# Miniature Fuel Processors for Portable Fuel Cell Systems

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**Pacific Northwest National Laboratory**

Operated by Battelle for the U.S. Department of Energy

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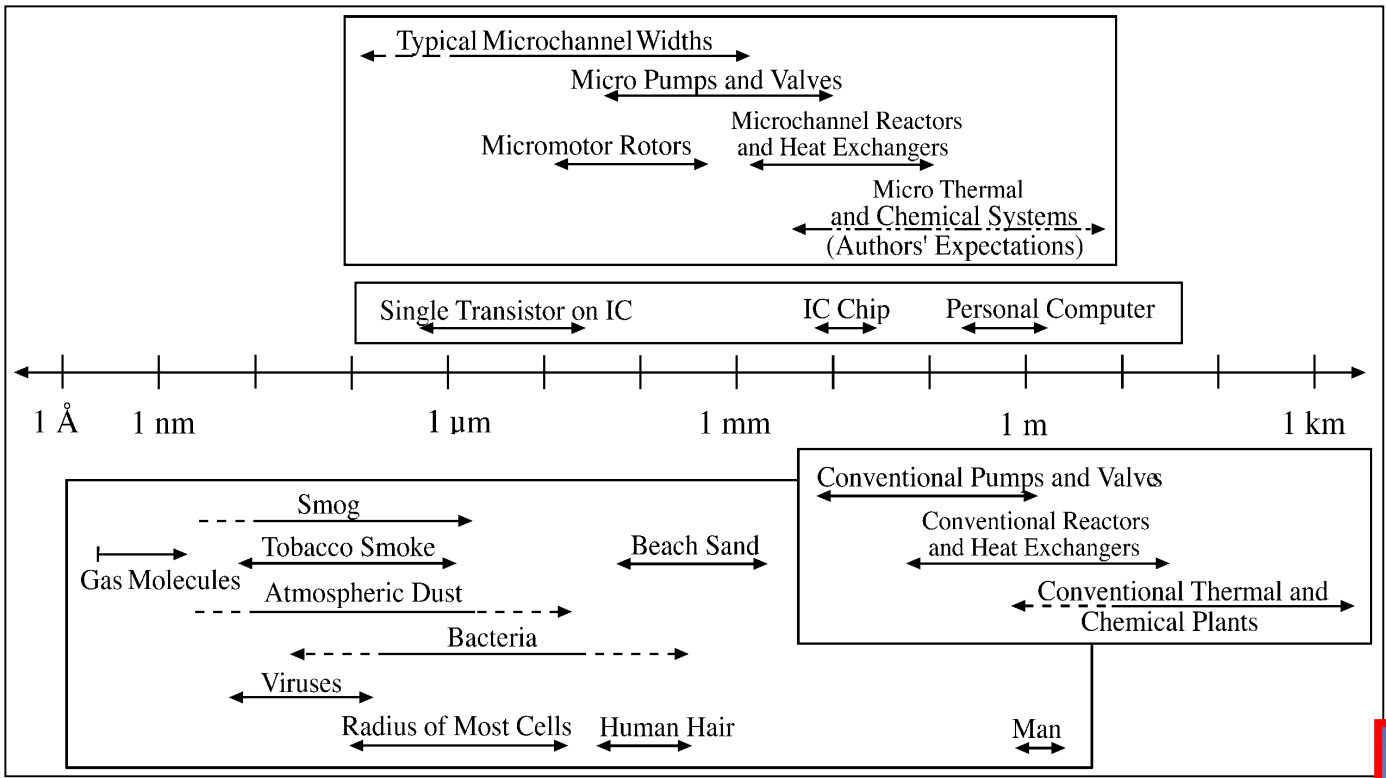
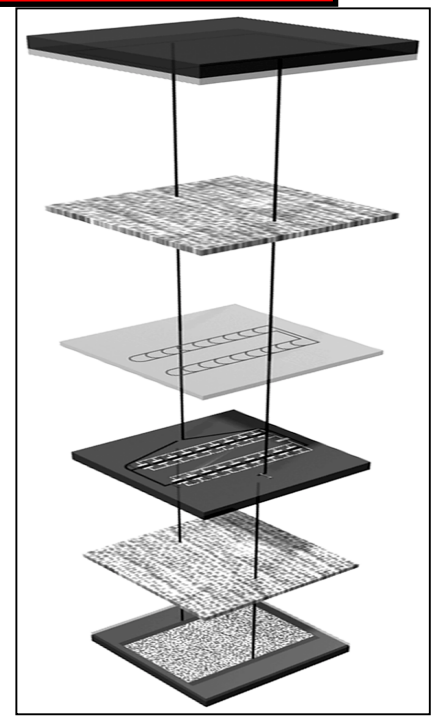
# Motivation

