# Steam Methane Reforming for Air-Independent Solid Oxide Fuel Cell Systems

2014 Fuel Cell Seminar

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# Fuel Cells at NASA

- Gemini, Apollo, and Space Shuttle used fuel cells as main power source for vehicle and water source for life support and thermal

  PEM (Gemini) and Alkaline (Apollo, Shuttle) fuel cells were used

  Ideal for short (less than 3 weeks) missions when the required O2 and H2 can be launched with the vehicle

- New missions that might require long-duration stays in orbit or at a habitat, cannot rely on the availability of *pure* reactants and should aim to be sun-independent – a problem for which Solid Oxide Fuel Cells might be the answer

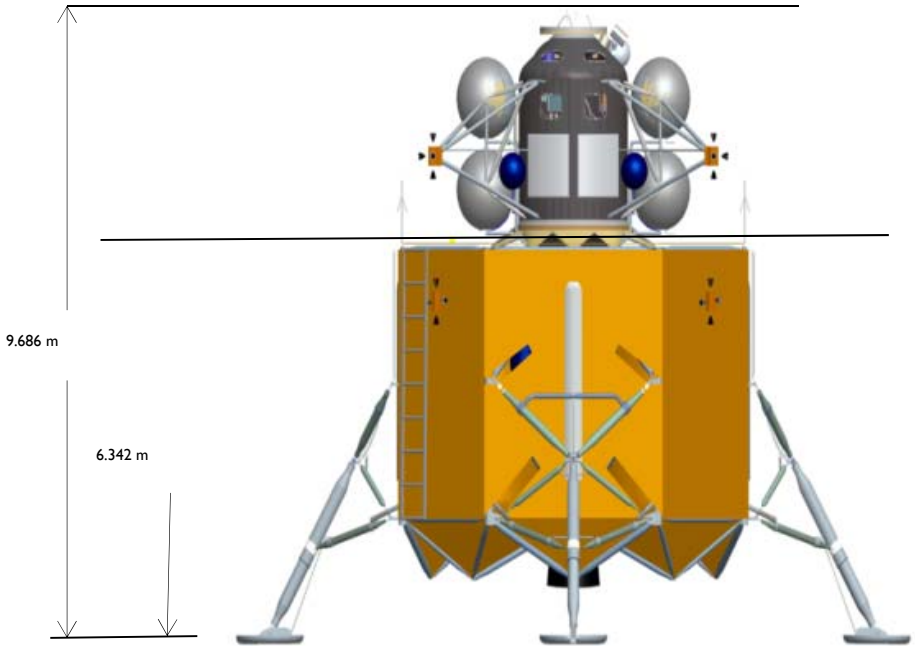
# Solid Oxide Fuel Cells for LOX/CH4 Landers

- Recently, NASA has investigated & developed LOX/$CH_4$-propelled landers (Altair, MORPHEUS). In order to preserve mission flexibility, fuel cells are being studied as a potential power source.

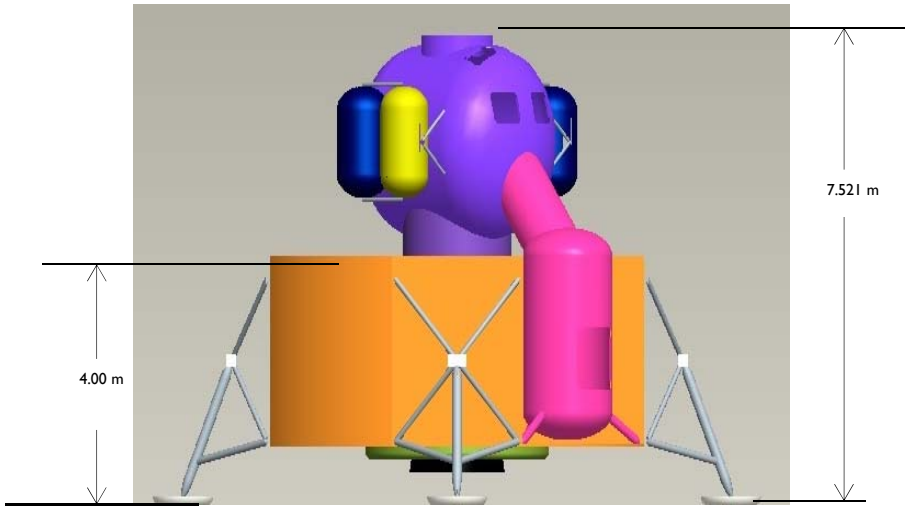
- Much of NASA's fuel cell development has been focused on creating dead-headed, non-flow through PEM fuel cells, which would weigh less and be more reliable than the existing Alkaline and PEM technology; however, LOX/CH4 as a propellant introduces SOFCs as a power option due to their ability to accept "dirty" reactants without much reforming.

