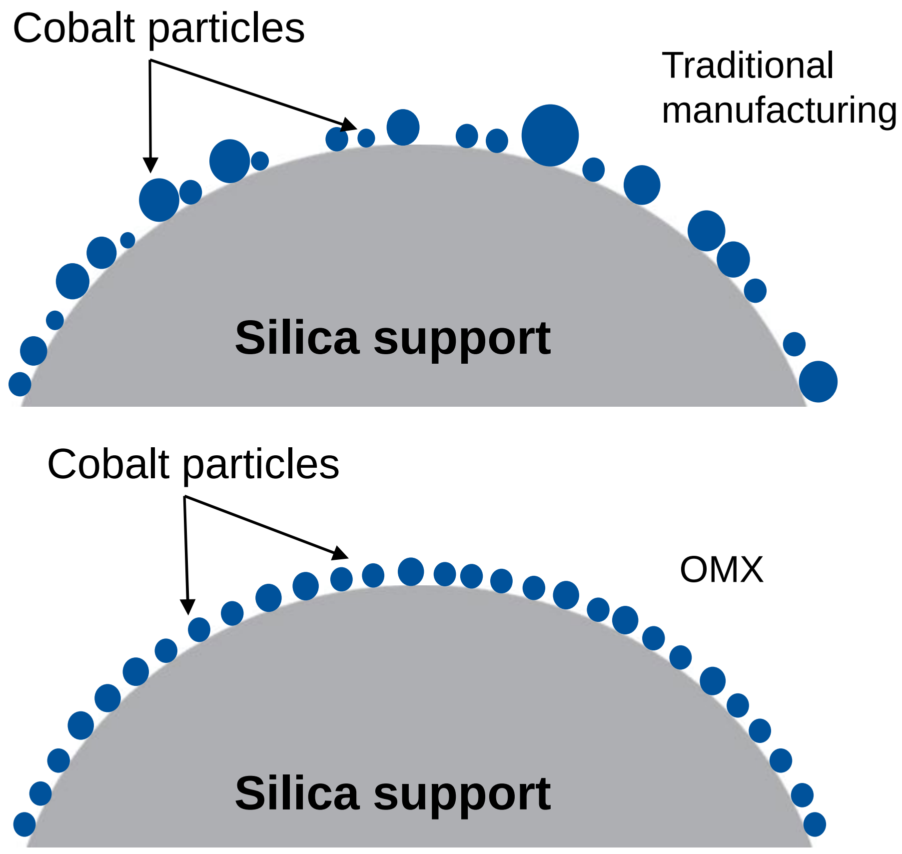
Key catalyst criterion: super-active catalyst

Velocys catalyst is an order of magnitude more productive than competitive FT catalysts

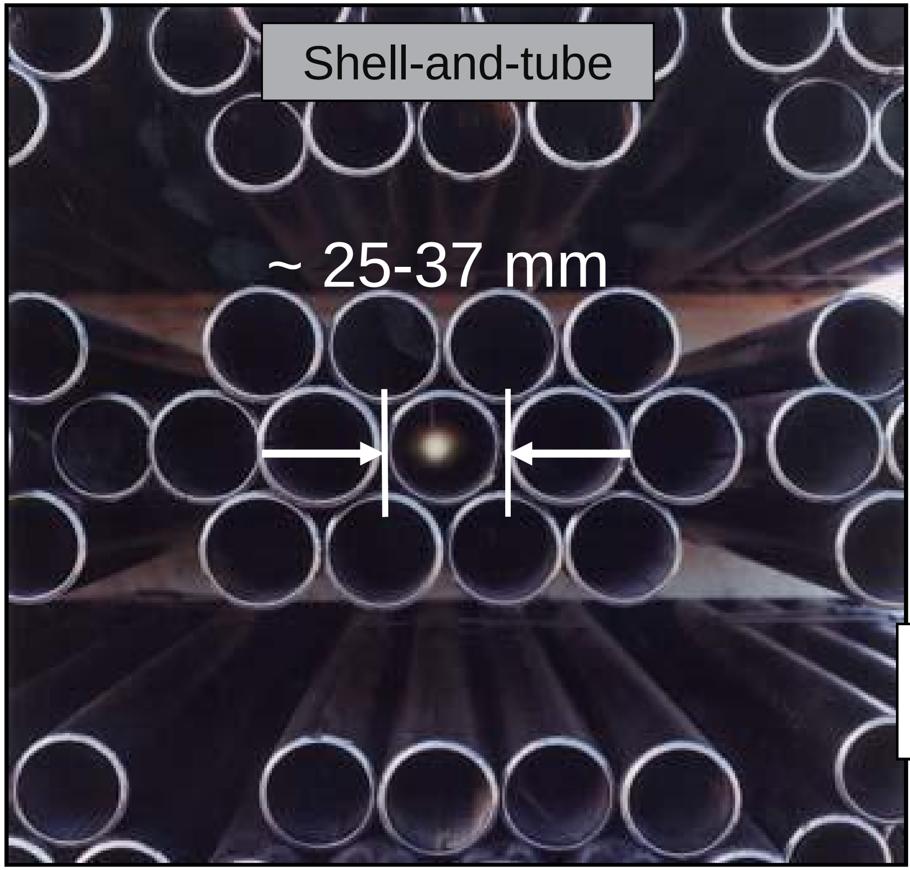


Origin of exceptional catalyst performance
Patented organic matrix combustion (OMX) method

