High Performance Fuel Cell and Electrolyzer Membrane Electrode Assemblies (MEAs) for Space Energy Storage Systems

Thomas I. Valdez[1], Keith J. Billings[1], Adam Kisor[1], William R. Bennett[2], Ian J. Jakupca[3], Kenneth Burke[2], and Mark A. Hoberecht[2]

[1]Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

[2]Glenn Research Center, Cleveland, OH

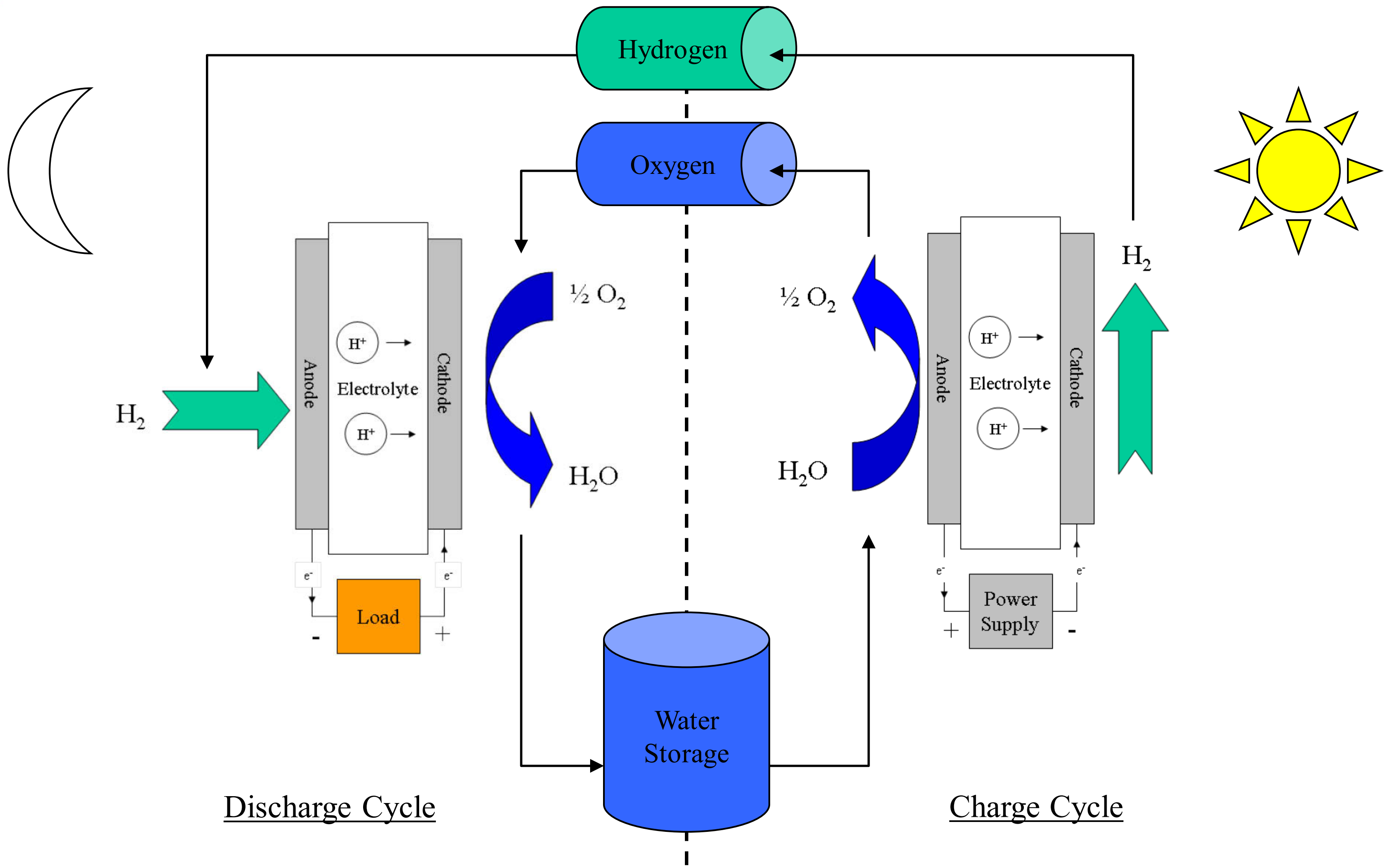
[3]Analex Corporation
Cleveland, OH

2012 Space Power Workshop
Manhattan Beach, CA

Presentation Outline

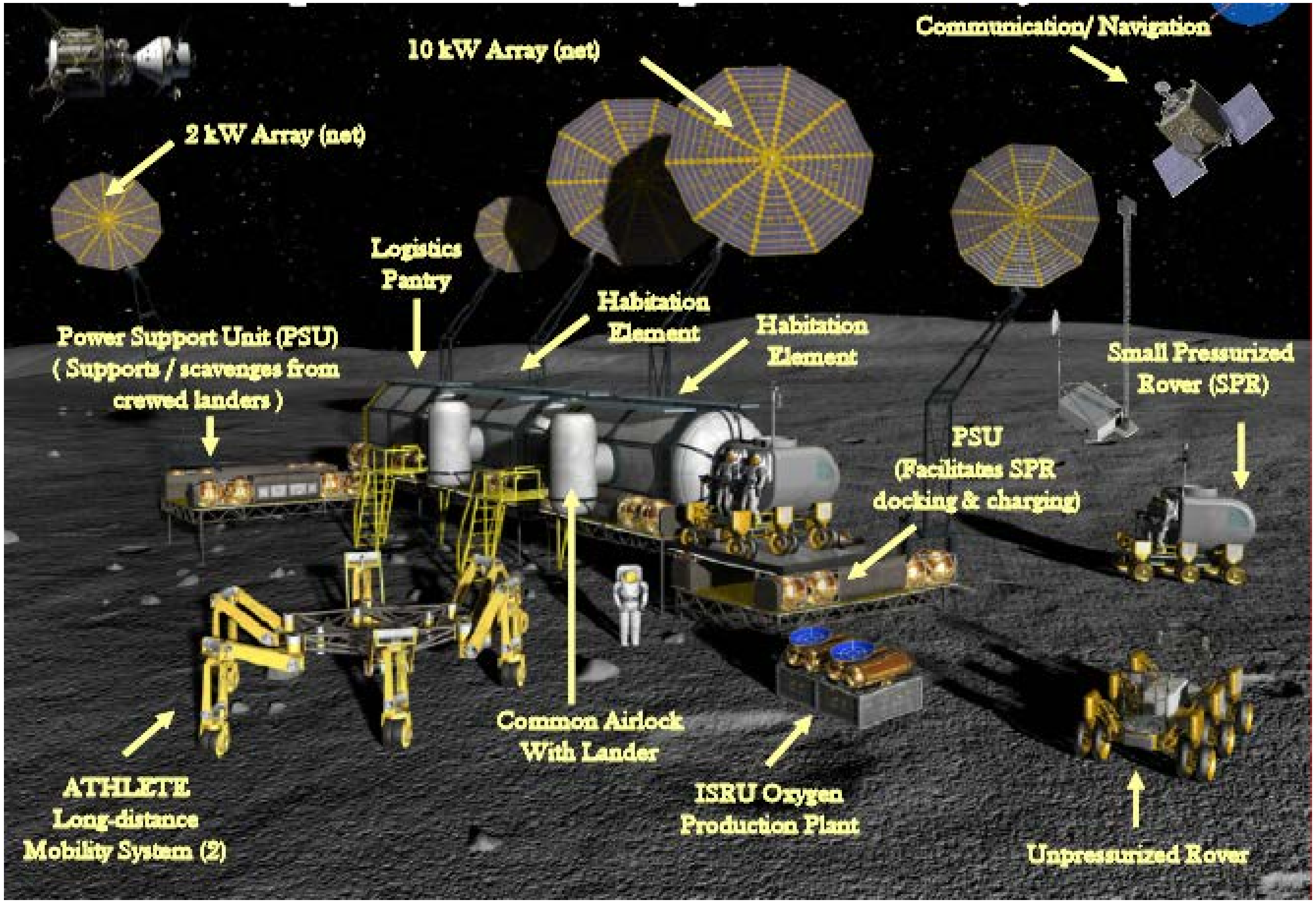
- Energy Storage: Regenerative Fuel Cell Systems
  - The Regenerative Fuel Cell Concept
  - Lunar Outpost Surfaces Systems
  - Key Performance Parameters
- NASA Fuel Cell Stack Development
- NASA Fuel Cell Membrane Electrode Assembly (MEA) Development
  - MEAs Fabricated for NFT Fuel Cell Systems
  - Vendor Tested MEAs
  - Advanced Electrode Structures
- NASA Electrolysis MEA Development
  - Catalysts Development
  - Electrolysis MEA Testing
- Fuel Cell Powered Mobility Systems
- Presentation Summary

The Regenerative Fuel Cell Concept



- The byproduct water recovered from the fuel cell reaction can be stored and electrochemically converted back into the required fuel cell reactants

