Air-Independent Solid Oxide Fuel Cells for NASA's LOX-CH_4 Landers

2013 Fuel Cell Seminar

Abigail C. Ryan/NASA JSC
Koorosh R. Araghi/NASA JSC
Serene C. Farmer/NASA GRC

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 but should also aim to be sun-independent – a problem for which Solid Oxide Fuel Cells might be the answer

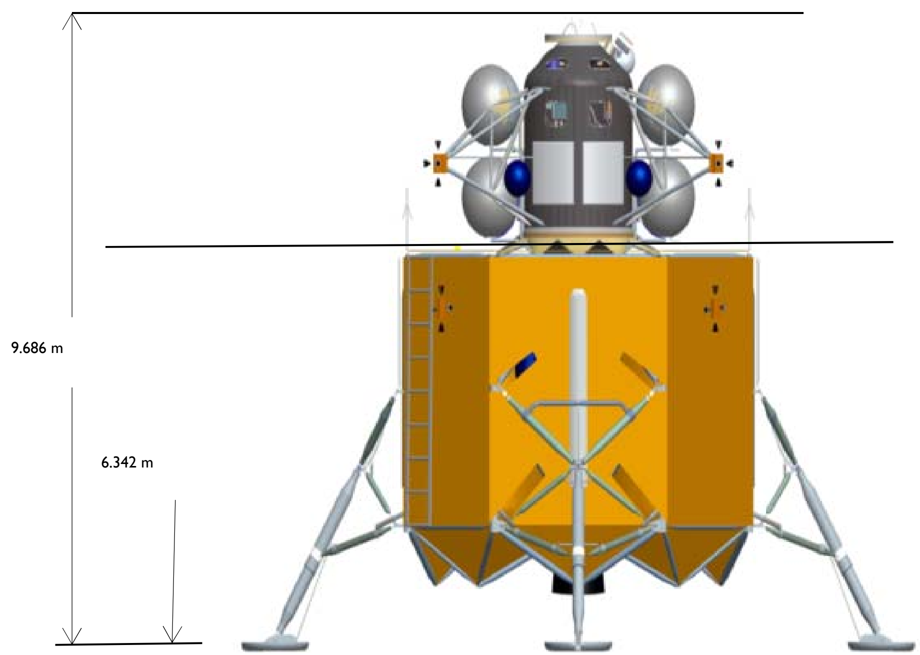
Solid Oxide Fuel Cells for LOX/CH4 Landers

- 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.

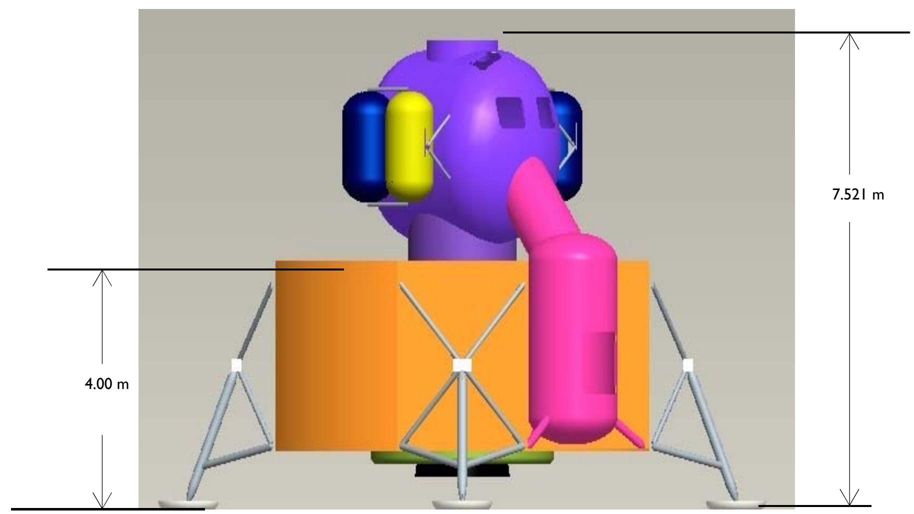
- Much of NASA's fuel cell development has been focused on creating a dead-headed, non-flow through PEM fuel cells which would weigh less and be more reliable than the existing Alkaline and PEM technology; however, LOX/CH4 as a propellant introduces SOFCs as a power option due to their ability to accept those 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