- *Micro-electronics – increased demand for high energy density power supplies*
- *Current Li-ion Batteries*
  - *<0.15kW$_e$-hr/kg*
- *Hydrocarbon fuels*
  - *Diesel = 13.2 kW$_t$-hr/kg*
  - *Methanol = 5.6 kW$_t$-hr/kg*
- *Even at 10% system efficiency a fuel cell with a reformer would have higher energy density than a battery.*

# Microsystems: A New Class of Process Technology



Exploitation of Heat and Mass Transport Advantages in Engineered Microstructures

**Fuel Vaporizer, R&D 100 Award 1999**

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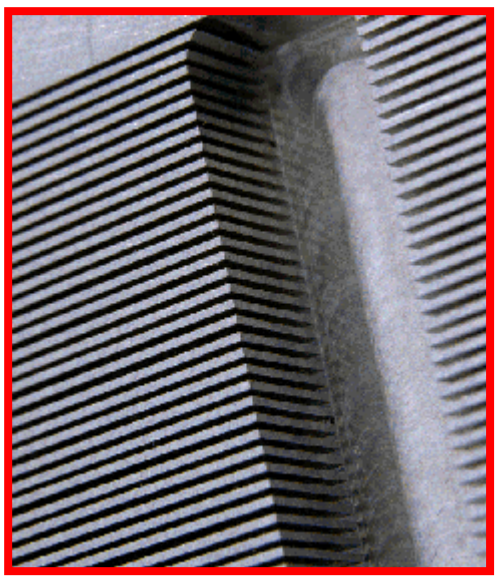
# Microchannel Architecture

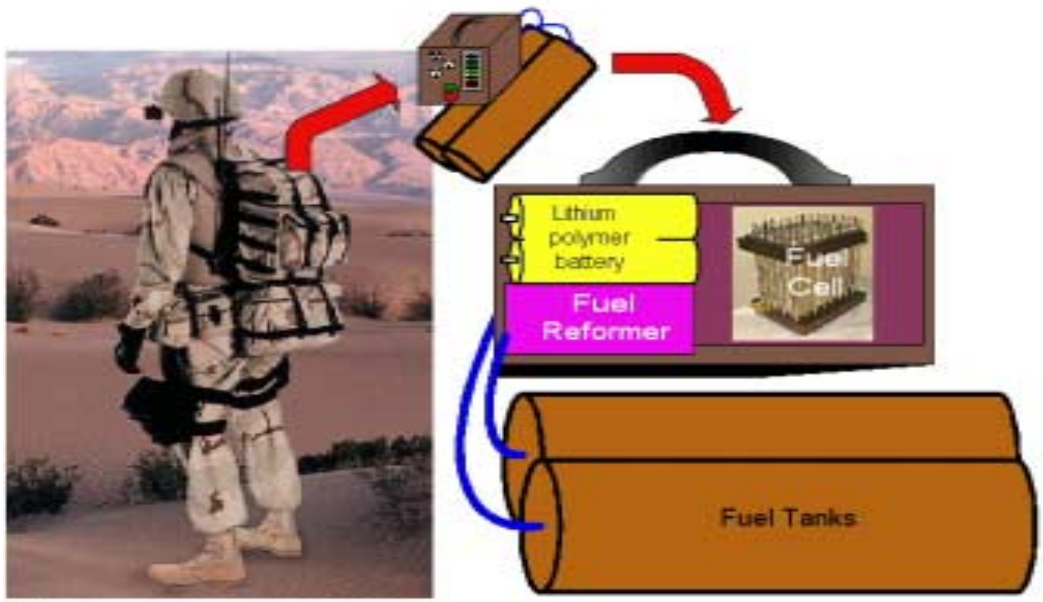


- *Micron-Scale Dimensions*
  - *50-500 μm channels*
  - *high aspect ratios*
  - *negligible pressure drop*
- *Reduced heat & mass transfer resistances*
  - *allows use of more active catalysts*
- *Integrated Monolith Catalysts*
- *Laminate Fabrication Method*

# Soldier Portable Power (SPP): Goals

## Soldier Needs

- *Radio*
- *Laser sights*
- *Sensors*
- *Helmet mounted video display*
- *Video/thermal sights*
- *GPS Receiver*




