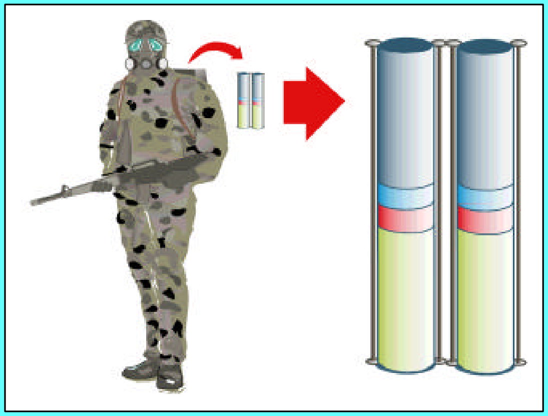
Microchannel Fuel Processing for Man Portable Power



Eric Daymo, Dave VanderWiel,
Sean Fitzgerald, Yong Wang, Mike LaMont,
Bob Rozmiarek, Lee Tonkovich

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Small Power Systems: Impact on National Security

LAND WARRIOR SOLDIER POWER

Goals

2003	270-Wh/kg
2005	1450-Wh/kg
2008	3100-Wh/kg
2018-25	5900-Wh/kg

Source: Land Warrior ORD (3 Aug 99), KPP

Soldier Power:
Current Battery Power Sources

Model	Type	Chemistry	Gravimetric Energy Density (Whr/kg)	Volumetric Energy Density (Whr/liter)
BA-5847B/U	Primary	$LiSO_2$	121	41
BB-2847/U	Rechargeable	Li-Ion	68	32
BA-x847A/U	Primary (2-Cell)	$LiMnO_2$	226	87
Day Pack	Primary (15-Cell)	$LiMnO_2$	308	107
Ammo Pack	Primary (5-Cell)	$LiMnO_2$	TBD	TBD

Current battery technology is insufficient for Land Warrior System by 2005!

What Energy Source?

Energy Source	Energy Storage Density (kW-hr/kg)
Diesel	13.2
Advance Battery	0.2 - 0.3
Hydrogen Storage	
Compressed	1.0
Metal Hydride	0.5

Conclusion - Liquid hydrocarbon fuels are decisively superior to other energy storage options

Microchannel Fuel Processing for Fuel Cell Power Systems

Battery replacement for long duration missions

Stored hydrocarbon **fuel** → [FP → H_2 → FC] → **Power**

FP/FC Energy Density: 2,000 – 4,000 Wh_e/kg
Batteries: 200 – 300 Wh_e/kg

Environmental Measurements
0.01- to 100-W_e

Laptops
50 - W_e

Automotive
50-kW_e

Overview

- Why microtechnology?
- Fuel Processor
  - Conceptual flowsheet
  - Demonstrated components
- Man Portable Power
  - Concept
  - Status

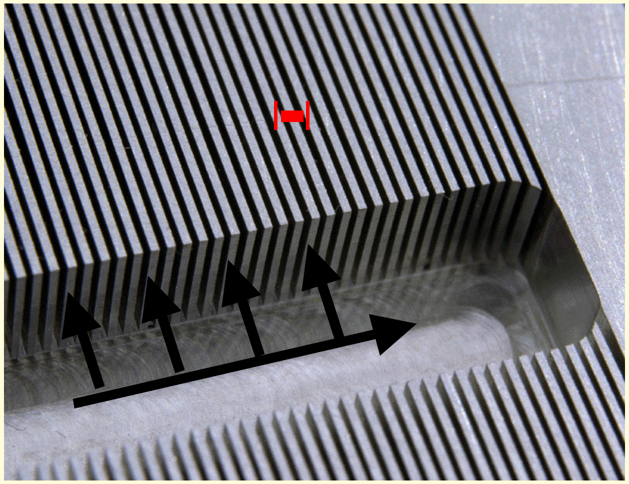
Why Microtechnology?

- **Microscale Advantage**
  - Reduce *heat transfer* resistance
  - Reduce *mass transfer* resistance
- **Component efficiency**
  - Microtechnology *~ 90% or better*
  - Conventional technology < microtechnology
- **Fuel Processor size (50 kW_e - Automotive application)**
  - Microchannel reactor *~ 8 Liters*
  - Conventional *~ 10x to 100x larger*

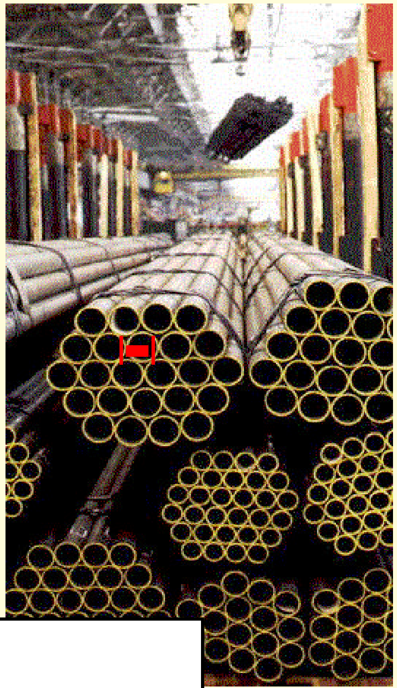
Compact processes need microtechnology

Compact Processes:
Highly effective Heat Transfer

- Reduce heat transfer resistance using microchannels



Vs.