# LOX/LH2 Lander vs. LOX/CH4 Lander

- Previous work at JSC has identified the volumetric and mass benefits of LOX/$CH_4$ propelled vehicles vs $LH_2$/$LO_2$




LH2/LO2 Lander Size

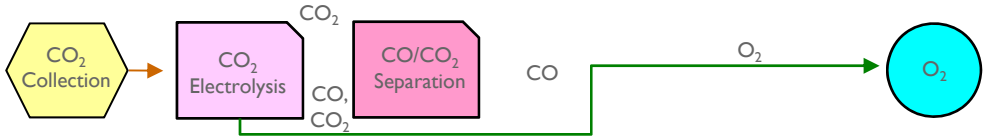



LOX/Methane Lander Size

# Advantages of $O_2/CH_4$ Propulsion

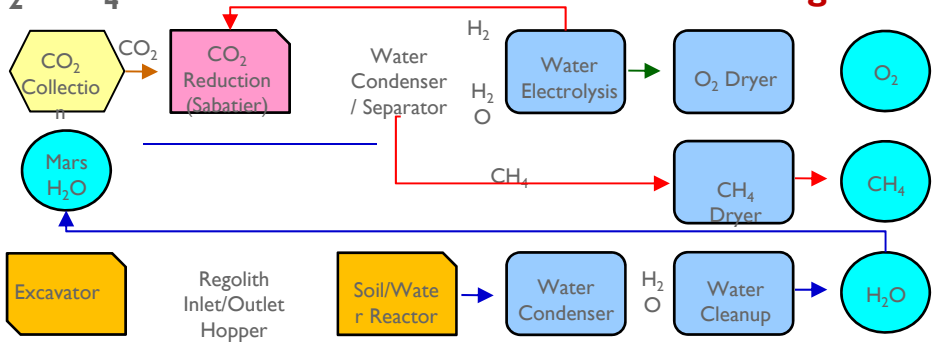
- Improved space storability
- Greatly reduced spacecraft volume
- Utilizes propellants that can be produced In-Situ on the Martian surface (i.e. ISRU)

## $O_2$ Only: Solid Oxide Carbon Dioxide [$CO_2$] Electrolysis (SOCE)




$2CO_2 \rightarrow O_2$ (+ 2CO waste)

