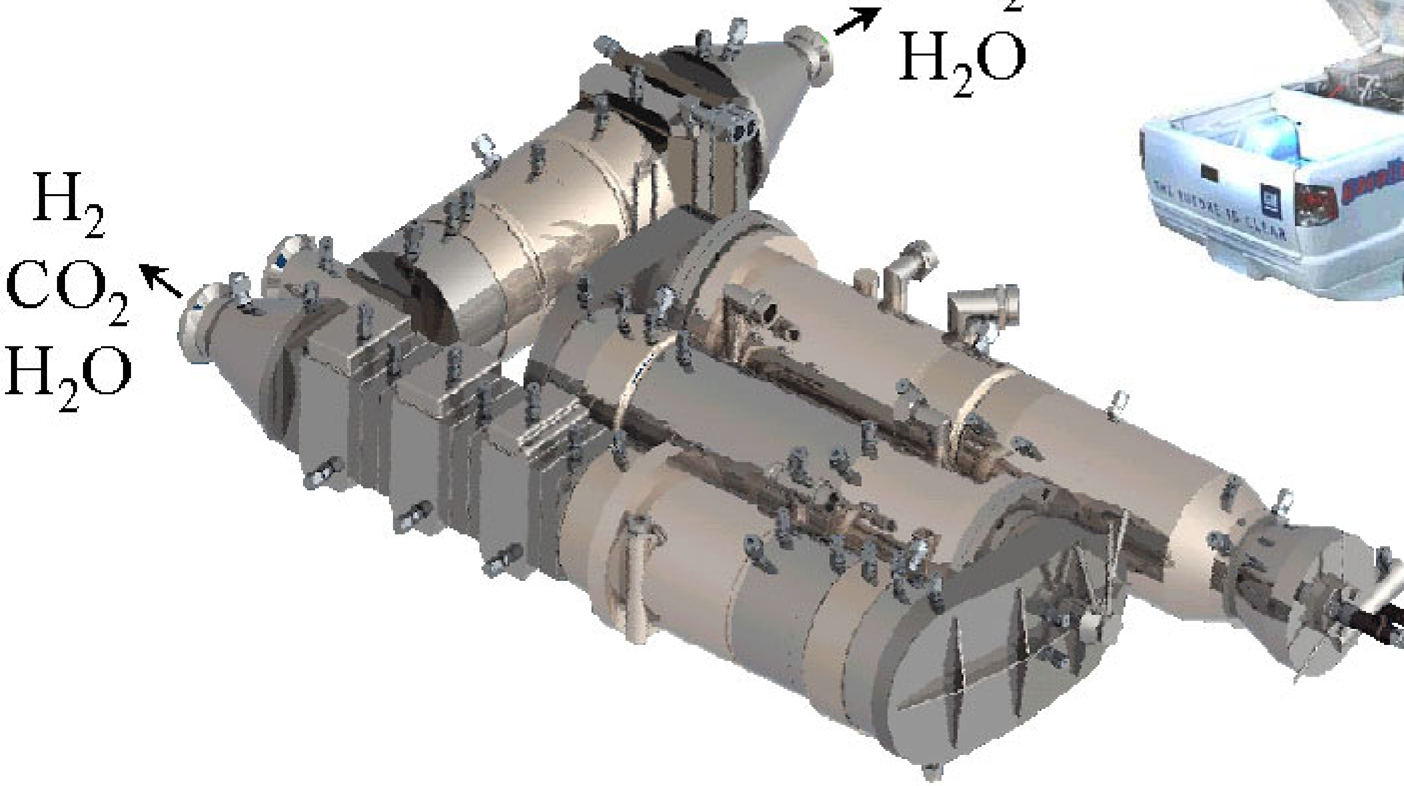
Challenge: Decrease Size and Cost of Fuel Processor



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DoE Fuel Processor Targets

(Excludes fuel storage)

Characteristics	Units	Current Status	Project Goal	Long-Term Goal
Energy efficiency	%	78	78	80
Power density	W/L	300	700	800
Specific power	W/kg	300	700	800
Cost	$/kW	85	25	10
Cold Startup @ -20 °C to Maximum Power	min	10.0	2.0	1.0
Cold Startup @ 20 °C to Maximum Power	min	<5	<1	<0.5
Transient Response (10 to 90 % power)	sec	15	5	1
Emissions		<Tier 2	<Tier 2	<Tier 2
Durability	hours	2000	4000	5000
Survivability	°C	-20	-30	-40
CO content steady state	ppm	10	10	10
CO content transient	ppm	500	100	100
H_2S content in product stream	ppm	<0.3	<0.2	<0.1
NH_3 content in product stream	ppm	<10	<5	<1

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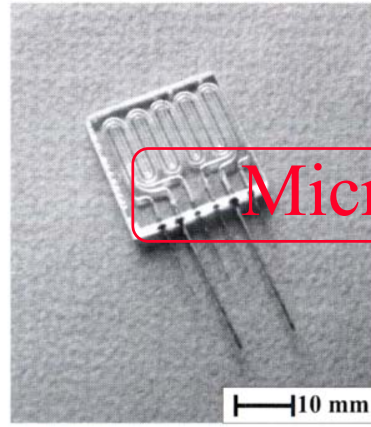
Fuel Processors for PEM Fuel Cells

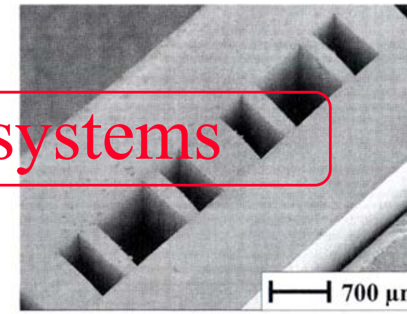
High Performance Materials

+

High Degree of Integration

+





Microsystems

Project Director: Levi Thompson (ltt@umich.edu)

Co-PIs: Gulari, Savage, Schwank & Yang (ChE); Assanis, Im, Ni & Wooldridge (ME); Dahm & Powell (Aero)

Subcontractors: MesoFuel (NM); Ricardo, Inc. (MI); *IMM (Germany)**

Funding: $5,937,184

Project Duration: 4 years (Go/No-Go after 3 years)