## *Targets*

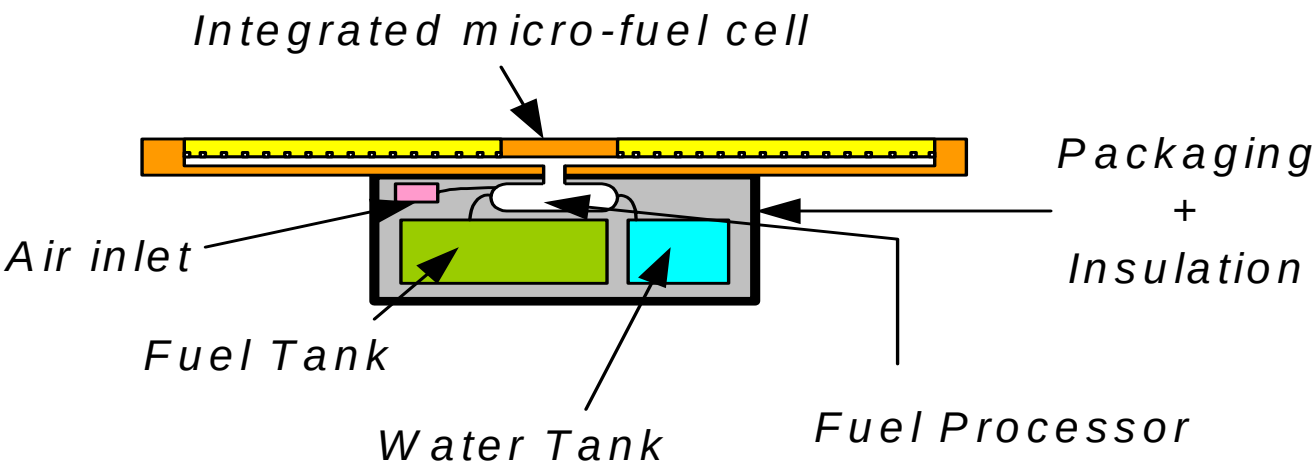
- *15 $W_e$ average,*
- *25 $W_e$ peak*
- *~100 $cm^3$*
- *~ 1 kg (excluding fuel)*

## *Development path*

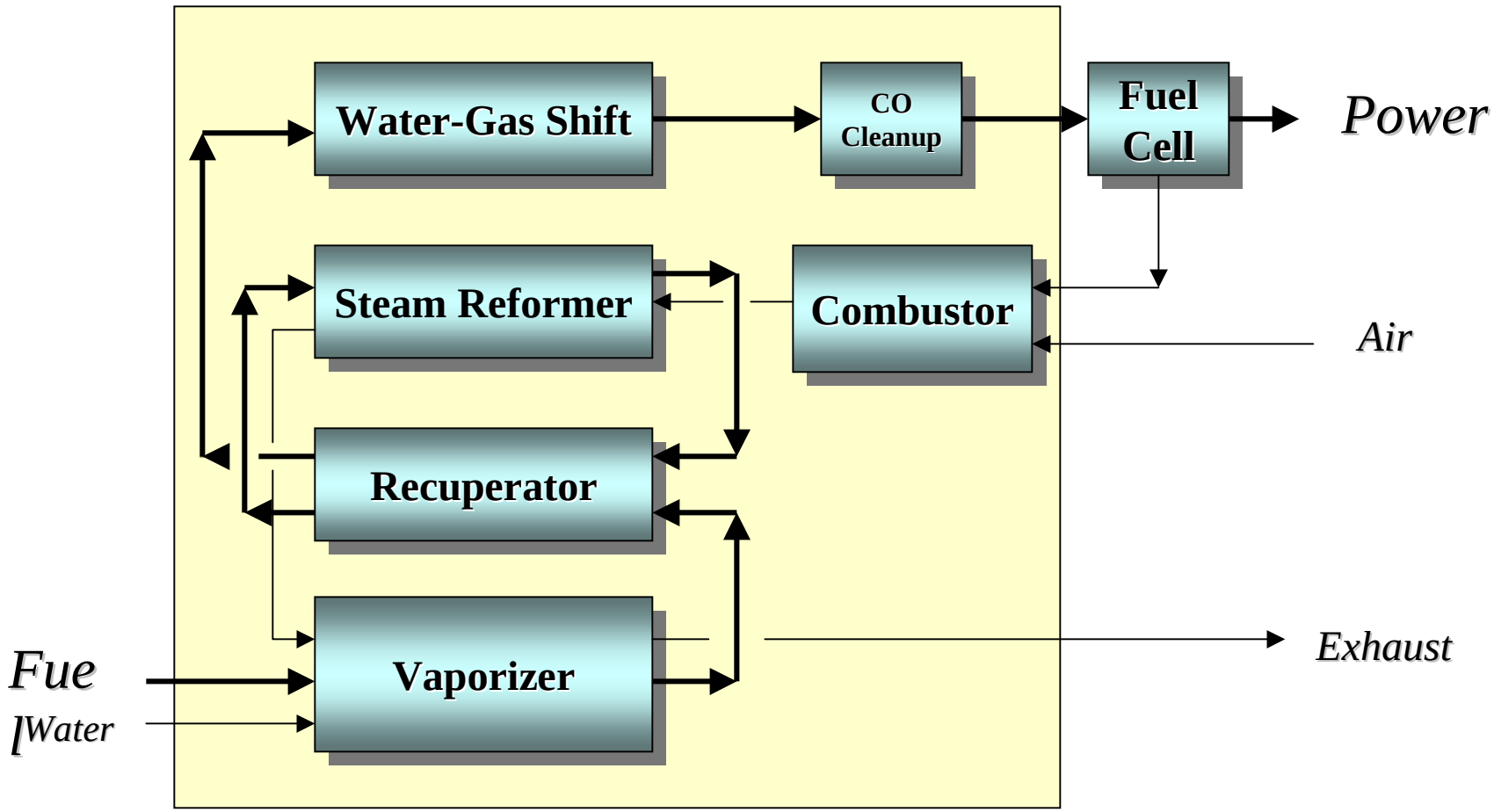
- *Test individual components*
- *Link components*
- *Dis-integrated system demonstration*
- *Integrated device prototype development*

