Fuel Processor Development for Small Power Supplies

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Need

- Broaden the possibilities for using self-sustaining devices in remote or difficult-to-access locations such as sensors or mobile devices.
- Battery replacement
- Self-sustaining portable power supply for wireless electronic devices
  - Wireless equipment & sensors
  - Remote operation
  - Sensors
  - MEMS
  - Hand-held devices

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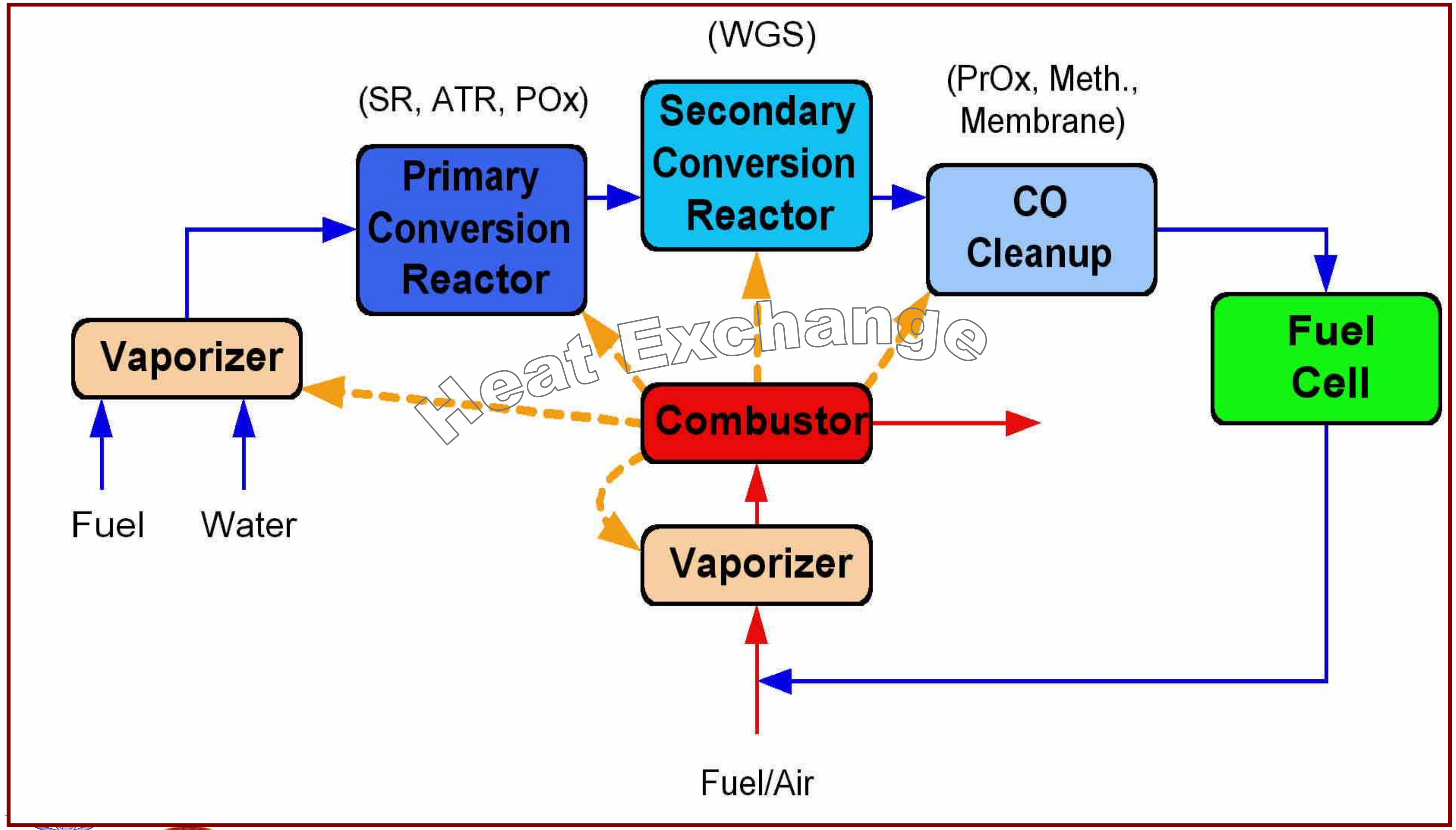
Required Fuel Efficiency to exceed battery performance

Fuel	LHV (kJ/mol)	Energy Density (kWh/kg)	Efficiency Required
Methanol 1:1 water:C	**639**	**5.6** 3.3	**5.5%**
***n*-Ocatane** 2:1 water:C	**5100**	**12.3** 3.0	**2.4%**
***n*-Dodecane** 2:1 water:C	**7552**	**12.3** 3.1	**2.4%**
H_2 storage	**242**	**0.5-1.0**	**30-60%**
$NaBH_4$ solution 1kg $NaBH_4$ + 950g H_2O	**495**	**3.6**	**12.1%**
Lithium polymer battery		**0.3 (projected)**	

Typical Fuel Processing System



Microtechnology

- Lightweight and compact
- Rapid heat and mass transport
- Extremely precise control of process conditions
- High performance
  - High throughput per unit hardware volume
- Cost economies through mass production
  - Versus economies of scale
- Available for distributed or mobile applications

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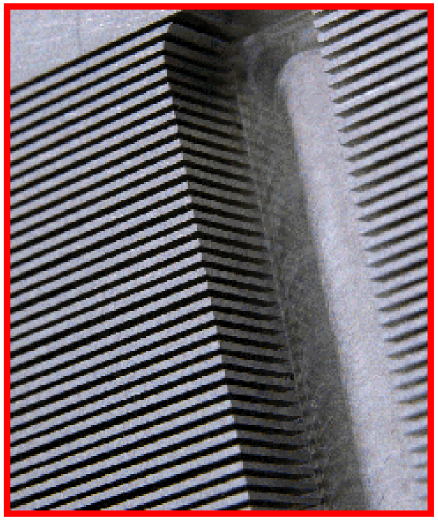
Microchannel Architecture



- Micron-Scale Dimensions
  - 50-500μm channels
  - high aspect ratios
  - negligible pressure drop
- Reduced heat & mass transfer resistances
  - allows use of more active catalysts
- Integrated Monolith Catalysts
- Laminate Fabrication Method