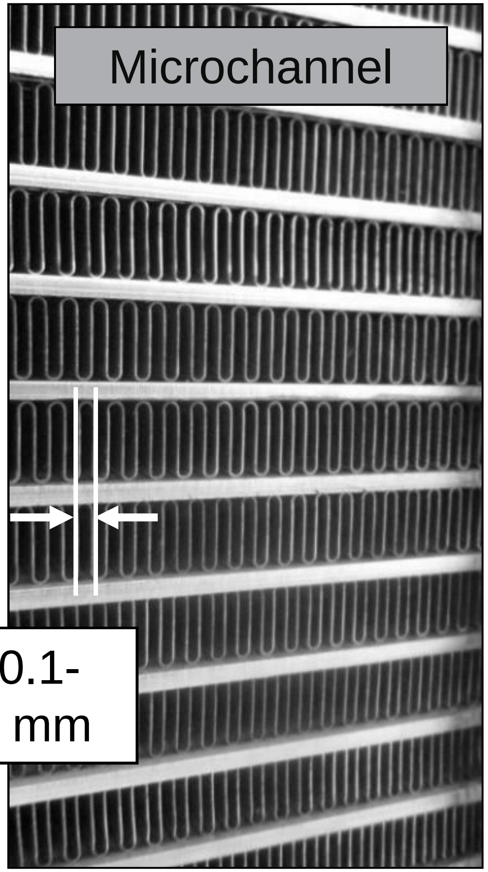
- **Traditional catalyst manufacturing**
  - — Produces broad distribution of cobalt particle sizes
- **OMX catalyst manufacturing**
  - — Produces optimized and more uniform cobalt particle sizes
  - — **Higher activity** from smaller particles
  - — **Greater stability** from narrower particle size distribution



Key reactor criterion: reaction intensification
Microchannels intensify chemical processes



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

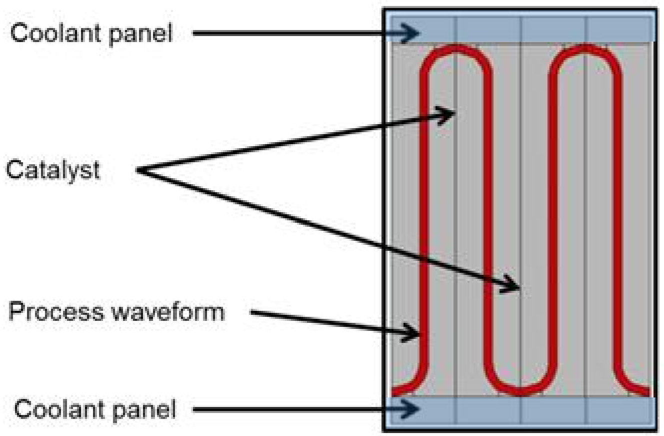


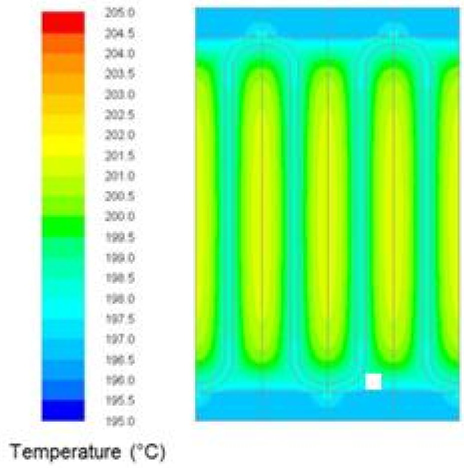
Enhanced mass and heat transfer

Velocys FT reactor
Tube length 2 feet (0.6 meters)

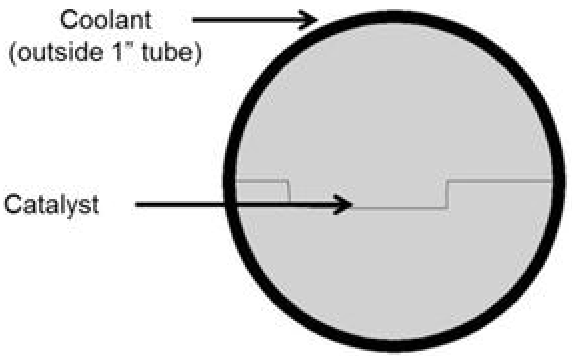
Key reactor criterion: exceptional heat removal
Microchannels keep the catalyst bed more isothermal

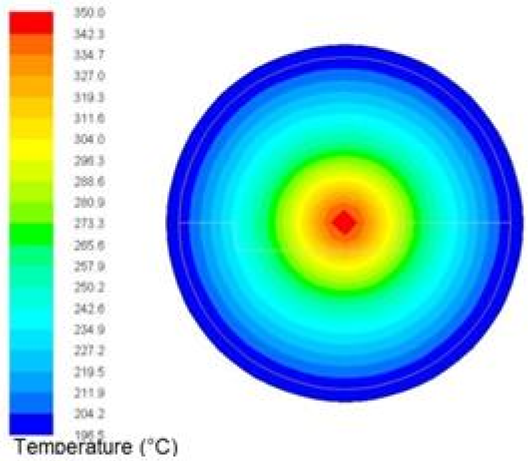
- **Microchannel** coolant and process channels more effectively transfer heat out of the catalyst bed giving better control and performance





- **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

Velocys Fischer-Tropsch reactor

Note: Reactor capacities differ considerably

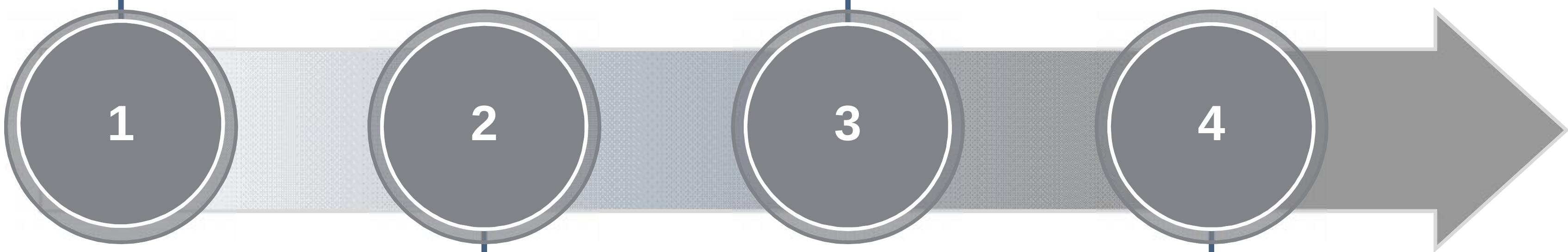
Commercialising our offer

Development tools & scale-up methodology

Commercial catalyst manufacturing
Ensure performance is maintained at commercial scale