* Not yet engaged

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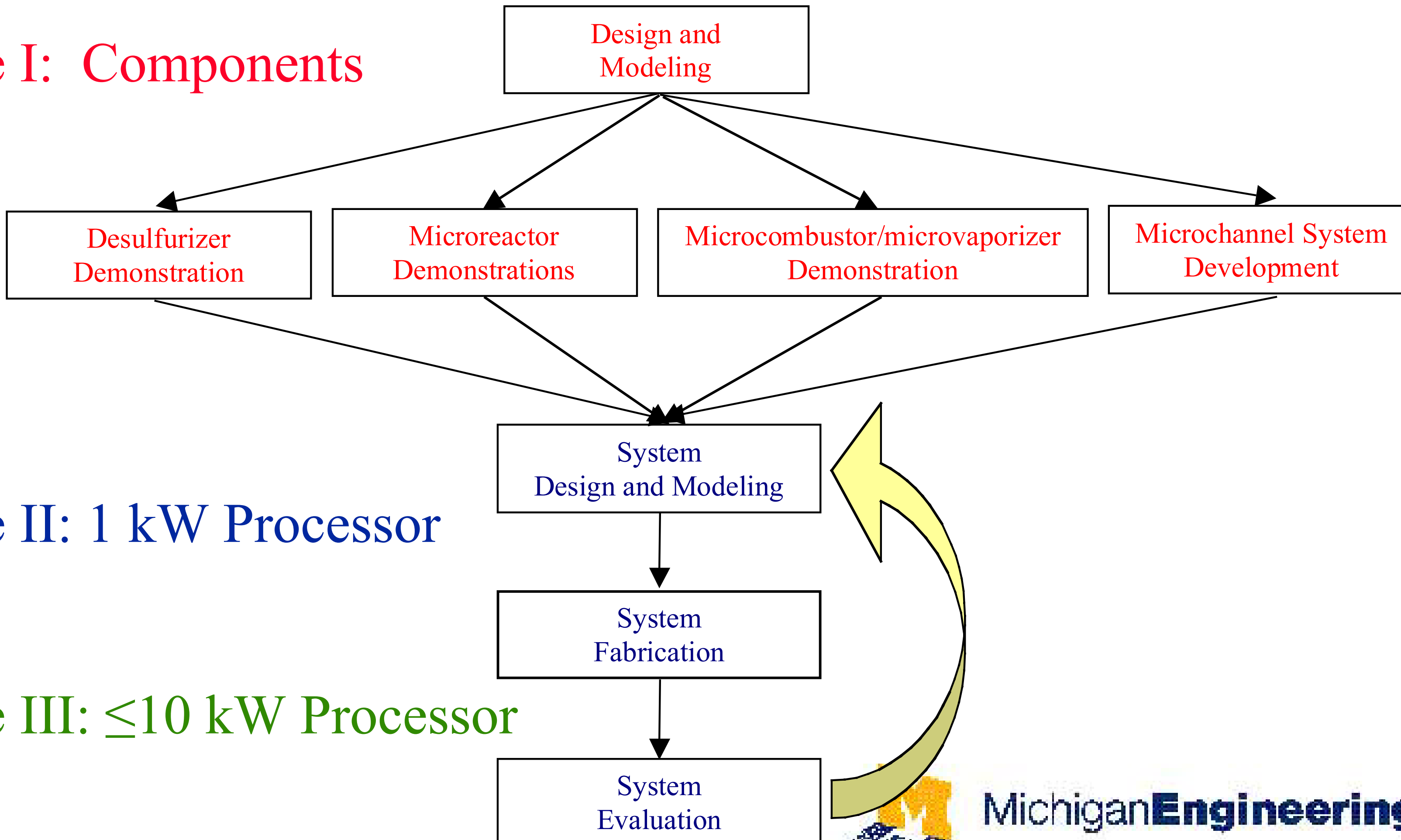
Technical Approach

Phase I: Components

Phase II: 1 kW Processor

Phase III: ≤10 kW Processor



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Major Tasks/Milestones

Task	Quarter															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Component design and modeling																
Sorbent development																
Catalyst development																
Microcombustor/-vaporizer developmt.																
Microchannel system development																
Component evaluations																
1 kW Fuel processor design /modeling																
1 kW Fuel processor fabrication																
1 kW Fuel processor evaluation																
10 kW Fuel processor design /modeling																
10 kW Fuel processor fabrication																
10 kW Fuel processor evaluation																
Cost Analysis																

11/01 $

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Thrust Areas

- Materials
  - Sulfur Adsorbents (Yang)
  - ATR Catalysts (Schwank)
  - WGS Catalysts (Thompson)
  - PrOx Catalysts (Gulari)
- Hardware
  - Micro-Reactors (Gulari, Ni, Thompson)
  - Micro-Combustor/Vaporizer (Dahm)
- Modelling (Savage, Assanis, Im, Powell)

If We Are Successful: 10 kW Fuel Processor

Component Weights (kg)	Current	Reduction Goal	Proposed Prototype	Comment
Fuel pump	0.45	50%	0.23	capillary action in microcombustor
Desulfurizer	2.42	35%	1.57	higher capacity liquid sorbents
Water tank	3.63	50%	1.81	better integration
Water pump	0.91	50%	0.45	capillary action in microcombustor
Fuel/water preheater	2.56	90%	0.26	microcombustor/microvaporizer
Reformer heat	4.40	90%	0.44	better thermal integration
Reformer	2.90	67%	0.96	better catalysts/microreactors
Shift reactors	11.88	67%	3.96	better catalysts/microreactors
Intercooler	2.27	90%	0.23	better thermal integration
Air compressor	0.60	0%	0.60	
Preferential oxidizer	3.30	67%	1.10	better catalysts/microreactors
Fuel cell air cooler	2.27	90%	0.23	better thermal integration
Fuel cell exhaust drier	0.23	50%	0.11	
Burner	3.40	50%	1.70	microcombustor/microvaporizer
Thermal insulation	0.91	50%	0.45	better thermal integration
Valves	0.28	0%	0.28	
Starter Battery	0.22	0%	0.22	
Instrumentation/controls	2.27	50%	1.13	novel strategies/sensors
Sub-total	44.9		15.74	
Component integration		10%	-1.57	
Total	44.9		14.17	Specific energy of 704 W/kg

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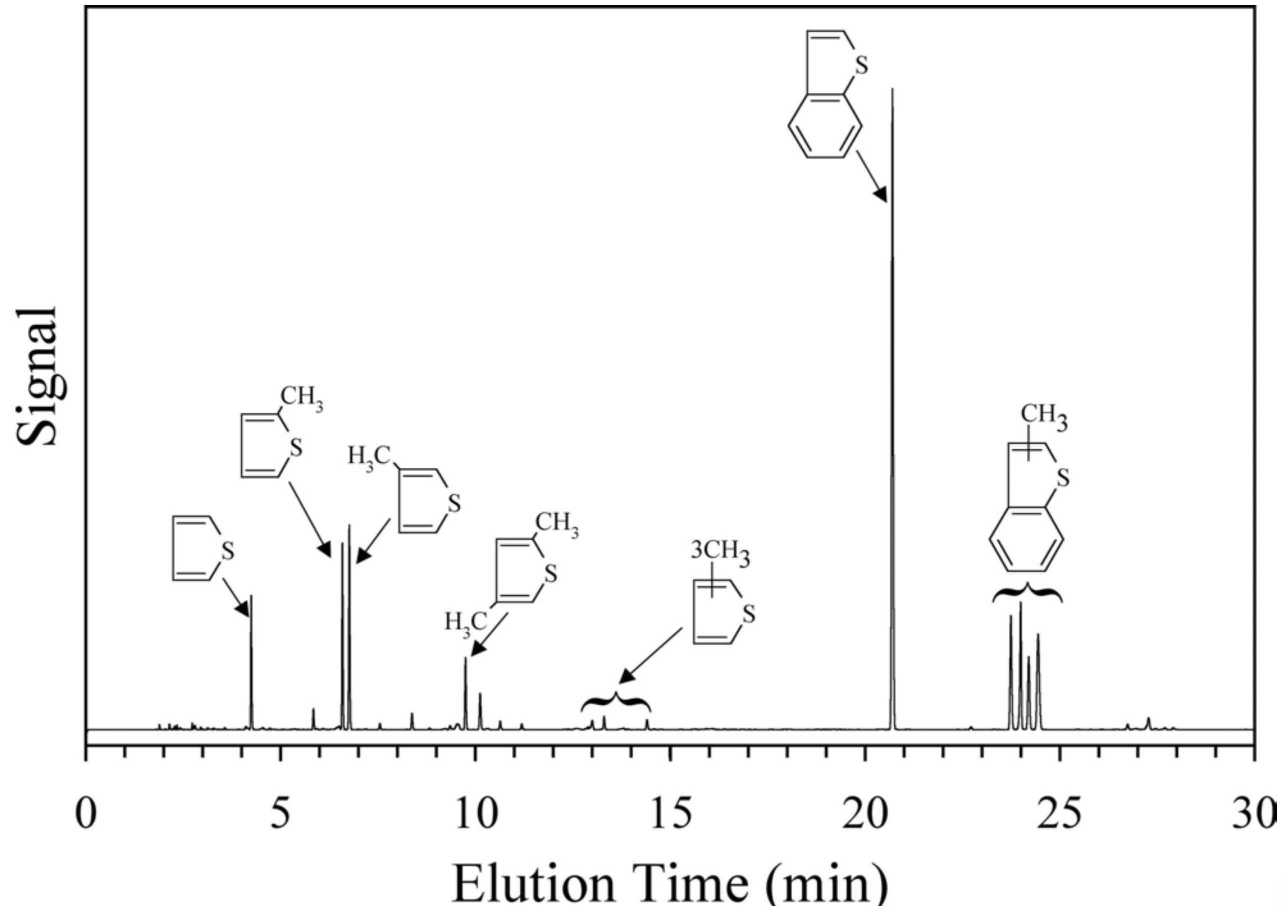
GC-FPD of Regular Gasoline



