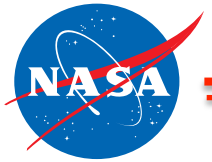

NASA Non-Flow-Through PEM Fuel Cell System for Aerospace Applications

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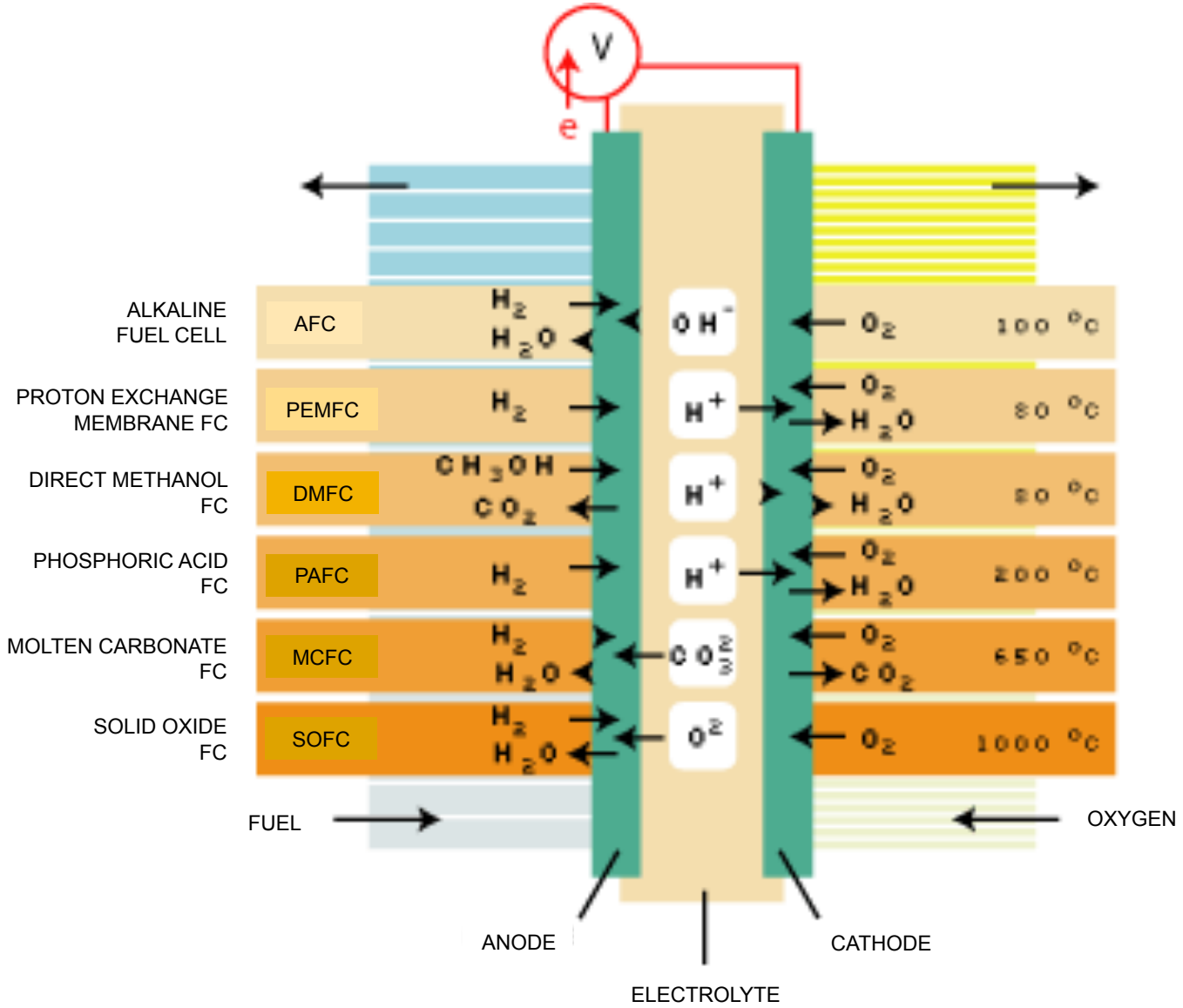
Overview

- Basic PEM Fuel Cell
- NASA PEM Fuel Cell Development History
- Top-level comparison of aerospace fuel cell systems: Flow through vs. Non-Flow-Through (NFT)
- Recent NASA Fuel Cell Development Activities
- Details of NFT Fuel Cell systems
- Testing and Test Results of NFT fuel cell stacks
- Future Activities
- Summary