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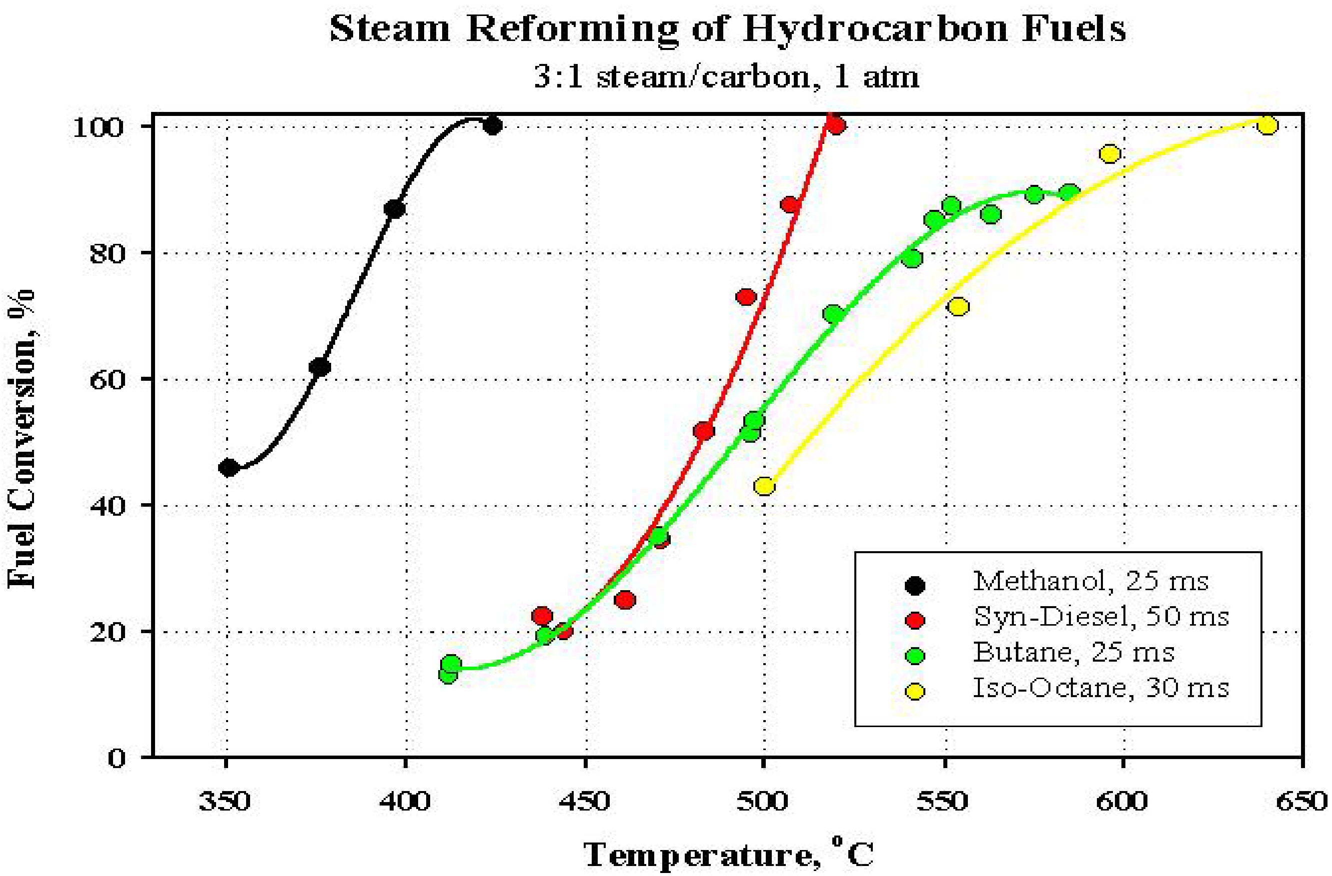
Novel Monolith Catalysts

- “Foam” supports
- Pore diameter ≤ 200 μm
- Large effectiveness factors
  - low mass transfer resistances
  - utilize high activity of catalysts
- Low ΔP through monolith

Hydrocarbon Reforming



GHSV = 72,000

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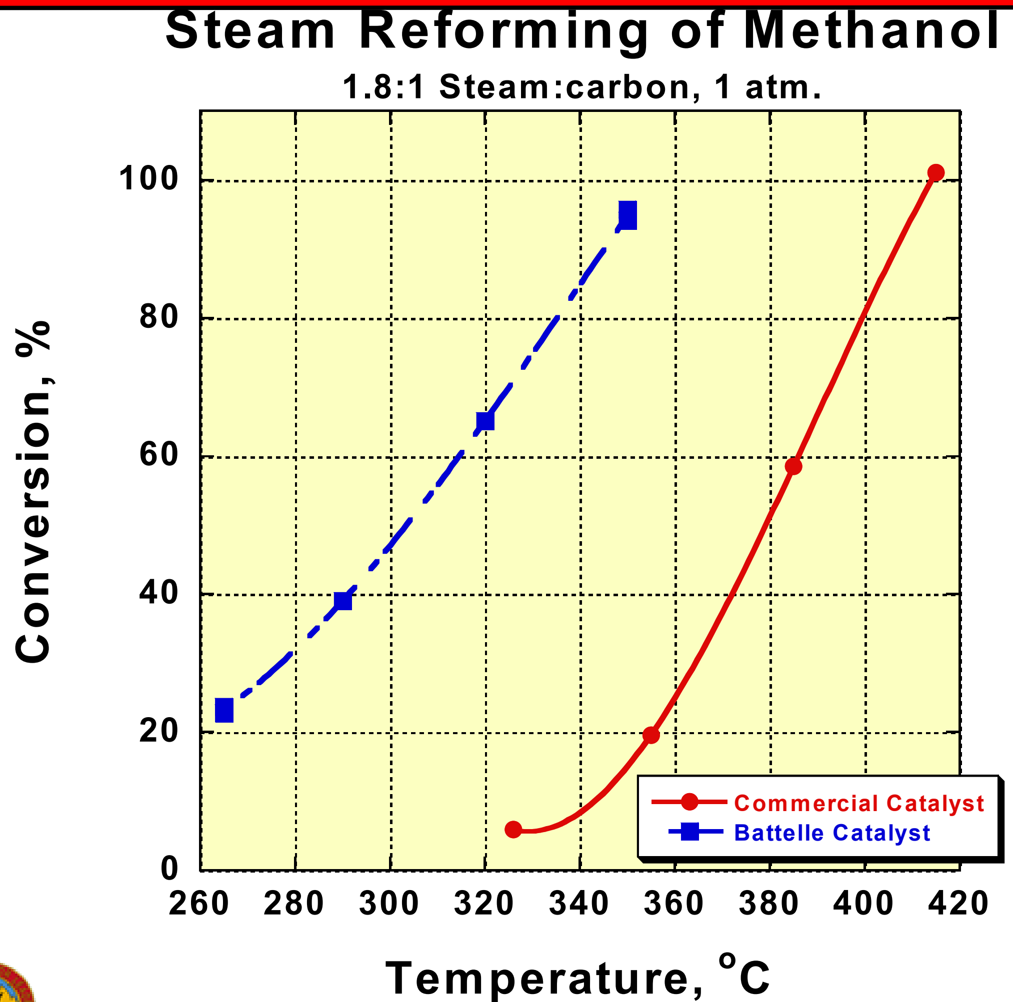
Methanol Reforming



