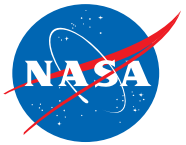

2011 Fuel Cell Seminar and Exposition

October 31st- November 3rd 2011

Walt Disney World Swan and Dolphin Resort, Orlando, FL

NASA Non-Flow-Through PEM Fuel Cell System Development and Test Results for Aerospace Applications

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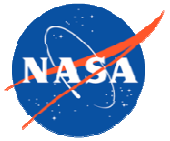
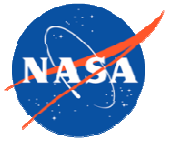
Overview



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

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

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

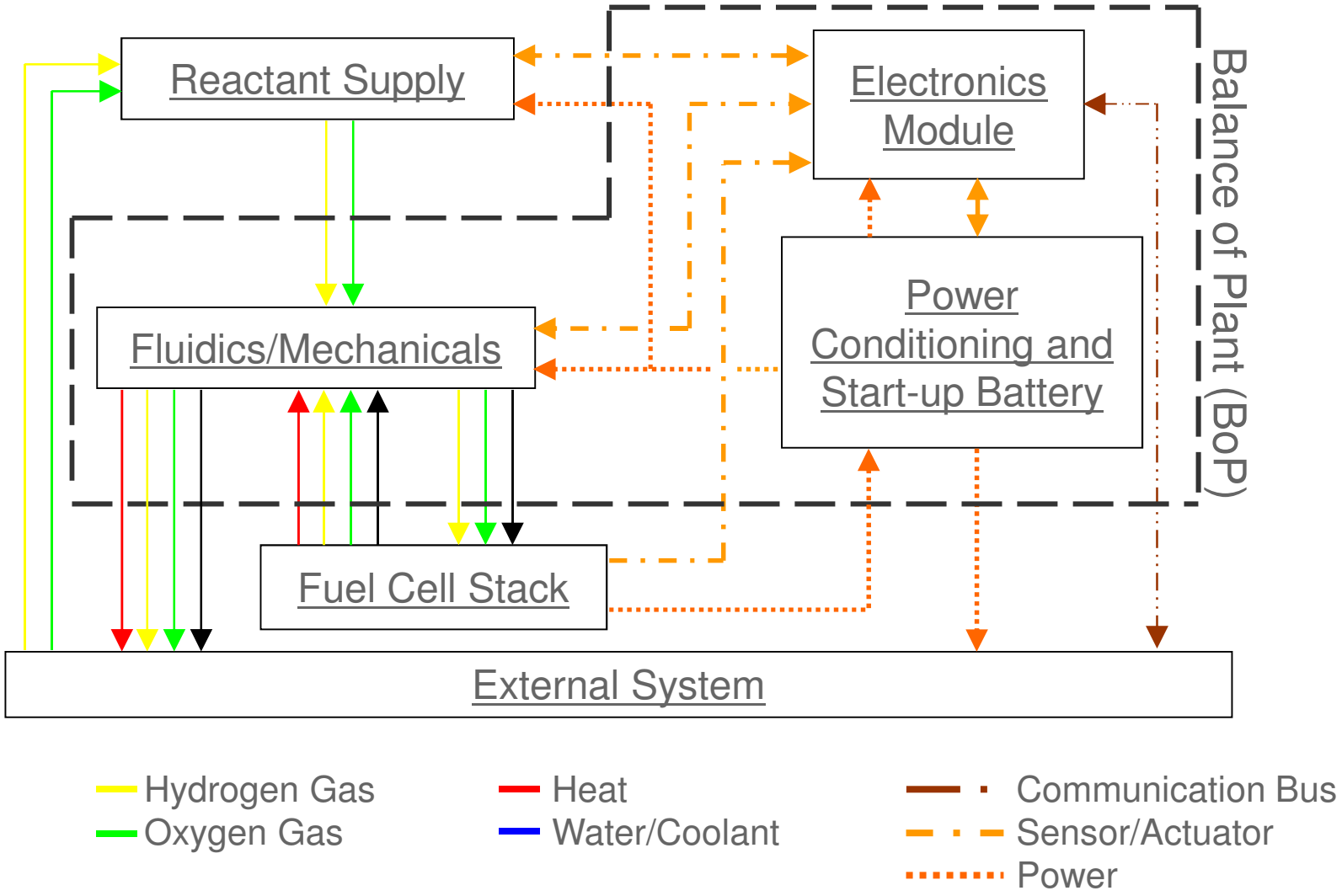
- RLV transitioned into NGLT, SLI, and eventually ETDP programs (2001-2007)
  - Two vendors selected for Breadboard development
  - One vendor down-selected for Engineering Model development
  - Disadvantages of flow-through PEMFC systems became evident during testing of Engineering Model; ***balance-of-plant 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)