## $O_2/CH_4$: Sabatier/WE with Mars Soil Processing

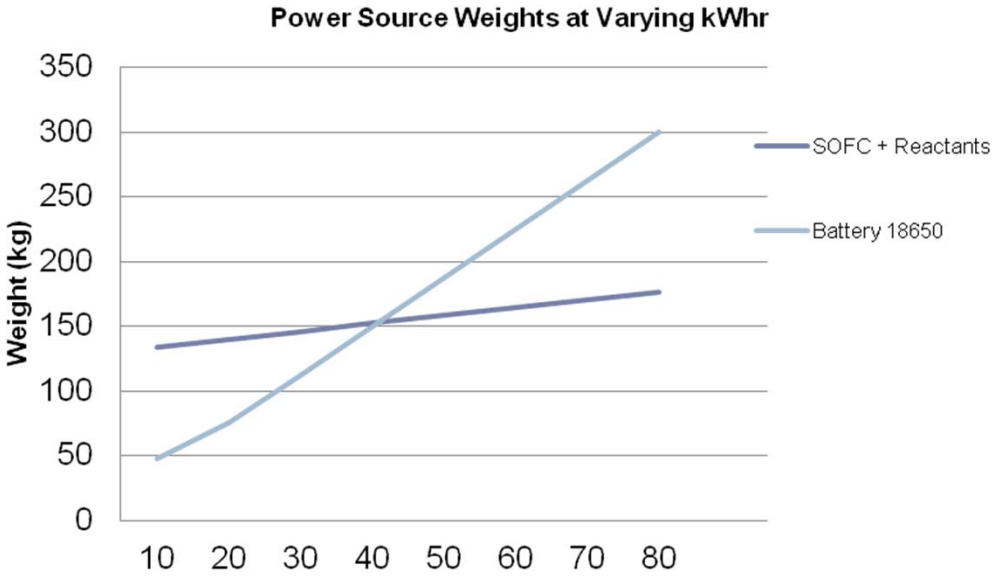


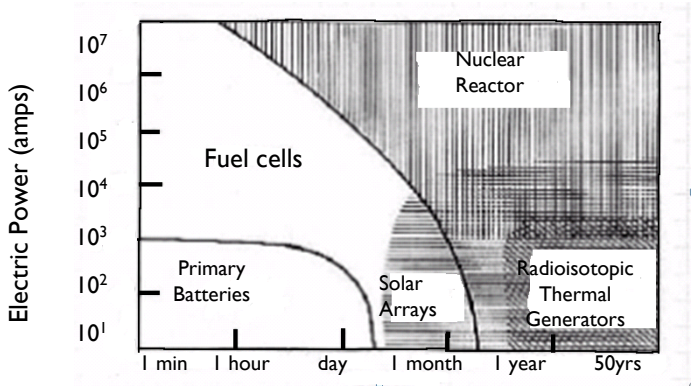

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ & $4H_2O \rightarrow 4H_2 + 2O_2$

$CO_2 + 4H_2 \rightarrow CH_4 + 2O_2$

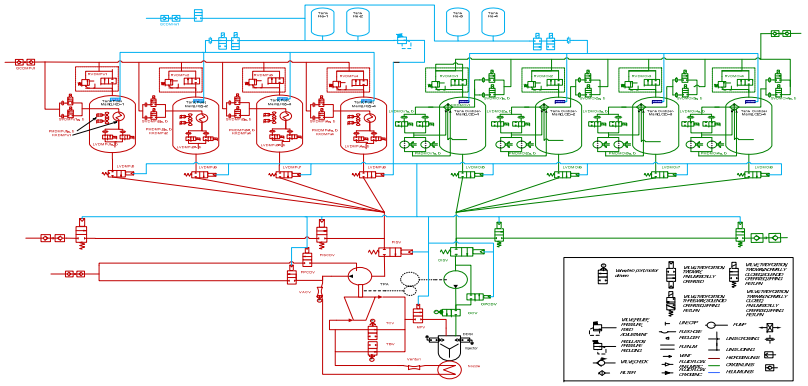
# Fuel Cells as Power Option

- Depending on various mission profiles, different power sources will be desirable.
- For continuous loads of multiple kilowatts for more than a day, fuel cells trade well, particularly with batteries.
- Fuel cells can decrease overall system complexity by tying into ECLSS and Active Thermal systems
- In order to preserve mission flexibility, provide multiple kilowatts of power, and be sun-independent, fuel cells should be considered as a power source for manned-spacecraft.