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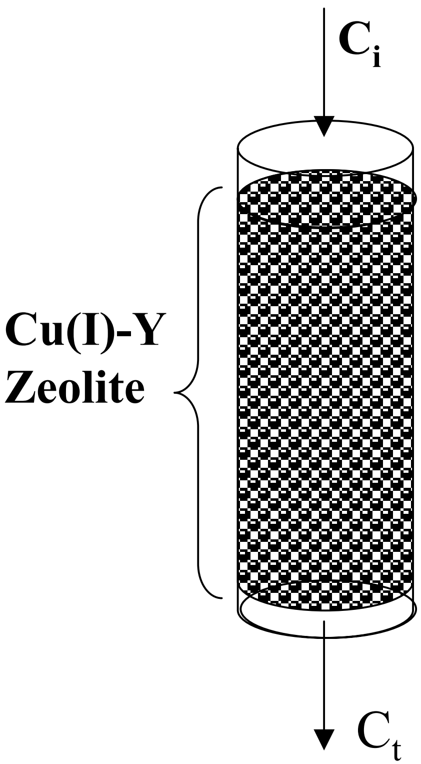
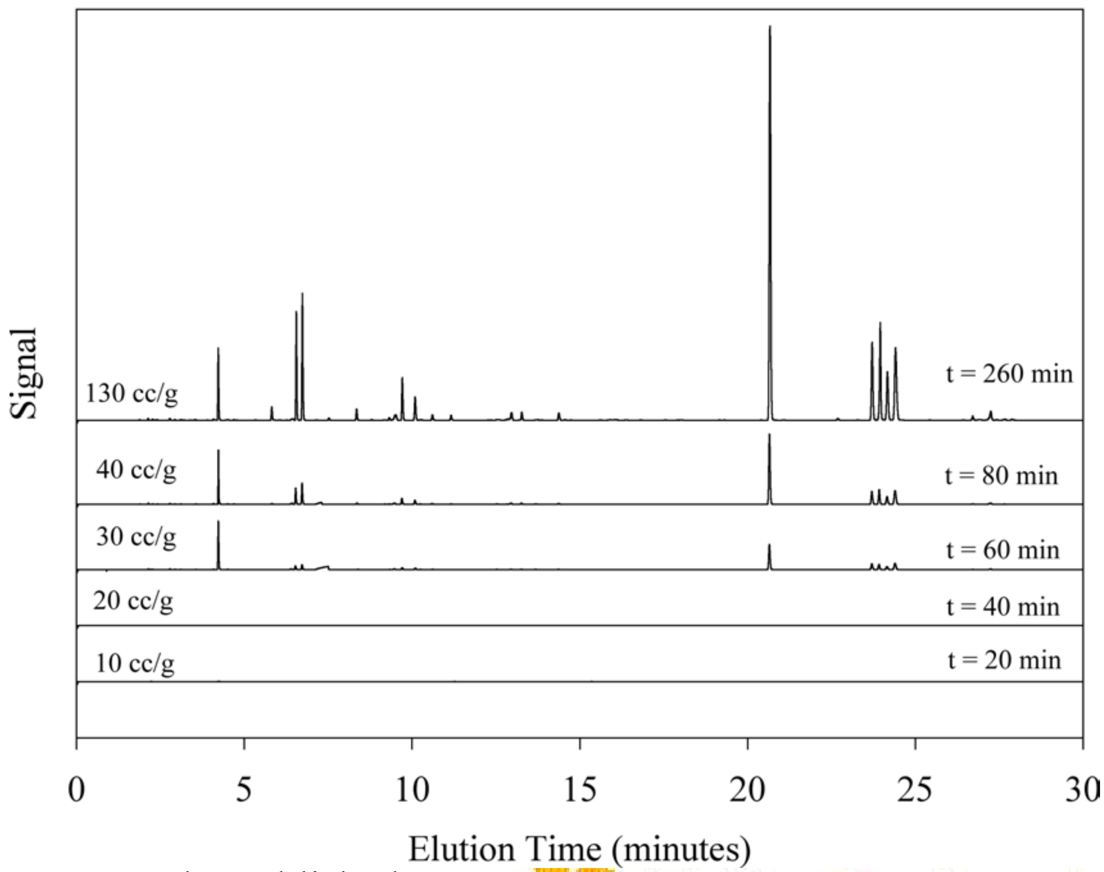
Desulfurization of Gasoline and Diesel by Adsorption



GC-FPD for Desulfurization of Gasoline with AC/Cu(I)-Y



A. J. Hernandez-Maldonado and R. T. Yang, to be published.
Yang et al., U.S. and foreign patents applied.

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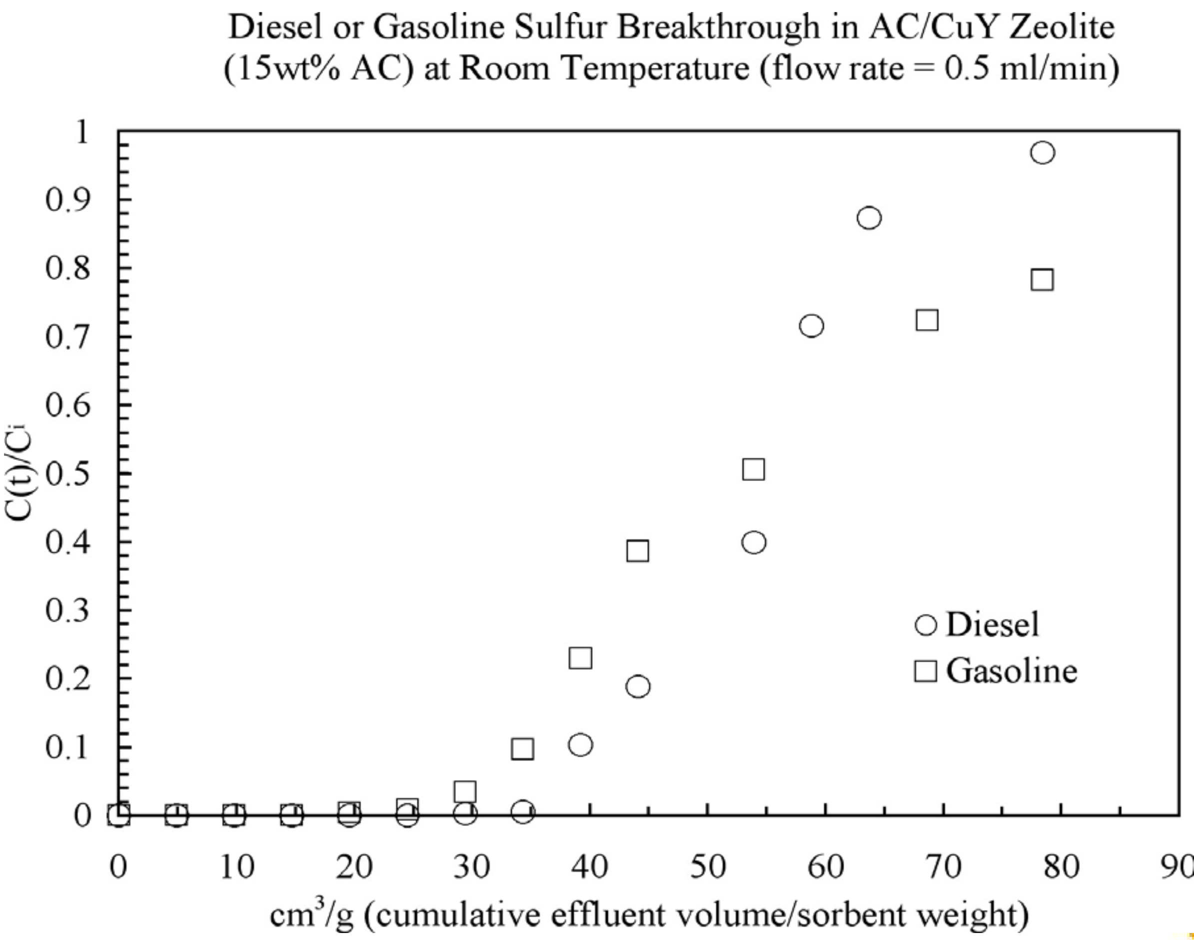
Desulfurization of Gasoline and Diesel by Adsorption