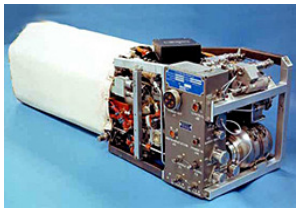
Overview of a Fuel Cell System



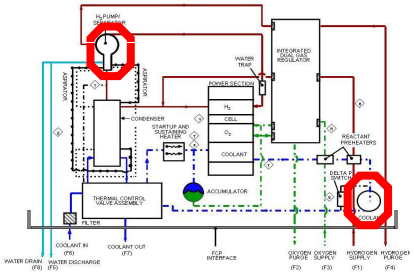
Johnson Space Center

UTC Power
A United Technologies Company

Shuttle "Active BOP" Alkaline



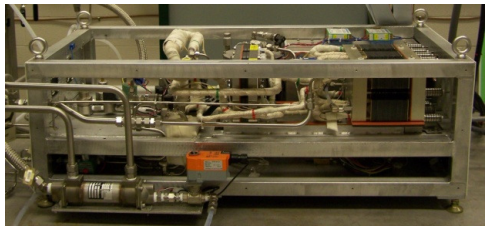
Flow-Through



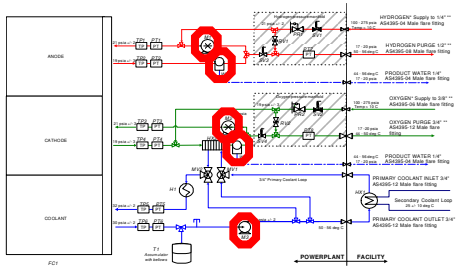
Glenn Research Center

TELEDYNE ENERGY SYSTEMS, INC.
A Teledyne Technologies Company

"Active BOP" PEM



Flow-Through



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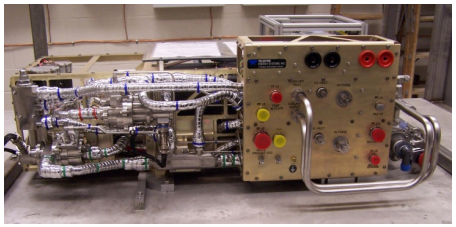
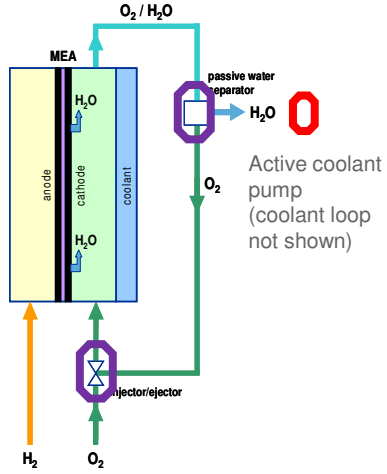
TELEDYNE ENERGY SYSTEMS, INC.
A Teledyne Technologies Company