Lab scale
gram quantities produced multiple runs

Pilot scale
Multiple runs yielding a combined 1.5 MT



Developmental scale
kg quantities produced multiple runs

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

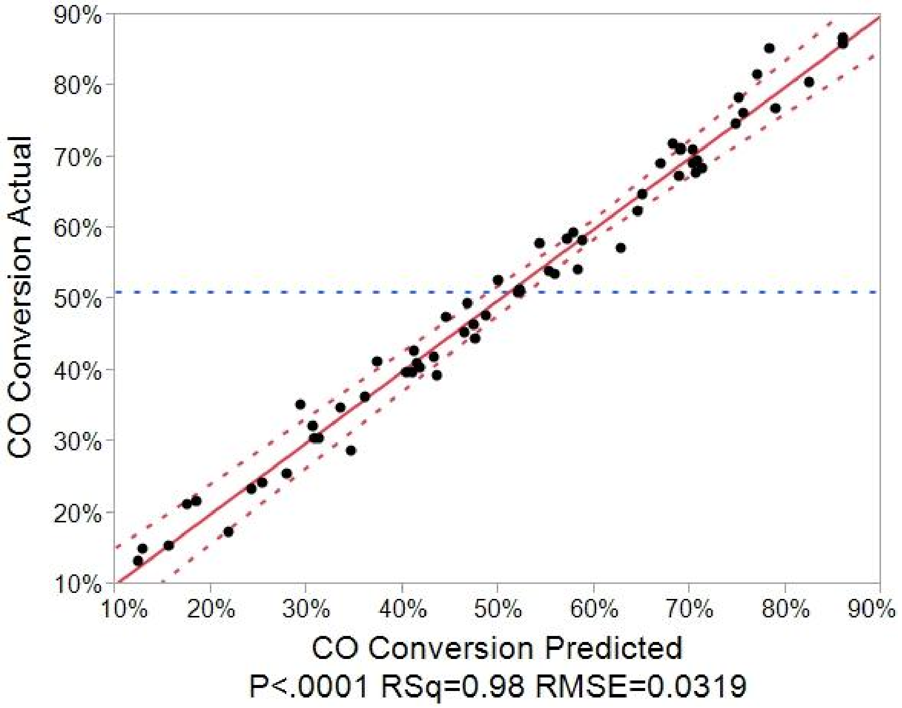
Commercial

- 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

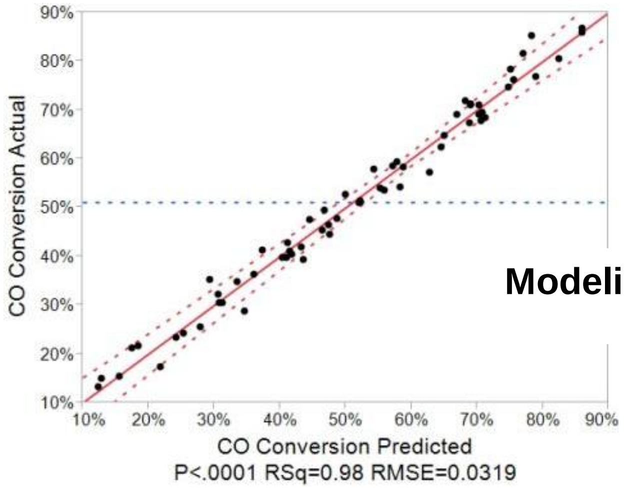
Process model development

- Designed experiments to cover wide range of FT operations
- Independent variation of parameters: e.g. P_{co}, P_{H_2}
- >60 data points
  - — Close monitoring of outlet 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**

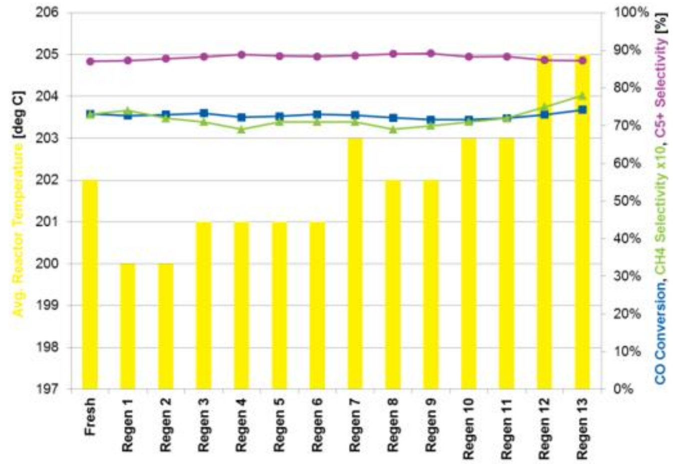


Inlet pressure: 200 – 450 psig
Inerts: 10% – 70%
Contact time: 150 – 500 ms
Feed H_2:CO ratio: 1.4 – 4.5
Temperatures: 175 – 235 °C

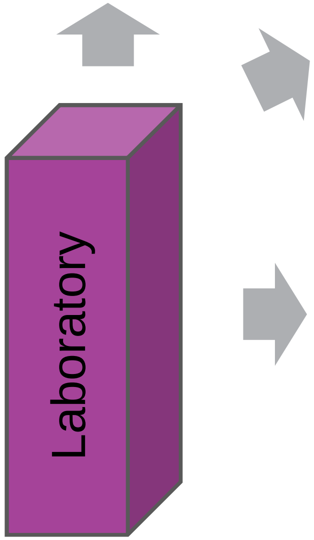
Verified performance and scale up methodology

