# Microchannel Catalytic Process for Converting Biomass Derived Syngas to Transportation Fuels

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ACS Meeting

New York City

September 8, 2003

# Outline

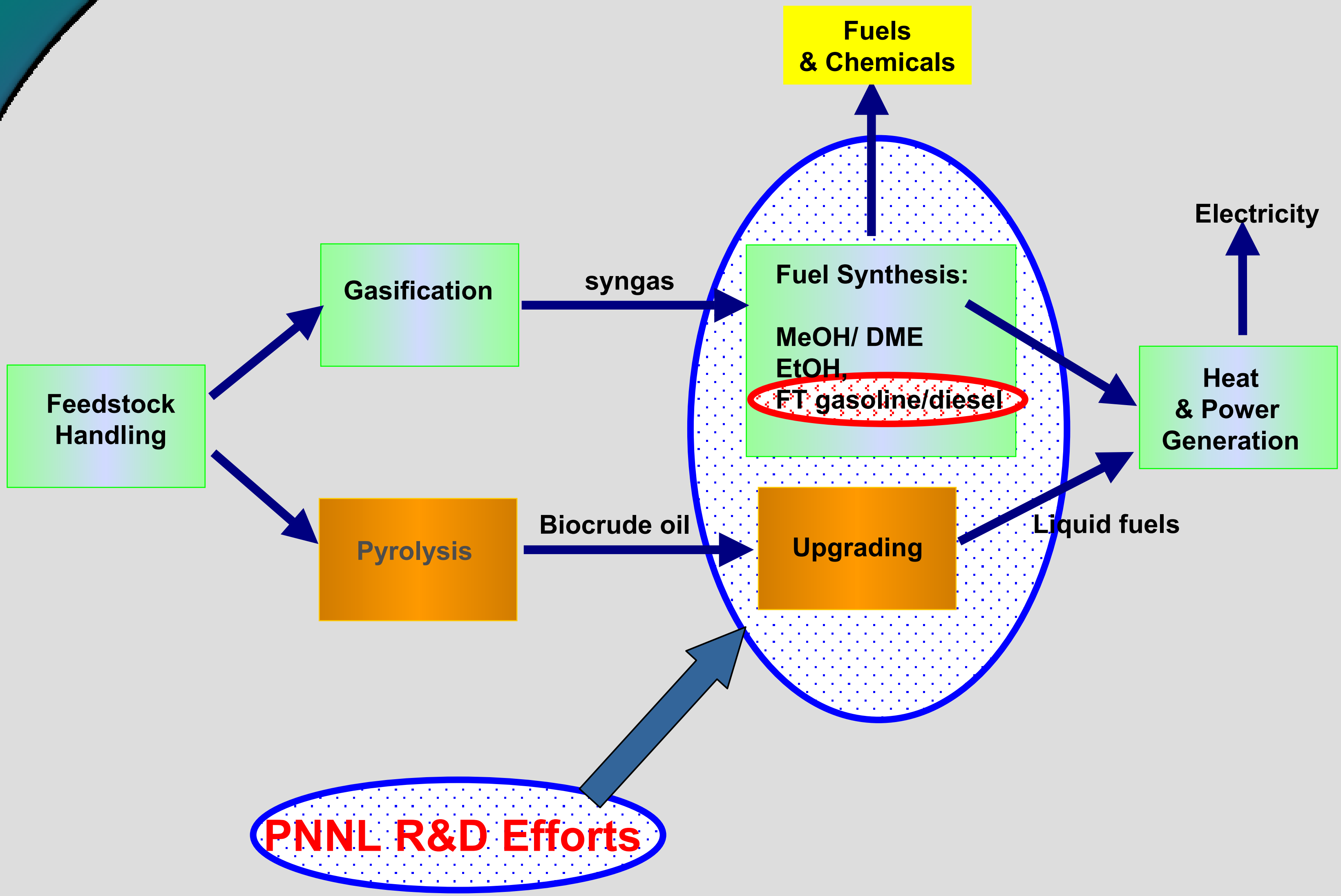
- Biomass derived syngas to fuels
  - Background
  - Challenges
- Conventional GTL technology vs. Microchannel Reactor Technology
- Microchannel reactor-engineered catalysts performance demonstration
- Modeling for catalyst optimization
- Microchannel GTL reactor conceptual design