"Passive BOP" PEM



Flow-Through



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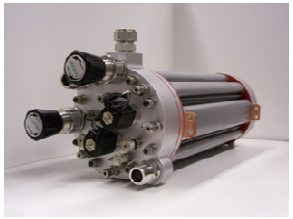
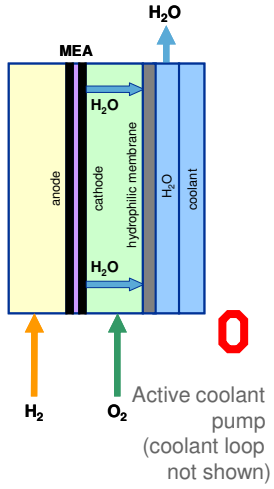
Infinity

"Passive BOP" PEM



Non-Flow-Through



= Active Mechanical Component (pump, active water separator)

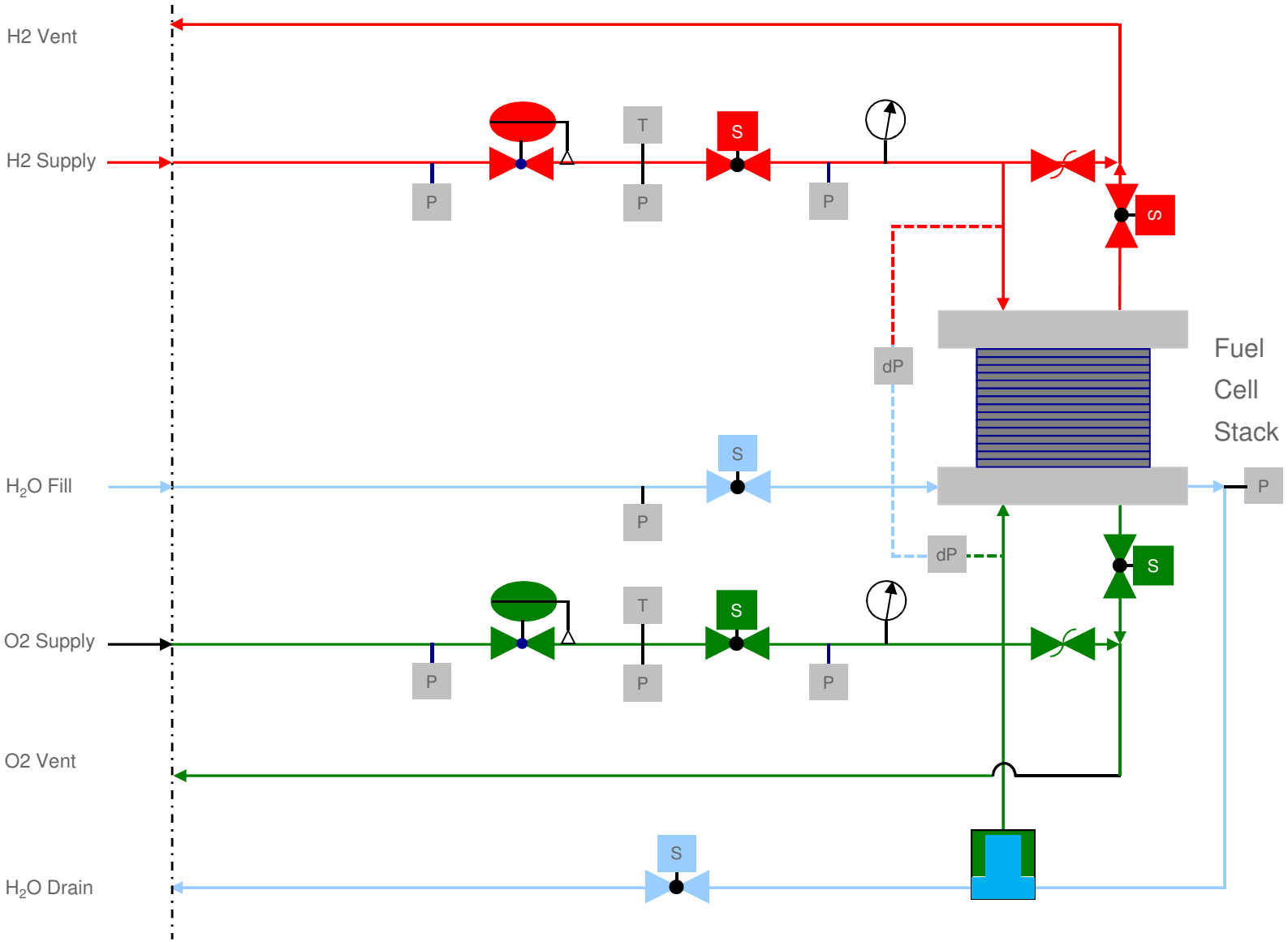
= Passive Mechanical Component (injector/ejector, passive water separator)