Commercial Catalyst = $Cu/Zn/Al_2O_3$

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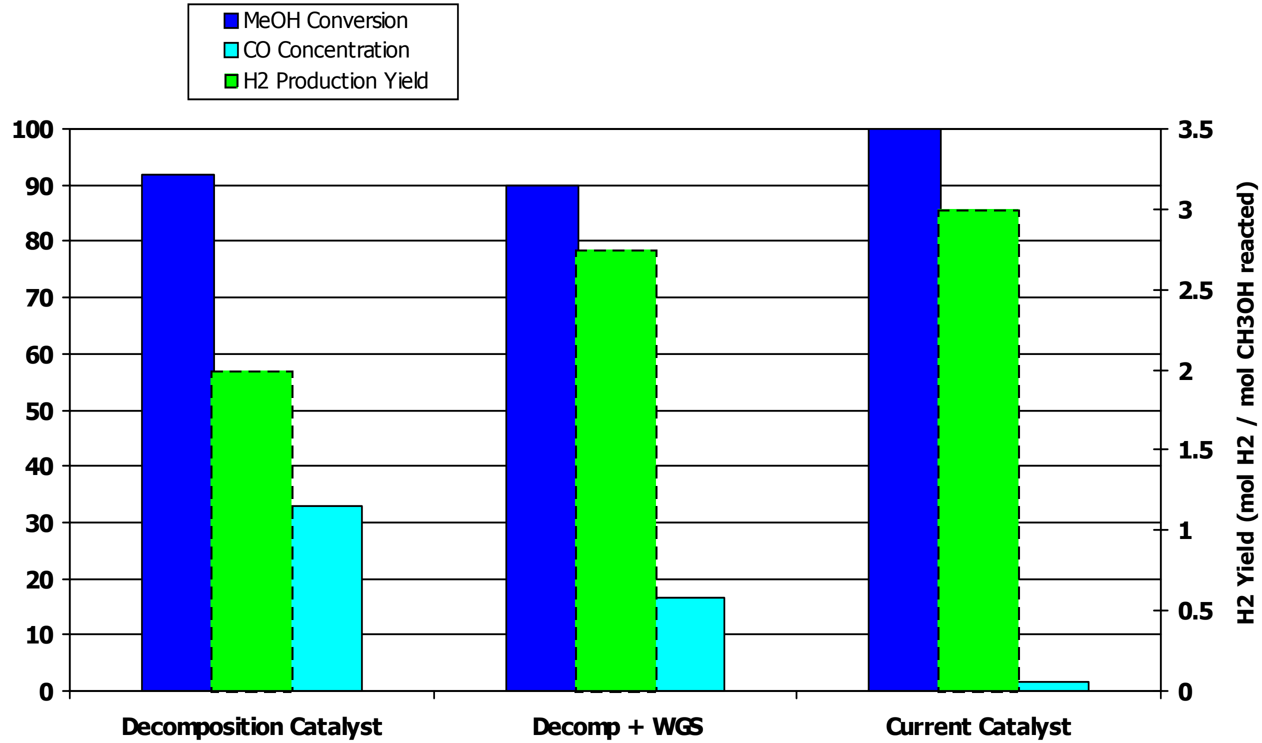
Methanol SR Catalyst:

Different Approaches on Steam Reforming of Methanol

(100 ms contact time, $H_2O/C=1.8$, 300°C and 1 atm)



- For methanol reforming the H_2 yield is close to theoretical maximum
- CO Concentration (~1 vol.%) low enough to eliminate the need for additional reactors

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Soldier Power Goals

- Targets
  - 15 W_e average (25 W_e peak)
  - < 100 cm^3
  - < 1 kg (excluding fuel)
  - Operate on logistics fuel?