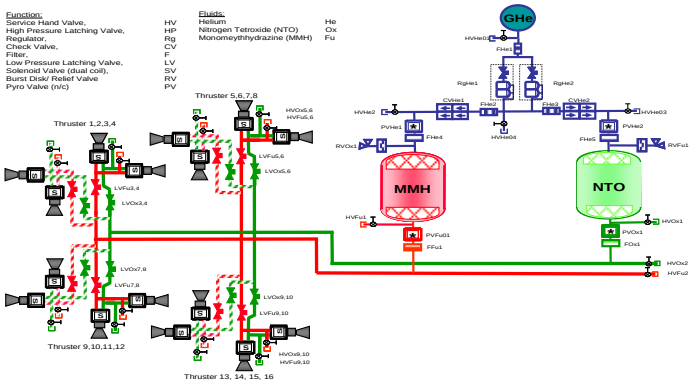


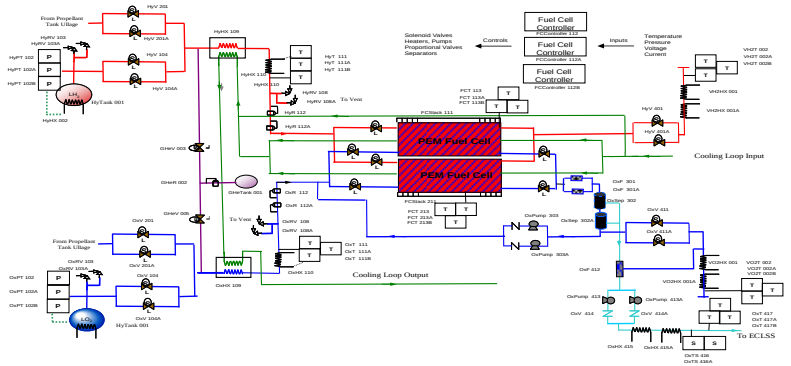
# Separate Lander Systems



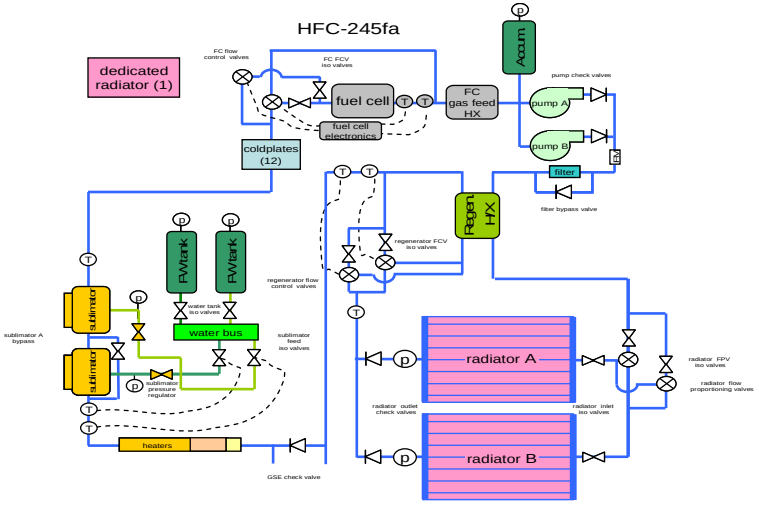
**Main Prop**




**RCS**

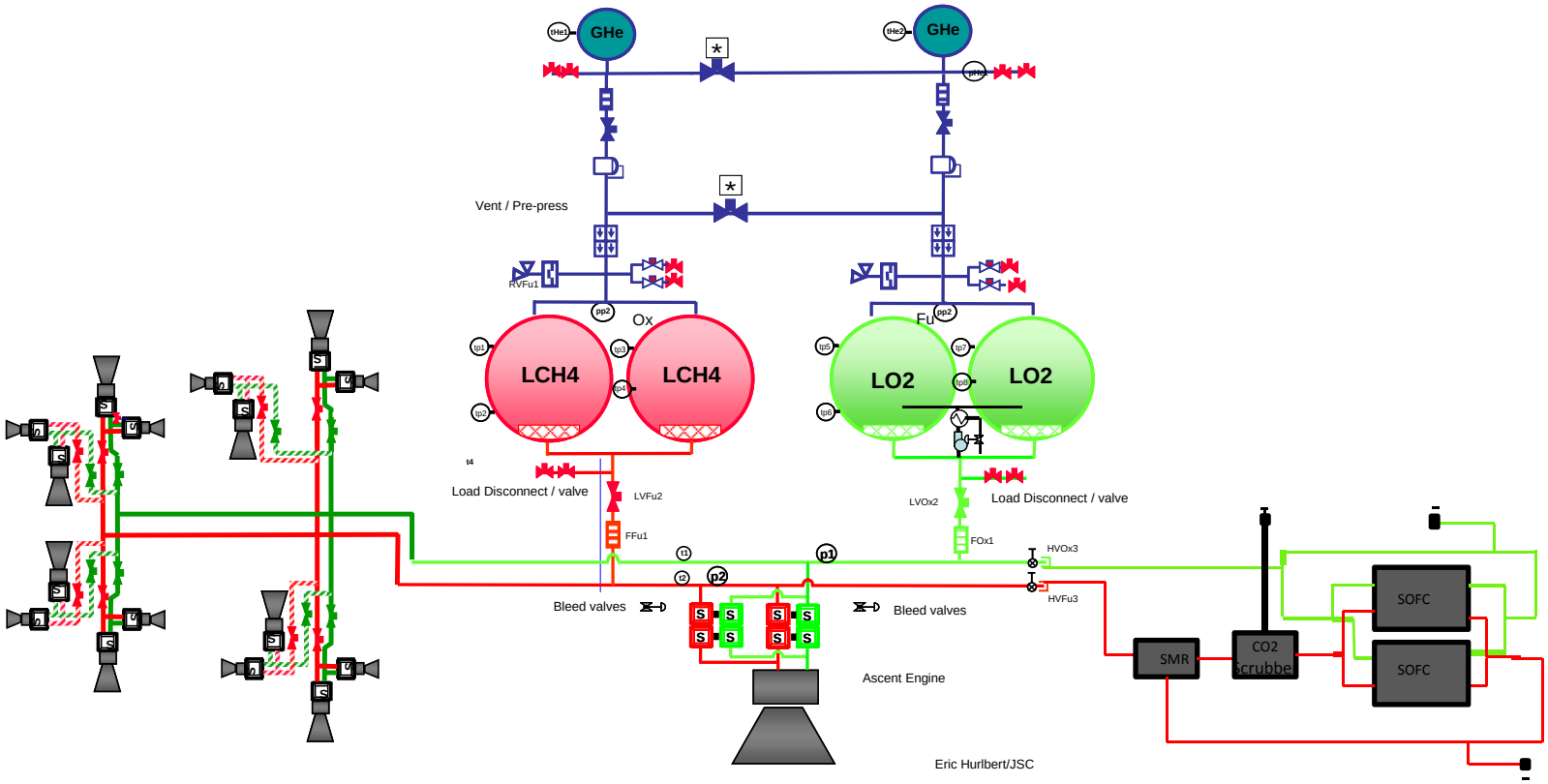



**Power**




**Thermal**

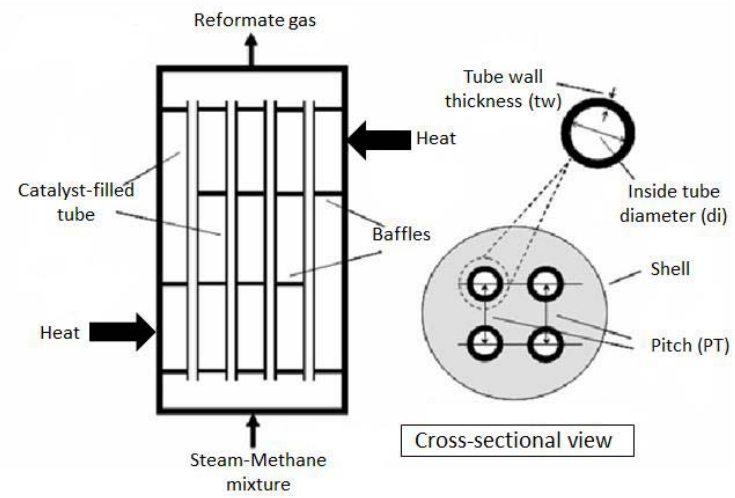
# Integrated Propulsion and Power System



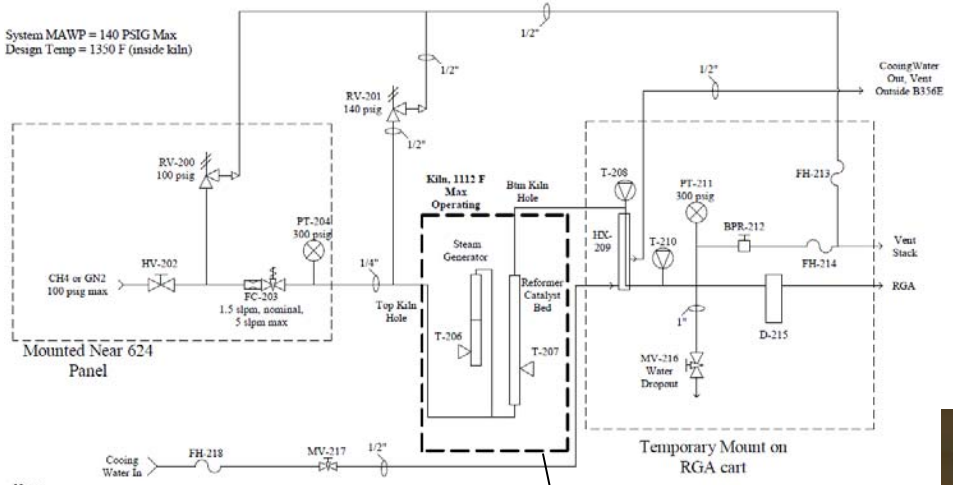
# SOFCs at NASA JSC

- NUWC has shown viability of air-independent SOFCs using oxygen and a methane-rich fuel source via PROX-reforming, which uses 25% more of the $O_2$ required for power production
- Testing and characterizing a steam reformer output flow is first step to creating a more $O_2$ efficient and dead-headed SOFC system