Major Fuel Cell Types

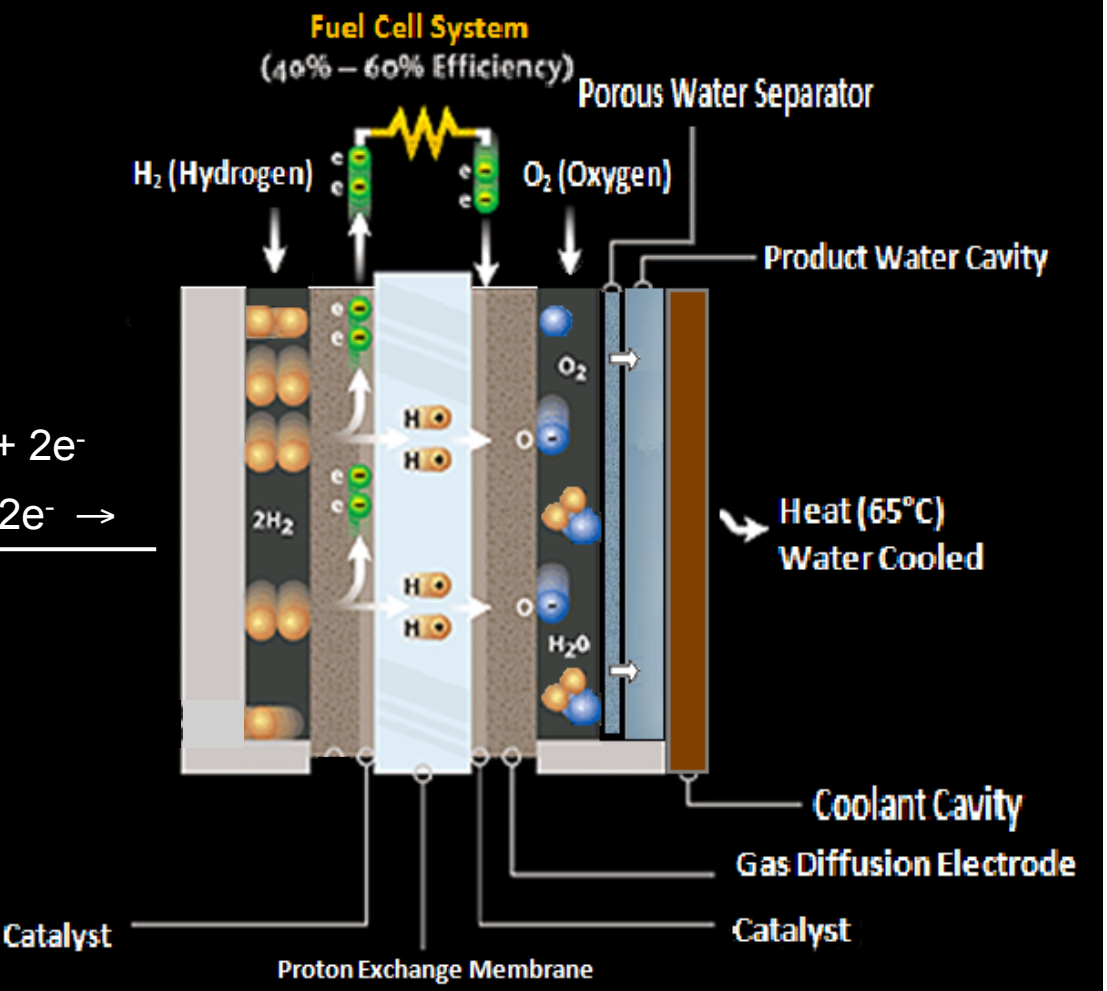


Proton Exchange Membrane (PEM) Fuel Cell Basics

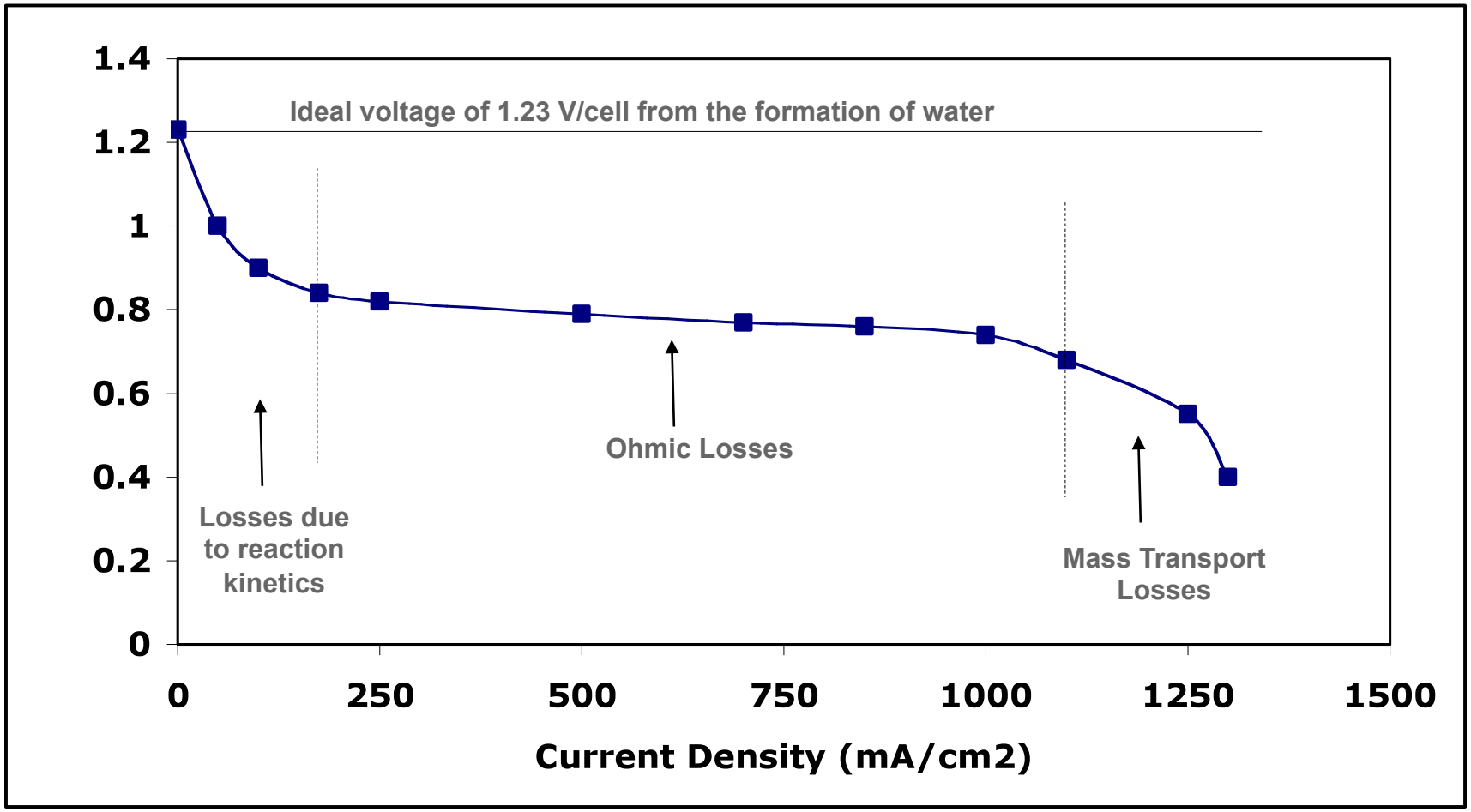
Anode Reaction $H_2 \rightarrow 2H^+ + 2e^-$