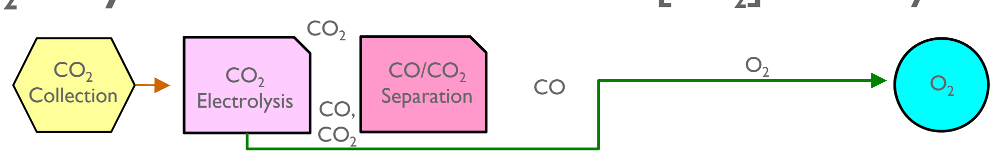


LOX/Methane Lander Size

Advantages of O_2/CH_4 Propulsion

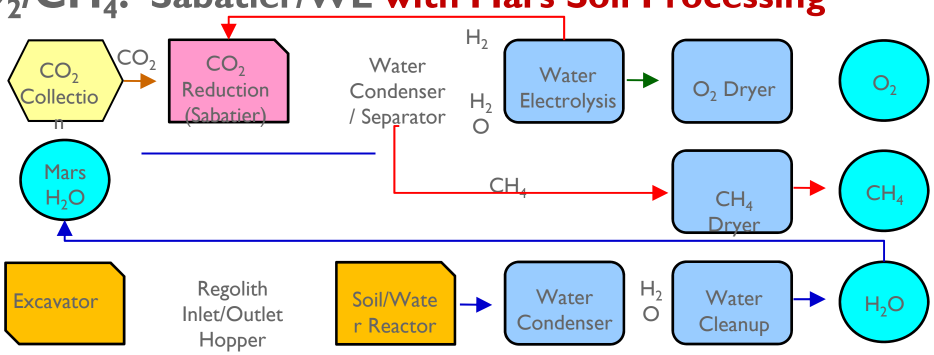
- Improved space storability
- Greatly reduced spacecraft volume
- Utilizes propellants that can be produced In-Situ on the Martian surface (i.e. ISRU)

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



$2CO_2$ O_2 (+ 2CO waste)

O_2/CH_4: Sabatier/WE with Mars Soil Processing

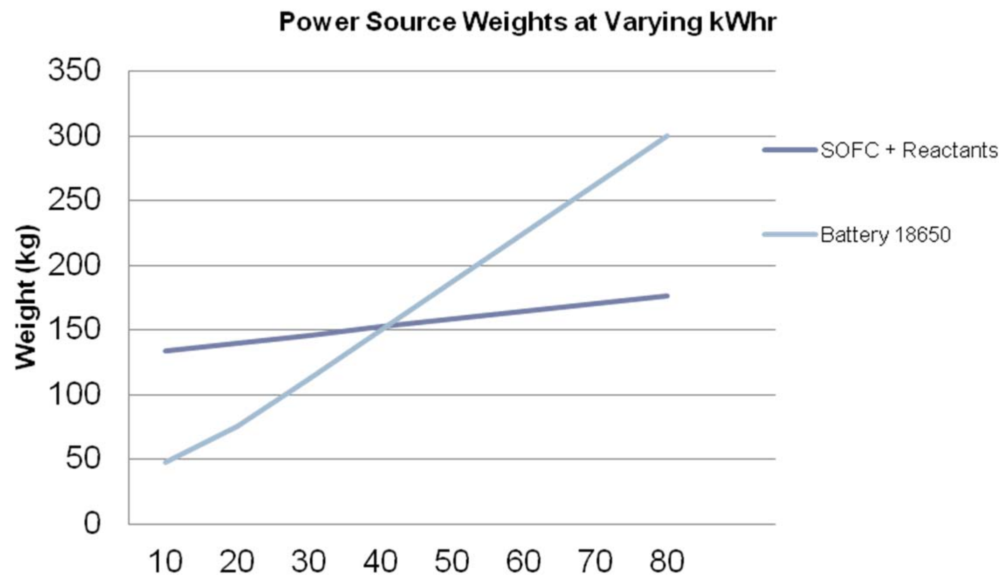


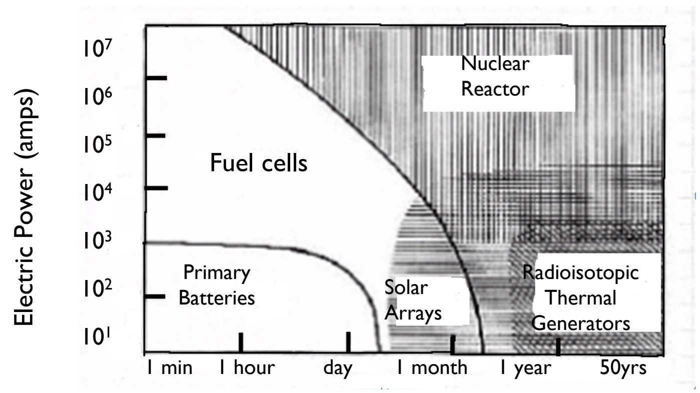
$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ & $4H_2O \rightarrow 4H_2 + 2O_2$

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

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.