30-cell stack




# SOFCs at NASA JSC




Gas concentrations (after water has been dropped out)
48% H2
27% CH4
22% CO
3% CO2

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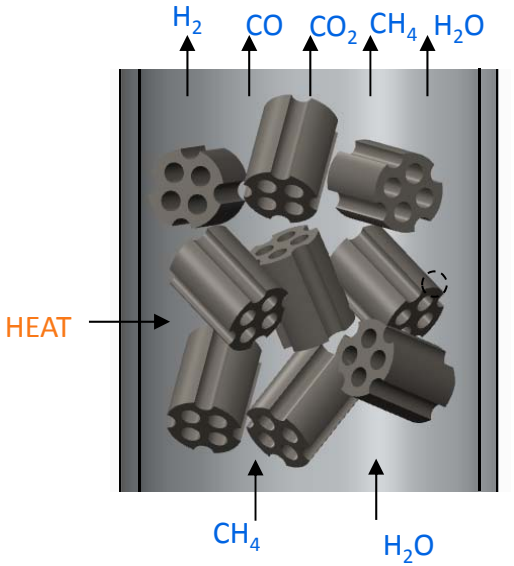
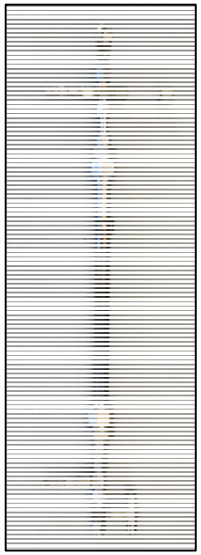
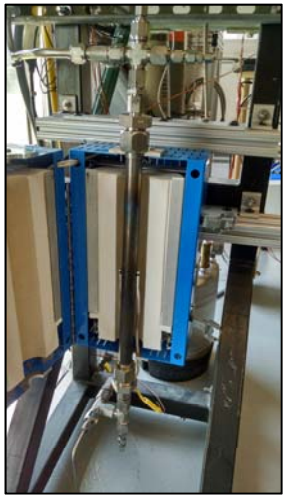
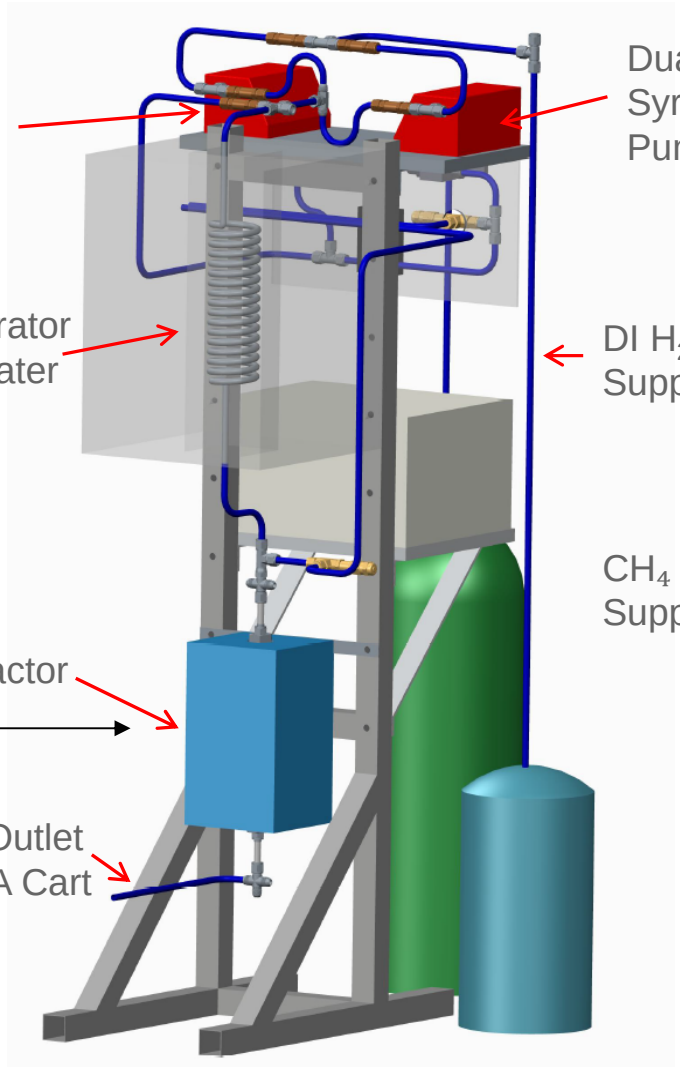
# Improved Test Stand Design