Conceptual Lunar Outpost Surface System



C. R. Mercer, A. L. Jankovsky, C. M. Reid, T. B. Miller, and M. A. Hoberecht, Energy Storage Project, Final Report, NASA/TM-2011-216963, 2011

Key Performance Parameters, Energy Storage Project

Customer Need	Performance Parameter	SOA (alkaline)	Current Value* (NFT PEM)	Threshold Value** (@ 3 kW)	Goal** (@ 3 kW)
Altair:	System power density				
3 kW for 220 hr continuous, 5.5 kW peak.	Fuel Cell	49 W/kg	44 W/kg	88 W/kg	136 W/kg
	RFC (without tanks)	n/a	n/a	25 W/kg	36 W/kg
	Fuel Cell Stack power density	n/a	51 W/kg	107 W/kg	231 W/kg
	Fuel Cell Balance-of-plant mass	n/a	2 kg	21 kg	9 kg
Lunar Surface Systems: TBD kW for 15 days continuous operation	MEA efficiency @ 200 mA/cm^2				
	For Fuel Cell	73%	72%	73%	75%
	Individual cell voltage	0.90 V	0.89 V	0.90 V	0.92 V
Rover: TBD	For Electrolysis	n/a	83%	84%	85%
	Individual cell voltage	n/a	1.48	1.46	1.44
	For RFC (Round Trip)	n/a	60%	62%	64%
	System efficiency @ 200 mA/cm^2				
	Fuel Cell	71%	64%	71%	74%
	Parasitic penalty	2%	8%	2%	1%
	Regenerative Fuel Cell***	n/a	n/a	43%	54%
	Parasitic penalty	n/a	n/a	10%	5%
	High Pressure penalty	n/a	n/a	20%	10%
Maintenance-free lifetime	Maintenance-free operating life				
Altair: 220 hr (primary)	Fuel Cell MEA	2500 hr	13,500 hr	5,000 hr	10,000 hr
Surface: 10,000 hr (RFC)	Electrolysis MEA	n/a	n/a	5,000 hr	10,000 hr
	Fuel Cell System (for Altair)	2500 hr	n/a	220 hr	220 hr
	Regenerative Fuel Cell System	n/a	n/a	5,000 hr	10,000 hr

*Based on non-flow-through test hardware with 4-cells and heavy end plates, scaled to 3 kW

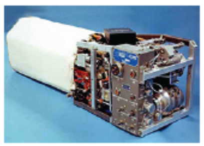
**Threshold and Goal values based on full-scale (3 kW, 300 cm^2) fuel cell and RFC technology.

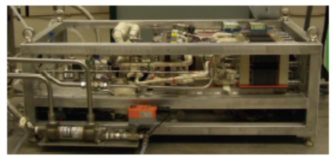
***Includes high pressure penalty on electrolysis efficiency 2000 psi

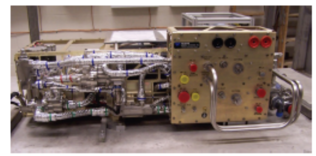
C. R. Mercer, A. L. Jankovsky, C. M. Reid, T. B. Miller, and M. A. Hoberecht, Energy Storage Project, Final Report, NASA/TM-2011-216963, 2011

NASA Fuel Cell Stack Development

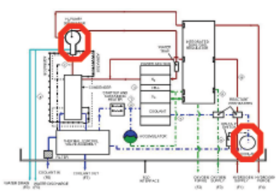
Johnson Space Center	Glenn Research Center	Glenn Research Center	Glenn Research Center Infinity
Shuttle "Active BOP" Alkaline	"Active BOP" PEM	"Passive BOP" PEM	"Passive BOP" PEM