- 5 kg sorbent produces 170 L sulfur-free diesel, or 2,500 mile driving range (assumes 60 miles/gal)
- Order of magnitude better than others (Ma et al., *Catalysis Today*, **77**, 107 (2002))

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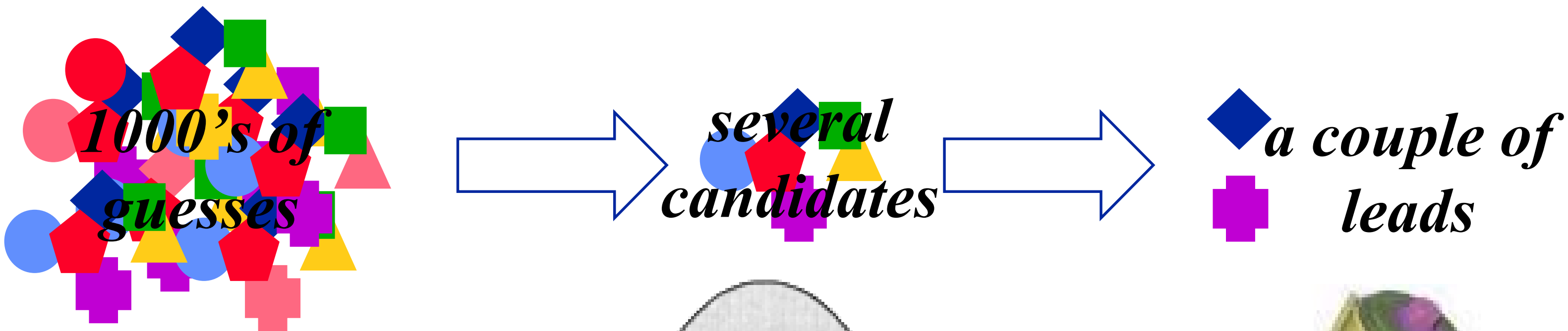
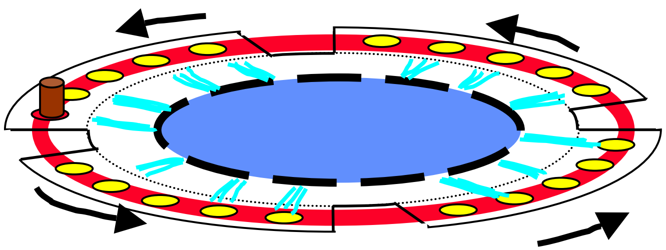
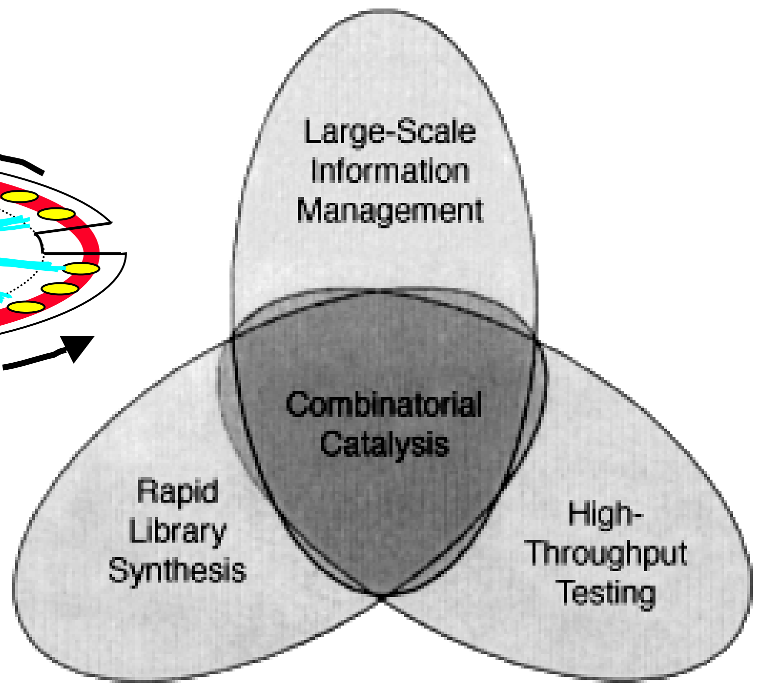
Combinatorial Catalysis







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Novel ATR Catalyst Formulations

- Ni-Ce/Zr mixed oxide
  - Prepared by sol-gel technique (urea hydrolysis) and impregnation
    - Effect of varying Ce:Zr molar ratios (optimum: $Ce_{0.75}Zr_{0.25}$)
    - Ni loading (5-15%)
- Ni/β"-alumina (material with high Na^+ ion mobility)
  - Prepared by conventional impregnation and flame spray pyrolysis
- Ni/yttria stabilized zirconia, Ni/CeO_2 , Ni/TiO_2
- Supported Pt and Pt-Ni