PEMs vs SOFCs

Chemistry	Proton Exchange Membrane (PEMFC)	Solid Oxide Fuel Cell (SOFC)
Fuel Capability	H_2 from “clean” reformate	CO & H_2 from “dirty” reformate
Operating Temp	~80°C	~800°C
Quick start?	Yes	No
Operating Life Limiter	Humidity Control	Thermal Cycles
Pros	• Higher TRL for spacecraft • Space flight experience • Easily contained and useable water for ECLSS • Bootstrap Start • No issues with load swings	• Less sensitivity to reactant purity/high carbon content • High quality waste heat • Smaller reforming system • No active cooling required
Cons	• Larger radiator required • Active cooling required • Larger powerplant • Multi-stage reformer required •Water management	•Start-up/cool down ~3hrs long • Possibly requires a battery • Lower TRL, no space flight

PEM vs SOFC Weight Trade

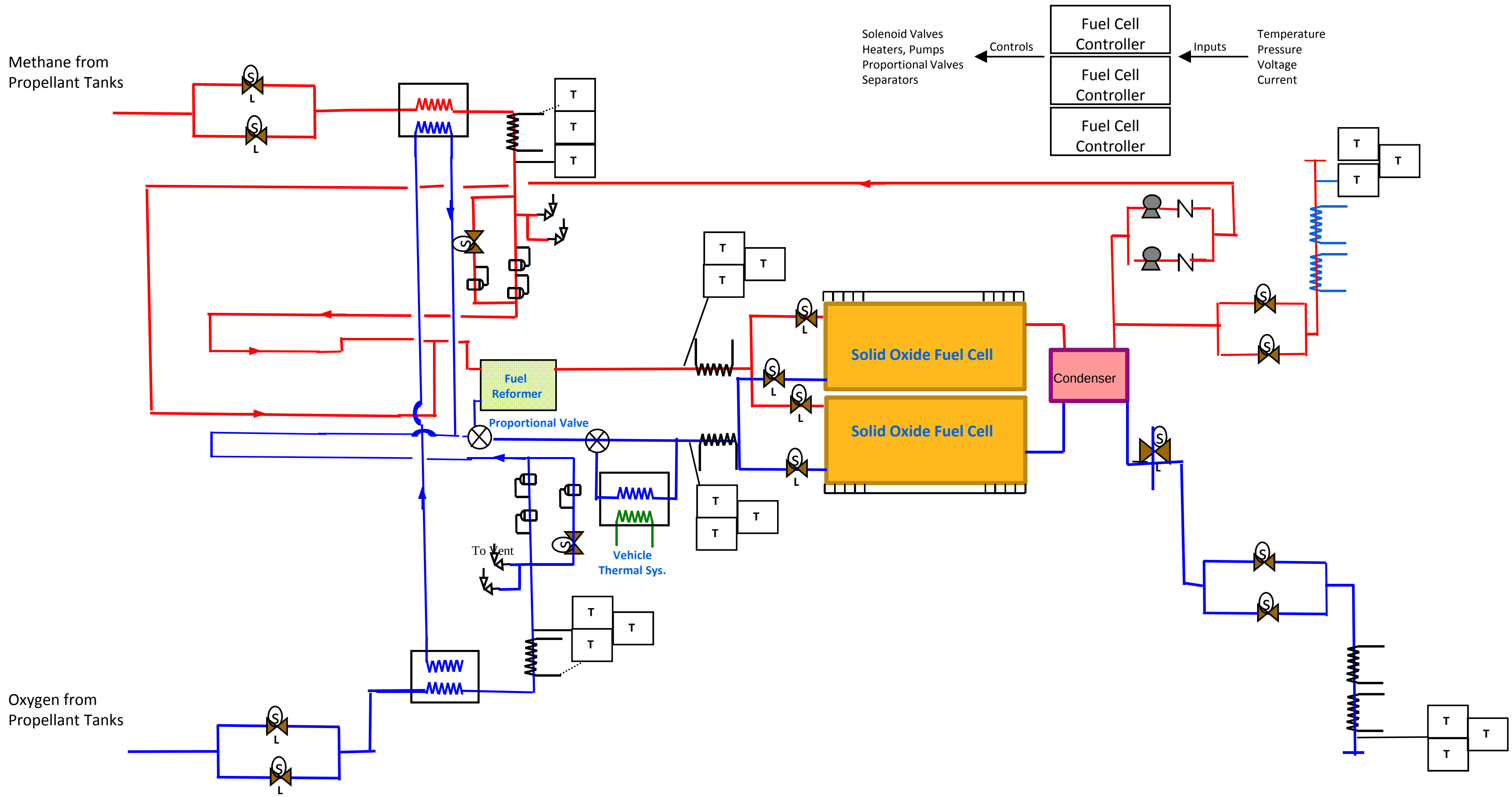
Mass Summary			
Description Powerplant and radiator weights are based on having two stacks for redundancy. Reactant weights could vary greatly based on efficiency of reformer/system. Based on 3kW for 14 days	PEM NFT FC using Pure H2	PEM NFT FC using Methane	SOFC Steam Reformer without Water Recovery
Fuel Cell Power Plant Mass (kg)	145	166	128
Stacks + BoP (kg)	145	147	88
Reformers (kg)	0	19	10
Steam Condenser (kg)	0	0	30
Cooling (kg) - Active	164	164	0
Methane (kg)	0	200	200
Oxygen (kg)	430	430	473
Pure H2 Plus tank (kg)	200	0	0
Waste Heat (W)	1780	1780	640
Battery (if needed) (kg)	0	0	10
Sub-Total Power Source (kg)	**939**	**960**	**811**