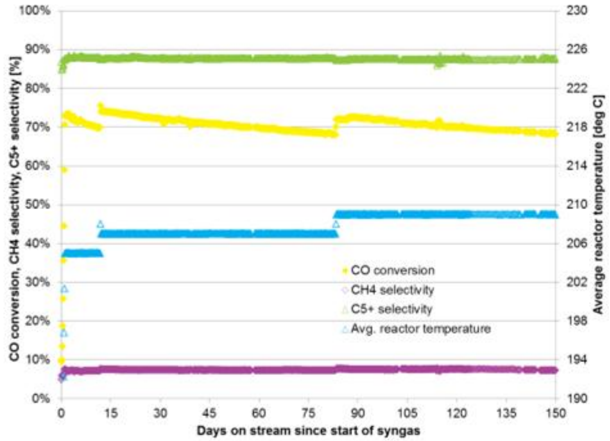


Modeling



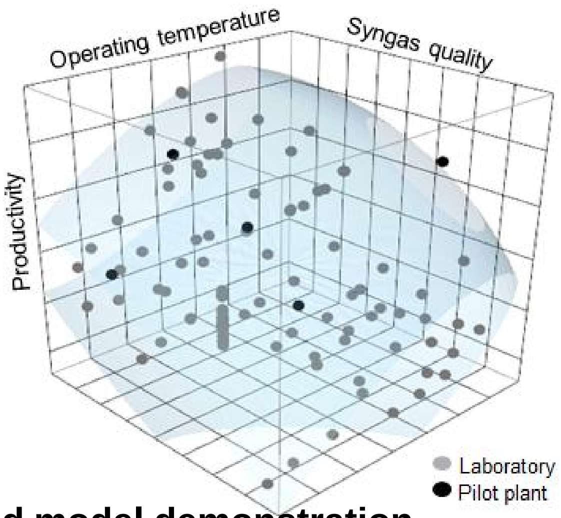
Multiple regenerations



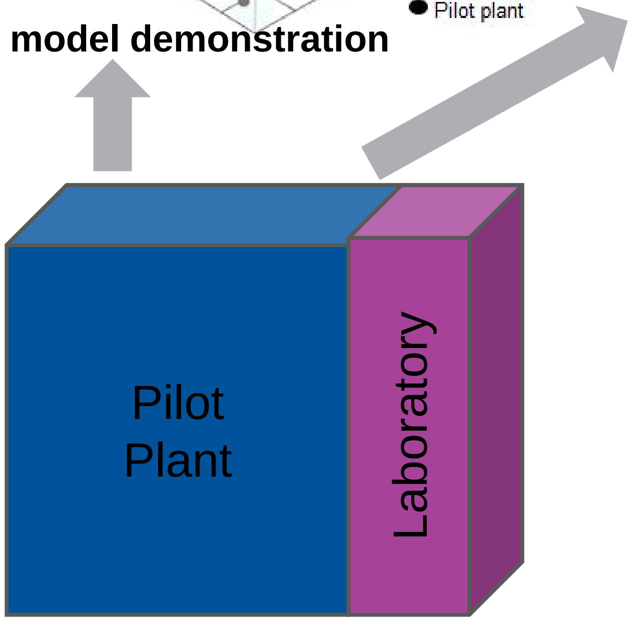


Catalyst testing

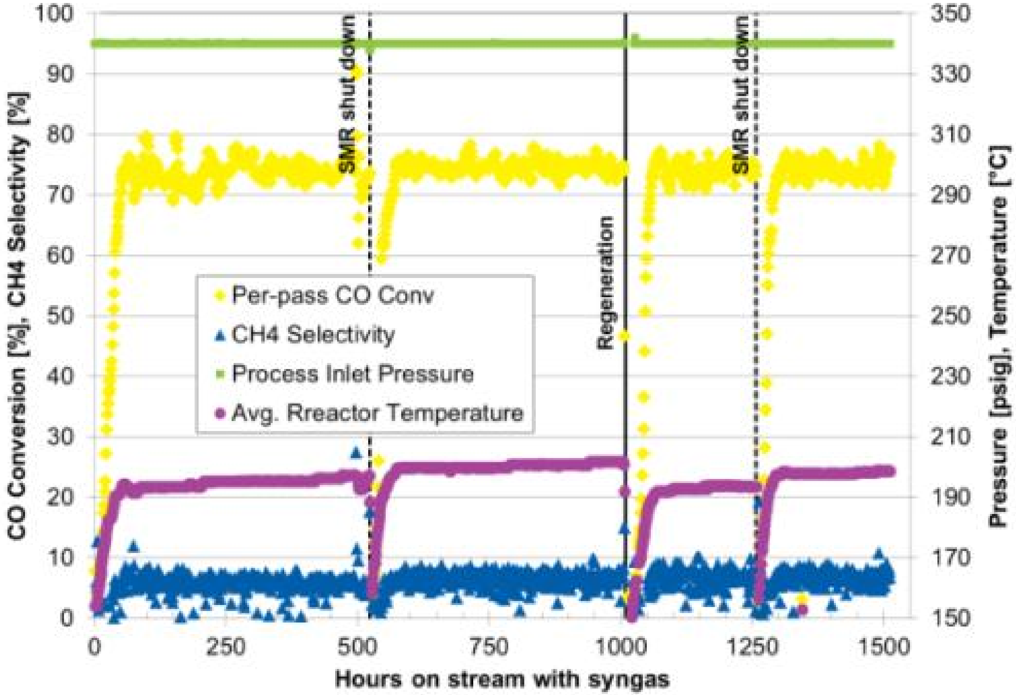
Verified performance and scale up methodology