# Clean Fuels from Biomass

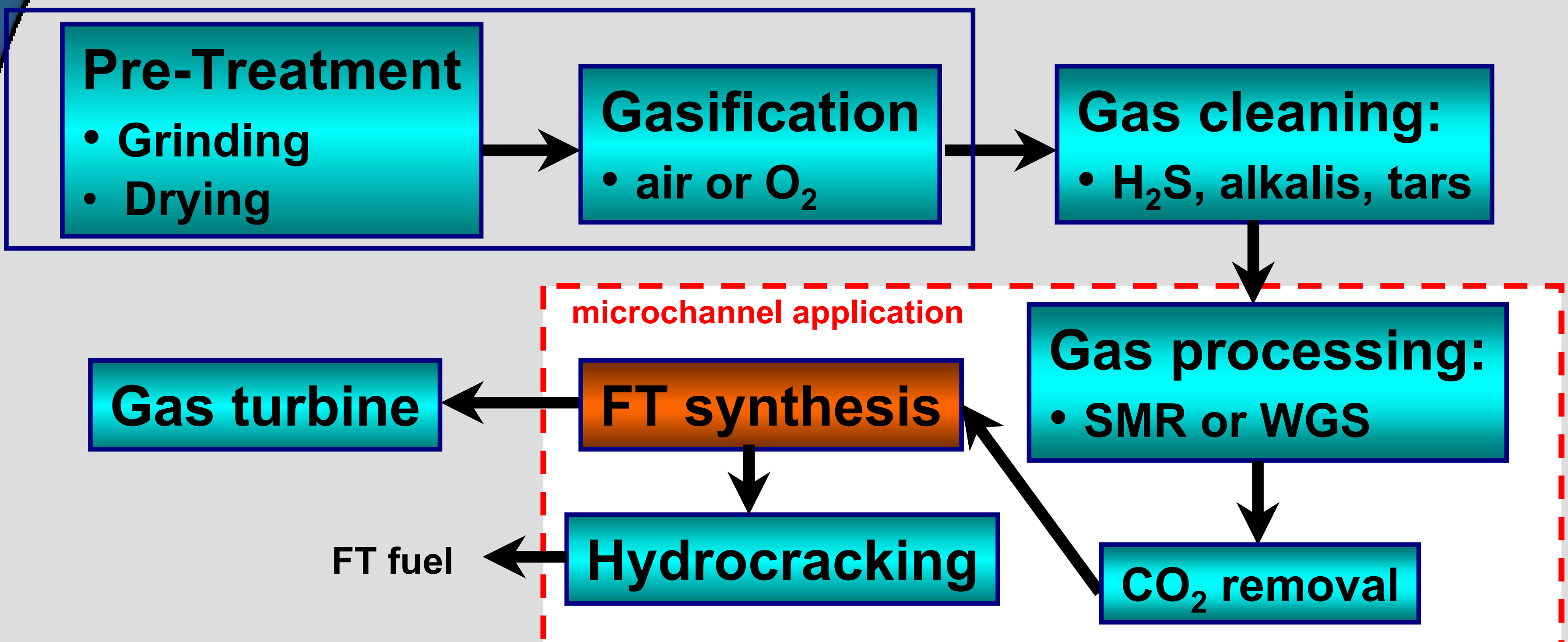
- Compared to the fossil fuels,  Biomass—Renewable energy source when $CO_2$ emissions for its use is absorbed by newly grown biomass.

- Growing interest: Fuels from biomass ---Environmental concerns such as green house gas emission control.

# DOE Biomass SYNGAS Platform



# Fischer-Tropsch Fuels From Biomass



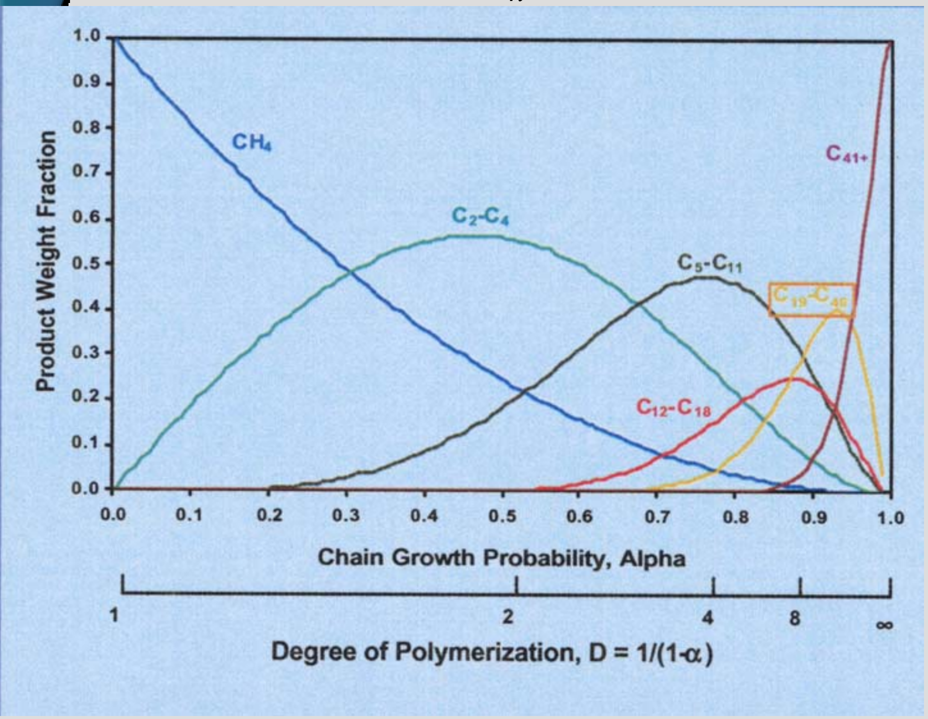
# Fischer-Tropsch Synthesis Reactions

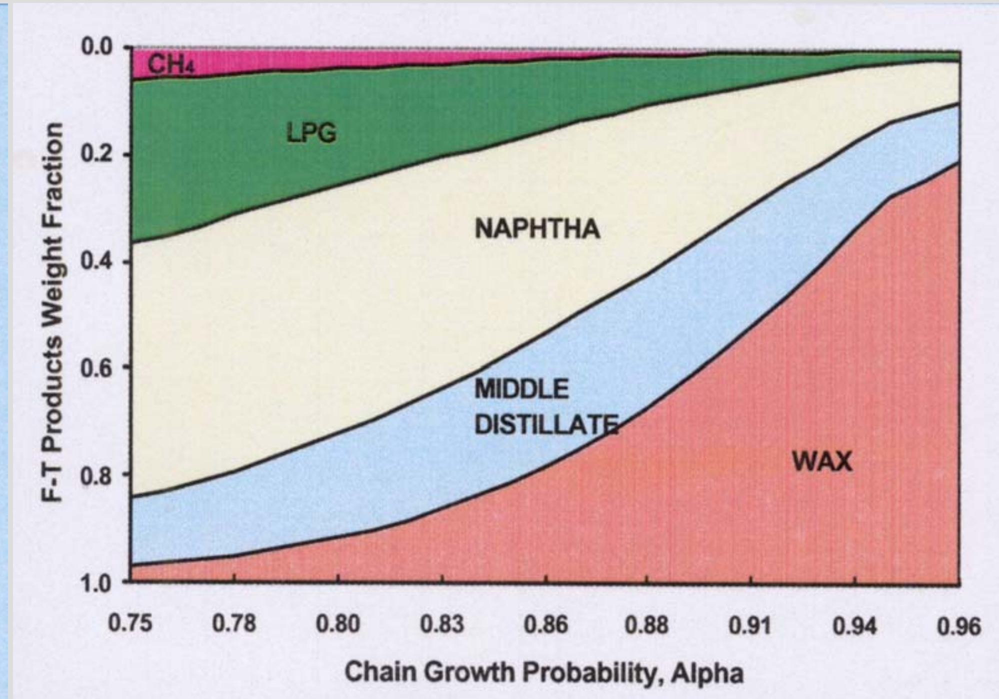
- Paraffins: $(2n+1)\ H_2 + nCO \text{--->} C_nH_{2n+2} + nH_2O$
- Olefins: $2n\ H_2 + nCO \text{--->} C_nH_{2n} + nH_2O$
- Alcohols: $2n\ H_2 + nCO \text{--->} C_nH_{2n+1}OH + (n-1)\ H_2O$
- Water gas shift: $CO + H_2O \text{--->} CO_2 + H_2$
- Boudouard Reaction: $2\ CO \text{--->} C + CO_2$
- Coke formation: $H_2 + CO \text{--->} C + H_2O$