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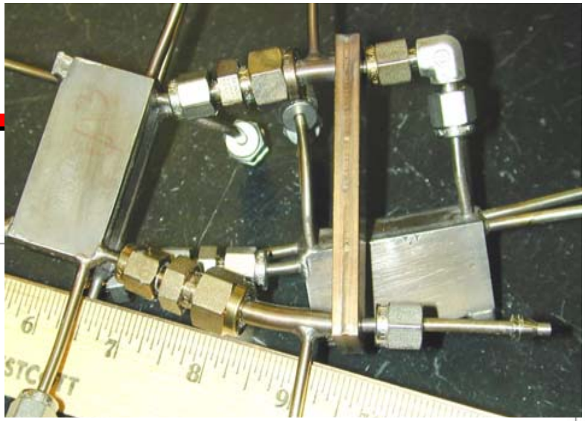
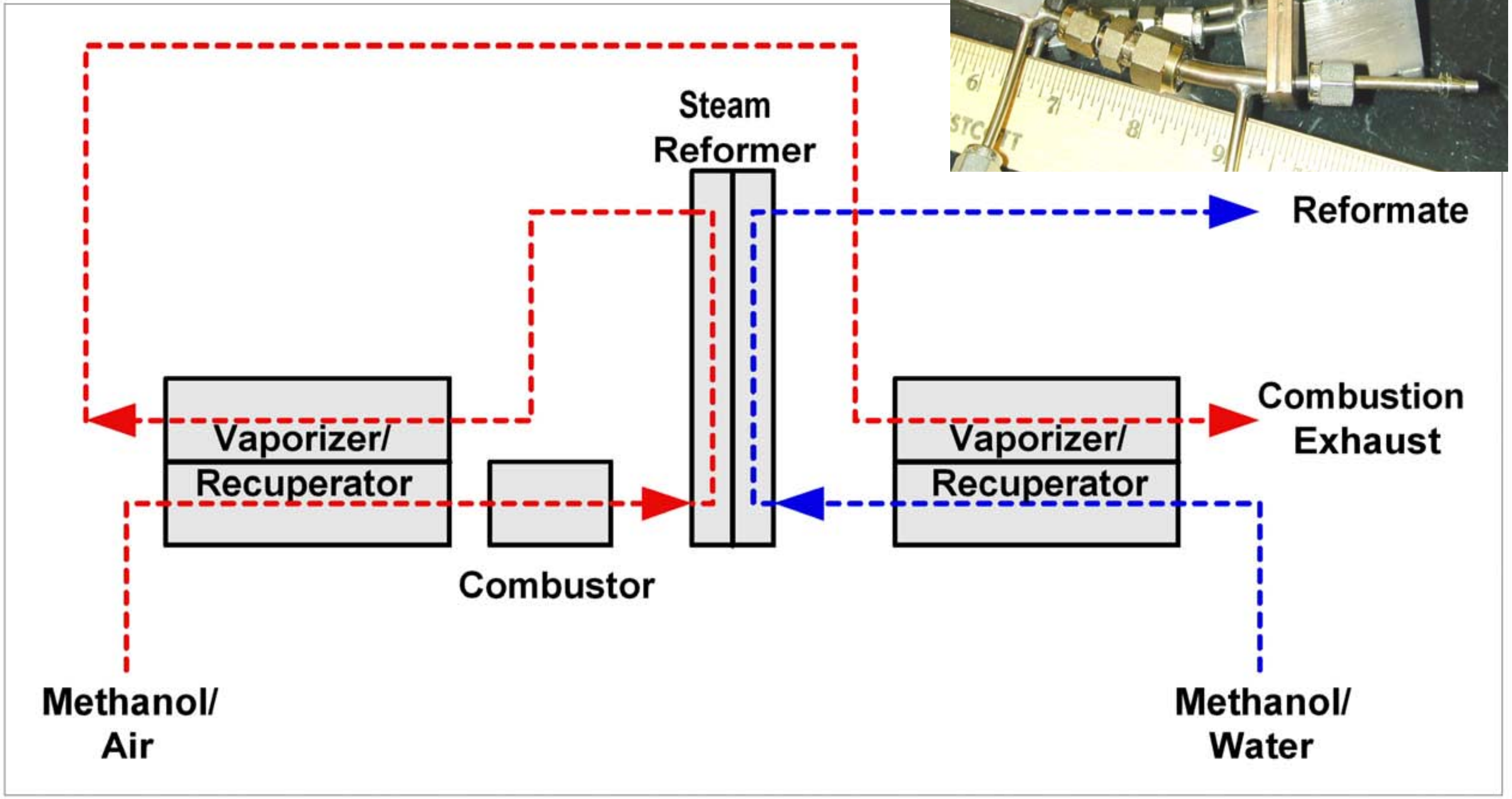
System Process Testing
(not thermally integrated)





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System Process Testing Results

Estimates based on 14-day mission, 1-kg processor/fuel cell:

- System Test Results
  - Thermally independent after startup
  - Fuel/water = 6.1 L
  - System weight = 6.1 kg
  - Energy density = 720 W-hr/kg
  - Processor efficiency = 45%
  - Overall efficiency = 22%

Li-ion battery (200 W-hr/kg) weight to provide the same energy = 22 kg

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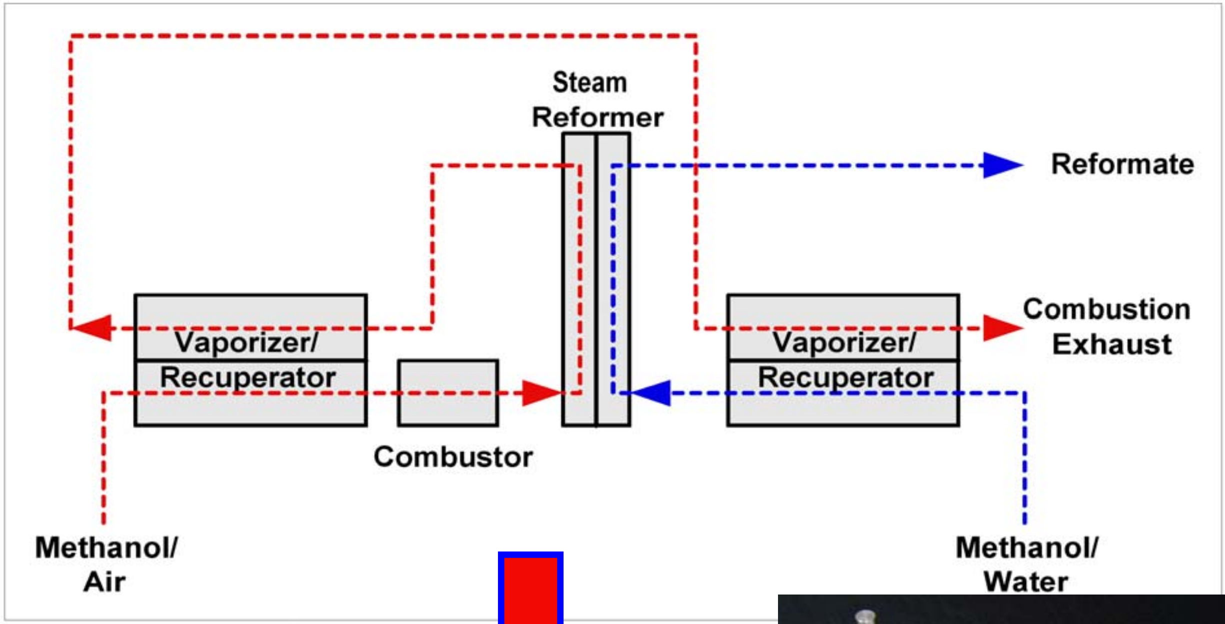
Fuel Processor Thermal Integration