Fuel Cell Technology Progression to Simpler Balance-of-Plant

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

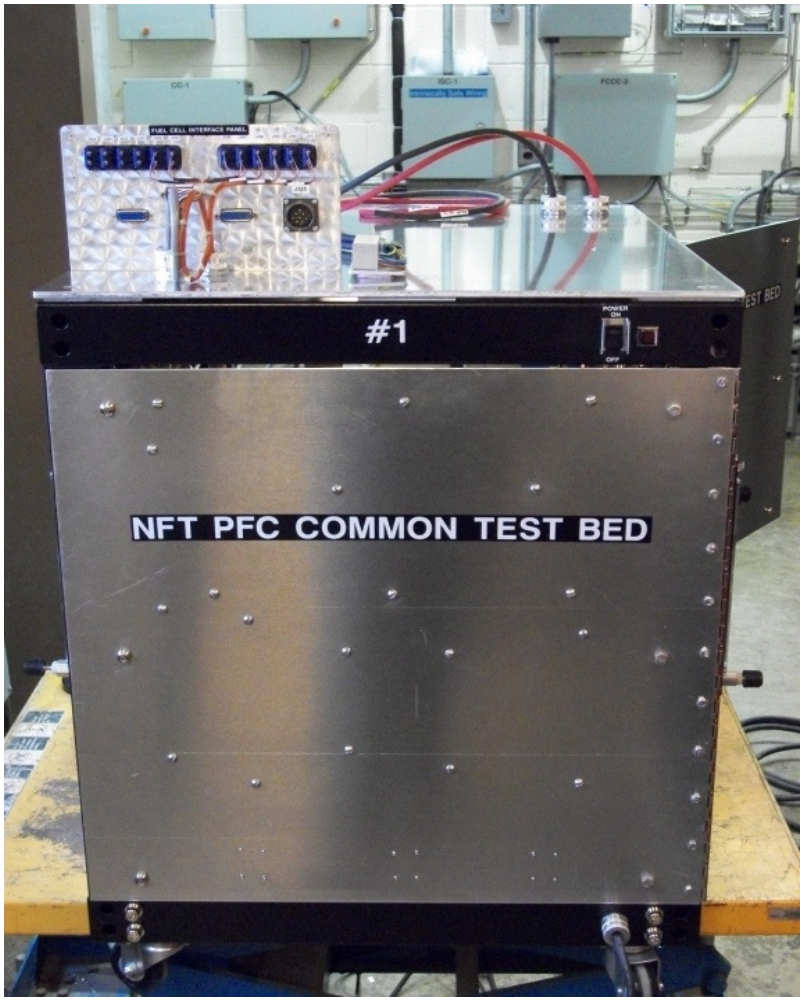
Design Parameter	Flow-Through	Non-Flow-Through
Efficiency	–	–
Mass		✓
Volume		✓
Parasitic Power		✓
Reliability		✓
Reactant Utilization		✓
Equivalent Reactant Storage "Depth-of-Discharge"		✓
Life		✓
Cost		✓
TRL	✓	

