NASA's First Year Progress with Fuel Cell Advanced Development in Support of the Exploration Vision

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Abstract. NASA Glenn Research Center (GRC), in collaboration with Johnson Space Center (JSC), the Jet Propulsion Laboratory (JPL), Kennedy Space Center (KSC), and industry partners, is leading a proton-exchange-membrane fuel cell (PEMFC) advanced development effort to support the vision for Exploration. This effort encompasses the fuel cell portion of the Energy Storage Project under the Exploration Technology Development Program, and is directed at multiple power levels for both primary and regenerative fuel cell systems. The major emphasis is the replacement of active mechanical ancillary components with passive components in order to reduce mass and parasitic power requirements, and to improve system reliability. A dual approach directed at both flow-through and non flow-through PEMFC system technologies is underway. A brief overview of the overall PEMFC project and its constituent tasks will be presented, along with in-depth technical accomplishments for the past year. Future potential technology development paths will also be discussed.

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Energy Storage Project

- Exploration Technology Development Program (ETDP)
  - Focused technology development program that address critical technology areas required to implement the Vision for Exploration
- Energy Storage Project – Addresses Batteries and Fuel Cells
- Fuel Cell Applications
  - Lunar Precursor and Robotic Program (LPRP)
  - Lunar Surface Access Module (LSAM)
  - Rovers and habitats
  - Surface bases
- Technology development to achieve TRL 6 - phased to meet technology insertion dates

Fuel Cell Team Overview

- NASA/Industry/Academia Partnership
  - NASA Centers – GRC (lead), JSC, JPL, KSC
  - Industry – Lockheed Martin
  - Grants – Texas A&M
  - SBIRs – Infinity Fuel Cell and Hydrogen, Inc; ElectroChem, Inc; Distributed Energy Systems; Giner, Inc

Fuel Cells for Exploration Missions

- Fuel cells/Regenerative fuel cells – enabling for Exploration surface power
  - Potable water production
  - Enable longer mission durations than batteries
  - RFC's enabling for near-term implementation of storage for base power – combined with PV
- NASA PEM fuel cell development effort leverages commercial technology development
- Unique NASA fuel cell requirements compared to terrestrial systems
  - Pure oxygen as oxidant (versus air)
  - Product water separation and removal in a multi-gravity environment (zero-g in space, multiple-g's during launch/landing)