Cathode Reaction $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$

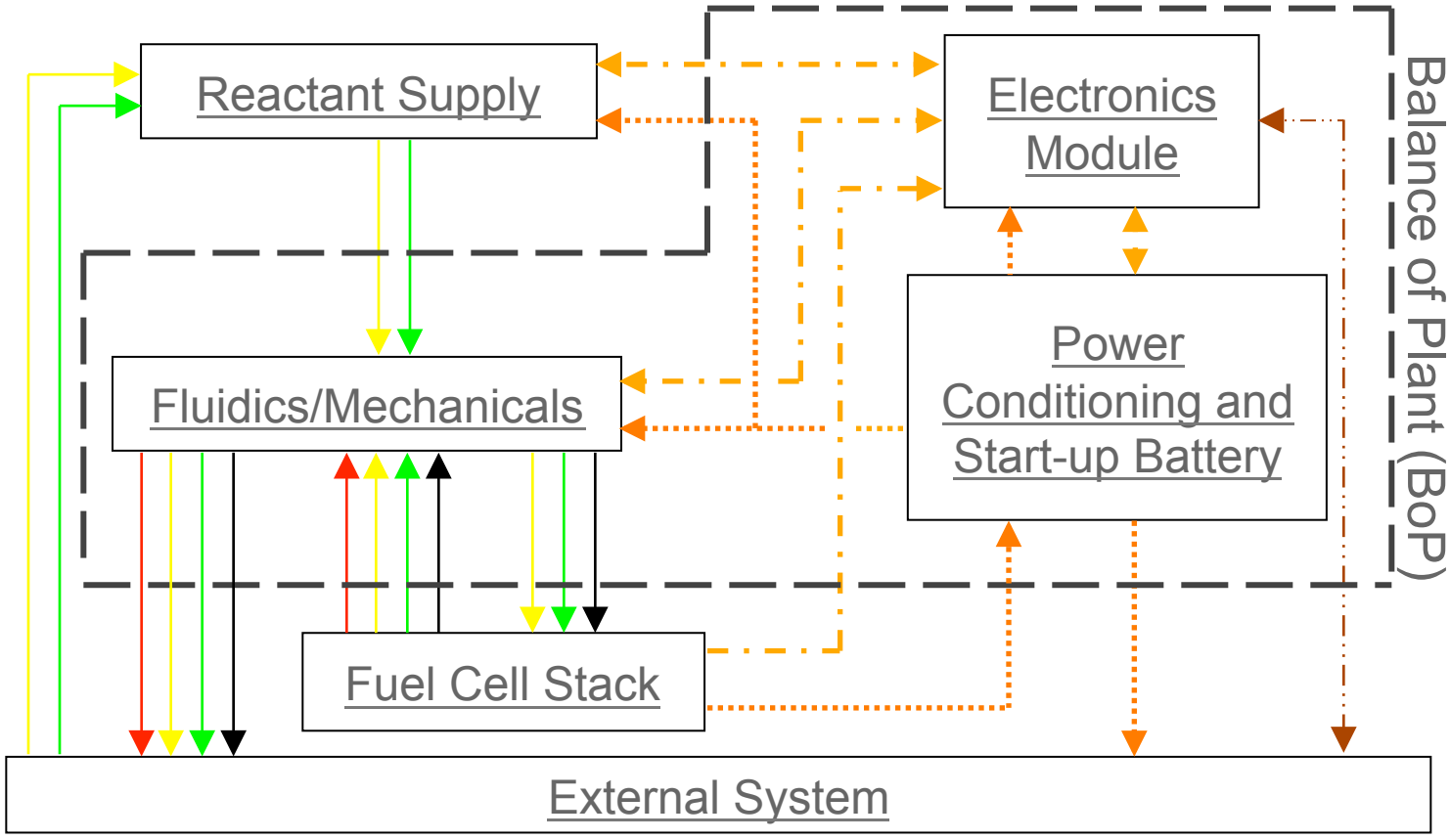
Net Reaction $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$