~ 0.05-0.1 cm

~ 5-10 cm

- Reduce transport distance
- High surface area to volume ratio
- Low pressure drop through channels

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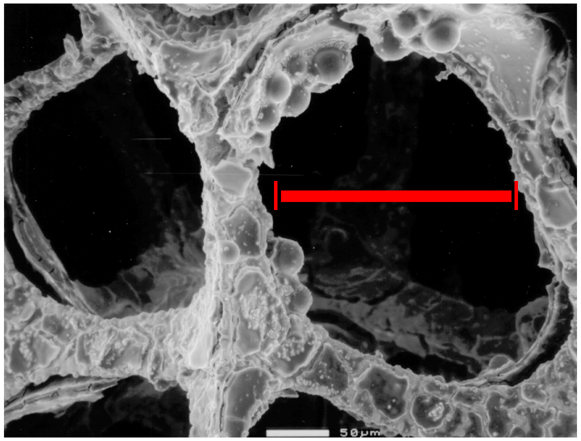
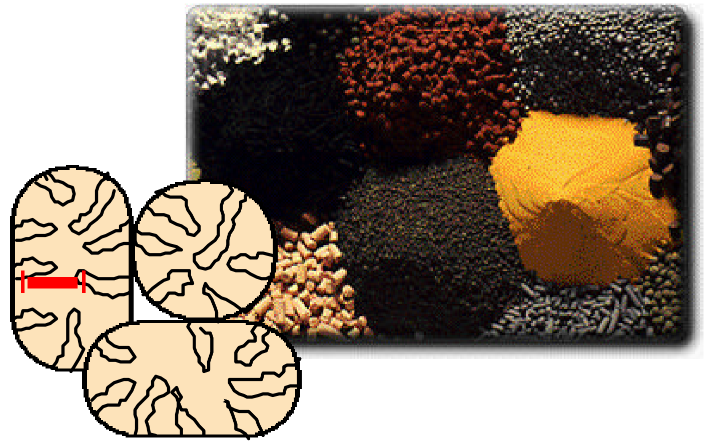
Microchannel Reactors:
Enhanced mass transfer reduces process volume



vs.



~ 0.02 cm

~ 2 cm

- **Transport distance reduced by several orders of magnitude**
- **Convective vs diffusive transport brings reactants to catalyst**

Compact Water Gas Shift Reactor

$$CO + H_2O \Rightarrow CO_2 + H_2 \quad \text{(desired)}$$
$$\Rightarrow CH_4, C(s) \quad \text{(undesired)}$$

Conventional technology:

- τ = 1 sec
- 300 - 500 °C

Compact microtechnology:

Patent pending

- τ = 25 msec
- 300 - 500 °C

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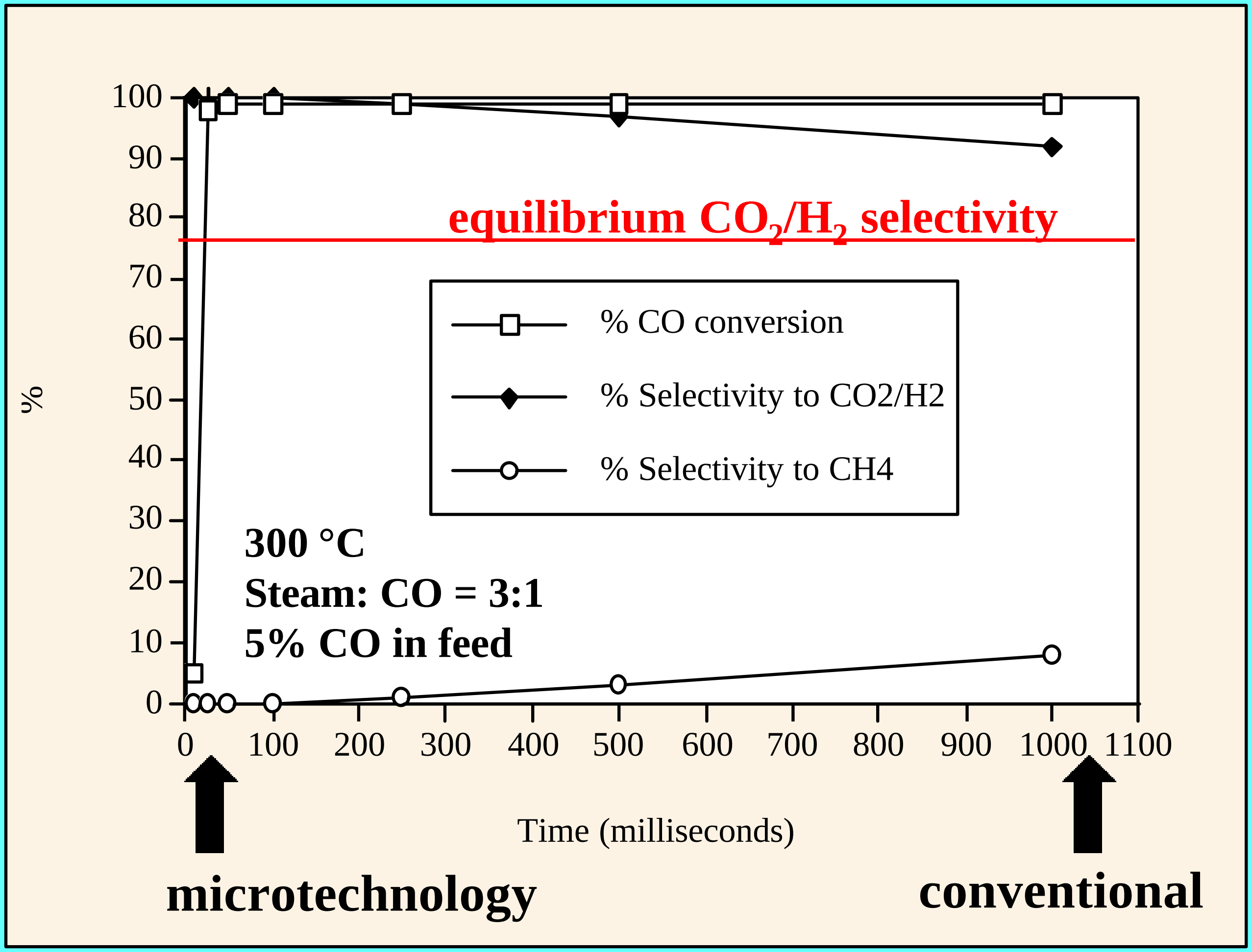
Compact Water Gas Shift Reactor