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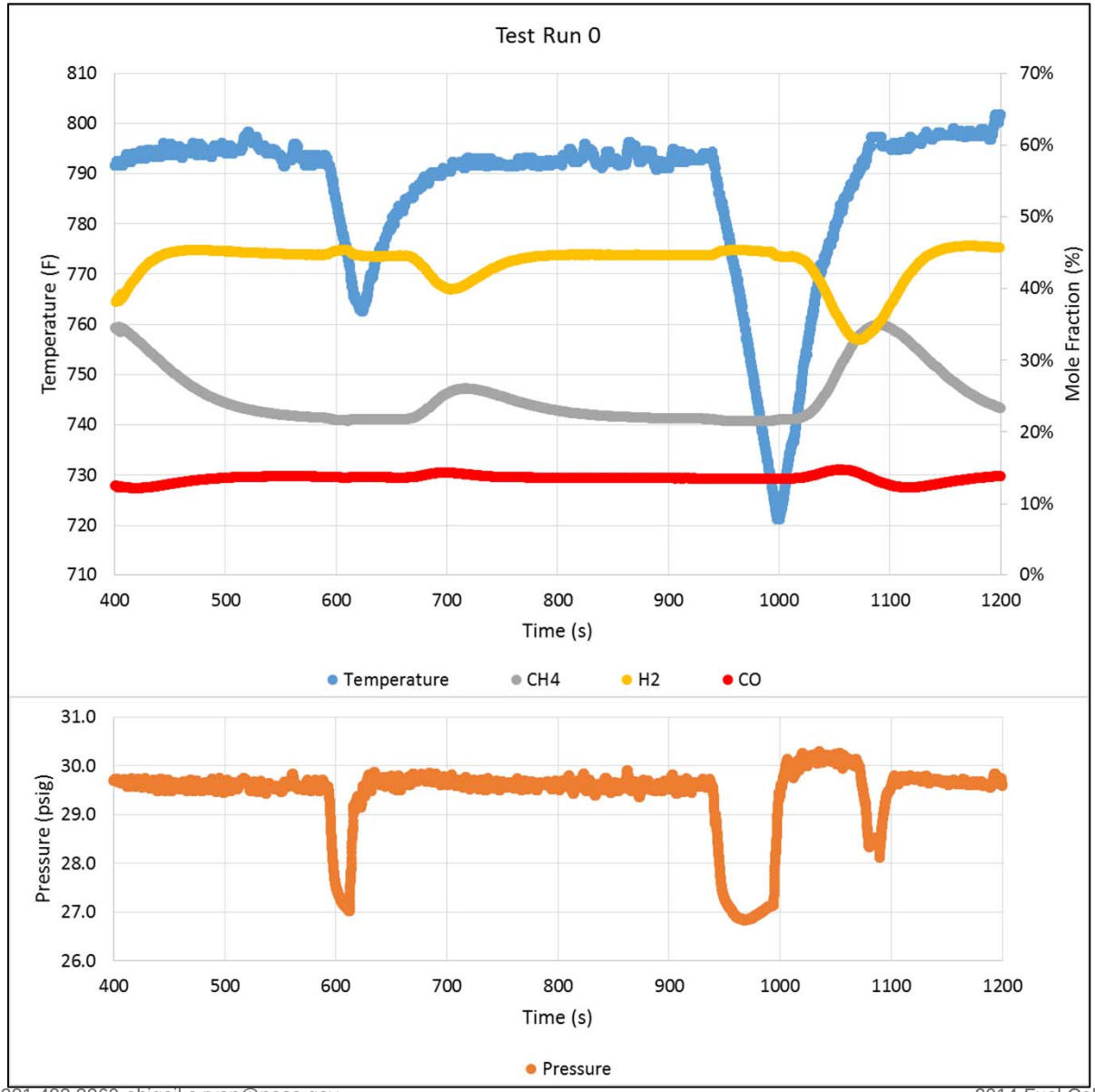
# Initial Results