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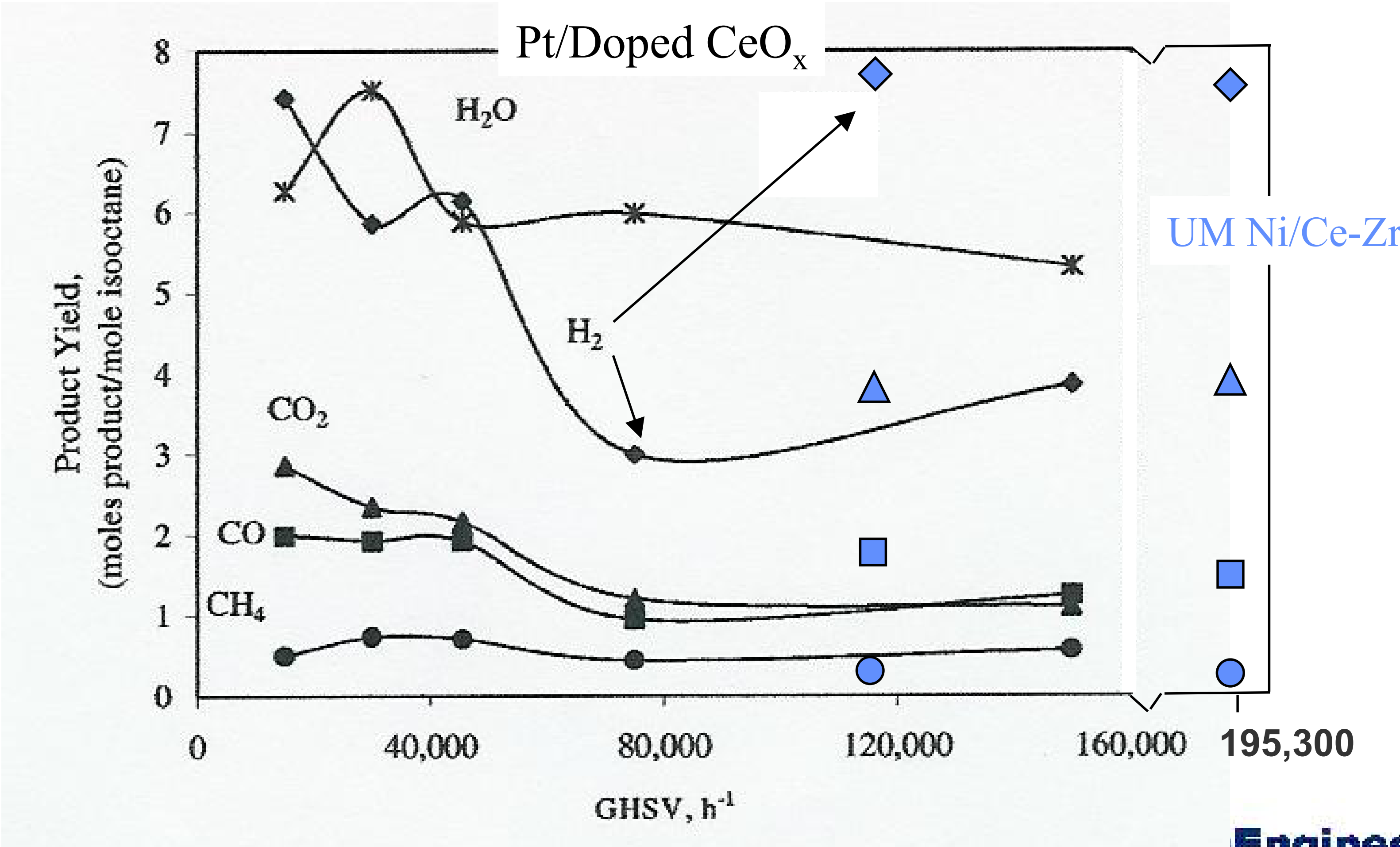
ATR of Isooctane

M. Krumpelt et al. , Catal. Today 77 (2002) 3-16



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Novel Water Gas Shift Catalysts

Au/Ag/Ru on Reducible Oxides

- Au/MO_x highly active — Stephanopoulus et al., 2001
- Questions about stability — Löffler et al., 2002

Early Transition Metal Carbides

- Catalytic properties similar to Pt-group — Levy and Boudart, 1973; Oyama, 1992
- Highly active for WGS — Thompson et al., 2000
- Tolerant to sulfur — Manoli et al., 2001

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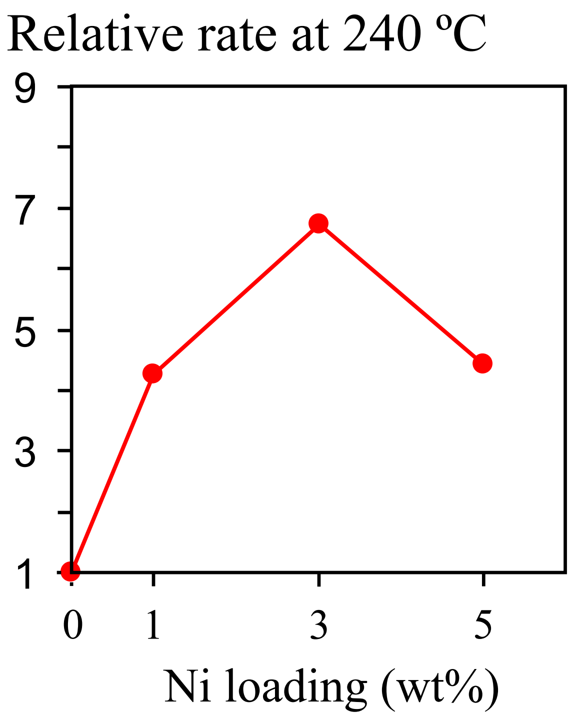
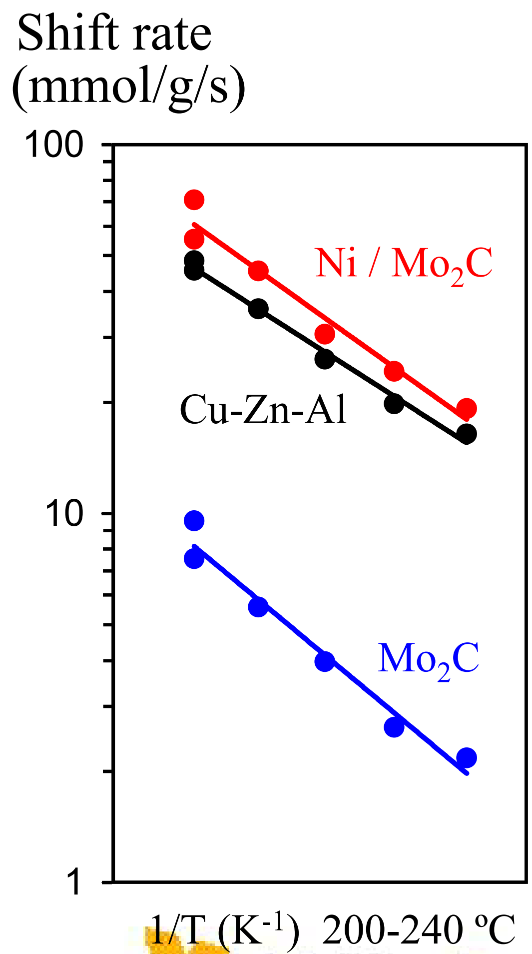
Mo_2C Supported Ni

- Effect of metal loading:





- No methanation

DoE Targets: Water Gas Shift Catalysts

Characteristics	Target	Cu-Zn-Al†	UM Catal.
GHSV (hr^{-1})	30,000	30,800	>78,000
Conversion (%)*	>90	76	89
H_2 Selectivity (%)	>99	>99	>99
Volume (L/kW_e)	<0.1		
Weight (kg/kW_e)	<0.1		
Durability (Hrs.)	5000		
Cost ($\$/kW_e$)	<1		

* 38 % H_2, 16% N_2, 10% CO, 6% CO_2 and 30% H_2O: T=240 °C: X_{eq}=96.5%
† Tested at the UM.