# Sub-Watt Power: Goals

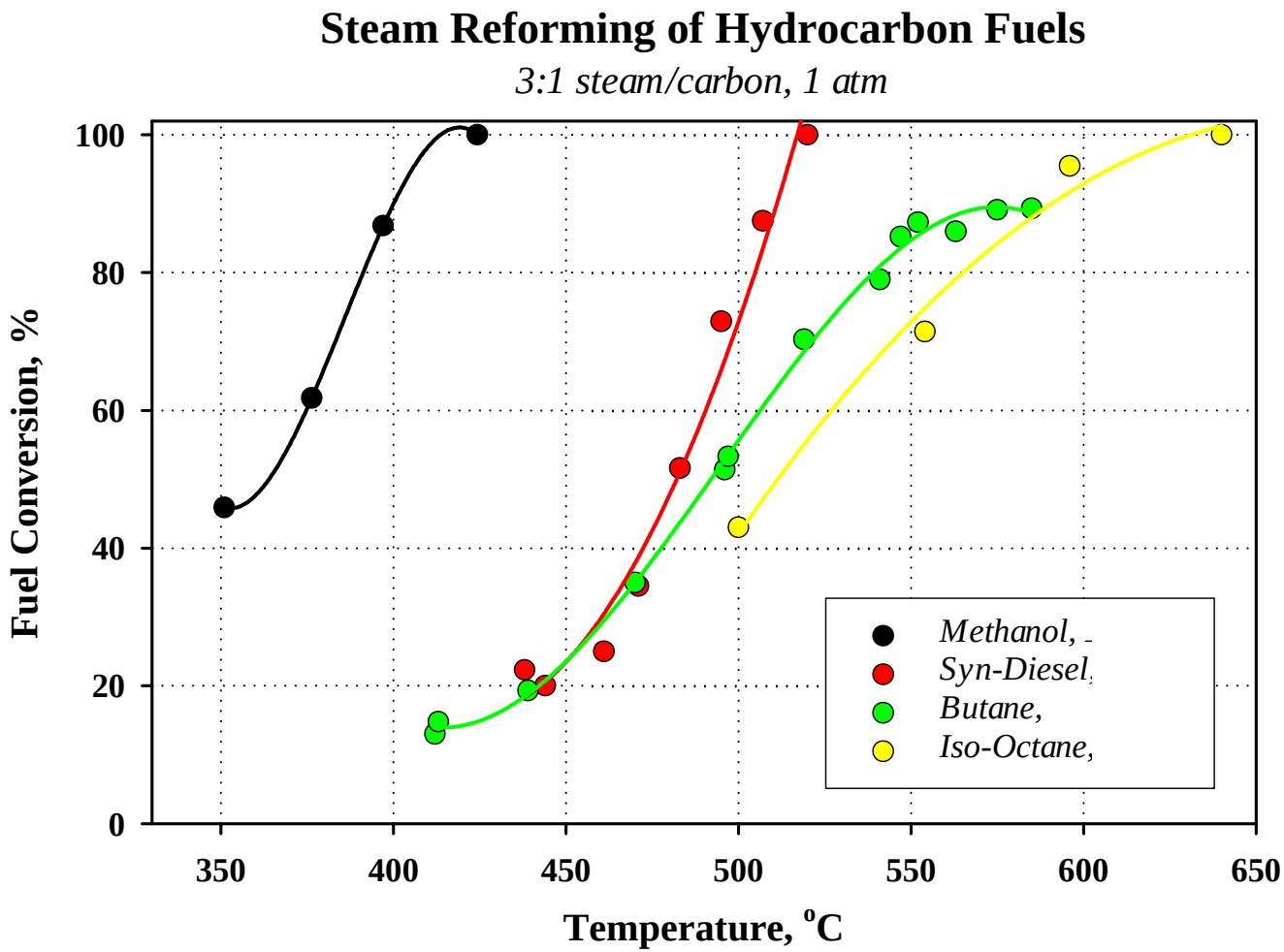
- *Demonstrate 10-100 $mW_e$ fuel processor*
  - *Target- 20% efficiency (not including the fuel cell)*
- *Demonstrate 10-100 $mW_e$ fuel cell. (CWRU)*
- *Demonstrate integrated $mW_e$ fuel processor and fuel cell system.*