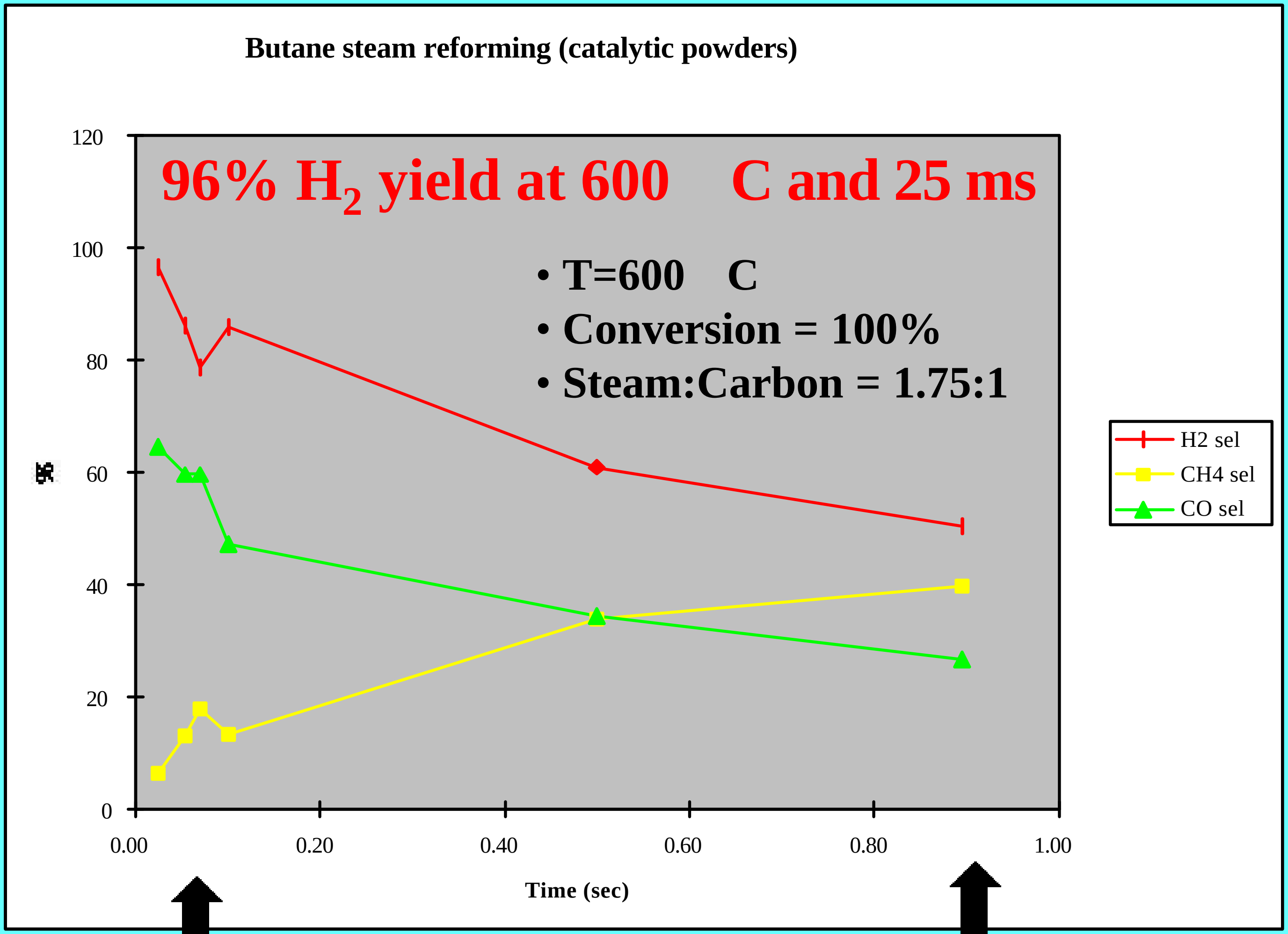


Non-equilibrium products at short contact times:

< 80% selectivity to H_2 at equilibrium

>99.9% selectivity observed

Compact Steam Reformer



Implication

Fast kinetics = compact process

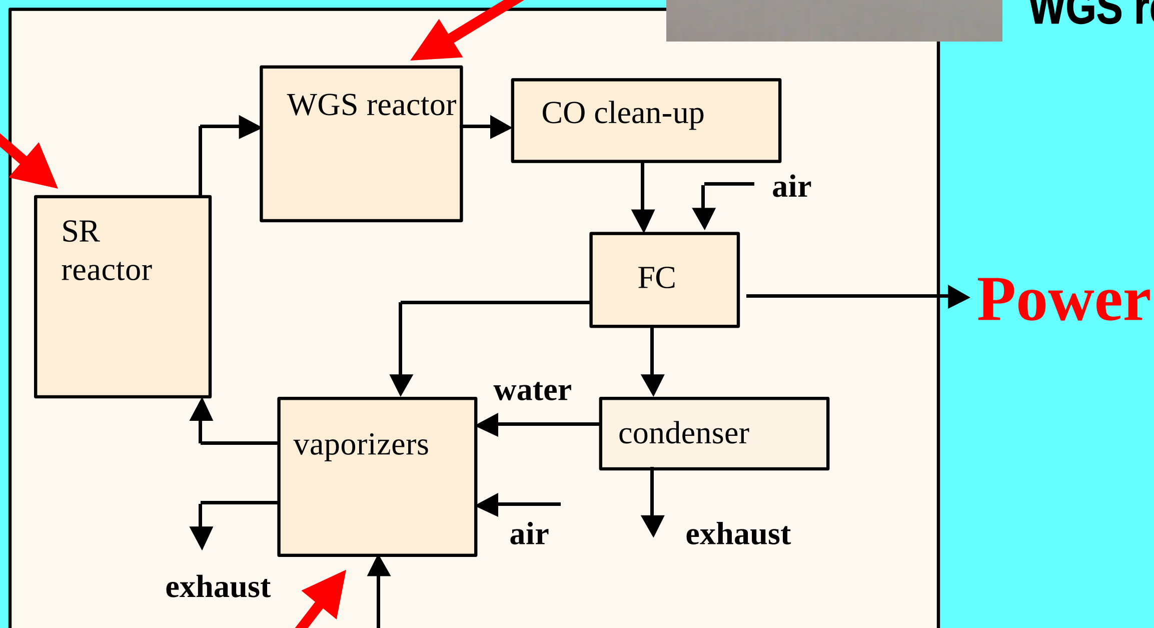
microtechnology

conventional

Microchannel Fuel Processing

1.1-kW$_e$ automotive
SR reactor, < 2-in^3

10-W$_e$
man portable
WGS reactor



R&D
R&D Award

50-kW$_e$
automotive
gasoline vaporizer

Stored hydrocarbon
fuel for multi-
week operation

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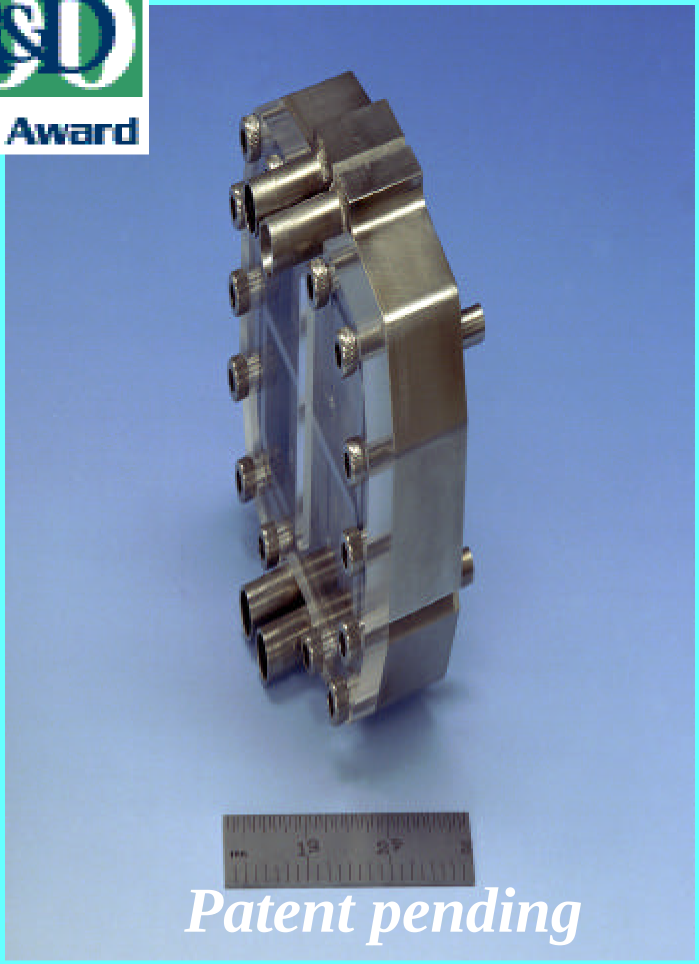
Microchannel Gasoline Vaporizer:
Compact 50-kW$_e$ (Automotive) Fuel Processor