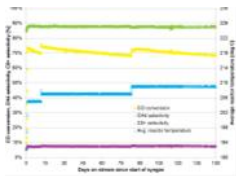


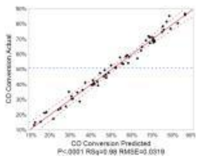
Field model demonstration

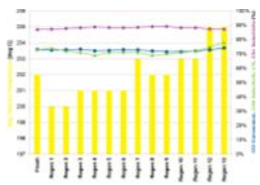


Sustained stable operation

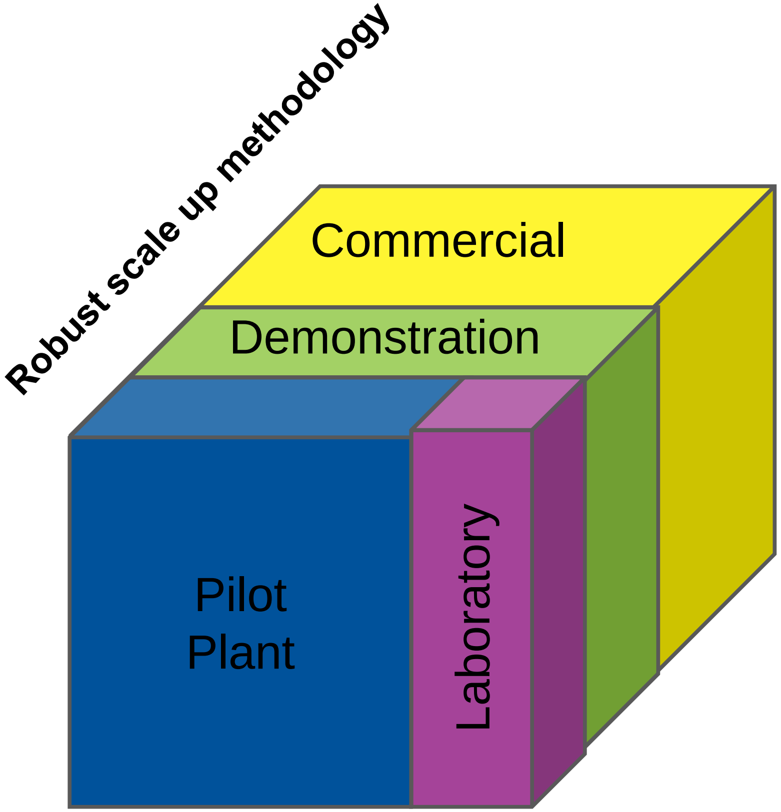


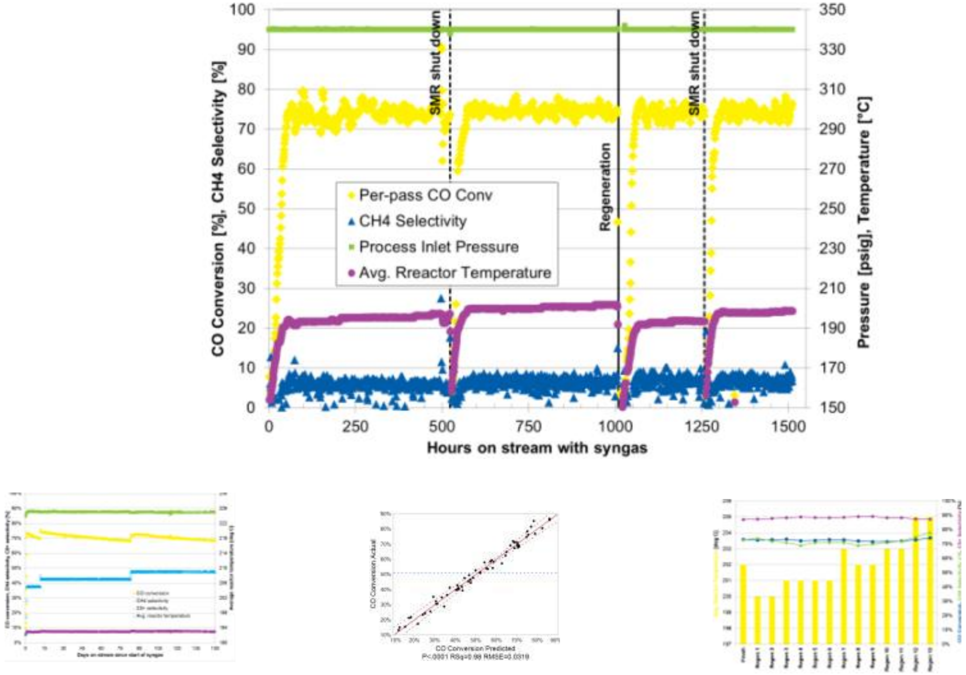




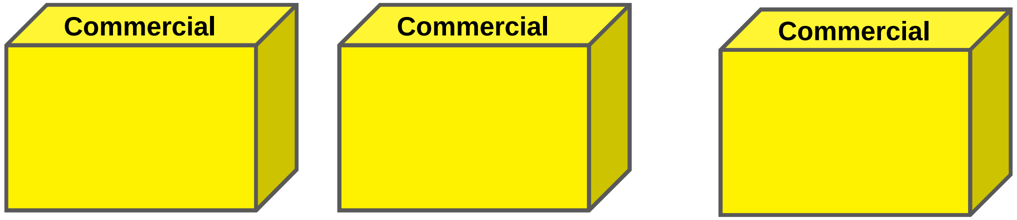


Verified performance and scale up methodology

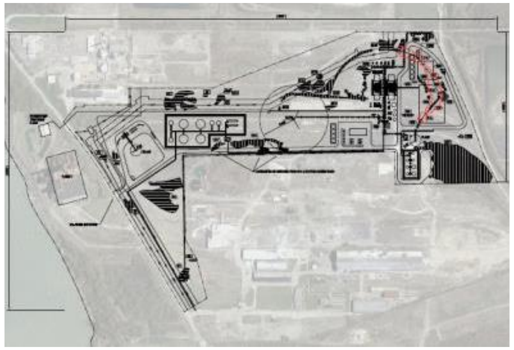


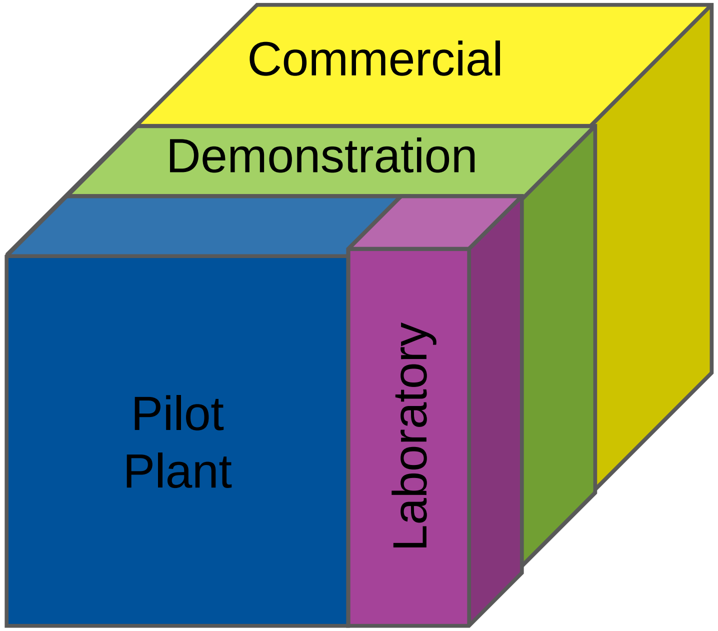


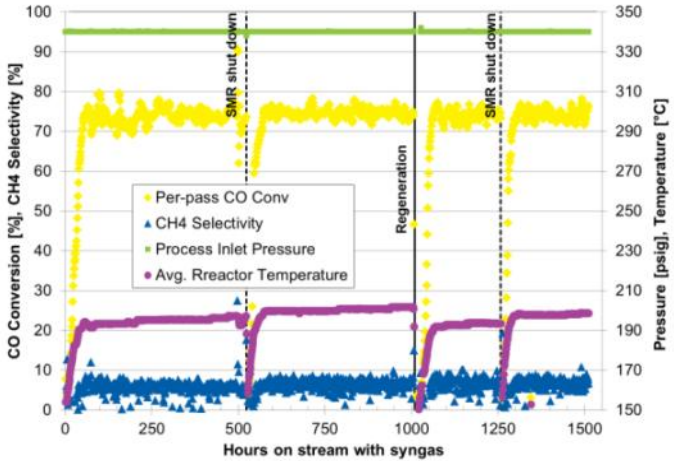
Verified performance and scale up methodology

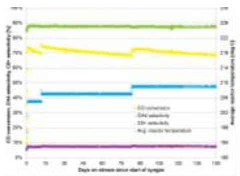


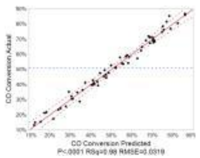
Duplicate reactors and trains for commercial facilities