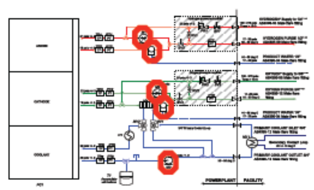


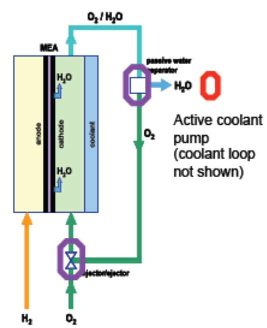


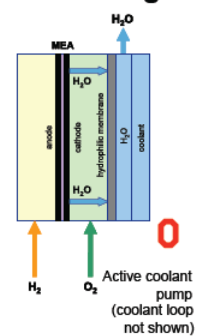


Flow-Through | **Flow-Through** | **Flow-Through** | ***Non*-Flow-Through**









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

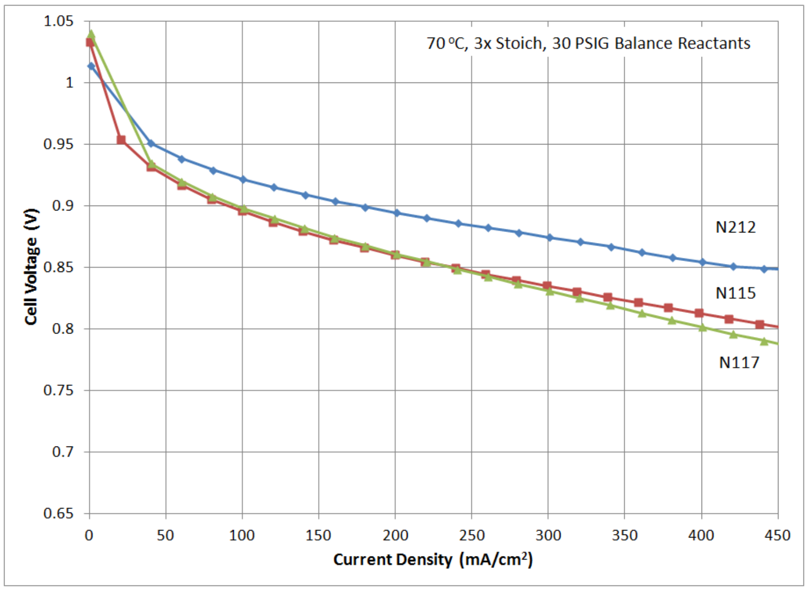
= **Passive Mechanical Component (injector/ejector, passive water separator)**

Fuel Cell Technology Progression to Simpler Balance-of-Plant

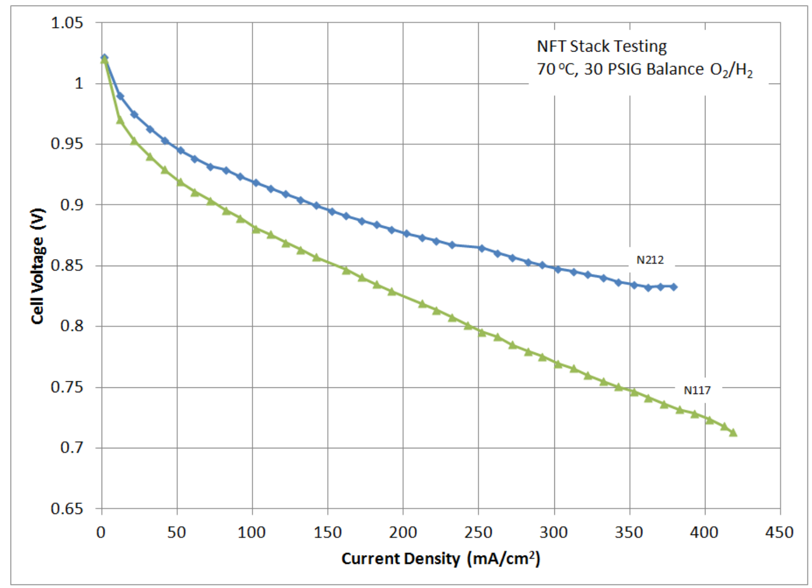
M. A. Hoberecht, NASA PEMFC Development Background and History, {Presented at NUWC, Newport, RI, 2010

Advanced MEAs for Non-Flow-Through (NFT) Fuel Cell Systems

Single Cell Hardware (Conventional)