# Overall System

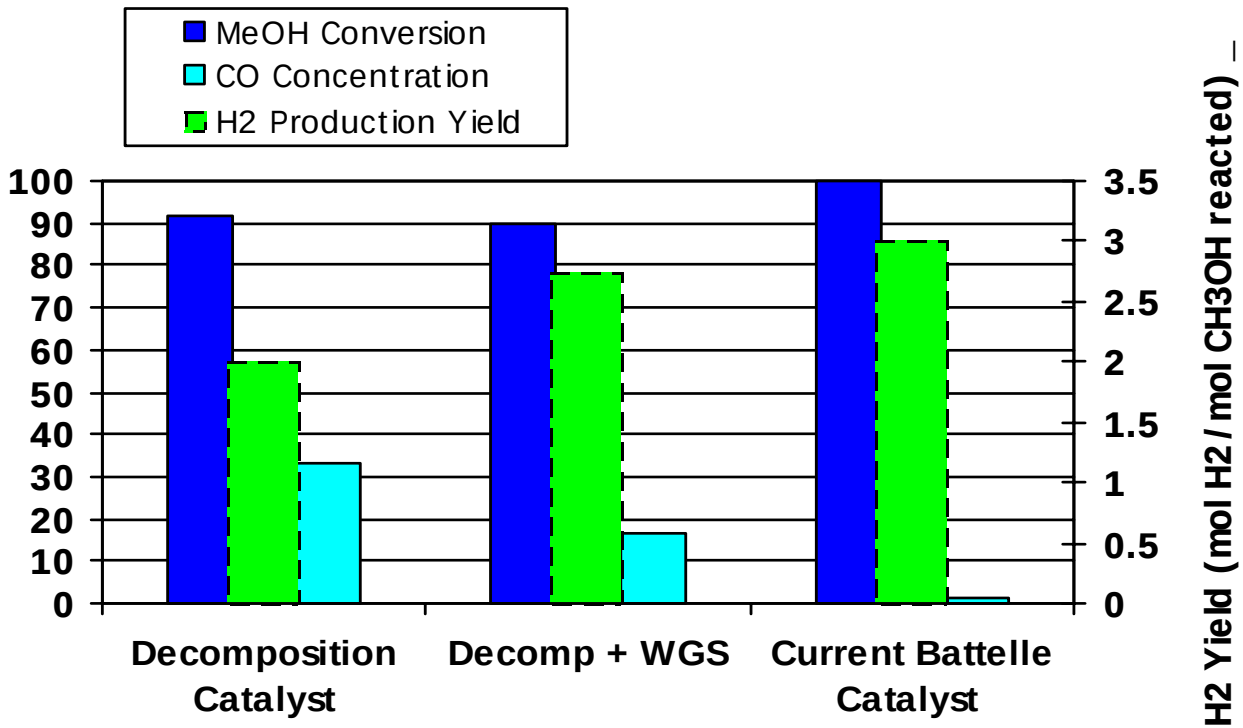


# Multi-Fuel Catalyst Testing- Steam Reforming of Different Fuels



# Methanol Specific SR Catalyst

**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%, dry gas basis) low enough to eliminate the need for WGS*

# Methanol Reforming Reactions

## Water-Gas-Shift Pathway

$$CH_3OH \rightarrow CO + 2H_2$$

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

## Overall Reaction:

$$CH_3OH + H_2O \rightarrow CO_2 + 3H_2$$

## Alternate Pathway

$$CH_3OH \rightarrow HCHO + H_2$$

$$HCHO + H_2O \rightarrow HCOOH + H_2$$

$$HCOOH \rightarrow CO_2 + H_2$$

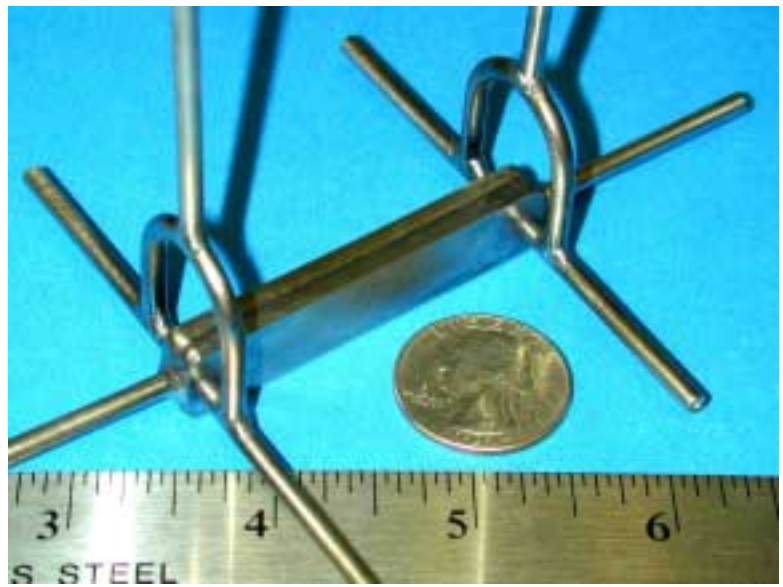
## Overall Reaction:

$$CH_3OH + H_2O \rightarrow CO_2 + 3H_2$$

# SPP: MeOH Integrated SR and CR Performance

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

- *Current system (22.4 $W_e$)*
  - *Fuel/water = 6.6 L*
  - *System weight = 7.3 kg*
  - *Energy density = 1000 $W_e$hr/kg*
  - *Processor efficiency > 75%*