Residual Scavenging

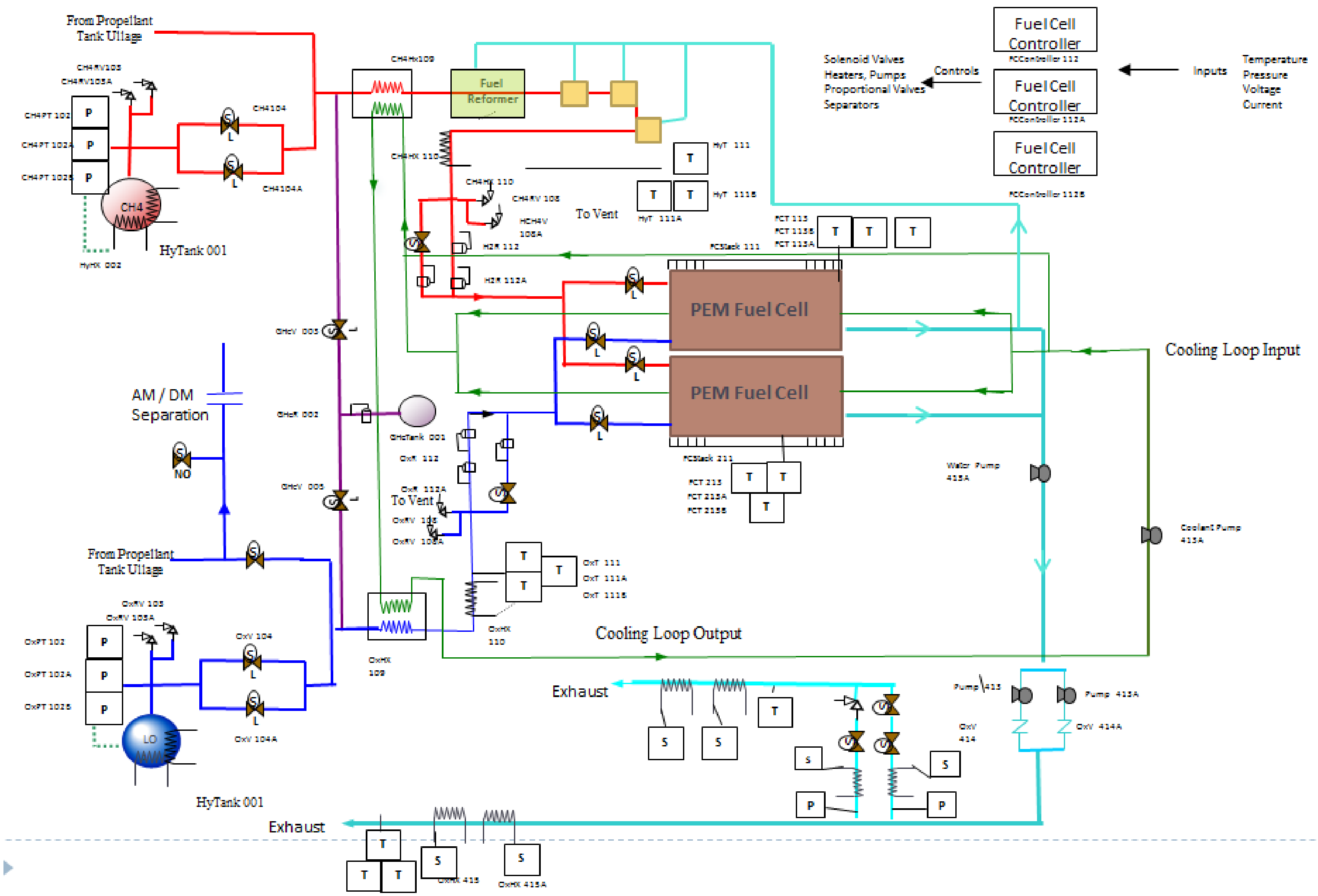
- Based on propellant calculations for the notional MOPHEUS (3kW for 14 days) mission, residuals can cover some fuel cell reactant weight