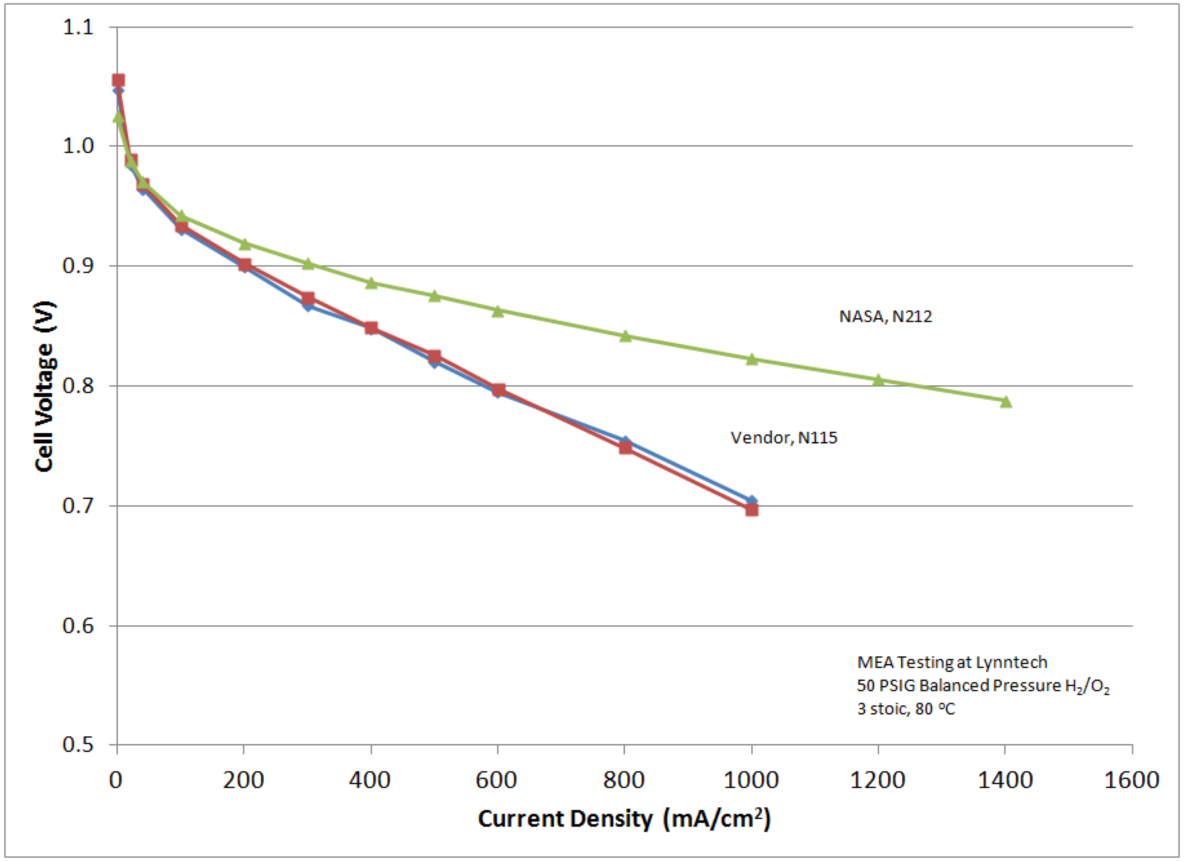


NFT Stack



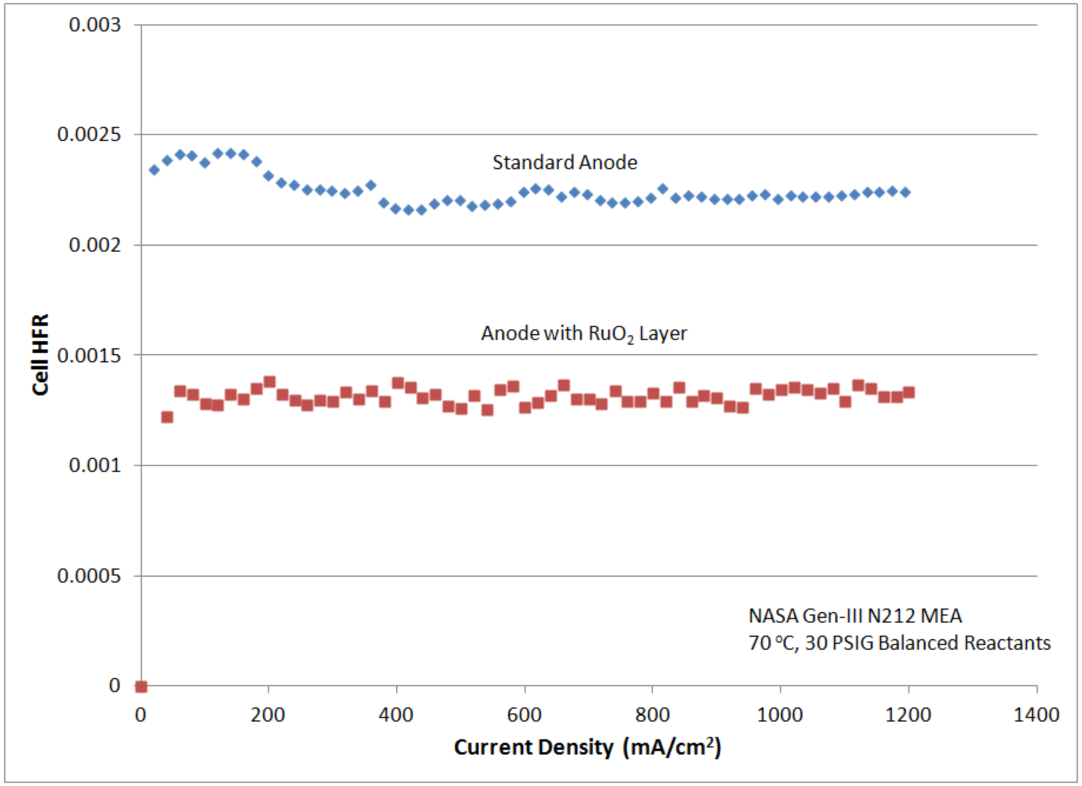
- MEAs developed for NASA NFT Stacks tested in conventional fuel cell hardware
- MEA performance is a strong function of MEA thickness this is more pronounced in NFT hardware
- MEA Performance in NFT hardware, 0.88 Volts at 200 mA/cm^2, 30 PSIG Balanced Pressure Reactants