Non-Flow-Through PEMFC System Schematic



Calculated Value

NFT Fuel Cell Common Test Platform



- Based on common system architecture
- Used to test and evaluate NFT stacks from multiple vendors
- Extensive stack testing capability
  - Up to 1-kW in power
  - As many as 40 cells
- NASA customized software

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

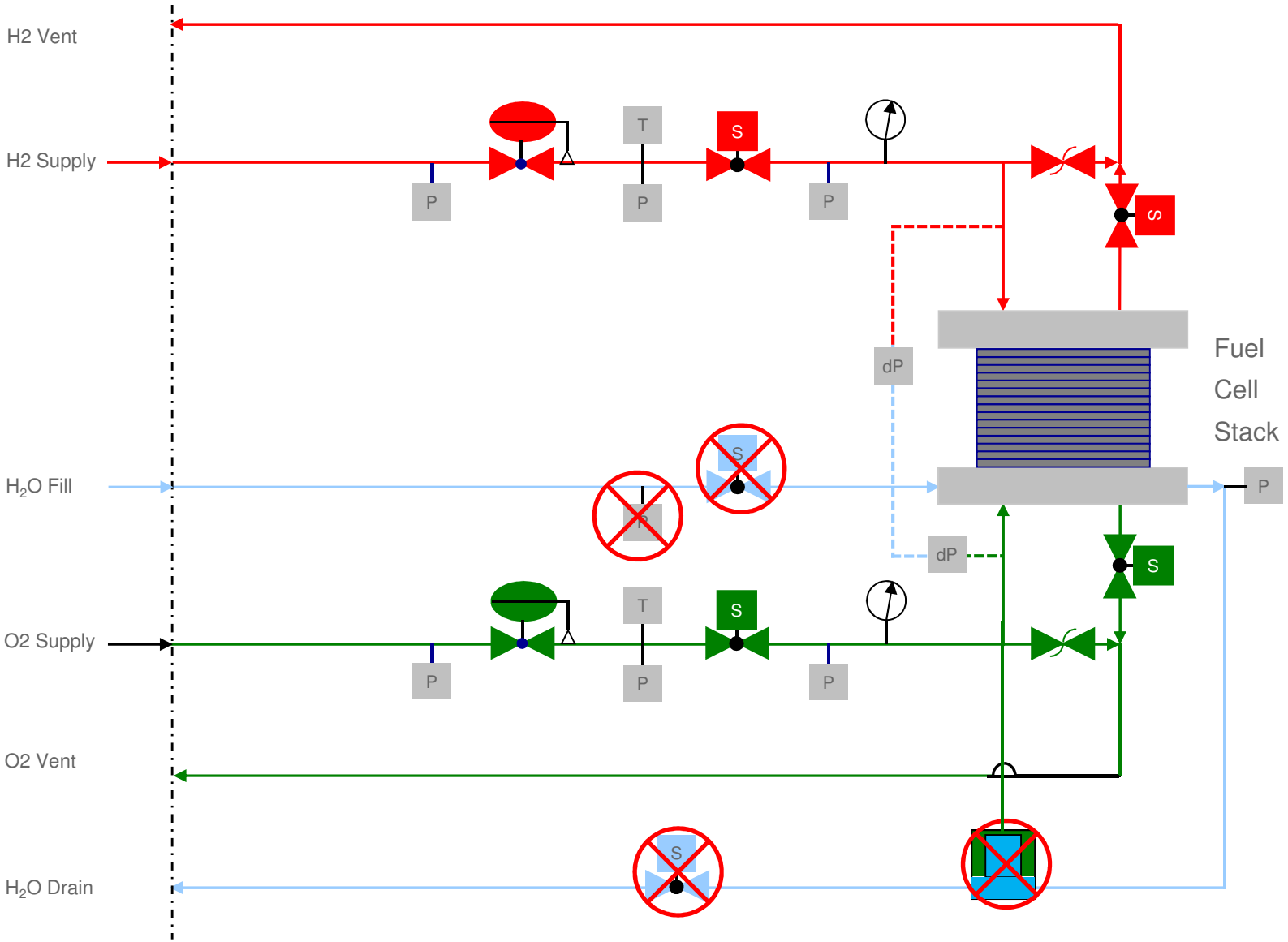
[3] = NASA Defined 4-hour Load profile ranging from 0 to 500 mA/cm^2