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Thermally Integrated 15-25 Watt Fuel Processor

Dimensions:
3.4” x 0.75” x 0.22”

Volume:
~9.2 cc
(w/o tubes)

Weight:
50 grams
(w/o tubes)

System Process vs TIFP

	System Process	TIFP
Power Level, W_e	13	14
Reformer Exit Temperature, °C	350	320
CO in Dry Gas, %	0.70	0.43
Energy Density, Whr/kg*	720	**850**
Efficiency, %, thermal (electric)	45 (22)	**60 (29)**
Total System Weight, kg (lbs)*	6.6 (14.5)#	5.3 (11.7)

*assuming 1-kg FP/FC system, 14-day mission
#scaled to 14 watts

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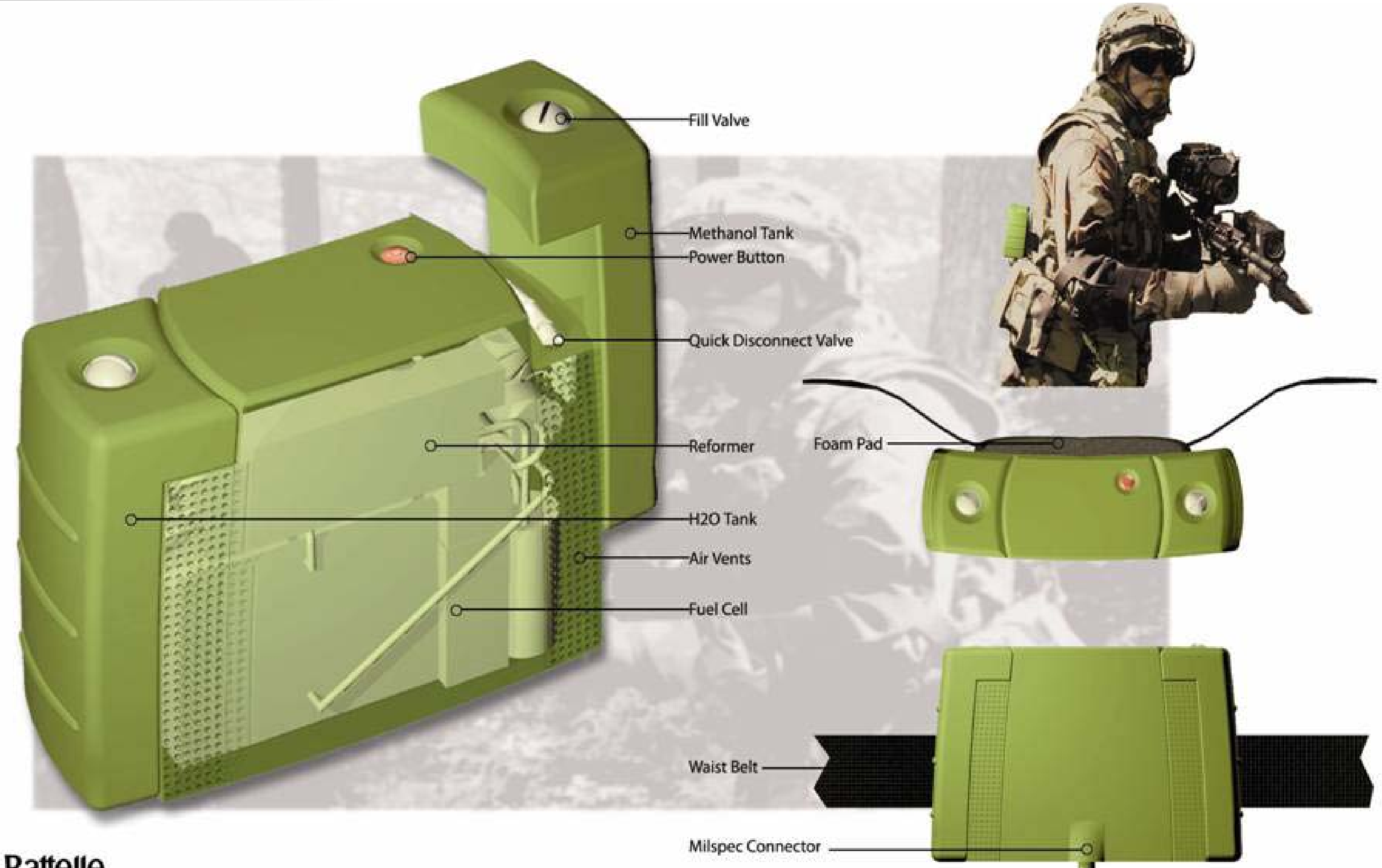
Comparison to ARMY Batteries

(14-day mission, 23.3 W_e continuous)

Model	Chemistry	Energy Density (Whr/kg)	Weight (kg)	Energy Density (Whr/L)	Volume (L)	Recharge or Refill Time
BB-2590U	Li-Ion	84	93	109	71	Hours
L17	Li-ion	118	65	180	43	Hours
LI 1.5	Li-Ion	136	57	128	60	Hours
LM11	$LiMnO_2$	196	40	265	29	Disposable
BA-x847A/U	$LiMnO_2$	226	34	87	89	Disposable
LMP 13.5	$LiMnO_2$	308	25	107	72	Disposable
Fuel Processor	**Methanol Reforming**	**850**	**9**	**985**	**8**	Minutes

Table adapted from Scott Feldman, GTS, L.L.C., Contractor to the NSC-Warrior Systems Integration Team. "Developing Power & Energy Design Goals for Land Warrior."
Presented at the Institute for Defense Analyses Soldier Systems and MEMs Meeting, November 2, 1999, Alexandria, New Jersey.
Additional information provided by Steve Slane, U.S. Army CECOM RD&E Center, Fort Monmouth, New Jersey.

System Concept



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Future Work

- CO cleanup
  - Goal: <100 ppm
- Brassboard demonstration
  - Fuel processor
  - Fuel cell
  - Peripherals
- Lifetime demonstration
  - >14 days continuous
  - Thermal cycling

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Sub-Watt Reformer: Goals and Objectives

- Develop an integrated fuel cell and fuel processor for microscale (10- to 500-mW_e) power generation.
- Demonstrate 10-500 mW_e fuel processor.
- Demonstrate 10-500 mW_e fuel cell.
- Demonstrate integrated mW_e fuel processor and fuel cell system.