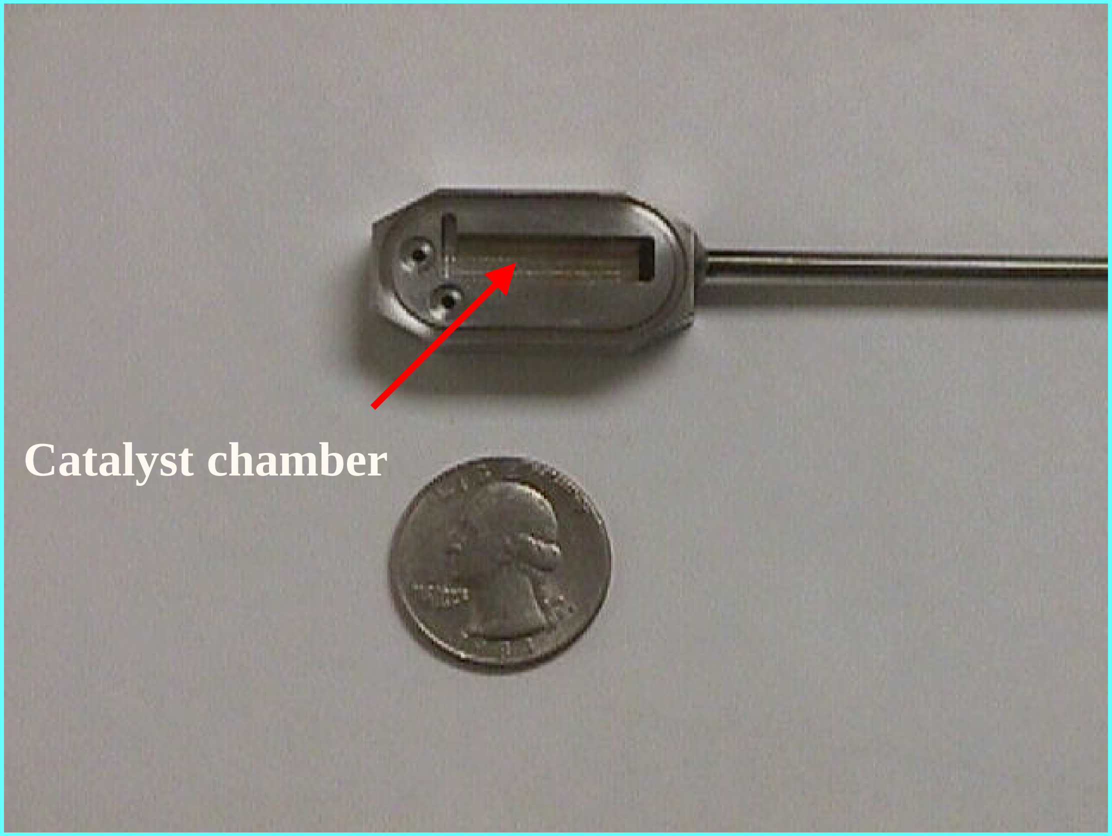
R&D Award



- Attributes: Four parallel cells
- Size: 8 cm by 10 cm by 4 cm
- Capacity: Gasoline (~ 300 mL/min)
- Implications: Complete fuel processor system = 8 Liters
- Fabrication: Laminate process
- Pressure drop: DP < 2psi (through microchannels at ~ 1400 SLPM)