  - *Overall efficiency ~ 39%*




**Weight= 33.2 g (including tubing)**

**Volume= 4.6 cc (excluding tubing)**

**Equivalent Li-ion battery weight at 200 Whr/kg ≈ 37.6 kg**
**(200 Whr/kg is the anticipated Li-ion battery energy density)**

# SPP: MeOH Integrated SR and CR Base Case Performance

*T = 335 °C, P = 1 atm, steam:carbon = 1.8*

- MeOH conversion= >99%
- Dry gas composition
  - $H_2$ = 73-74%
  - $CO_2$ = 24.5-24.7%
  - CO = 1.3-1.5%
- Selectivity
  - to $H_2$ = 100%
  - to $CO_2$ = 95-97%
  - to CO = 3-5%
- $H_2$ Production
  - Flow rate = 260 sccm
  - Thermal power = 46.7 $W_t$ (LHV of $H_2$)
  - Assumptions
    - FC efficiency = 60%
    - FC $H_2$ utilization = 80%
  - Electric power = 22.4 $W_e$

# Soldier Portable Power:

## Summary

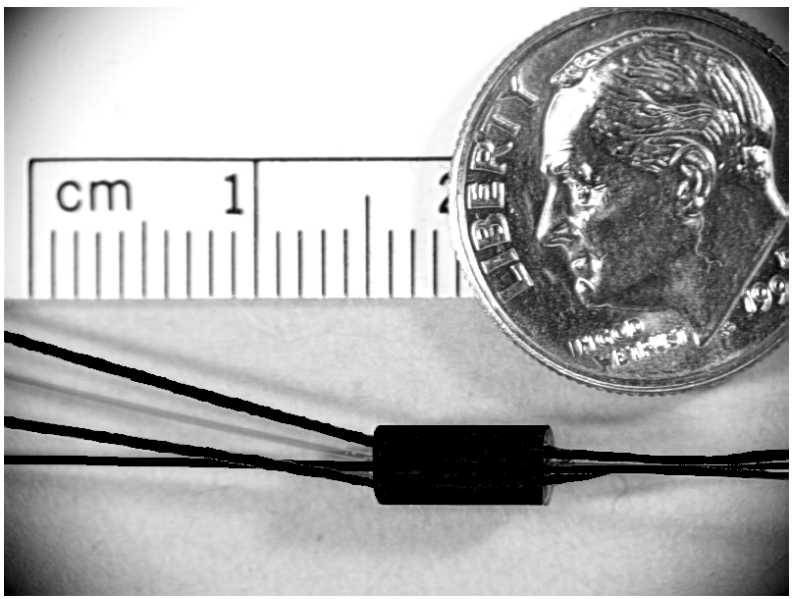
- Low operating temperature: 350°C
- Fuel processor efficiency: >75%
- Low CO concentrations out of steam reformer (<1%)
- Energy density = 1000 W-hr/kg
  - compare to Li-ion battery at ~150-200 W-hr/kg