- **Multiphase (G-L-S)**
- **Strongly exothermic ($\Delta H_r$ = -180 kJ/mol)**
- **Mass transfer limited**

# Degree of Polymerization Affects F-T Product Distribution

**ASF distribution:** $W_n = (1-\alpha)^2 n \alpha^{n-1}$



# Challenges of Biomass Syngas to Fuels

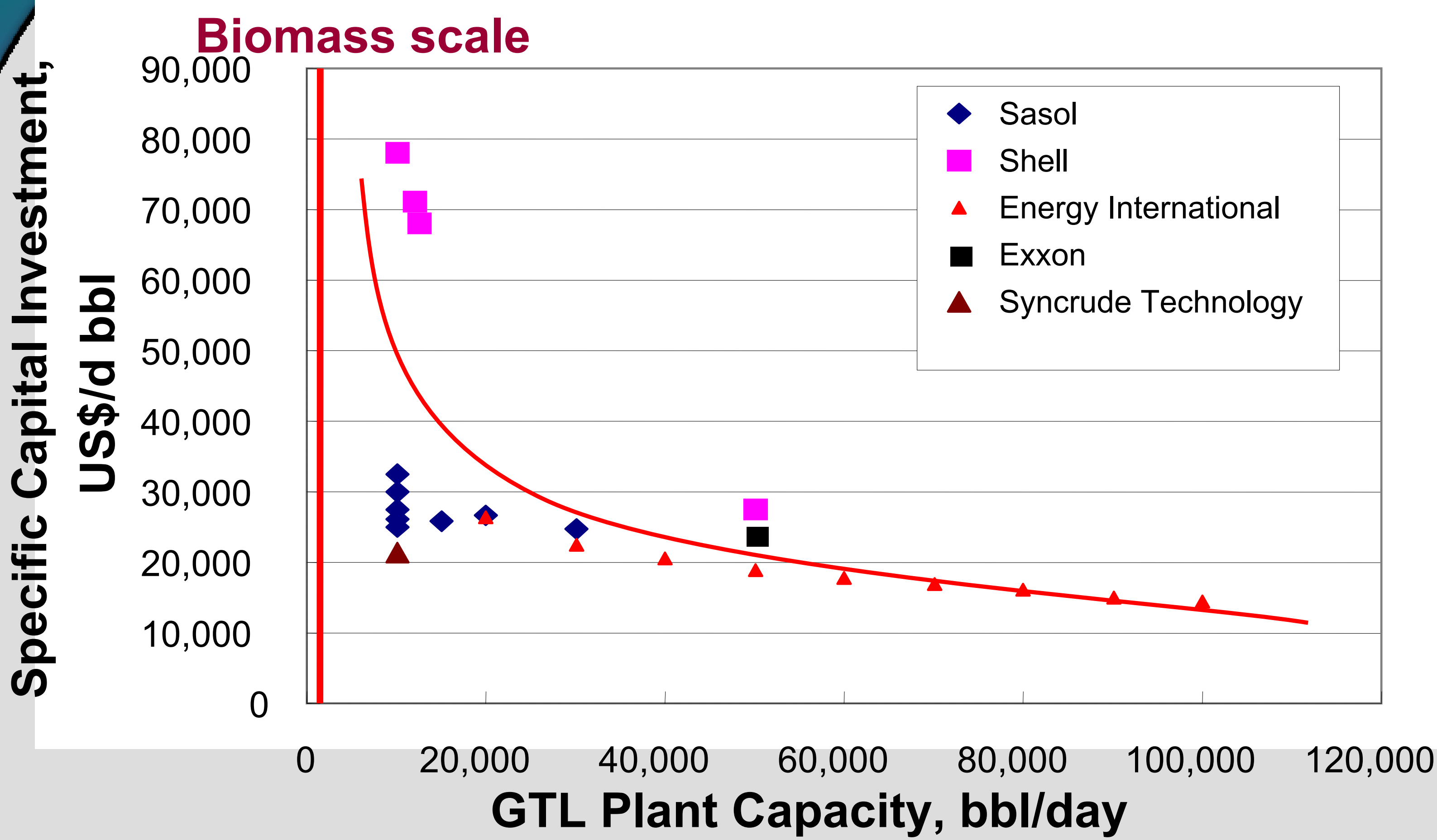
- Stranded feedstock
  - No existing pipelines to move syngas to large central facilities

- Conversion facilities are small in scale: <1000 tons biomass/day
  - Equivalent to <~1100BPD liquid FT fuels
  - Not economic to convert to fuels using conventional technologies