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Comparison of PrOx Catalysts

Catalyst	3%Au/Fe_2O_3	0.5%Pt/Al_2O_3	2%Pt/Al_2O_3	5%Pt/Al_2O_3-Fe_2O_3 (Engelhard)
SV (hr^{-1})	60,000	60,000	60,000	120,000
Conversion No H_2O, No CO_2	100% @ 50 °C		80% @175 °C	90% @90°C (1000 ppm CO, 10% H_2O, 20% H_2)
Selectivity	55-65%	45-55%	45-55%	~50-65%
Conversion 10% H_2O, 25% CO_2	92% @ 50 °C	100% @150 °C (CO < 5 ppm)	100% @130-160 °C (CO < 5 ppm)	~70%@100°C (North Carolina 30,000 hr^{-1})

Space velocity in units of L/hr•$kg_{catalyst}$

40-50% H_2, 20-25% CO_2, 10% H_2O, 1%CO, 1%O_2 and He

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Micro-Systems

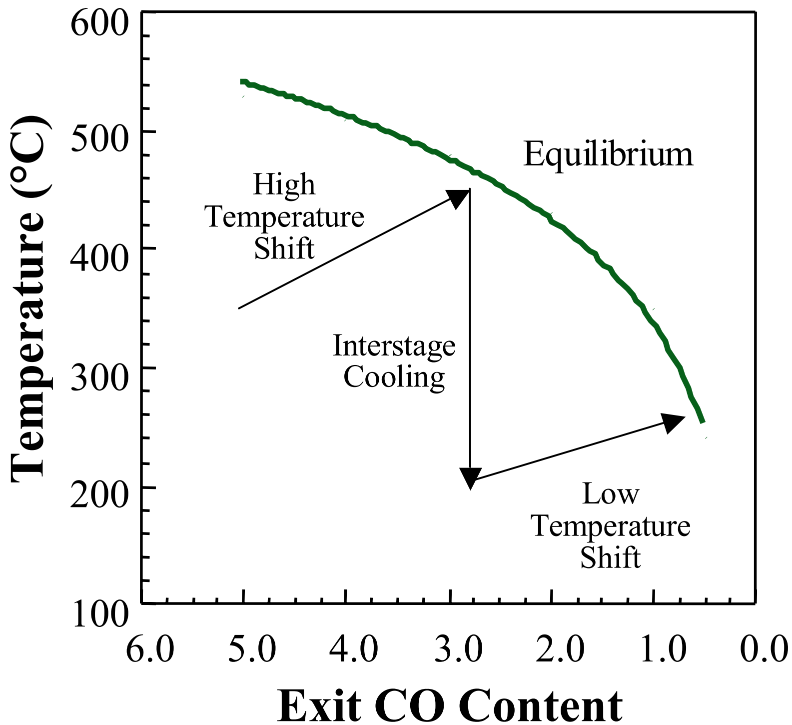
Reactors:

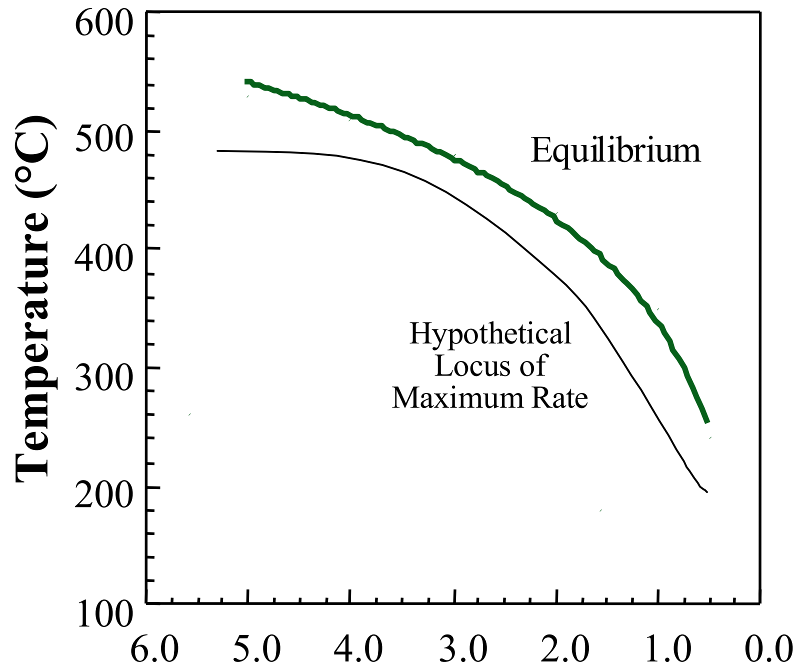
- Silicon Microfabrication
- Micromachined Metals
- Low Temperature Co-Fired Ceramics (LTCC)

Microcombustors/vaporizers

Micro-Systems

(1) Active cooling





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Micro-Systems

(1) Active cooling
(2) Reduced heat and mass transport resistances
(3) More efficient thermal coupling
(4) Better cold start and transient responses

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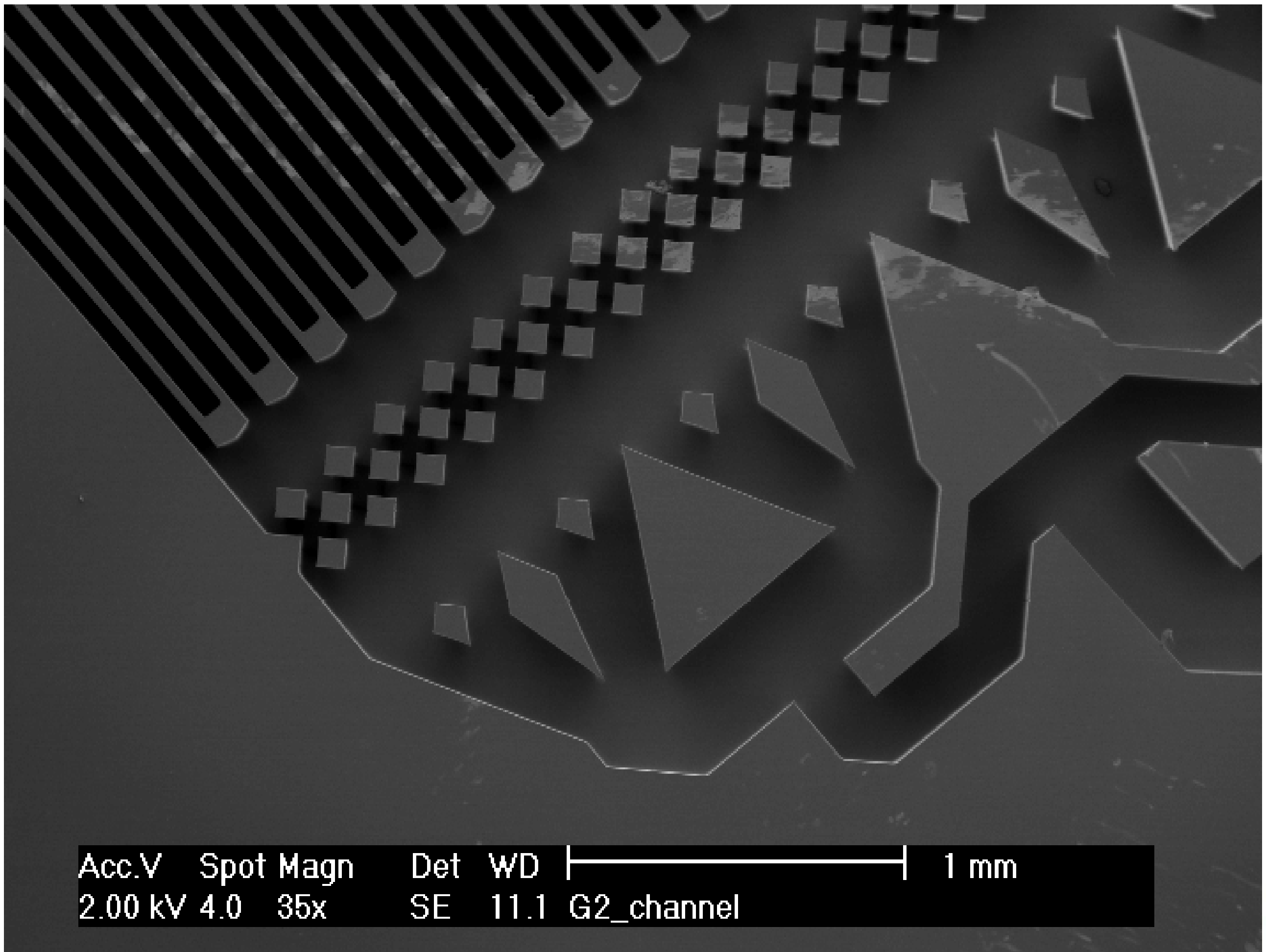
Silicon Microchannel Reactors