Advanced NASA Fuel Cell MEA, Vendor Tested



- Membrane thickness crucial at high current densities, N115, 5 mil, N212, 2 mil
- MEA Performance, 0.92 V at 200 mA/cm^2, 80 °C

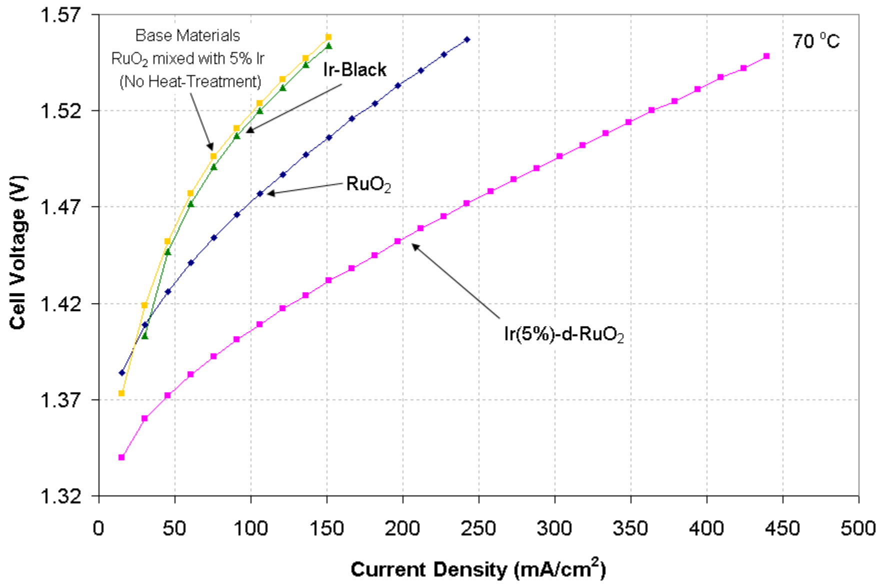
MEA Development, Optimization of RuO_2 Layers on Fuel Cell Anode



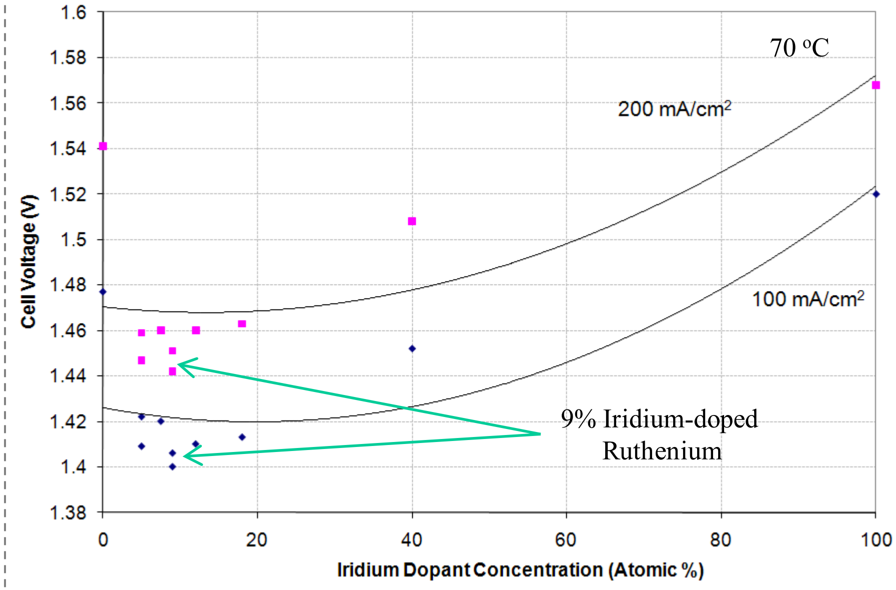
- RuO_2 deposition at the anode improves catalysts membrane interface can lower MEA high-frequency resistance (HFR) on the order of 1 mΩ with N212
- Deposition to be optimized, will increase cell voltages by 5 mV at 200 mA/cm^2 for MEAs fabricated with N212