- Costly $CO_2$ clean up
- Low Pressure, ~14bar

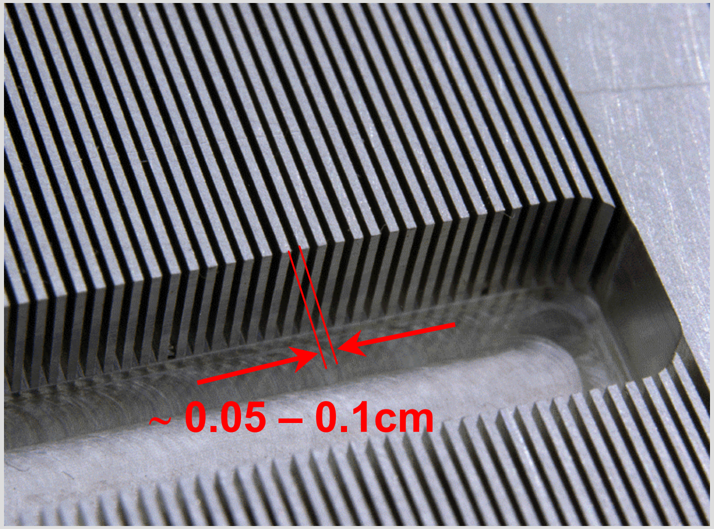
*Microchannel reaction technology provides the potential to cost effectively convert syngas to fuels*

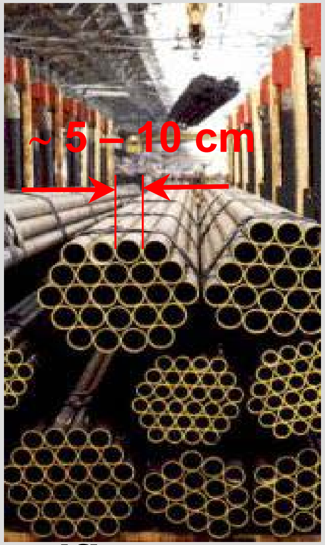
# Conventional GTL Plant Capital Investment




- **Conventional GTL plant is not cost competitive at the capacity typical of biomass feedstocks**

# Characteristics of Microchannel Reactor



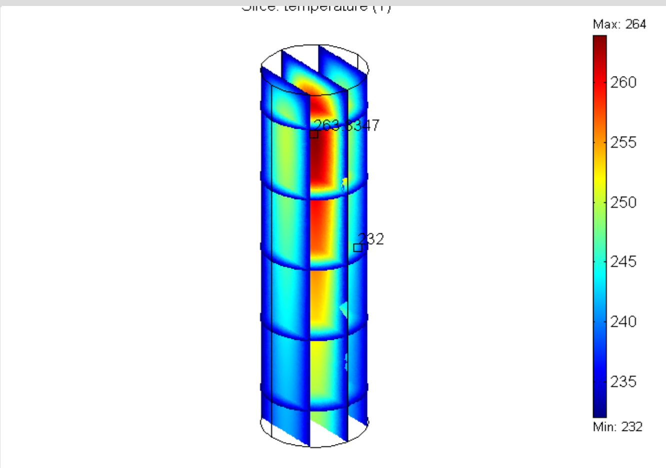

- Heat and mass transfer advantages -- Intensifies syngas-to-fuel process
  - Enhances productivity
  - Improves product selectivity
  - Minimizes catalyst deactivation
- Provides a potential cost-competitive solution at the scale relevant to biomass
- Allows potential integration of unit operations (simplification of gas conditioning with synthesis step

- Achieves advanced performance through
  - Microchannel reactor
  - Engineered catalyst

# Temperature Gradients in FT Reactors

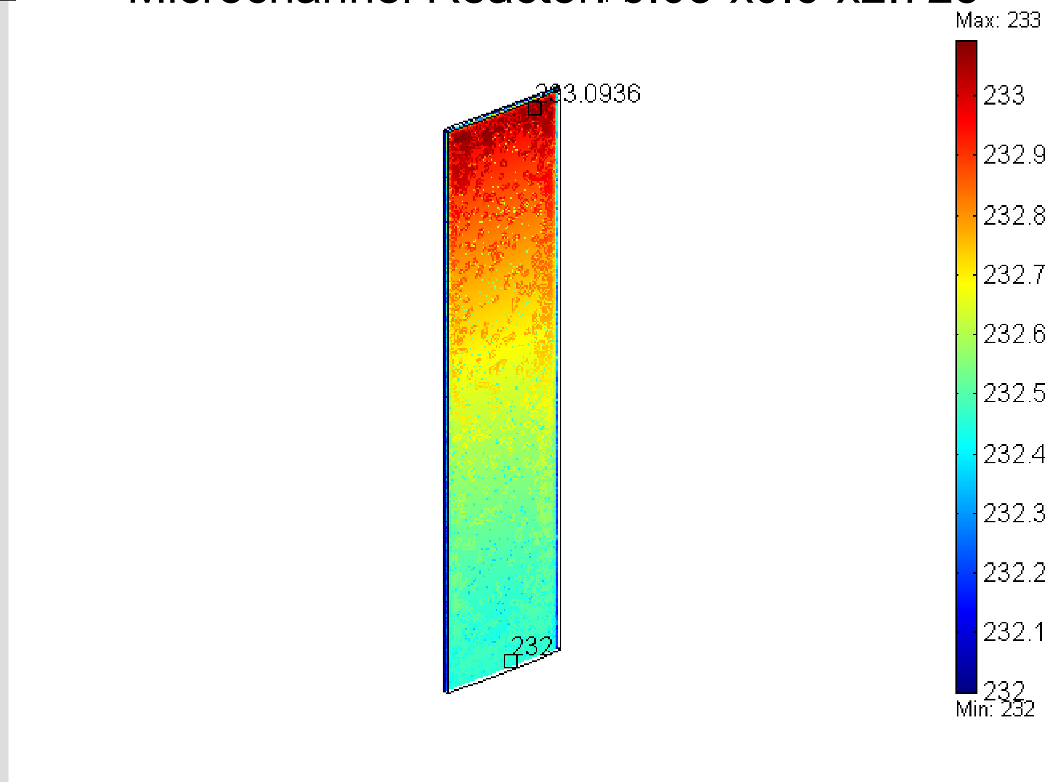
CT=0.3sec, P=20atm,  catalyst vol = 0.8cc