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Overall System and System efficiency

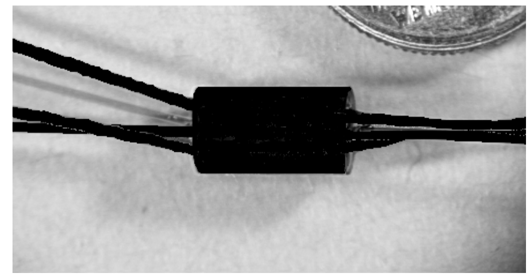
Fuel Steam Reformer:

Converts fuel and water into H_2 and CO_2 gas.

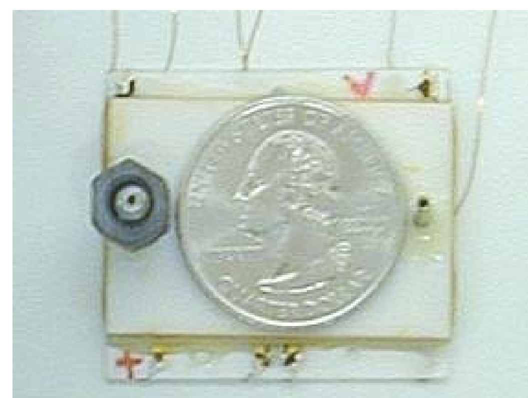
Fuel Cell:

Converts H_2 gas into H_2O and electricity.

$$\text{Efficiency} = \frac{\text{Hydrogen lhv}}{\text{Reformer Fuel lhv +CR Fuel lhv}}$$



$$\text{Efficiency} = \frac{\text{Electric power out}}{\text{Reformer Fuel lhv +CR Fuel lhv}}$$



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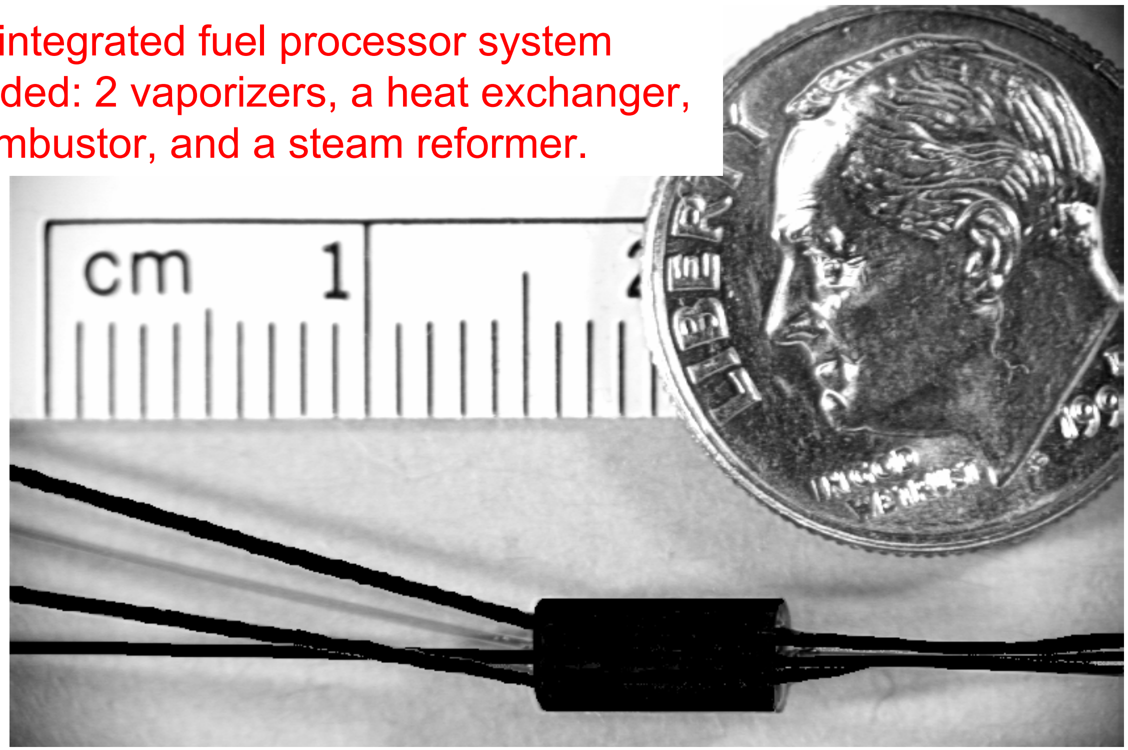
Experimental Reactor

The integrated fuel processor system included: 2 vaporizers, a heat exchanger, a combustor, and a steam reformer.



reformer volume: <5 mm^3

reformer capacity: 200 mW

combustor volume: < 5 mm^3

combustor capacity: 3 W

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Reforming Reactor Test Results

- Reactor Output:
  - H_2 flow = 0.1 –1.1sccm
  - Power = 18-200 mW_t
  - Efficiency 3%-9%
- Estimated electric power output
  - Assumptions
    - 60% efficient fuel cell
    - 80% H_2 utilization
  - Power 9-100 mW_e
  - Efficiency 1.5-4.8%
- Reactor Conditions:
  - Contact time: 50-300 mS
  - Temperature: 300-475°C
  - Pressure ~ atmospheric

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High Temperature Mesoscale Fuel Cells

- Joint Effort with PNNL and Case Western Reserve University
- Electrode areas ≈ 1 cm^2
- Electrodes, current collectors printed on PBI electrolyte membrane
- Cell interconnects, heaters, RTD printed on alumina
- Adhesive assembly of components
- Cathodes exposed to ambient air

Greek "*Mesos*"; middle

• this is an intermediate sized device, and the construction uses both microfabricated and conventionally fabricated components