PEM Fuel Cell I-V Curve



Overview of a Fuel Cell System



NASA PEMFC Development History

- NASA initiated PEMFC studies during Shuttle upgrade program in late 1990's at JSC
  - High DDT&E costs prevented switch from alkaline to PEM, in spite of several technical advantages

- Reusable Launch Vehicle (RLV) program funded initial development of PEMFC technology (2001)
  - A single vendor selected

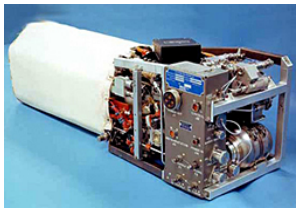
- RLV transitioned into Next Generation Launch Technology, Space Launch Initiative, and eventually Exploration Technology Development Program, programs (2001-2007)
  - Two vendors selected for Breadboard development
  - One vendor down-selected for Engineering Model development
  - Disadvantages of flow-through PEMFC systems became evident during testing of Engineering Model; ***balance-of-plant experienced multiple failures (rotating mechanical components)***

- Began investigation of "passive" balance-of-plant concepts for flow-through technology (2005)
  - Reactant pumps replaced with injectors/ejectors
  - Mechanical water separators replaced with membrane water separators

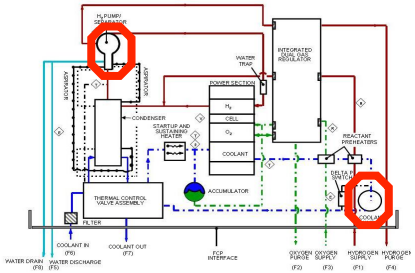
- In parallel, began investigation of non-flow-through technology through SBIR program (2005)
  - ***Single vendor awarded contract***
- ***Down-selected to non-flow-through technology over flow-through technology; initiated in-house development of balance-of-plant*** (2008)