Oxygen Evolution: Doped Ruthenium Oxide Catalyst

The Effect of Thermal Processing



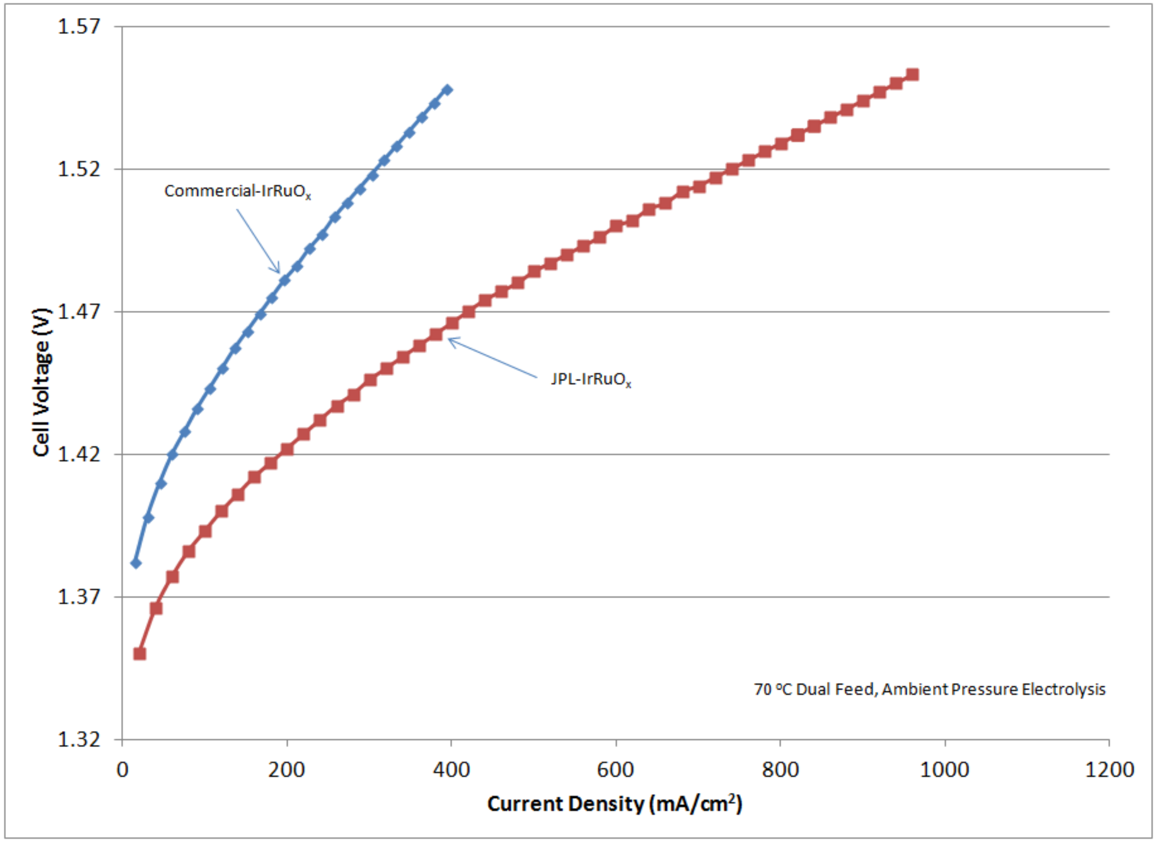
The Effect of Iridium Concentration on Ir-d-RuO_2 Catalysts



- Heat-treatment required to activate the doped ruthenium catalyst
- Expected Reaction: $M + RuO_2 \rightarrow MO_xRuO_{(2-x)}$ $(x \approx 0.05)$
- Ir-black dominates the performance of non-heat treated Ir-black mixed with RuO_2
- The 9% iridium-doped ruthenium catalyst performed the best of all iridium-doped ruthenium oxide compositions fabricated

Government sponsorship acknowledged.