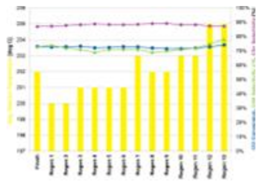




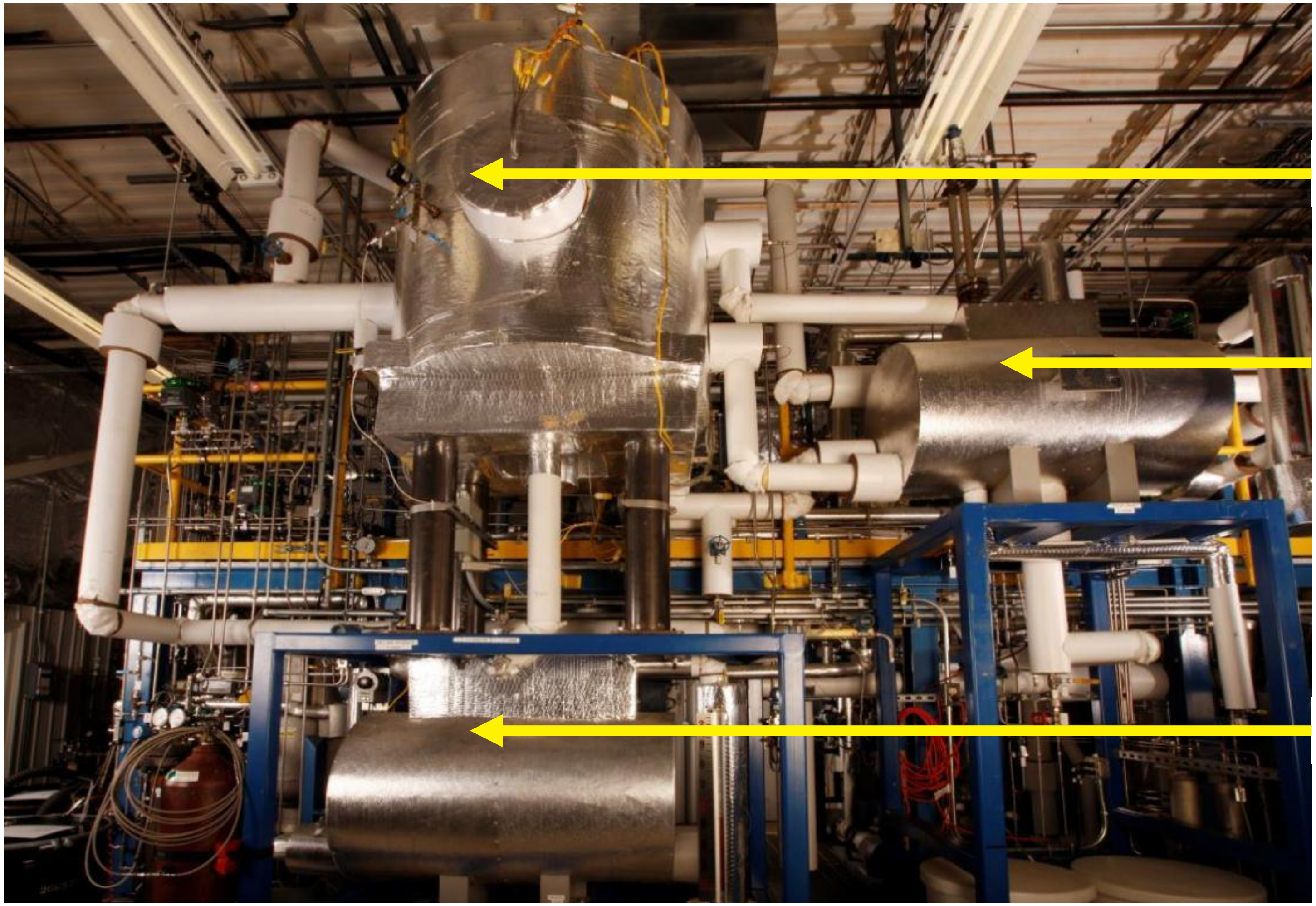








FT performance
Performance of the microchannel reactor and catalyst demonstrated in the Velocys Pilot Plant (VPP)