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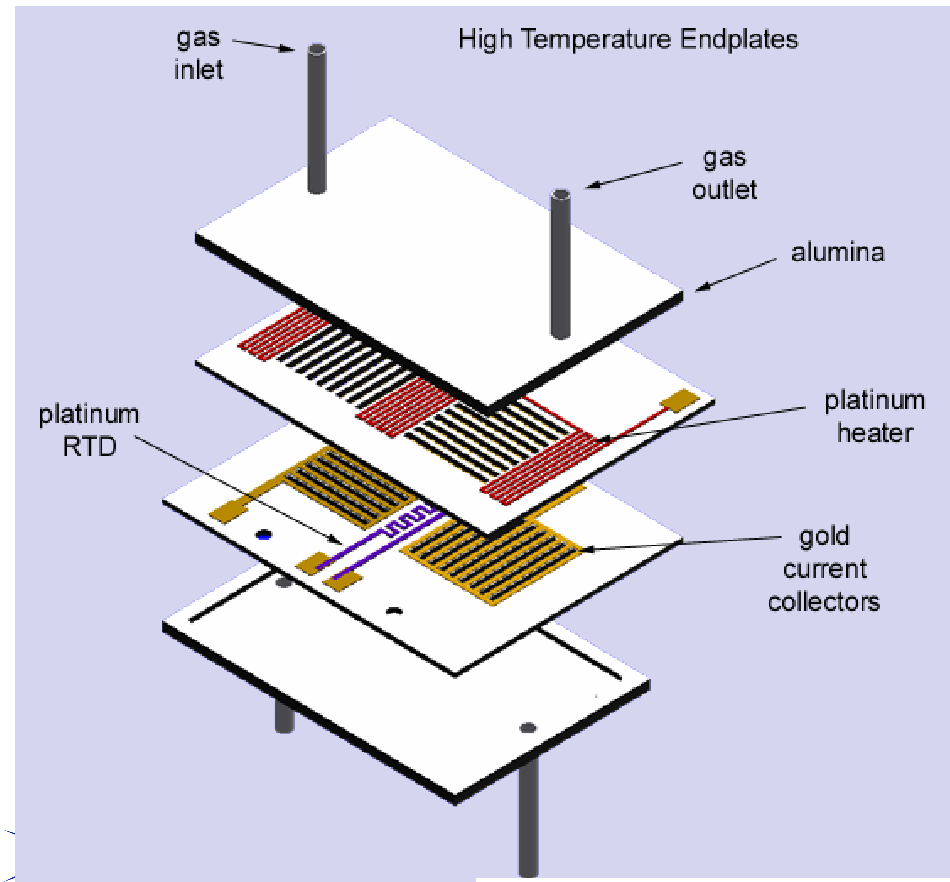
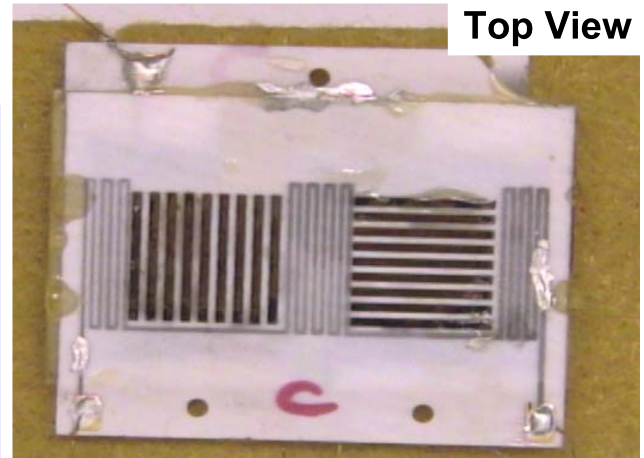
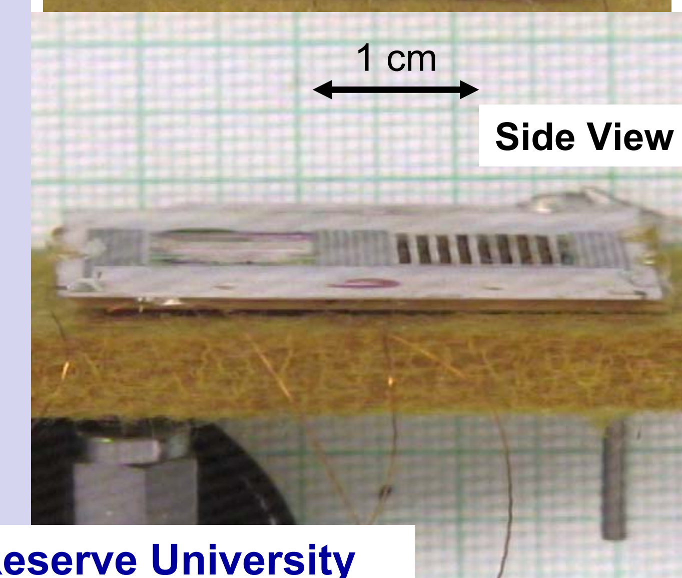
High Temperature Mesoscale Fuel Cells