	SOFC	**PEM**
Reactant Need Minus Residuals	260 kg O2 136 kg CH4	214 kg O2 136 kg CH4
Oxygen Tank Growth	.3m^3 or 300L	.25m^3 or 250L
Methane Tank Growth	.4m^3 or 400L	.4m^3 or 400L
Added H2 Tank	.5m^3 + added structure & tubing	.5m^3 + added structure & tubing

System Complexity: SOFC



System Complexity: PEM



Abigail C. Ryan/NASA JSC 281.483.3260 abigail.c.ryan@nasa.gov

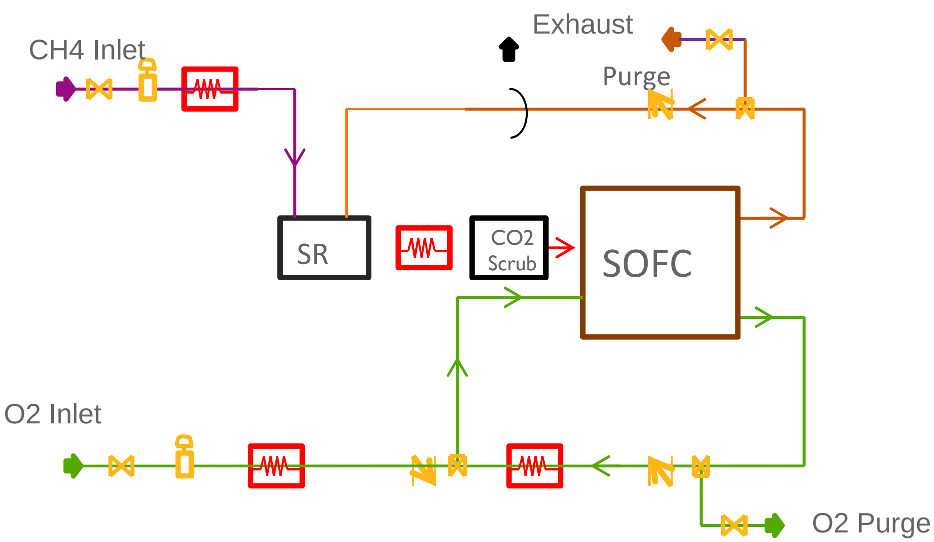
SOFCs at NASA

- Have fostered working relationship with ONR and NUWC; leveraging their previous air-independent SOFC work
- Acquired both a 1kW stack and a PROX reformer from NUWC
- Creating at JSC an SOFC system build up and test plan while learning about system-level integration with various NASA projects (MORPHEUS, ISRU)
- Materials research underway at GRC to create a stack designed for the rigors of space travel (load swings, vibration, cycling, etc)