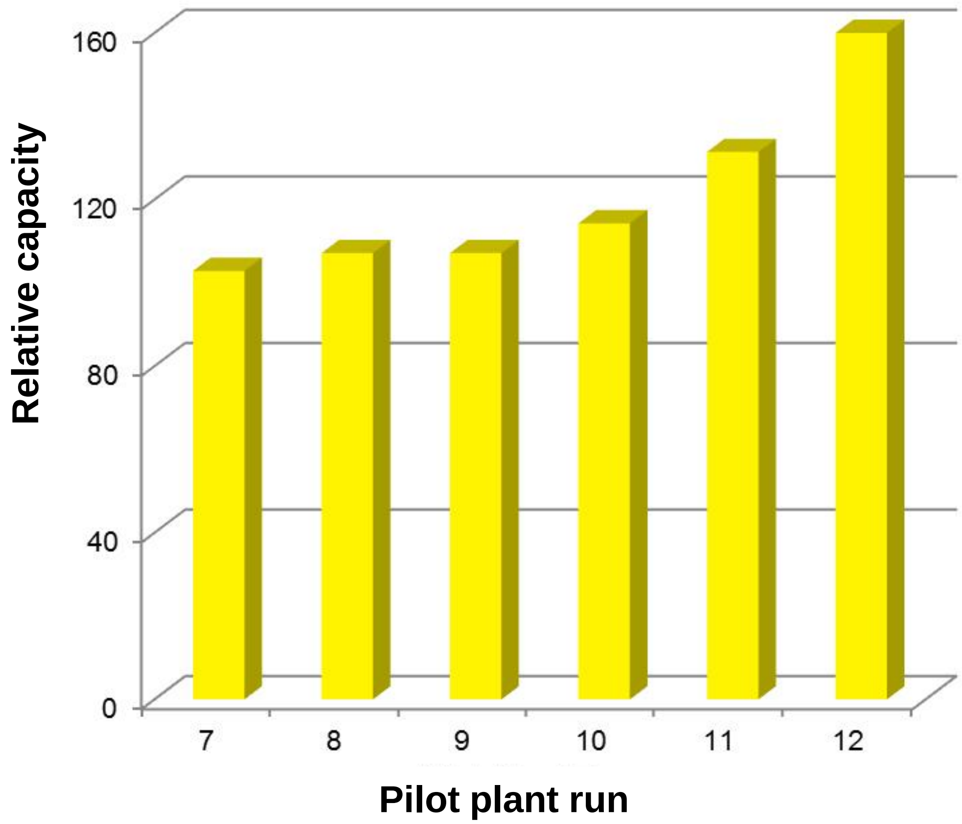
FT reactor

Steam drum

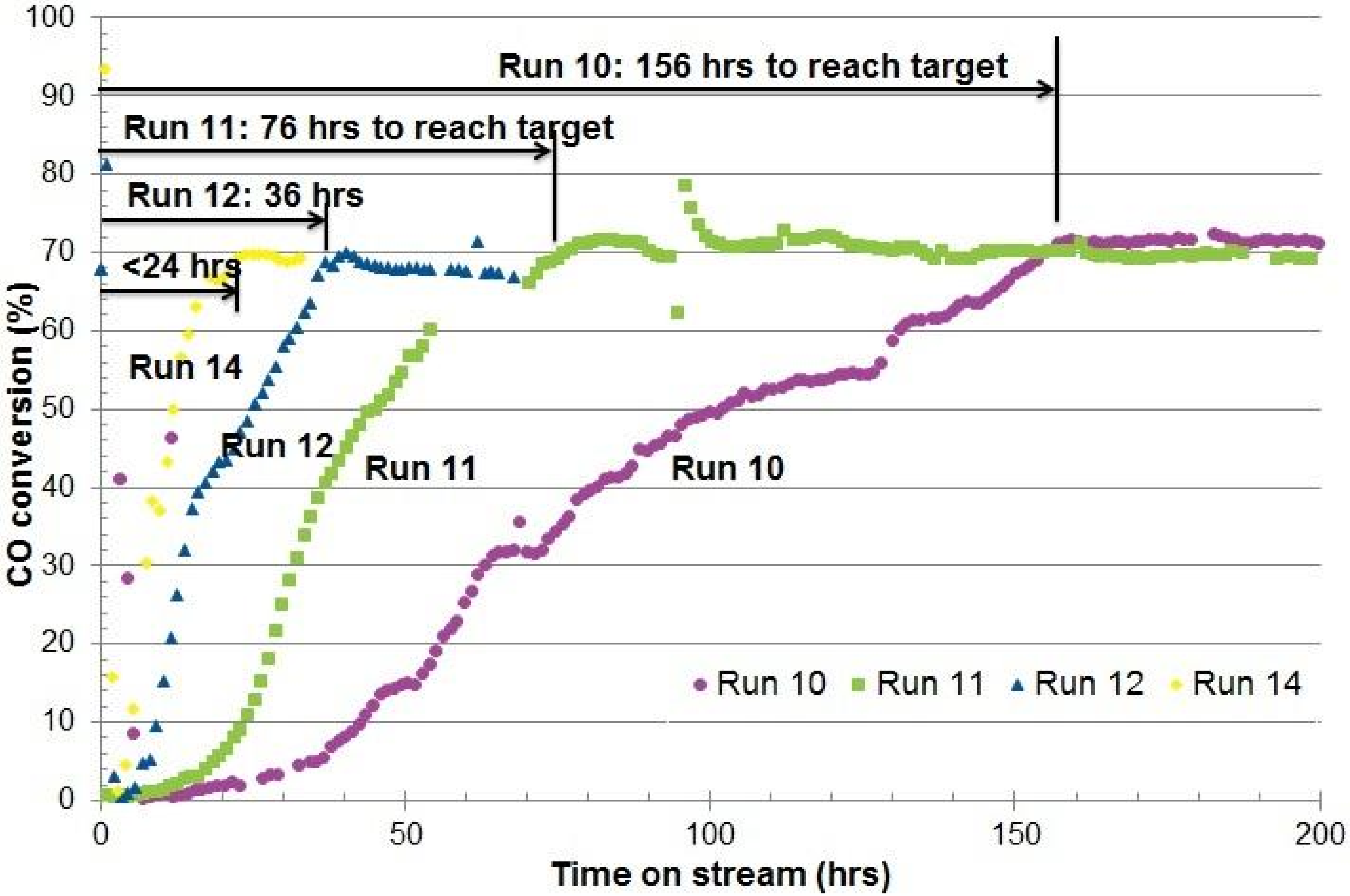
Wax drum

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



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