Packed Bed Reactor: 0.25”ID x 1 ” L

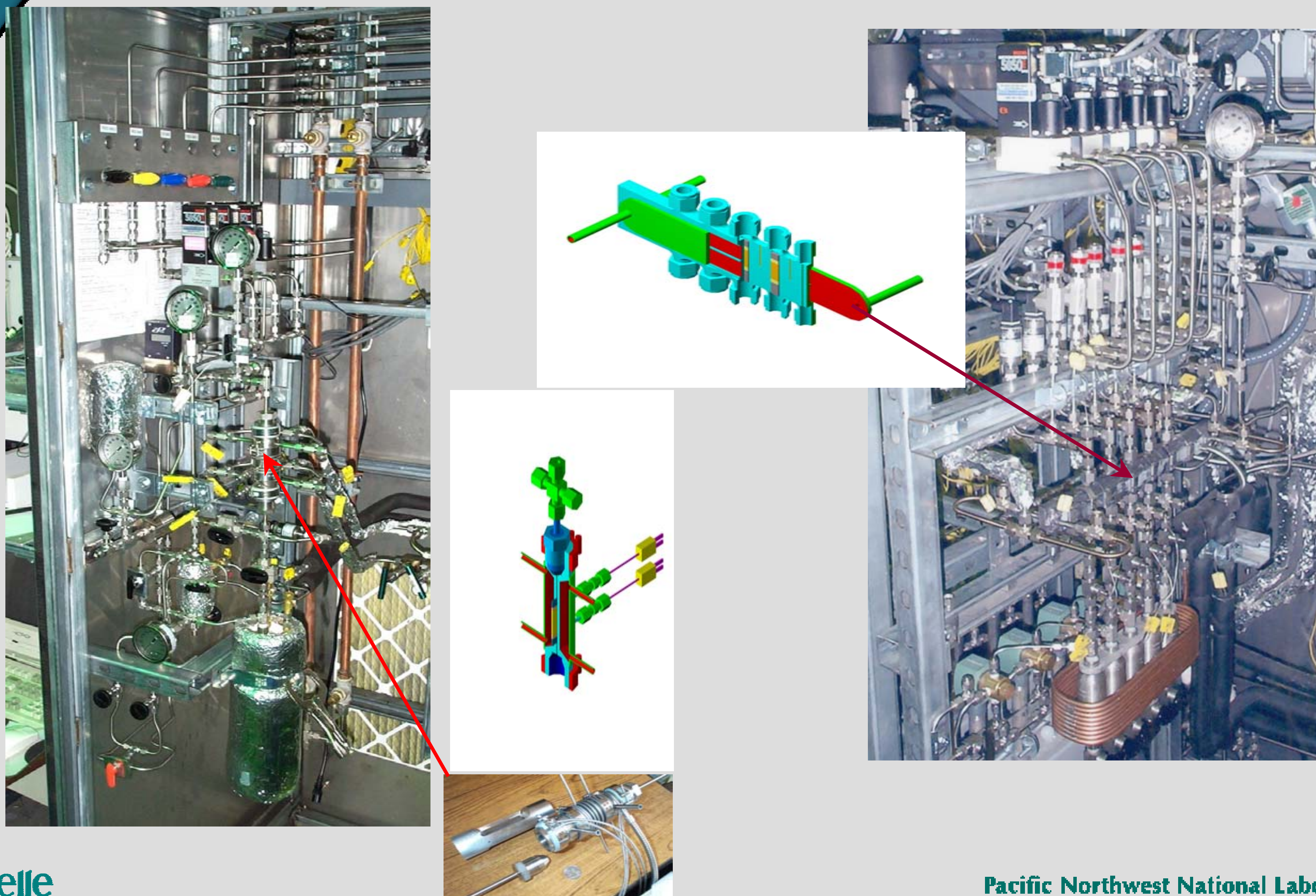



Hot spot: 262 C

Microchannel Reactor: 0.03”x0.6”x2.725”



# Microchannel reactor development @ PNNL

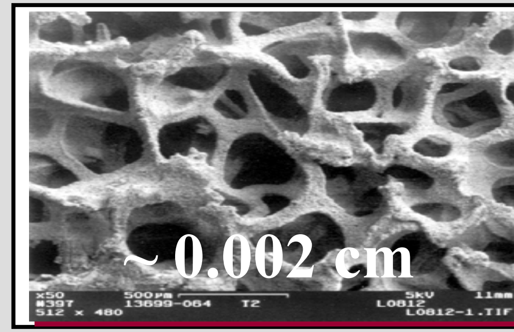


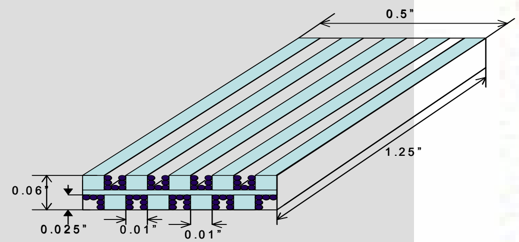
# Engineered Catalysts

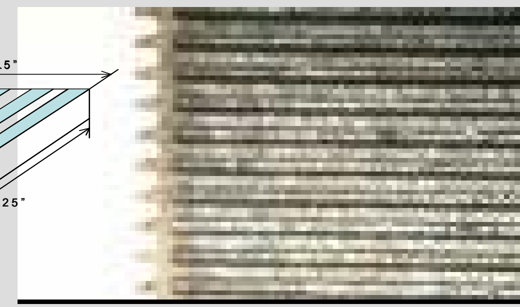
Catalyst tailored for microchannel reactor