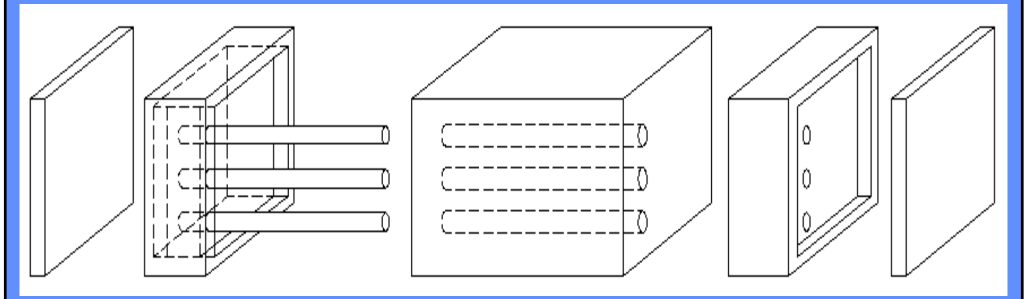


Micro-reactor showing flow distribution manifold

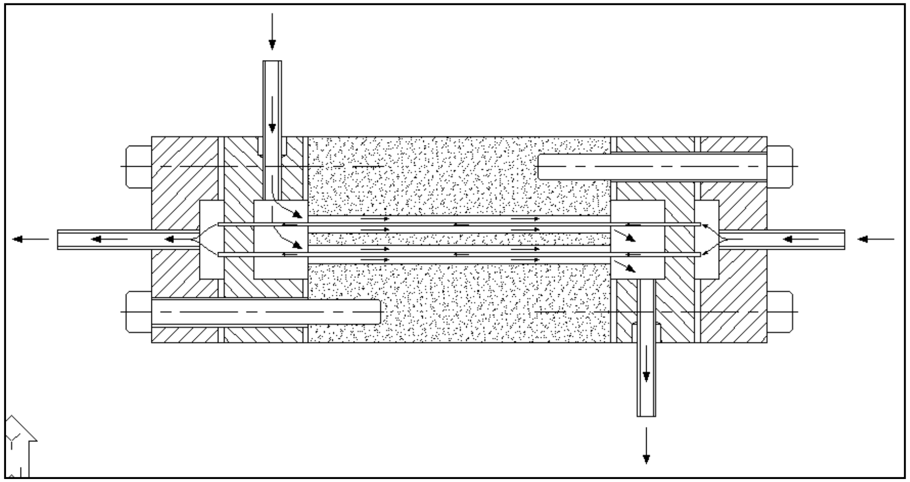
Very low pressure drop but catalyst loading was very low

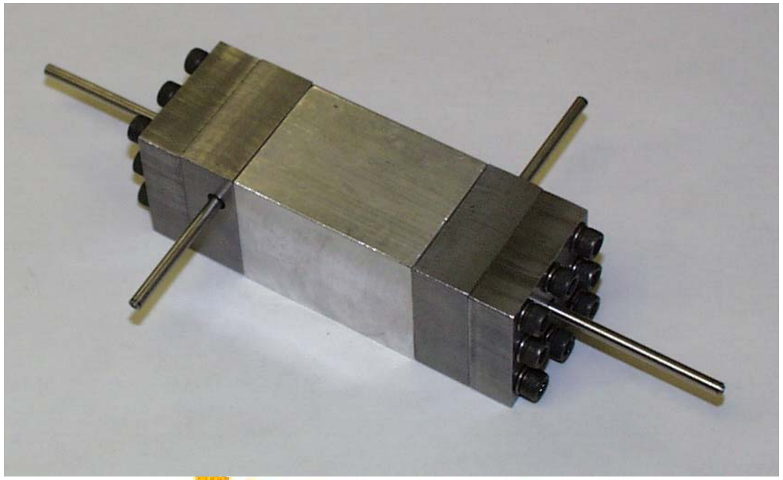
Microtube Prototype Design

- Initial prototype used available microtube technology
- Concentric channels to enhance heat exchange



Prototype Assembly





Difficult to integrate catalysts

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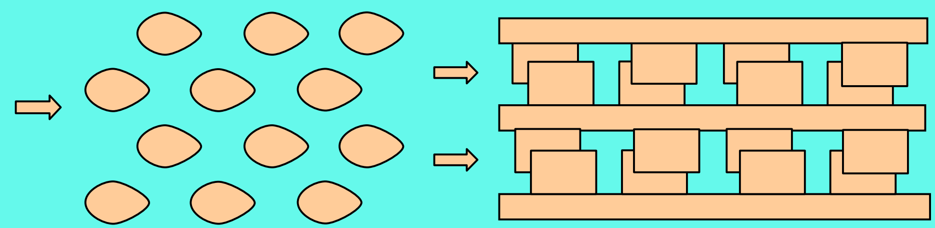
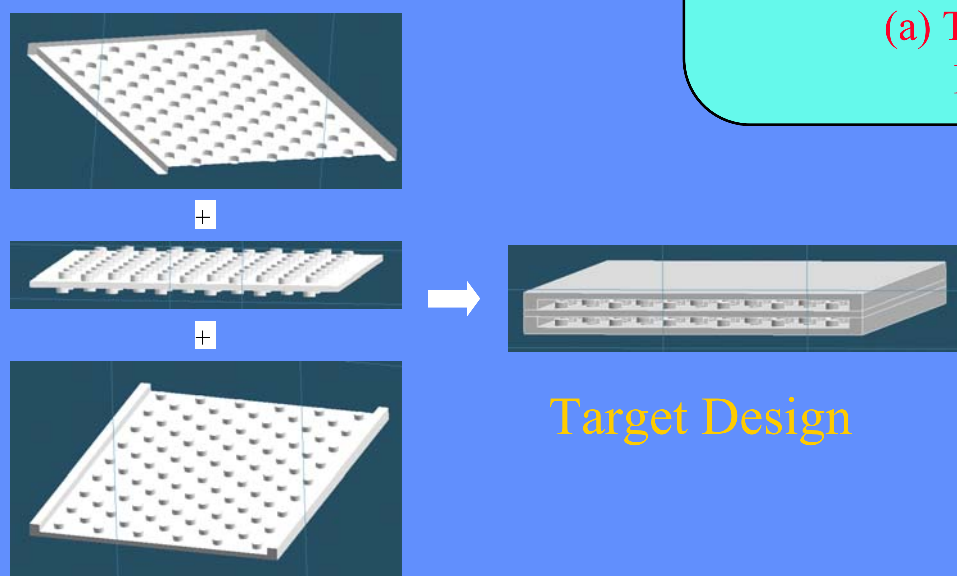
Target Design

The design goal is to achieve large surface area to volume ratio with minimum pressure drop.