WASTE MANAGEMENT


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

CO_2 wash column

Thank you

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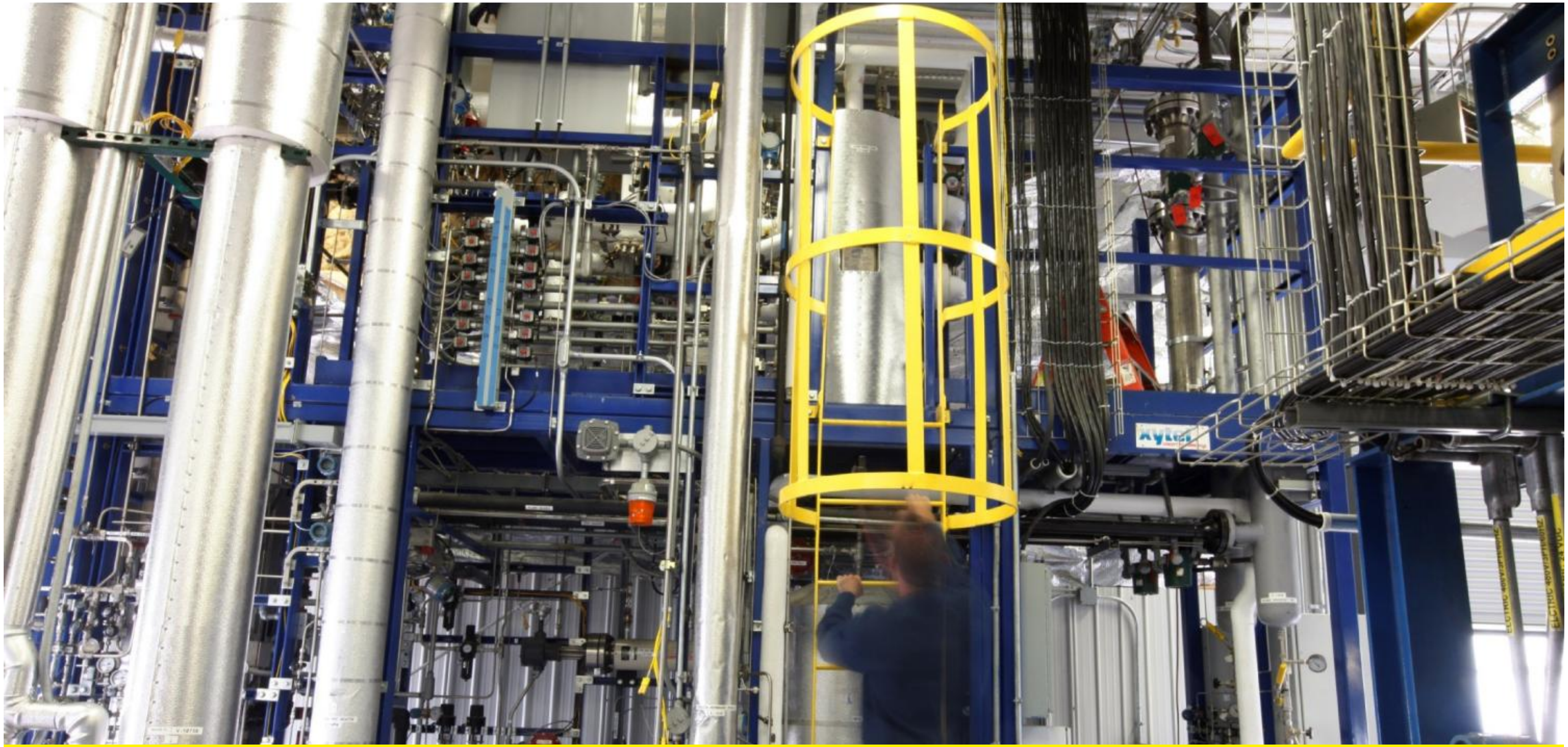

Think Smaller

VELOCYS