**Conventional**


**Microchannel**



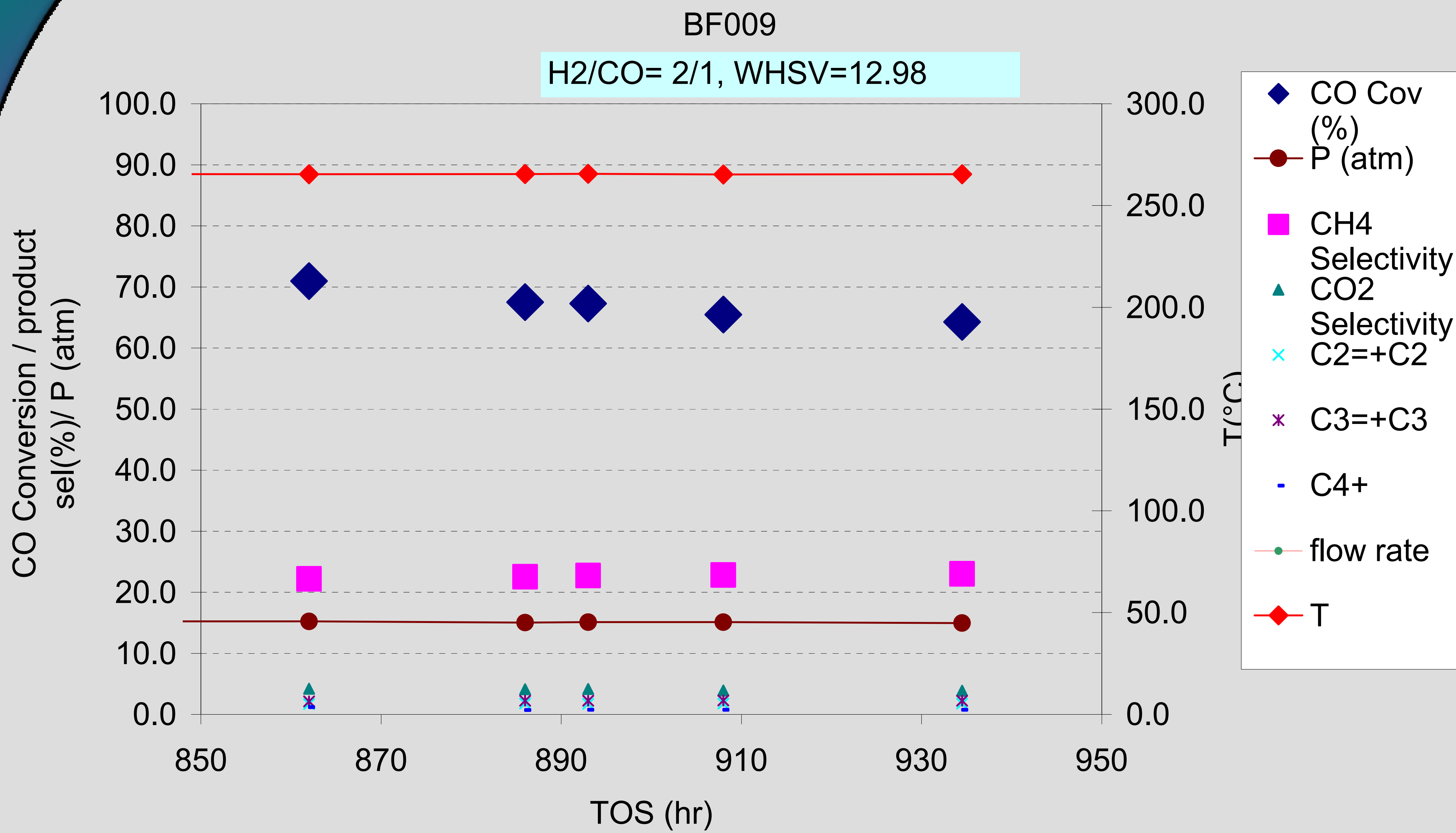



| Support | Porous Ceramic | Porous Metal and Metallic Structured Monolith |
|---|---|---|
| Heat Transport Efficiency | Low | High |
| Mass Transport Efficiency | Low | High |
| Activity | Limited | High |

# Accomplishments to Date

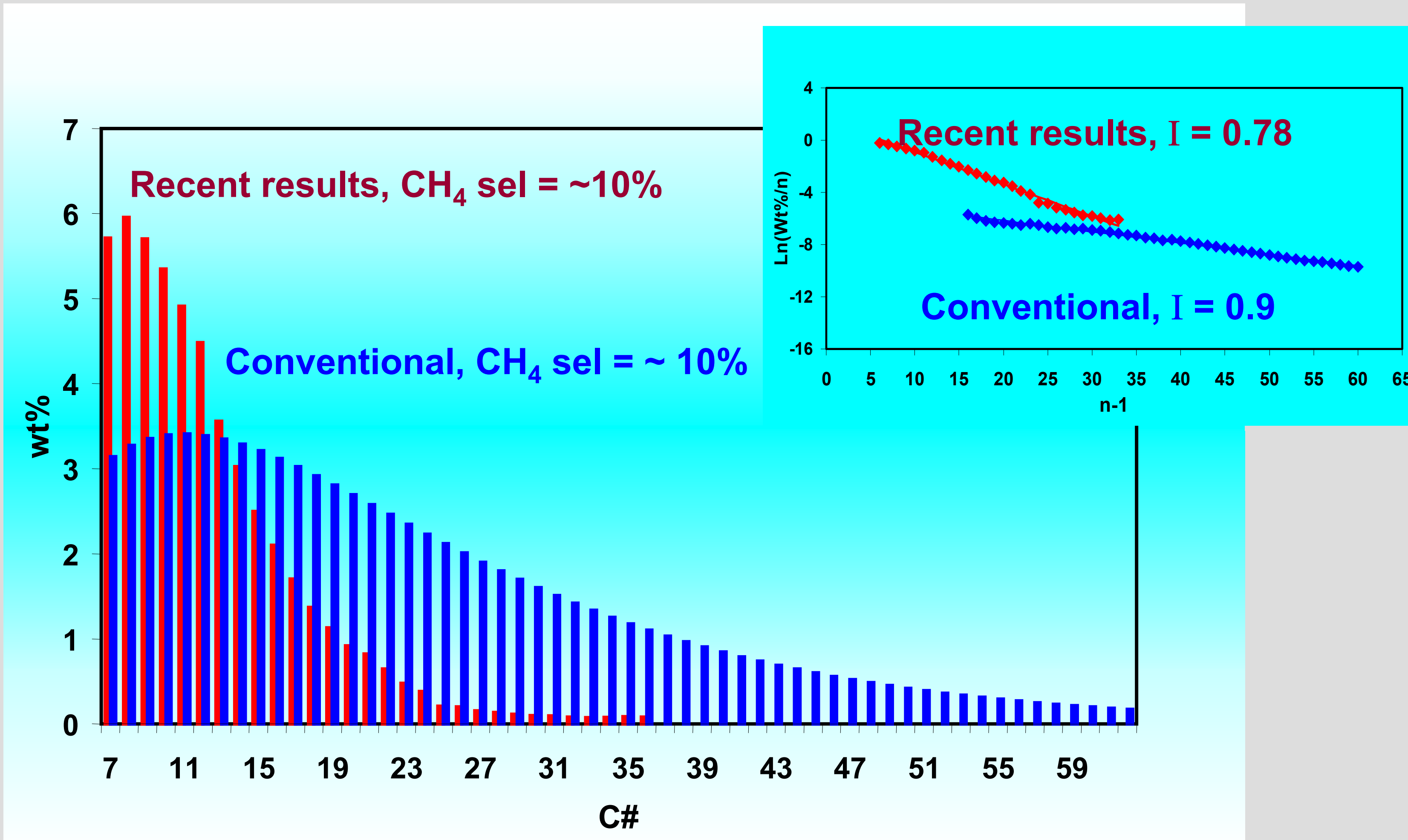
- High throughput: 60 x greater than conventional ($GHSV=60,000hr^{-1}$ at 15 atm, $H_2/CO$ = 1-2.5)
- Demonstrated tailored product distribution in gasoline and diesel slates ---potentially eliminate hydrocracker
- Preliminary results indicate the potential of no costly $CO_2$ separation
- Promising economics – low capital cost