PEM Fuel Cell Development

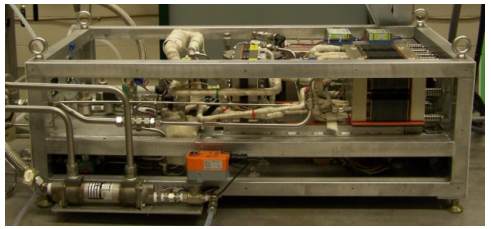
Shuttle "Active BOP" Alkaline



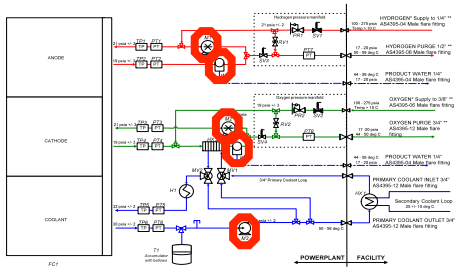
Flow-Through



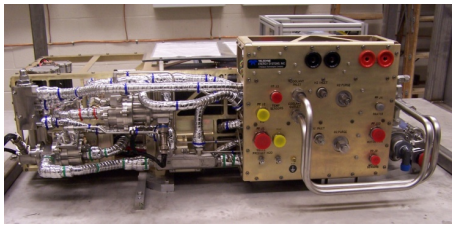
"Active BOP" PEM



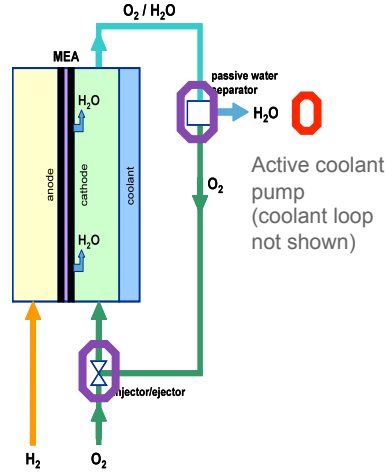
Flow-Through



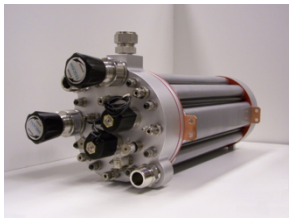
"Passive BOP" PEM



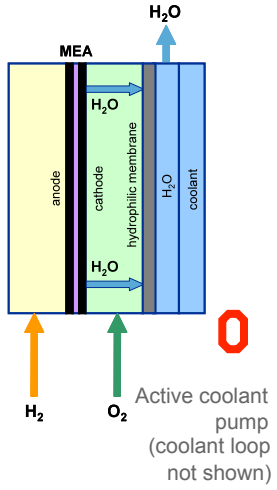
Flow-Through



"Passive BOP" PEM



***Non*-Flow-Through**



= **Active Mechanical Component (pump, active water separator)**

= **Passive Mechanical Component (injector/ejector, passive water separator)**

Fuel Cell Technology Progression to Simpler Balance-of-Plant

System-Level Comparison of Flow-Through vs. Non-Flow-Through PEMFC Technology

Design Parameter	Flow-Through	Non-Flow-Through
Efficiency	–	–
Mass		✓
Volume		✓
Parasitic Power		✓
Reliability		✓
Reactant Utilization		✓
Equivalent Reactant Storage "Depth-of-Discharge"		✓
Life		✓
Cost		✓
TRL	✓	

Fuel Cell Technical Approach: "Non-Flow-Through" Water Management

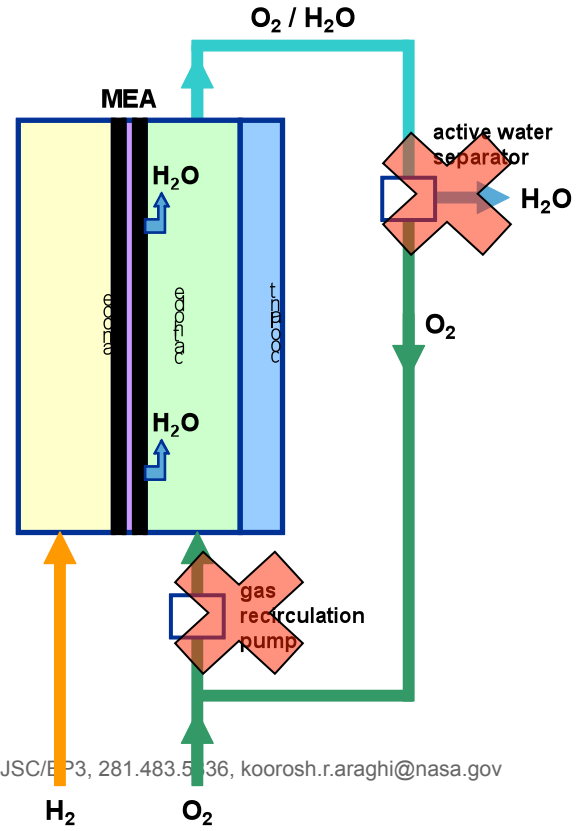
Develop "non-flow-through" proton exchange membrane fuel cell technology to improve system-level mass, volume, reliability, and parasitic power

Flow-Through components eliminated in Non-Flow-Through system include:

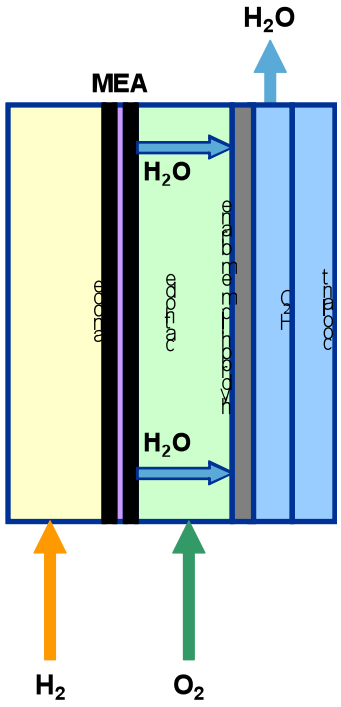
- Pumps or injectors/ejectors for recirculation
- Motorized or passive external water separators

Non-Flow-Through PEMFC technology characterized by dead-ended reactants and internal product water removal

- Tank pressure drives reactant feed; no recirculation
- Water separation occurs through internal cell wicking