Microreactor Development

- 10-W_e design for butane reforming and WGS

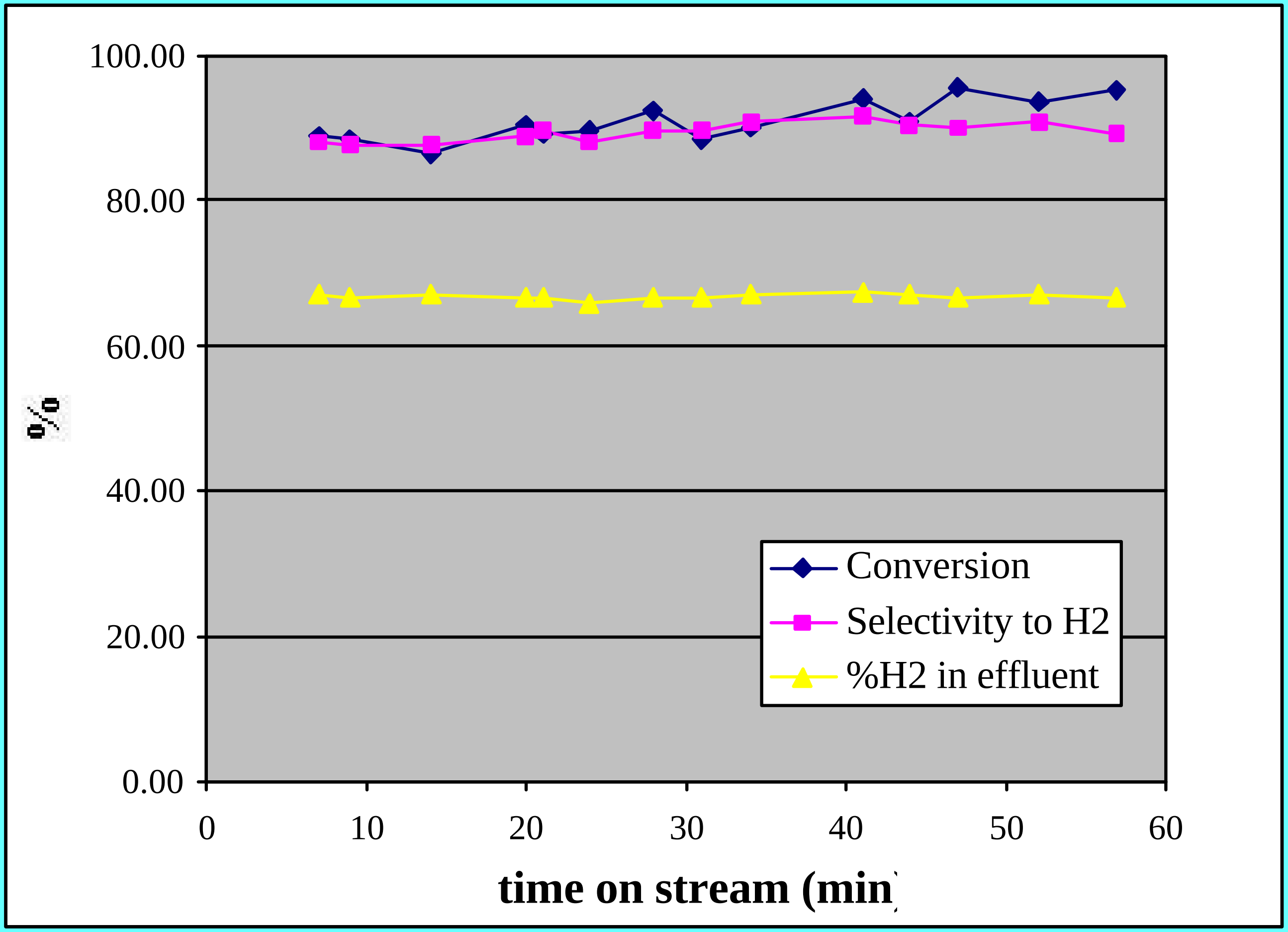


Steam Reformer:
Automotive Fuel Processor

- **Iso-octane steam reforming (gasoline simulant)**
  - $C_8H_{18} + 8\ H_2O = 8\ CO + 17H_2$ DH$_r$ = 1345 kJ/mol
  - $CO + H_2O = CO_2 + H_2$ (some high T shift)
  - Undesired side/series reactions:
    - $CO+CO = CO_2 + C(s)$
    - Cracking reactions
    - Methane formation
  - Conditions (conventional hardware):
    - Temperature ~ 800C
    - Steam : Carbon ~ 6+
    - Residence time > 1 sec

Iso-octane Steam Reforming:

Initial tests – World's First Microchannel Steam Reformer



τ=2.3 ms
T=650 C
S:C = 6
0.5-kW_e

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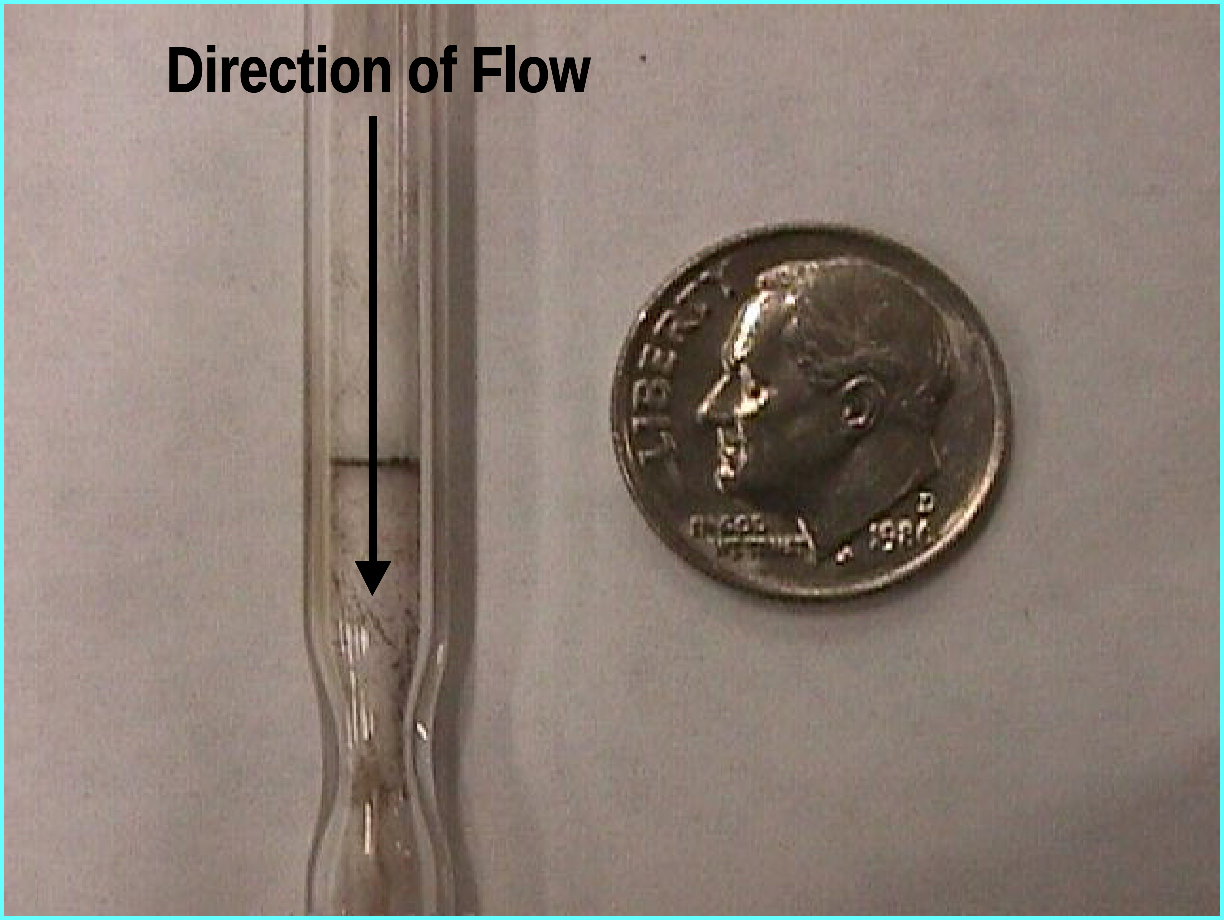
Steam Reformer Summary:
Isooctane