# P=15atm, 60,000 GHSV



# Tailoring of Product Distributions

**$H_2$/CO=2, 250°C, similar WHSV (3.73 gCO/gcat/hr)**

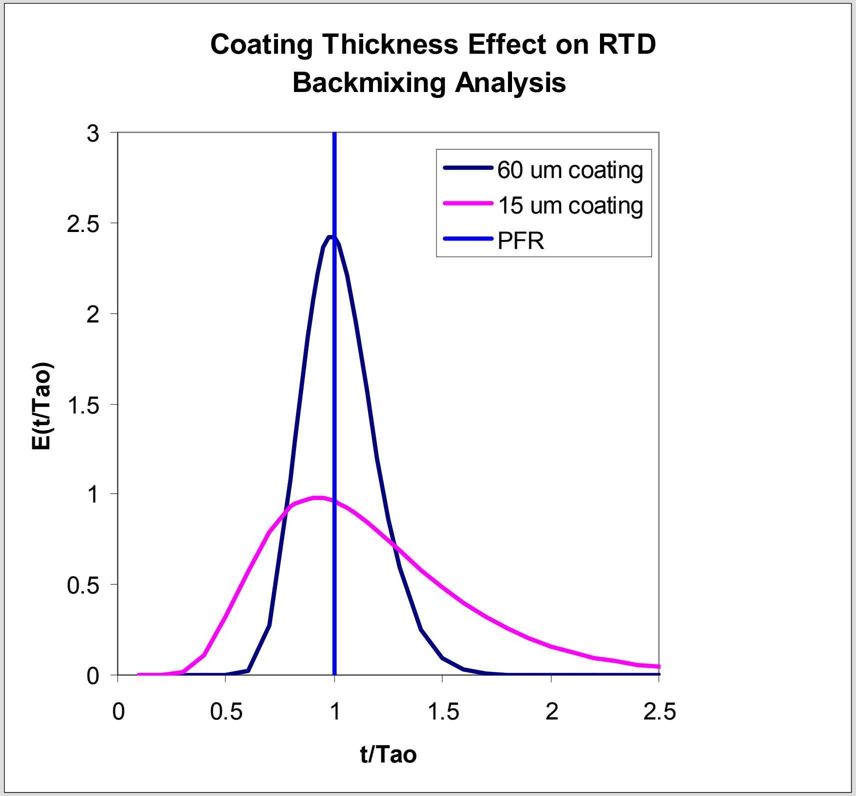



- Narrower product distribution
- Lower $CH_4$ selectivity and alpha

# Catalyst Modeling:
# --Optimizing coating thickness

Axial Dispersion:

$$\frac{\partial c}{\partial \theta} = \frac{1}{Pe}\frac{\partial^2 c}{\partial z^2} - \frac{\partial c}{\partial z}$$