# Initial Results

Initial testing shows that:

- Catalyst is not sufficiently reduced

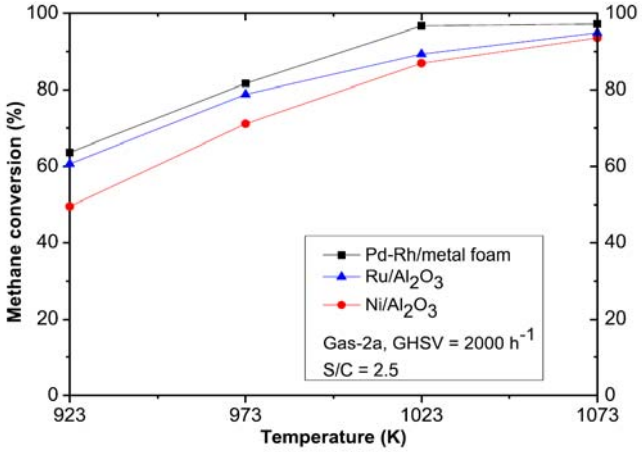
$$NiO + H_2 \leftrightarrow Ni + H_2O$$

- Need to increase thermal mass to heat up fluids to design temperatures
- Need to minimize hotspots that promote carbon deposition

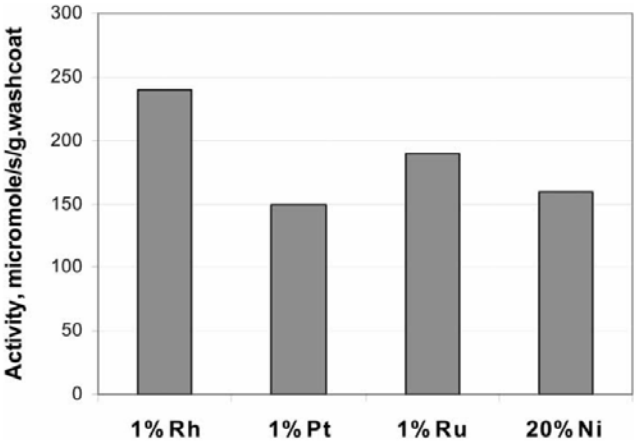
# Switching Catalysts: Metal Foam

| Heat Transfer | Mass Transfer |
|---|---|
| Higher thermal conductivity minimizes temperature gradients & hot spots | Porous structure provides more tortuous path for gas molecules |
| Helps favor the reactions we want and prevent those we don't | Better dispersion of the active metals coated on the metal foam structure |

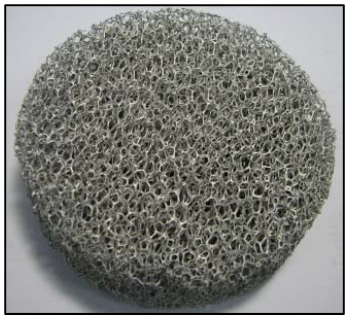
## More active noble metals for better conversion efficiency:




$CH_4$ conversion vs. temperature for different catalysts [5]




Catalyst activity for SMR as a function of wt% active metal [1]



Ordered Pd/Rh coated SIC metal foam catalyst, machined to SMR physical dimensions with through-hole for high temp temperature probe

# Future Work: SOFCs at NASA

**WSTF Simulated Altitude Testing**

First demonstration of SOFC at altitude, integration of Lox/LCH4 main propulsion and RCS integration at altitude

**Integrated Power and Prop**

TA 2: Milestones to LOx/CH4 TRL 6 - Perform system-level integration and test of the component technologies

**All-composite tank qualification test**

TA 12: Integration of composite tank technologies

**SOFC Space Power Profile**

TA 3: SOFC integrated test on space power profile is needed

**Sea-level integrated Main & RCS testing**

ECI Proposed demonstrations

JSC Investments and Leveraging

**EP-funded work on SOFC reformers, SOFC system build up**

**Deep Throttle Engine Development Testing**