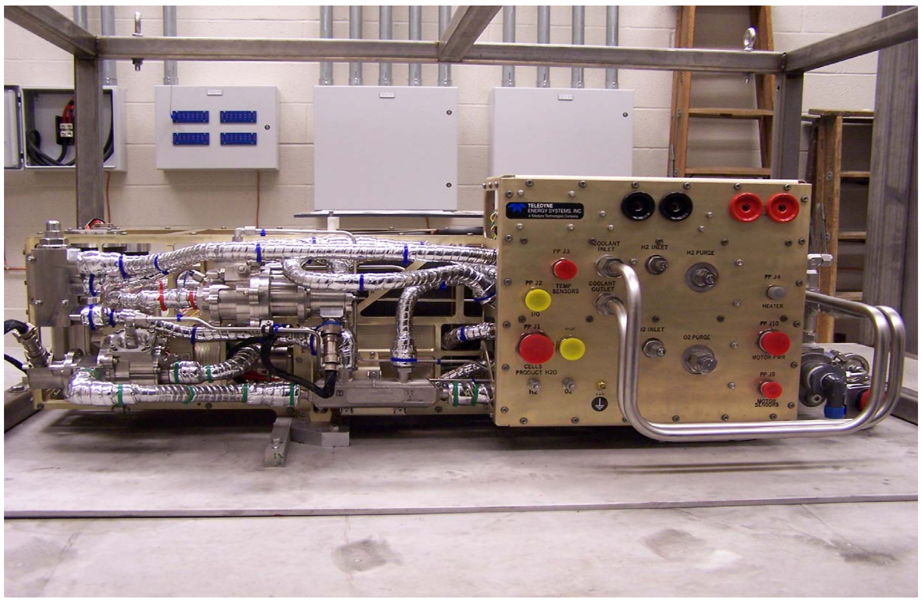
Fuel Cells for Exploration Missions

- Three classes of fuel cells originally planned for Exploration missions
  - < 1-kW fuel cells
  - ~ 8-kW fuel cells
  - 25-kW RFCs
- Initial fuel cell effort directed at 1-10 kW power range
  - Complete PEMFC power plant development
  - Parallel approach directed at both flow-through and non flow-through PEM fuel cell systems
  - Major emphasis on replacing active mechanical ancillary components with passive components
  - Generic PEM technology development efforts applicable to both primary and regenerative fuel cells

Engineering Model Development

- Completion of effort initiated in 2001 to capitalize on PEMFC advantages over alkaline technology