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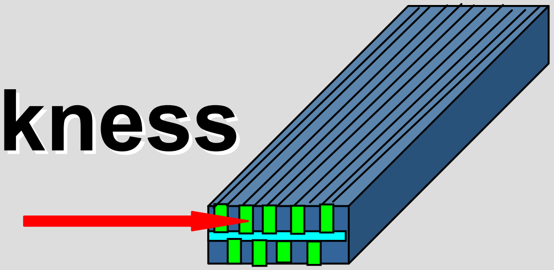
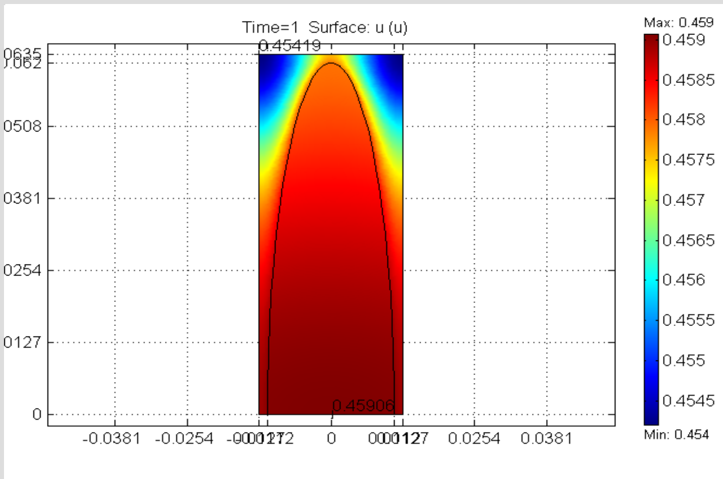
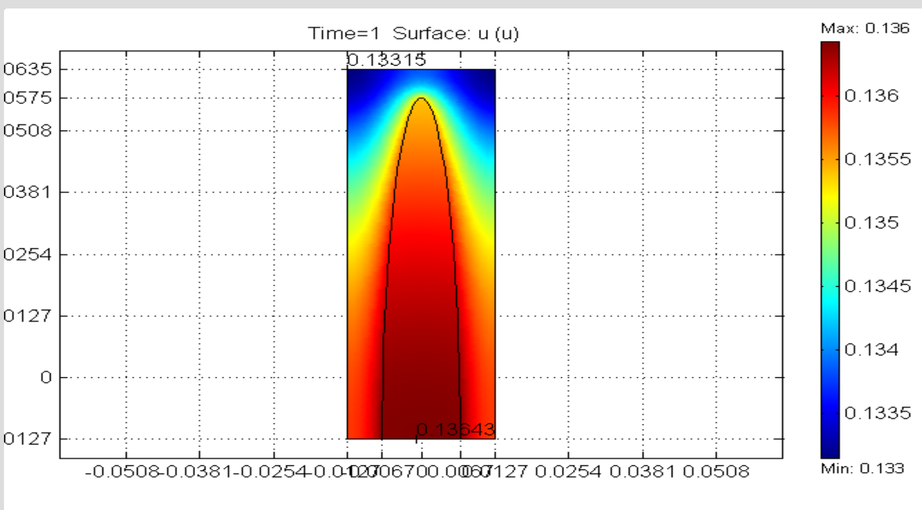




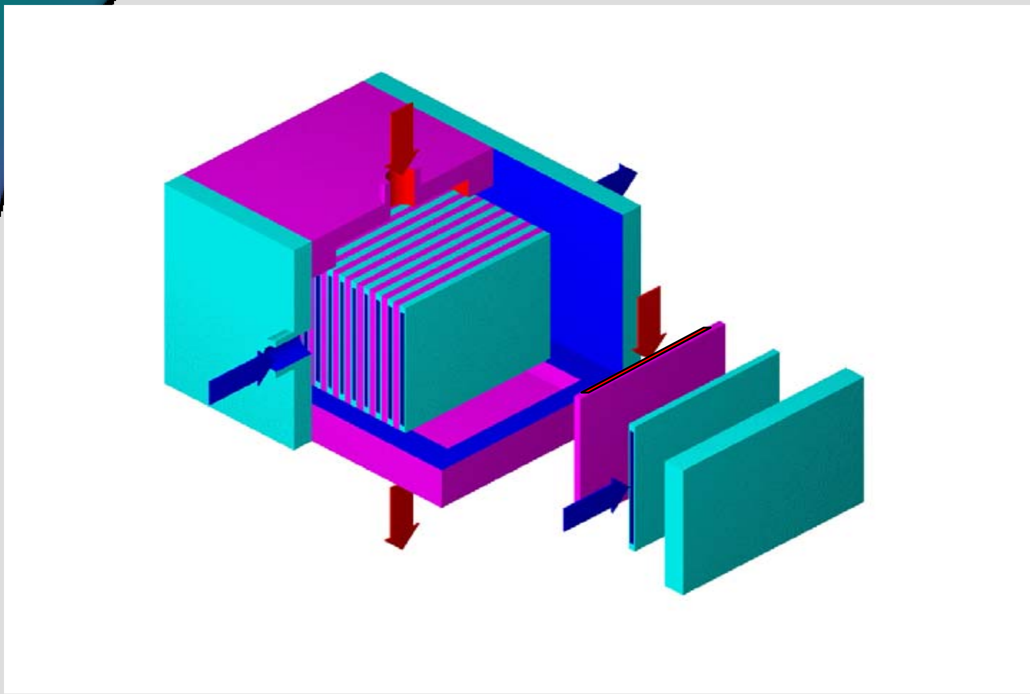

- Gas phase

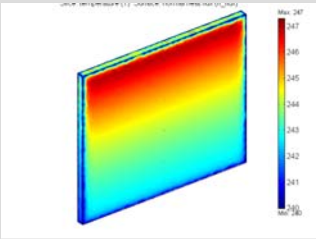
$$u(x, y)\frac{\partial c}{\partial z} = D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right)$$

- Wash coating catalyst phase

$$ke^{-\frac{E}{RT}}c = Deff\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right)$$

# Conceptual Design of Fischer Tropsch Synthesis Reactor for Biomass to Fuel Production





**Throughput: 1000 bbl/day**

- Module Design:
  - Cell dimension: 12”x18”x10”
  - Channel dimension: 12”x0.1”x10”
  - Number of channels: 5057
  - Number of cells: 168 (each cell contains 30 channels)
  - Total footprint: 210 cft
- Hydrodynamics and RTD
  - Pressure Drop: 16 psi
  - Re: 1,072
  - Pe: 27,000
- Max temperature gradient: 7 ºC

# Summary

- Developed a unique structured catalyst system suitable for the deployment in microchannel reactor applications. Provides high throughput GTL technology in converting biomass derived syngas to liquid transportation fuels.
- Experimentally demonstrated tailored product distribution for synfuel production with engineered catalysts integrated with microchannel reactors.
- Modeling approach was used for reactor/catalyst design and optimization.
- Compared to the conventional petroleum/natural gas based GTL technology, biomass-derived feedstock has the nature of small scale, and the use of microchannel reactor technology is potentially cost-competitive.

# Acknowledgements


- This work is sponsored  by the US DOE EE Renewable Energy, Office of the Biomass Program.

- Pacific Northwest National Laboratory is operated by Battelle for the US Department of Energy.