SOFCs at NASA

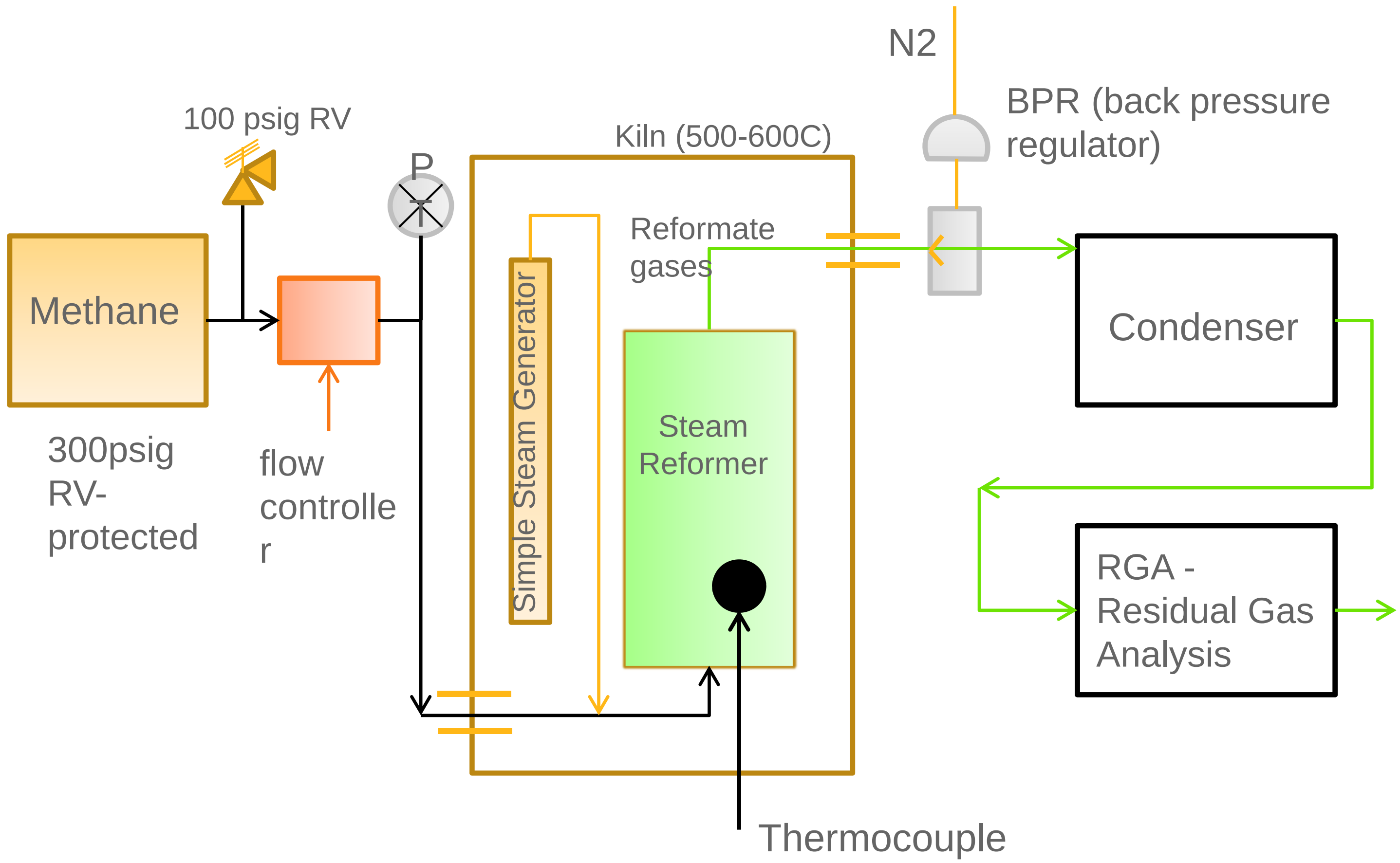
- NUWC has shown viability of air-independent SOFCs using oxygen and a methane-rich fuel source via PROX-reforming, which uses 25% more of the O_2 required for power production
- Testing and characterizing a steam reformer output flow is first step to creating a more O_2 efficient and dead-headed SOFC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

30-cell stack



SOFCs at NASA

- Proposed steam reformer test at JSC to analyze and optimize steam reformer performance



Future Work: SOFCs at NASA

- From testing the steam reformer with various steam to methane ratios, we can use the RGA to determine the correct mixture for maximum hydrogen production.
- JSC will then use this information to test a full SOFC system which uses its own water production to reform incoming methane into a hydrogen-rich stream
- Successful tests with the steam reformer would demonstrate a system that would require less Oxygen needed for SOFC operations (compared to using a PROX reformer) and make the SOFC option less massive and voluminous.