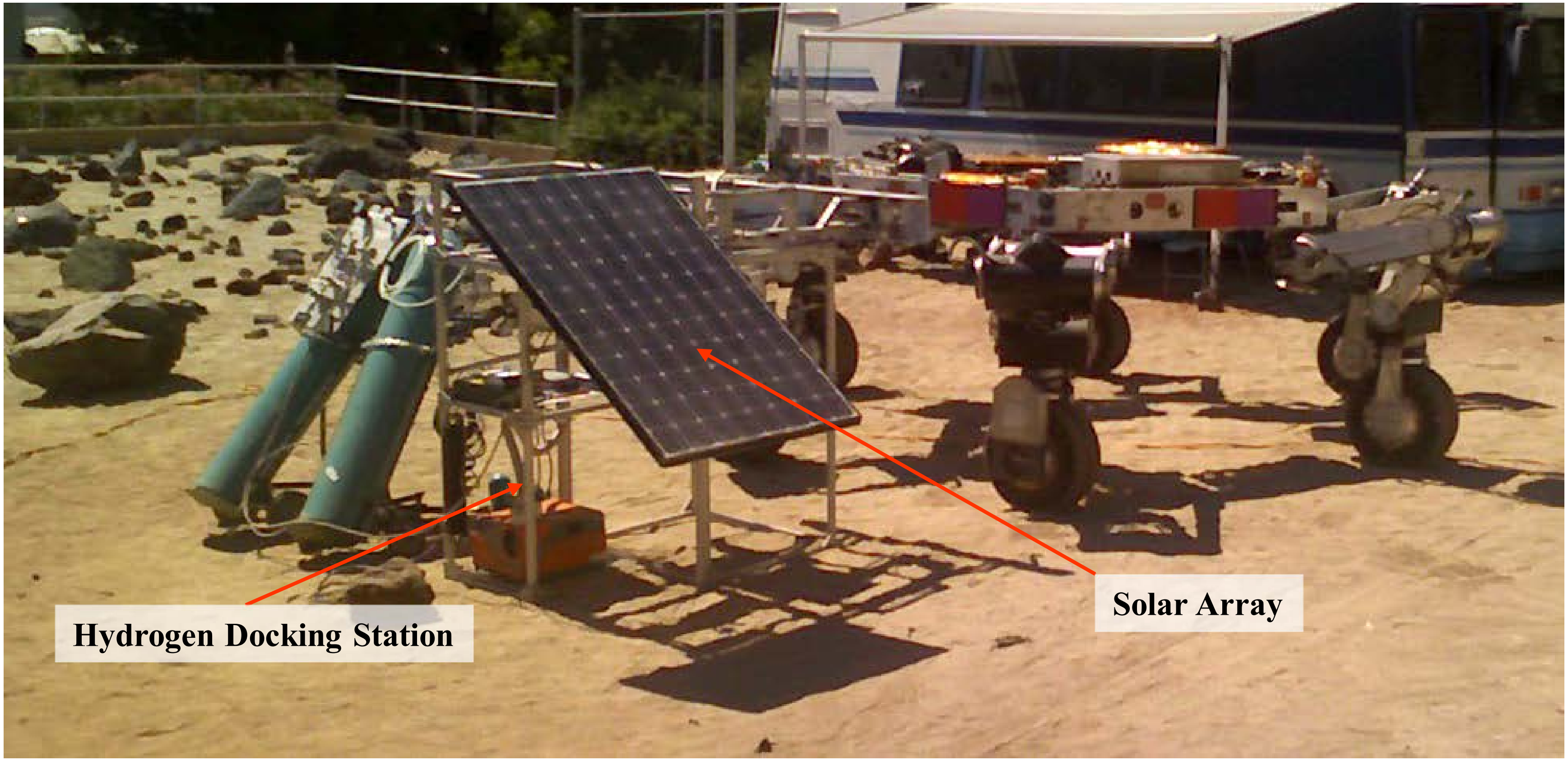
Electrolysis MEA Testing



•Advanced catalysts can meet the performance requirements of future NASA electrolysis systems

•MEA Performance, 1.42 V at 200 mA/cm^2, 70 °C

Fuel Cell Powered ATHLETE Mobility System



- Hydrogen docking stations can provide a pathway for robotic vehicles to traverse several kilometers while operating on fuel cell power.

Presentation Summary

- Regenerative fuel cells provide a pathway to energy storage system development that are game changers for NASA missions
- The fuel cell/ electrolysis MEA performance requirements 0.92 V/ 1.44 V at 200 mA/cm^2 can be met
- Fuel Cell MEAs have been incorporated into advanced NFT stacks
- Electrolyzer stack development in progress
- Fuel Cell MEA performance is a strong function of membrane selection, membrane selection will be driven by durability requirements
- Electrolyzer MEA performance is catalysts driven, catalyst selection will be driven by durability requirements
- Round Trip Efficiency, based on a cell performance, is approximately 65%

Acknowledgements

This work presented here was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with National Aeronautics and Space Administration.