- Leveraged advances from commercial sector with focus on requirements for space applications
  - Operation with pure oxygen as oxidant, rather than air
  - Water management (removal & separation) in multi-gravity environment
- Culminated in development of 2-12 KW Engineering Model power plant

Teledyne Engineering Model Power Plant Specifications



Teledyne Engineering Model

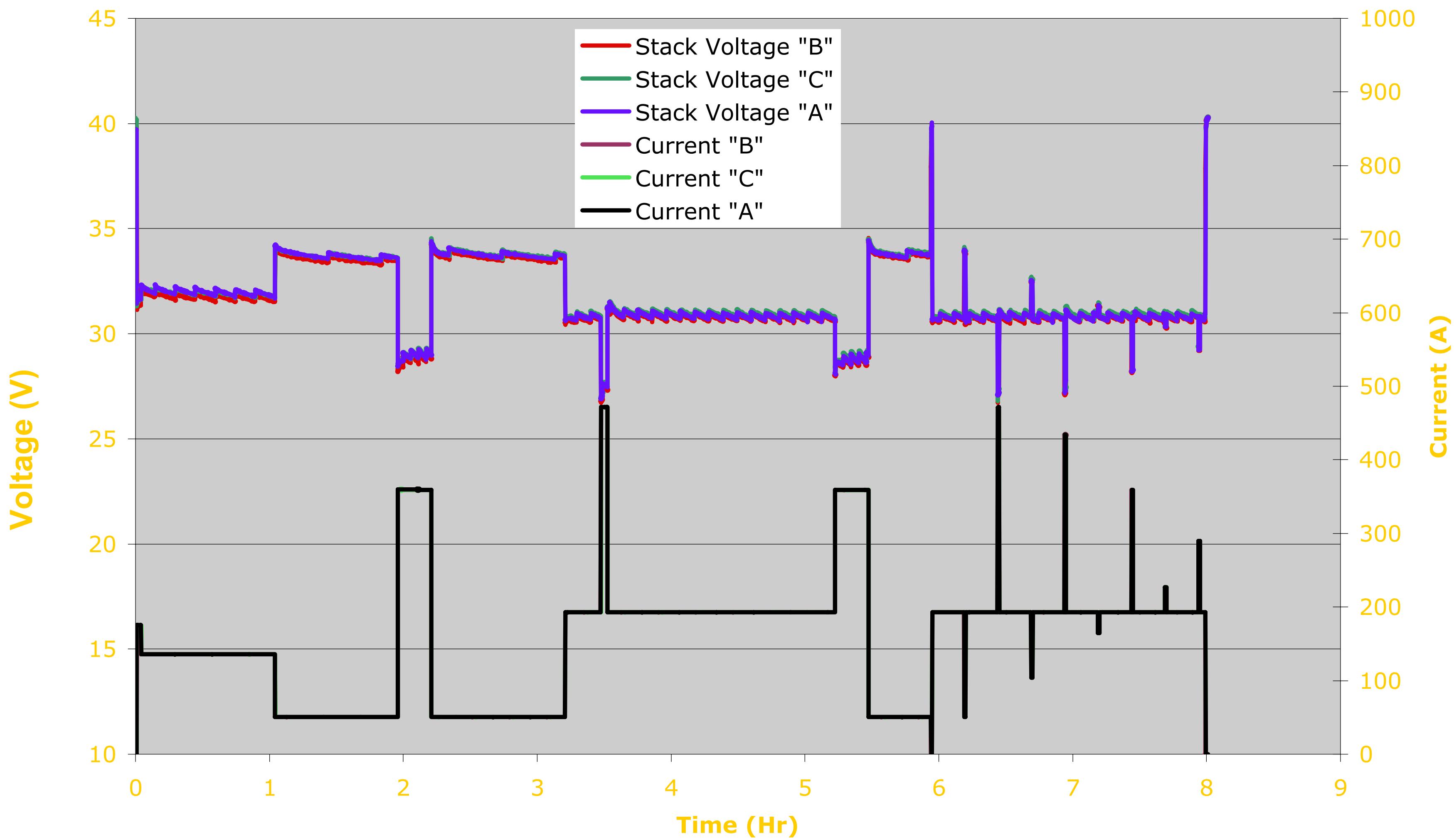
Power Range	2-12 kW
Operating Voltage	27-33 VDC
Number of Cells	117
39 Series Cells/Substack	
3 Substacks in Parallel	
Cell Active Area	302 cm^2
Nominal Power	6 kW
Nominal Voltage	30 VDC
Nominal Current	200 Amps
Peak Power	12 kW