[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

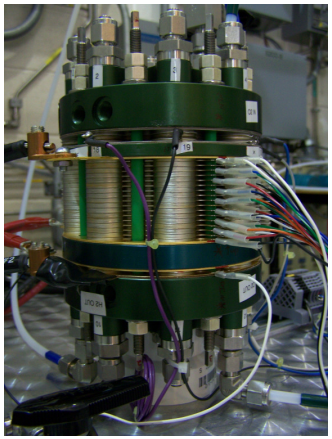


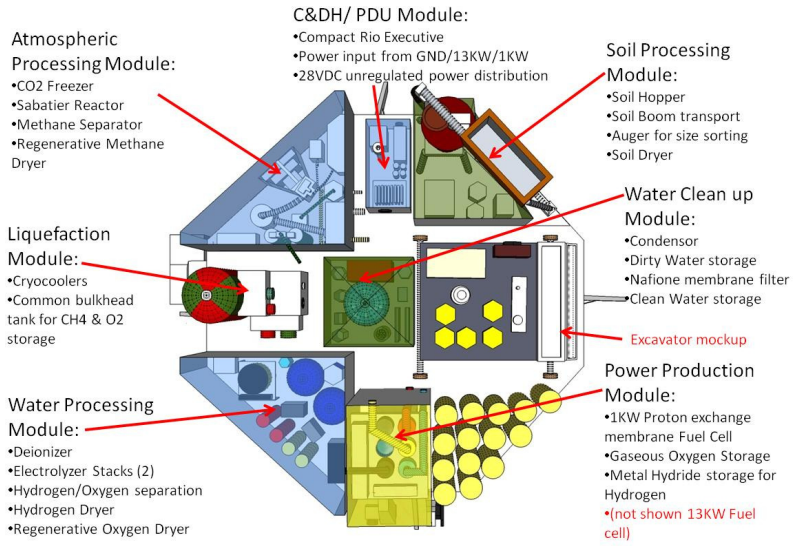
Calculated Value

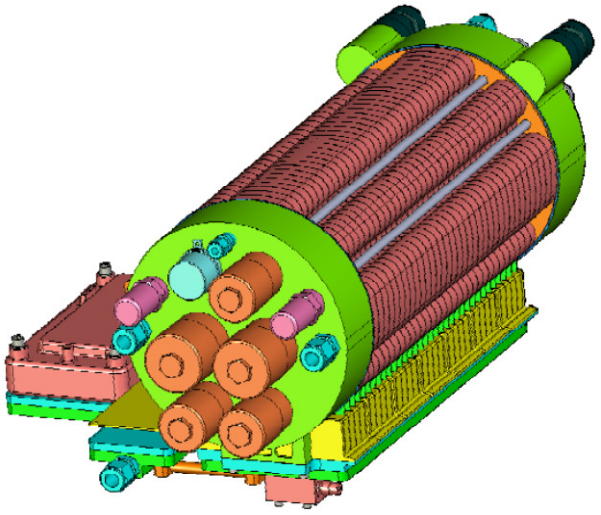
Future NFT Fuel Cell Power Systems

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

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

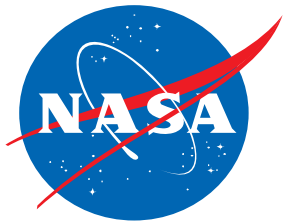






Summary

- NASA is researching passive NFT PEM fuel cell technologies for primary fuel cell power plants in atmosphere-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.


NASA