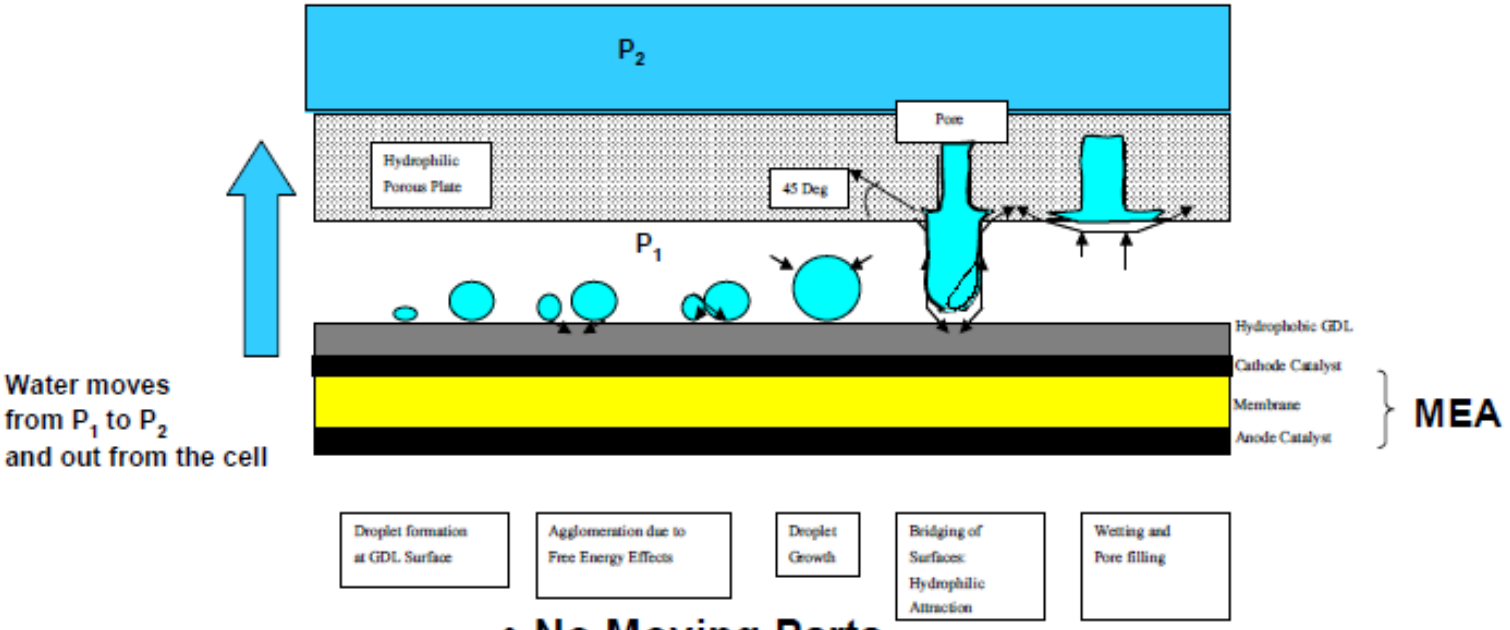


Flow-Through



Non-Flow-Through

Non Flow Through Water Management



- No Moving Parts
- Pure Liquid Water
- No Parasite Power

NFT Stack Test Results

Vendor	# Cells	Active Area	Vcc[1]	Steady State Test[2]	Load Profile Test[3]	Separator ΔP[4]	Max Current Density	Sensitivity	
								Inert[5]	Orientation
		cm^2	Volts	Pass/Fail	Pass/Fail	psid	mA/cm^2		
A	4	50	0.82	Pass	Pass	8	500	High	Not Tested
	4	50	0.83	Pass	Pass	8	500	Medium	None
[6]	4	150	0.81	Pass	Pass	8	800	Medium	None
	16	50	0.82	Pass	Pass	8	1,000	Medium	None
B	4	50	0.63	Pass	Pass	30	500	Medium	None
	4	200	0.75	Pass	Fail	30	350	Low	None
C	4	69	0.81	Pass	Fail	30	200	Medium	Not Tested
	2	69	0.84	Pass	Pass	30	500	Medium	Not Tested
D	4	86	0.83	Pass	Fail	4	400	Medium	Not Tested

Notes:

[1] = Average Cell Voltage at the Design point of 200 mA/cm^2

[2] = 200 mA/cm2 for 4 hours at design temperature and pressure

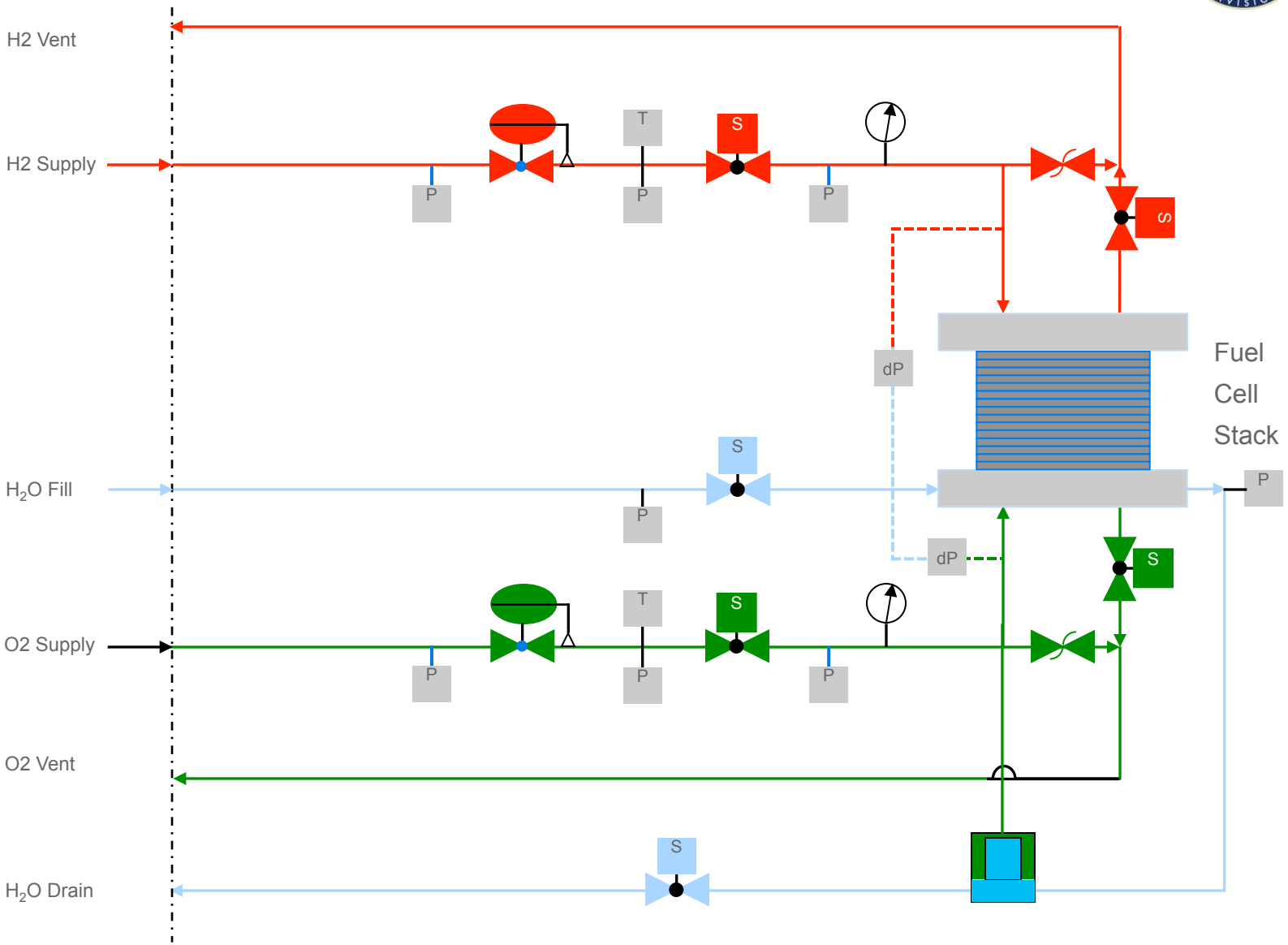
[3] = NASA Defined 4-hour Load profile ranging from 0 to 500 mA/cm^2

[4] = Maximum acceptable differential pressure between Oxygen and Water Cavities

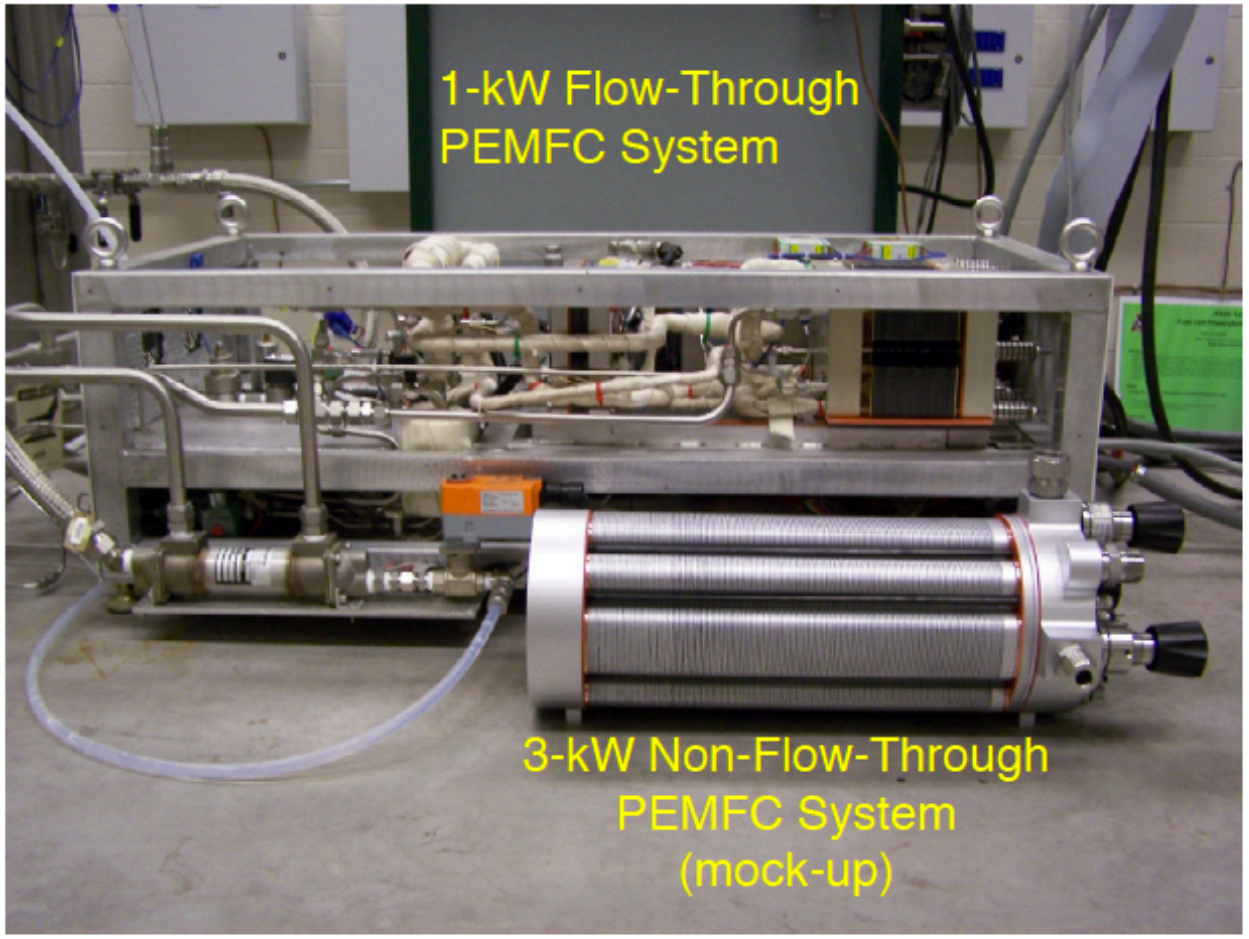
[5] = Based on vent frequency and vent duration for a normalized by current density and reactant purity