## Future Work

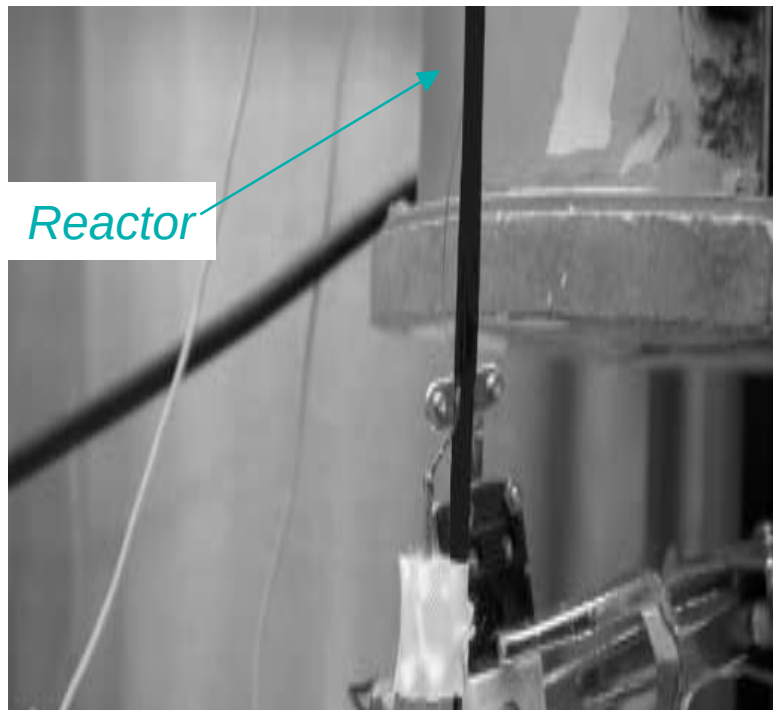
- Integrated prototype with methanol as fuel
- Catalyst life-time testing
- CO clean-up
- Integration of prototype with fuel cell
- Development of synthetic diesel reformer device