Fuel Cell Fabrication

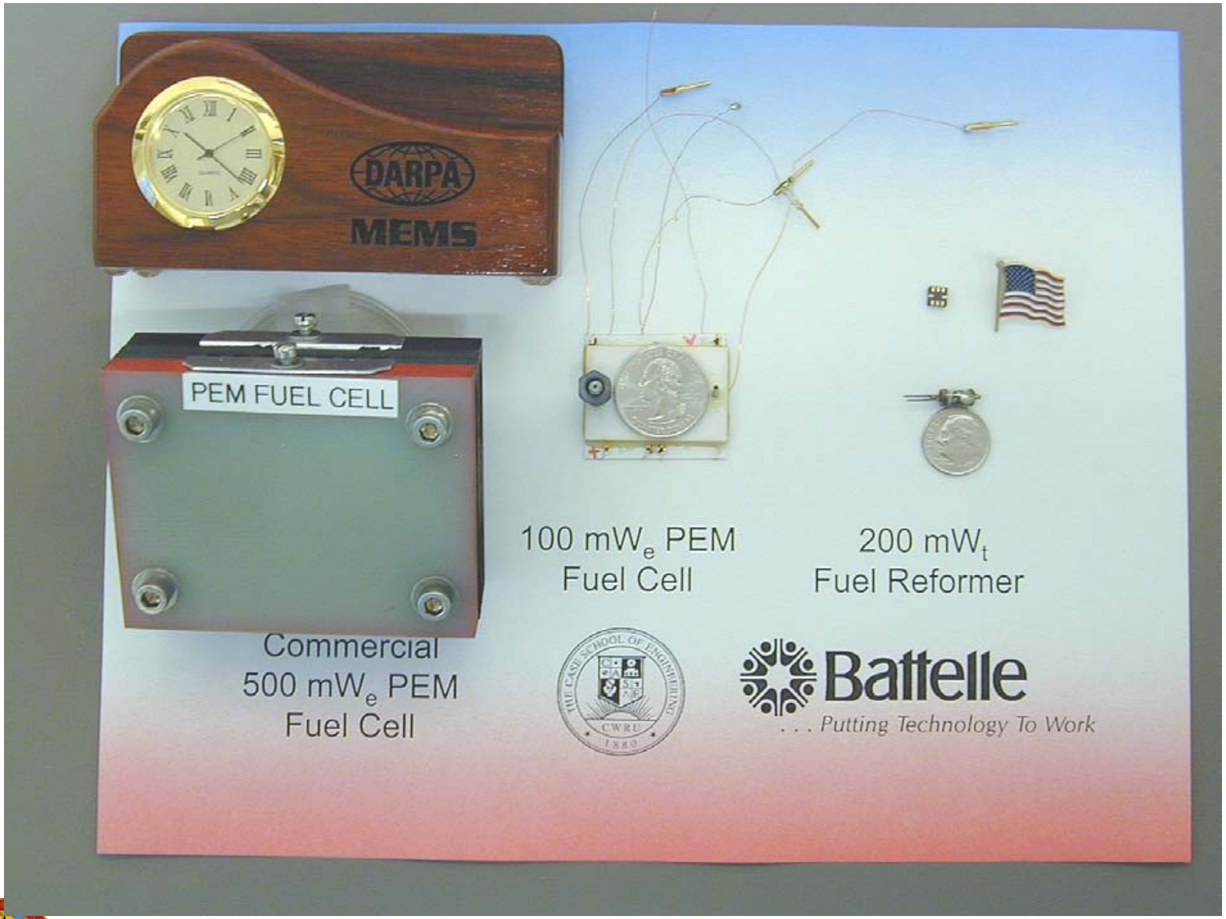






From Case Western Reserve University

Size Comparison



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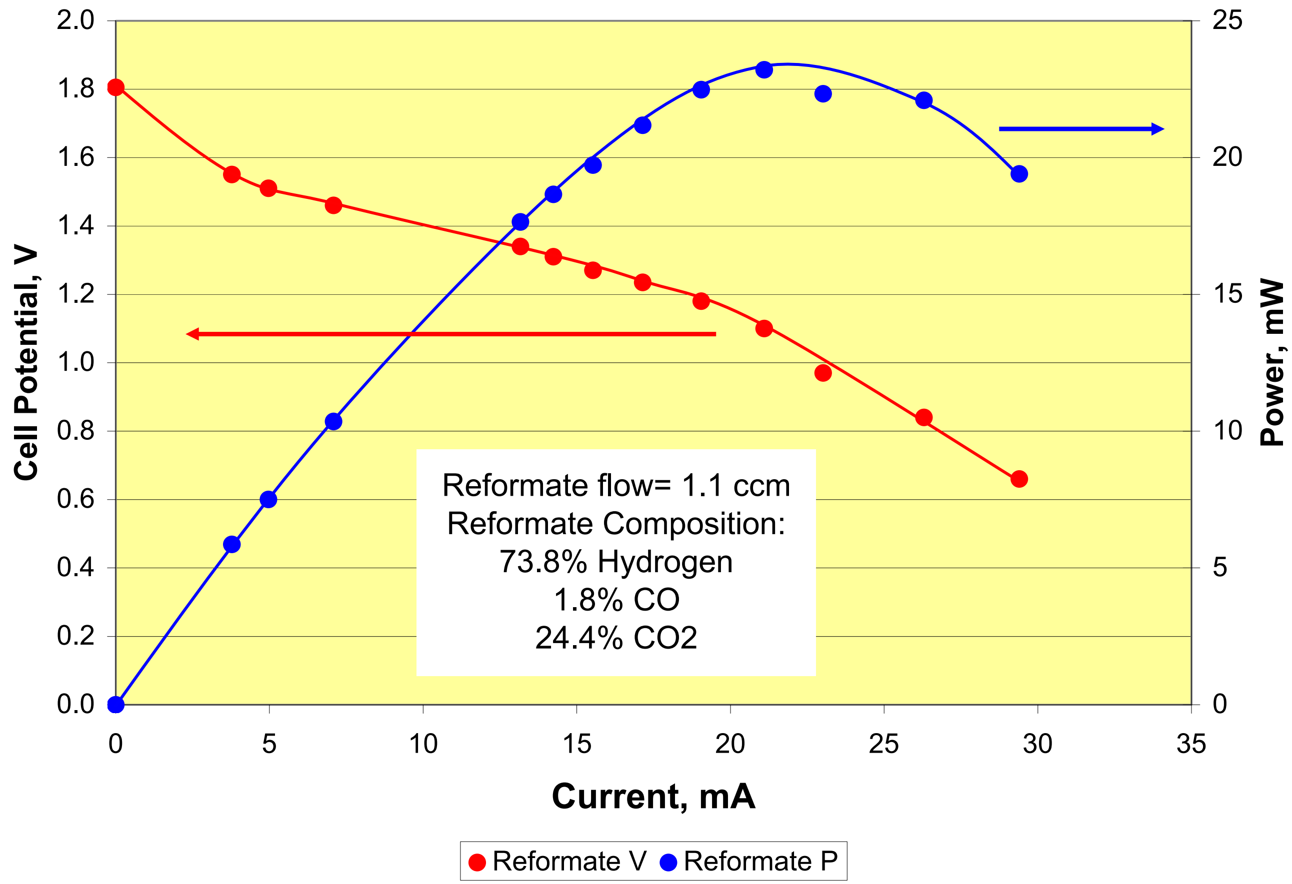
Fuel Processor and Fuel Cell System Testing



Future Work

Sub-Watt Power

- Improved System
  - Fuel processor development
  - Fuel Cell improvement
- Systemization
  - Thermal integration
  - BOP
- See us at www.pnl.gov/microcats/

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