[6] = Cell Voltage at start of test - Testing stopped at 1,330 hours due to facility computer failure

Non-Flow-Through PEMFC System Schematic



NFT Fuel Cell Power System vs. FT System



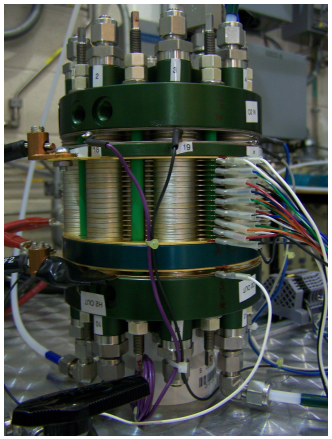
Non-flow-through PEMFC system has a substantially simpler balance-of-plant than conventional flow-through PEMFC system.

This offers significant advantages.

Future NFT Fuel Cell Power Systems

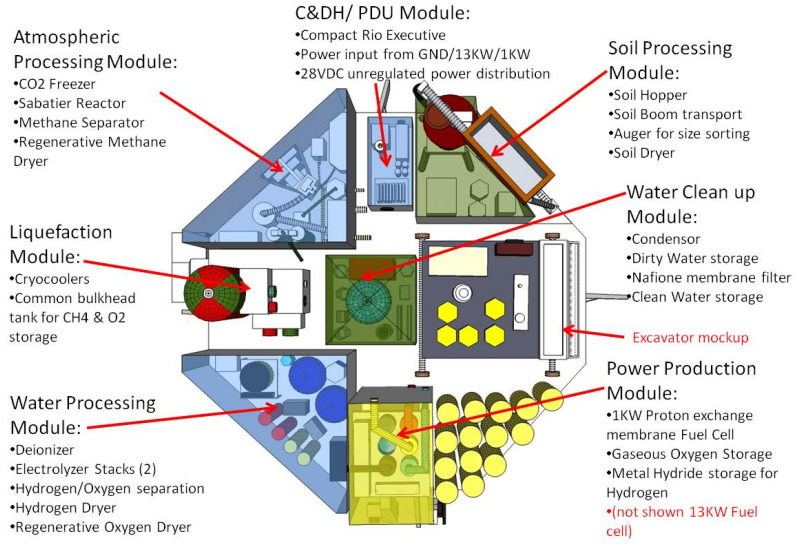
Demonstrations

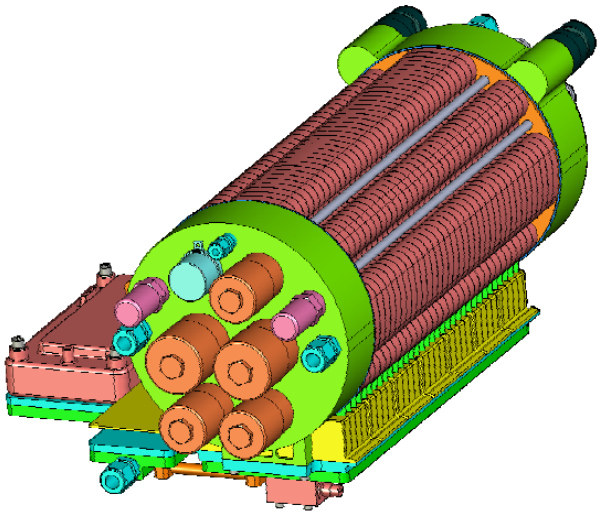
- Carnegie-Mellon Scarab Rover
- NASA MARCO POLO ISRU Lander



Future Tests

- Upgraded Water Separator Technology
- Miniaturized Electrical Packaging
- Integrated Passive Thermal Technology





Summary

- NASA is researching passive NFT PEM fuel cell technologies for primary fuel cell power plants in air-independent applications.
- NFT fuel cell power systems have a higher power density than flow through systems due to both reduced parasitic loads and lower system mass and volume. Reactant storage still dominates system mass/volume considerations.
- NFT fuel cell stack testing has demonstrated equivalent short term performance to flow through stacks. More testing is required to evaluate long-term performance.