- **Capacity (cell volume 29 cm^3)**
  - Initial experiments: 0.5 to 1.0-kW_e at 1 atm
  - Design point: 5-kW_e at 5 atm
- **Range of test conditions**
  - Residence time: 1.1 to 2.3 milliseconds
  - Steam:carbon : 3:1 to 6:1
  - Temperature: 630 to 670 C
- **Performance**
  - Conversion = up to 99%, low 90's typical
  - H_2 Selectivity = 91 to 99%, with H2 content = 67 to 72%
  - No degradation observed after 30 hours and 12 thermal cycles
- **Implications:**
  - **Automotive full-scale SR System (50-kW_e) ~4L**

Diesel Catalytic Combustion Tests



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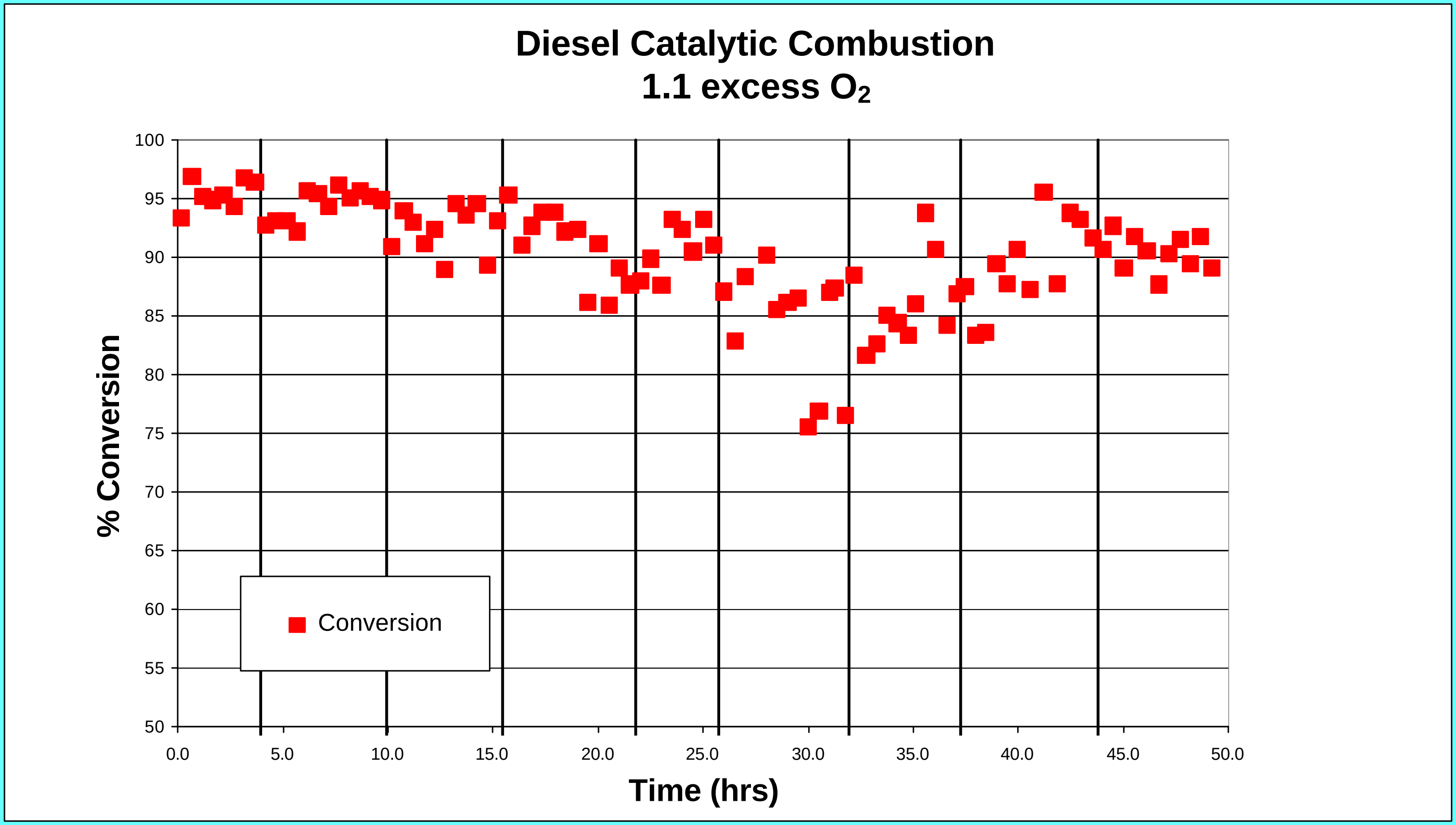
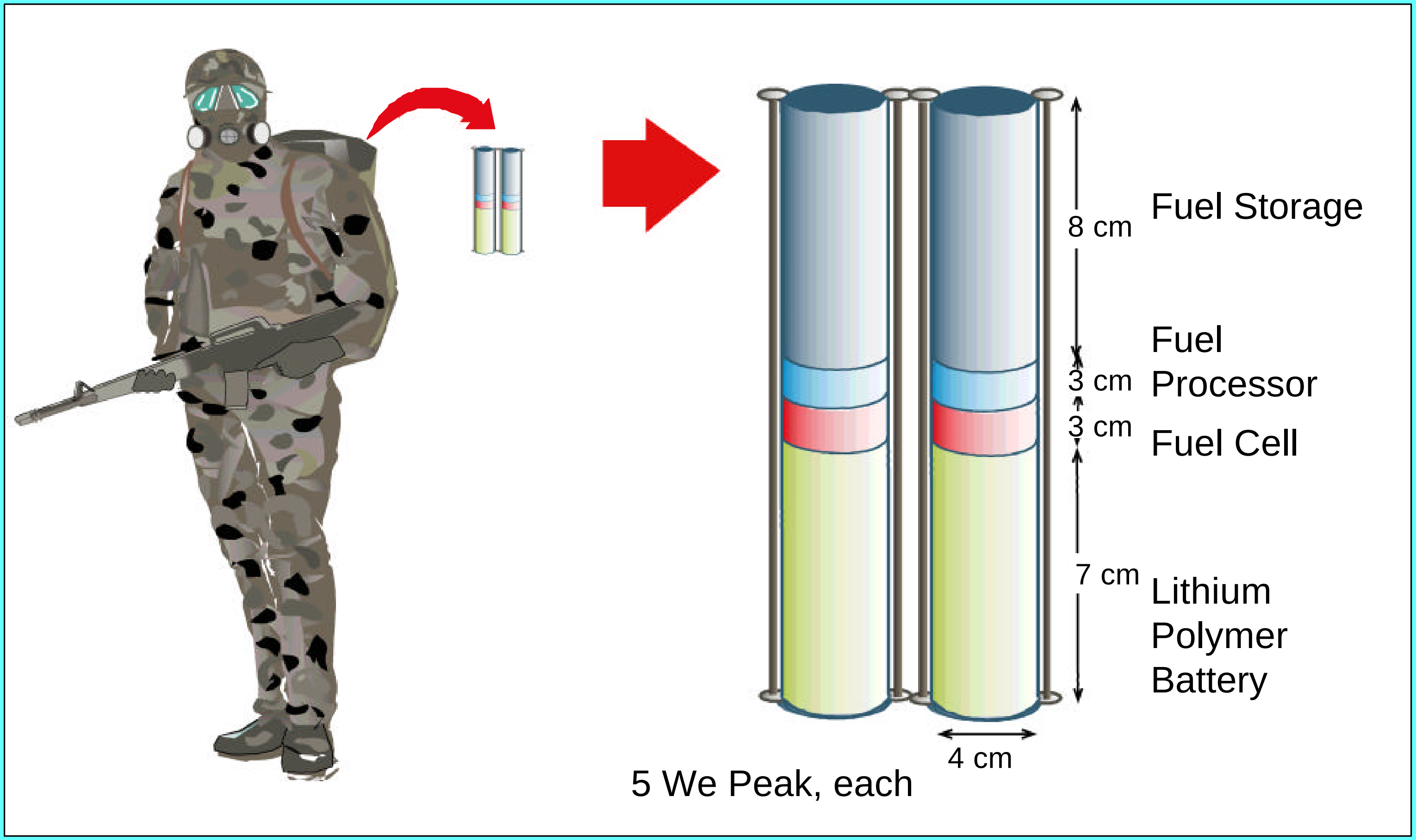
Diesel Catalytic Combustion
Duration Testing



<u>No sulfur poisoning/coking observed after 50 hours of operation</u>

Man Portable Power: System Concept



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Status: Man Portable Power

- Demonstrated feasibility of microchannel fuel reforming
- Demonstrated feasibility of microchannel water gas shift
- Demonstrated vaporizers and recuperative heat exchangers