# Sub-Watt Power-Fuel Reformer Integrated System

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




*The system was mounted inside a larger tube (0.16") for testing.*




*reformer volume: <5.0 mm³*

*reformer capacity: 200 mW*

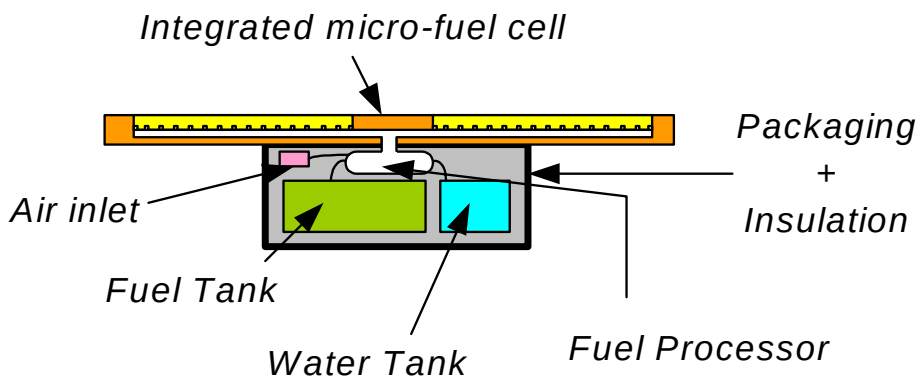
*combustor volume: <5.0 mm³*

*combustor capacity: 3 W*

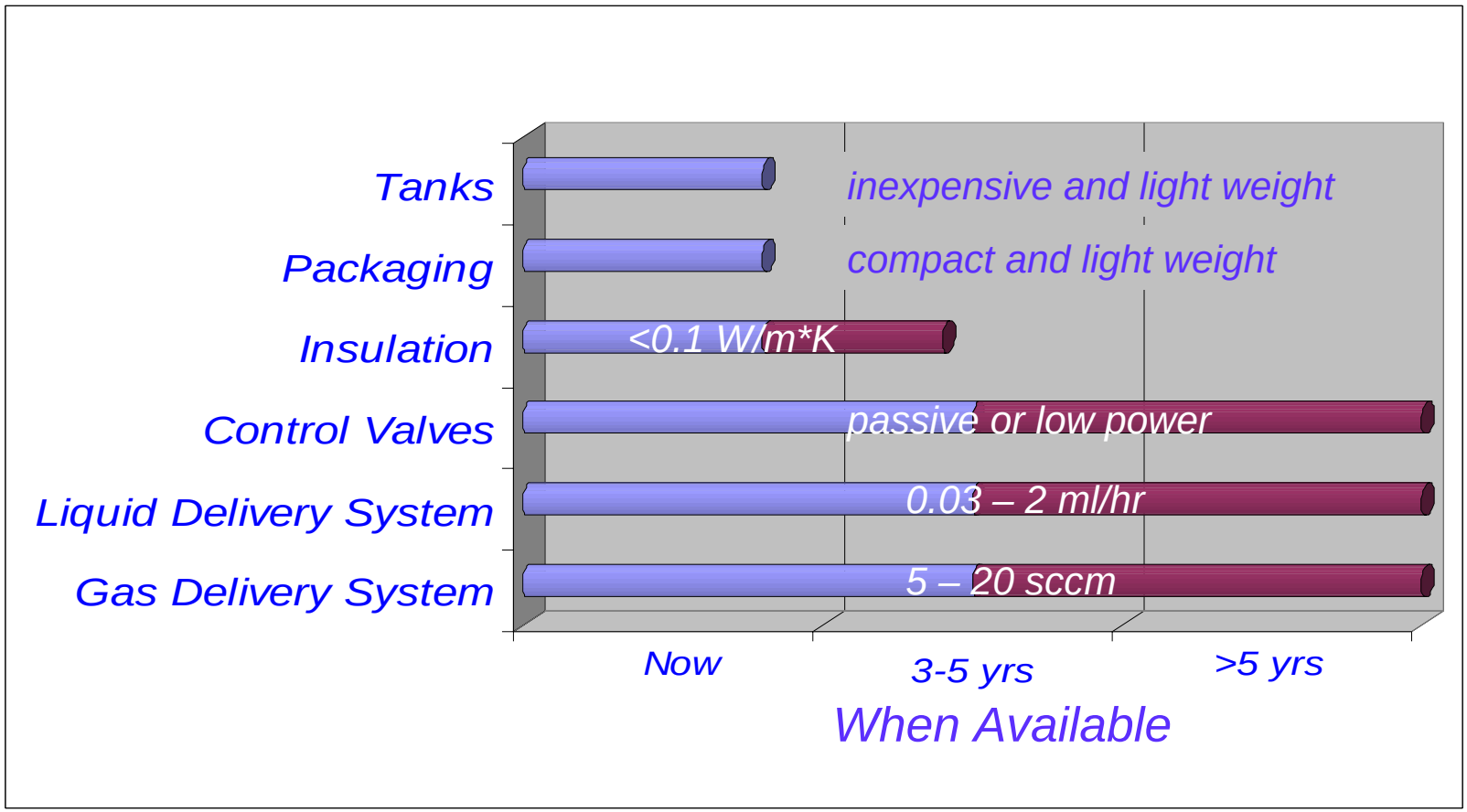
# Sub-Watt Power- Initial Results Reforming Reactor

- *Reactor Output:*
  - *$H_2$ flow = 0.1 –1.1 sccm*
  - *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%*

- *Reactor Conditions:*
  - *Contact time: 50-300 mS*
  - *Temperature: 300-475°C*
  - *Pressure ~ atmospheric*



# Sub-Watt Power: "Balance of Plant*"




*These systems are available for the man portable power project.

# Sub-Watt Power

## Summary

- Sub-Watt device developed
  - Self-sustaining operation attained
  - $H_2$ flow = 0.1 –1.1 sccm
  - Power 18-200 $mW_t$
  - 9 % thermal efficiency
- System development begun

## Future Work

- Reformer design improvements
- Integration with fuel cell
- System development
  - BOP investigation continued

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