(a) Top view (b) Side view

Illustration of design concept



Target Design

Dimensions:

- Size: 35x25x7 mm
- Pin: ϕ1 x 1 mm

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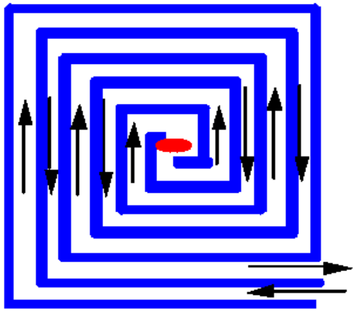
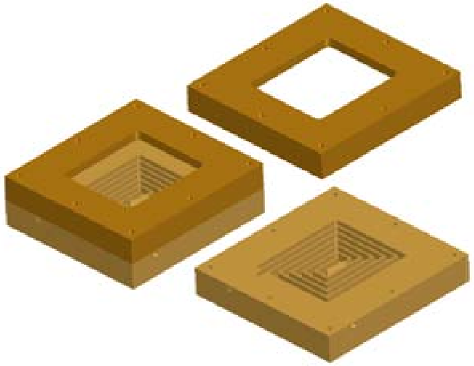
Combustor Approaches

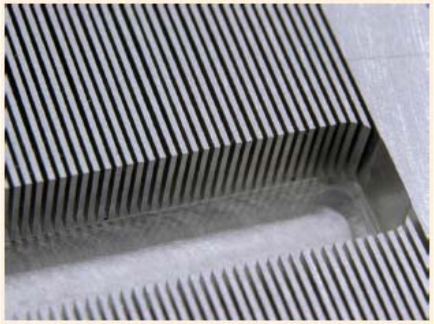
- Swiss roll, highly recuperative self-stabilizing "excess enthalpy combustors"

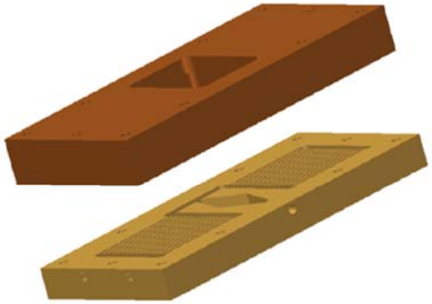


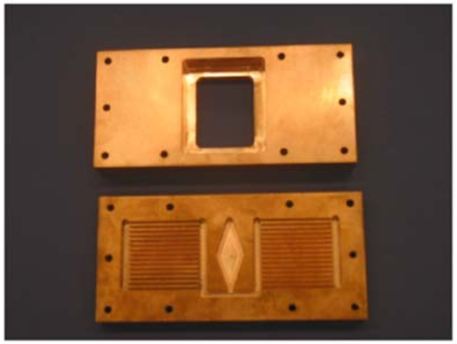
Swiss Roll Concept



- Microchannel combustors



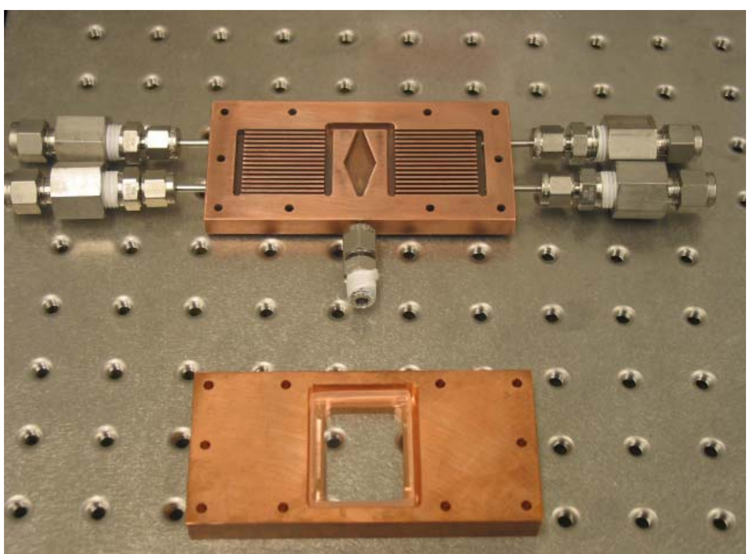




Combustor Test Hardware

- F-Burner scaled for i-octane vaporization on tailgas combustion
- W-Burner scaled for water vaporization on iso-octane vapor combustion
- Scaling model allows for design, initial sizing and optimization

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.



- Well-defined chamber designed for high turndown; “micro” channels provide heat extraction to surface-mated vaporizer
- Channel size set by heat transfer, oxidation, and mass considerations

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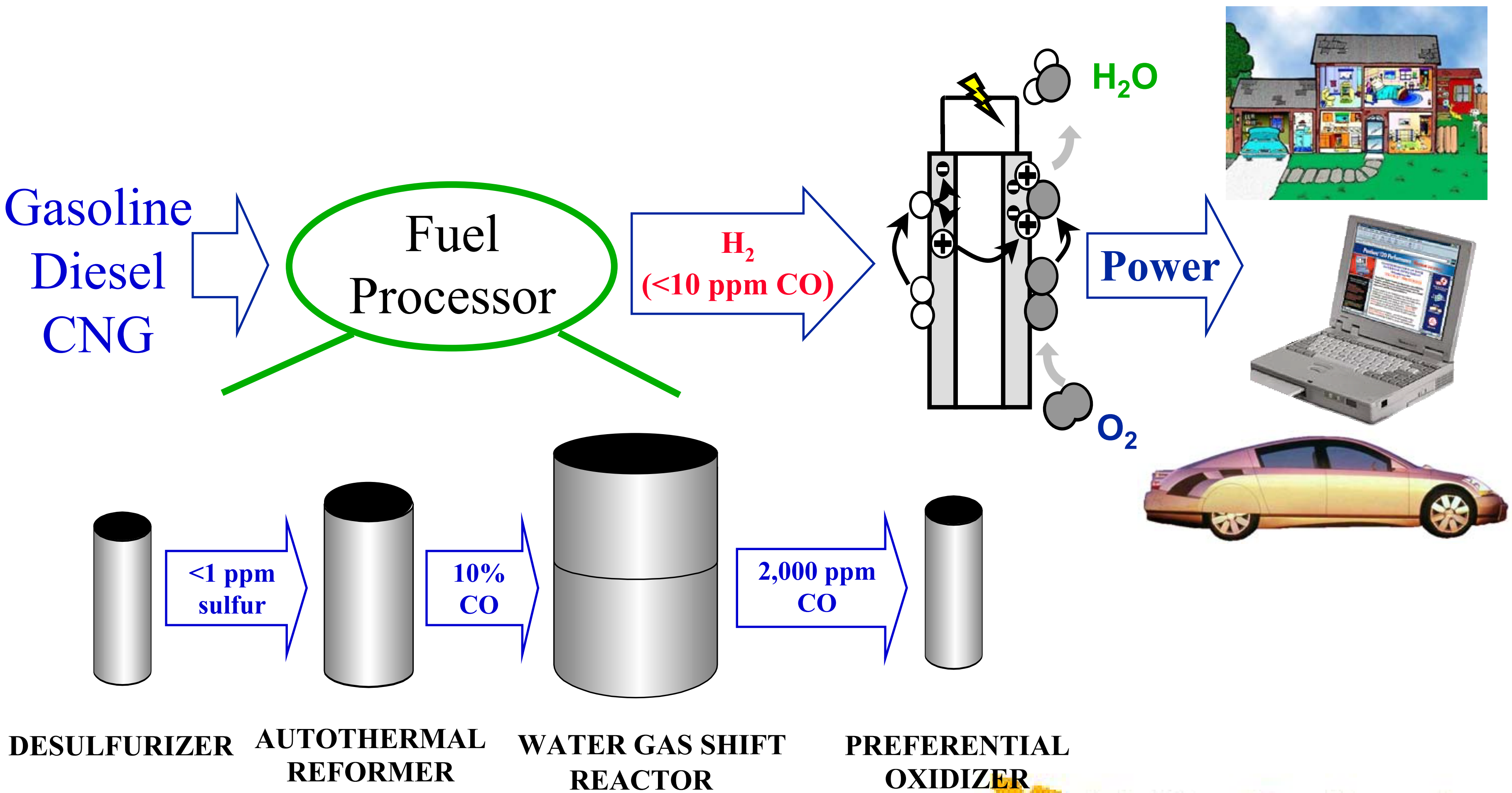
Other Issues

- Significant interactions or collaborations with others:
  - Program partners (MesoFuel; IMM)
  - Osram Sylvania
  - Working to exchange catalysts with ANL
- Plans and future milestones
- Challenges

Thank You!



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