Engineering Model successfully met all performance goals except system weight – 25% over.

Engineering Model Development Testing

- Engineering Model power plant delivered to NASA for independent testing
  - Multiple load profiles
  - Polarization curves
  - Start-up and shut-down testing
  - Mission profile tests
  - Limited endurance testing
  - Multiple orientation testing
  - Loss-of-coolant tests
  - Environmental testing
- Completed majority of testing before incurring regulator failure
  - Funding limitations and technology status led to decision to terminate testing program prior to completion of environmental testing

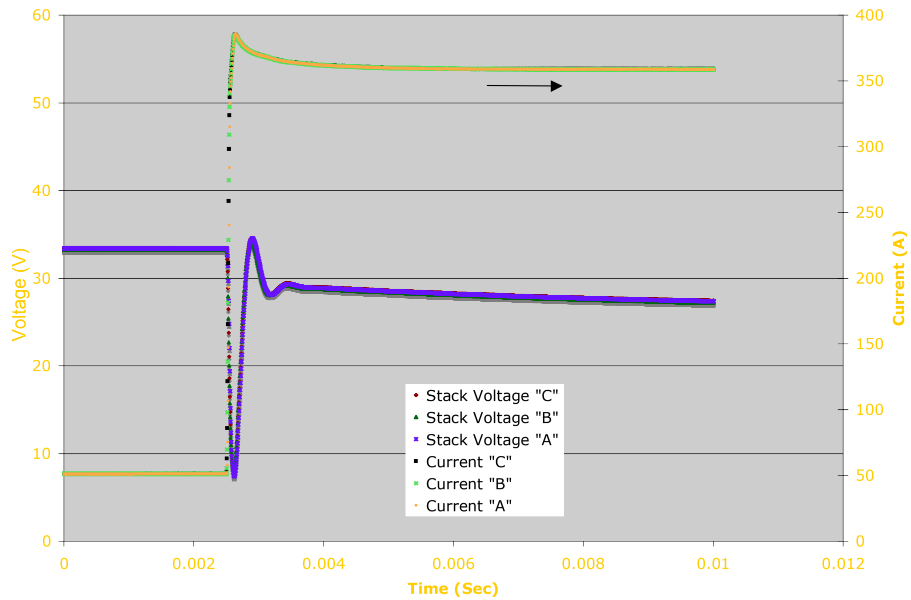
Performance Load Profile



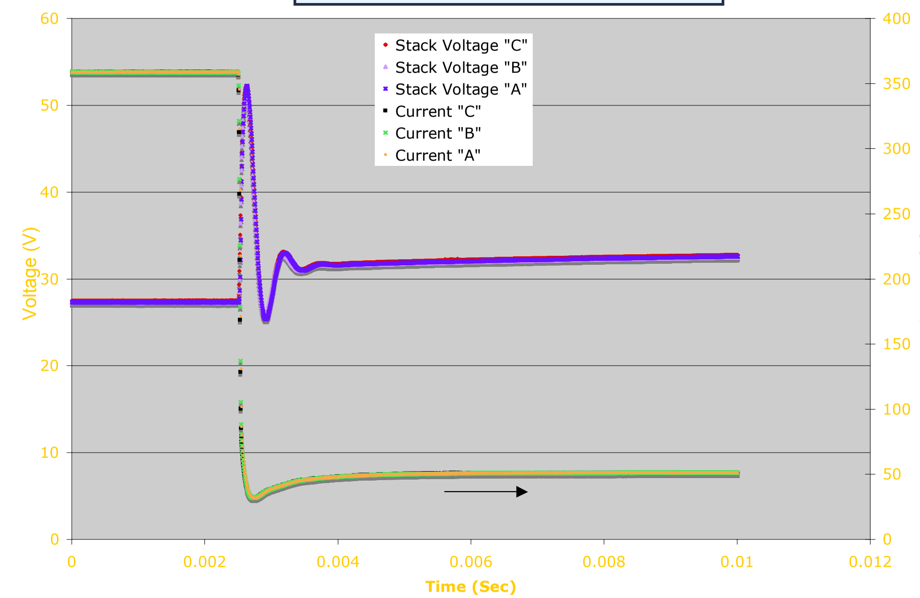
Engineering Model performance is independent of spatial orientation.

Transient Performance

51 Amps to 357 Amps



357 Amps to 51 Amps



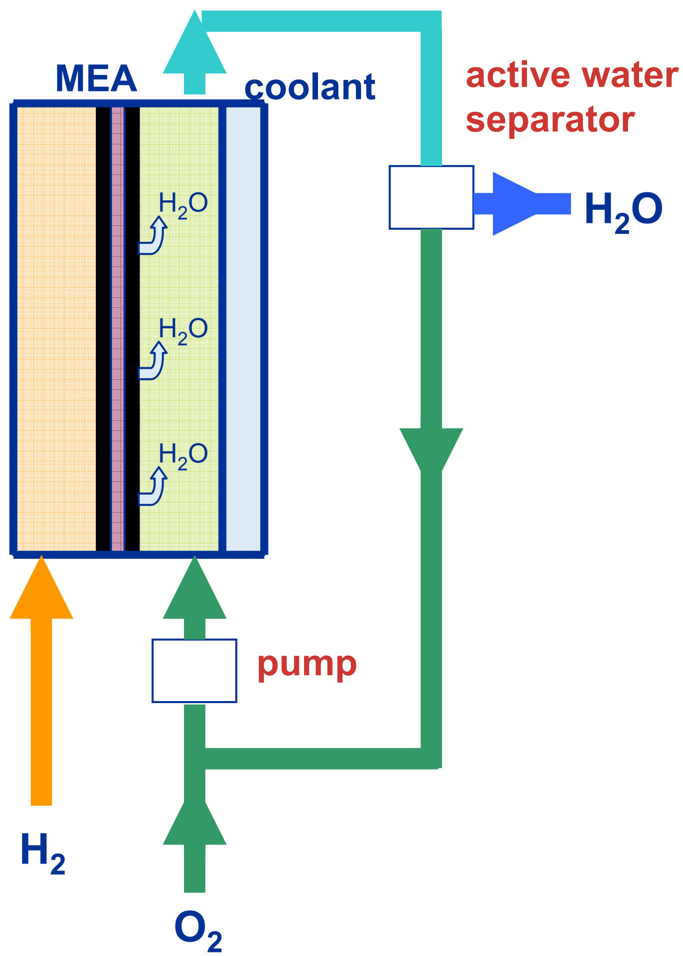
Engineering Model can achieve stable operation in less than a millisecond after experiencing large increases (7X) or decreases (7x) in the power load.

Engineering Model Development Summary

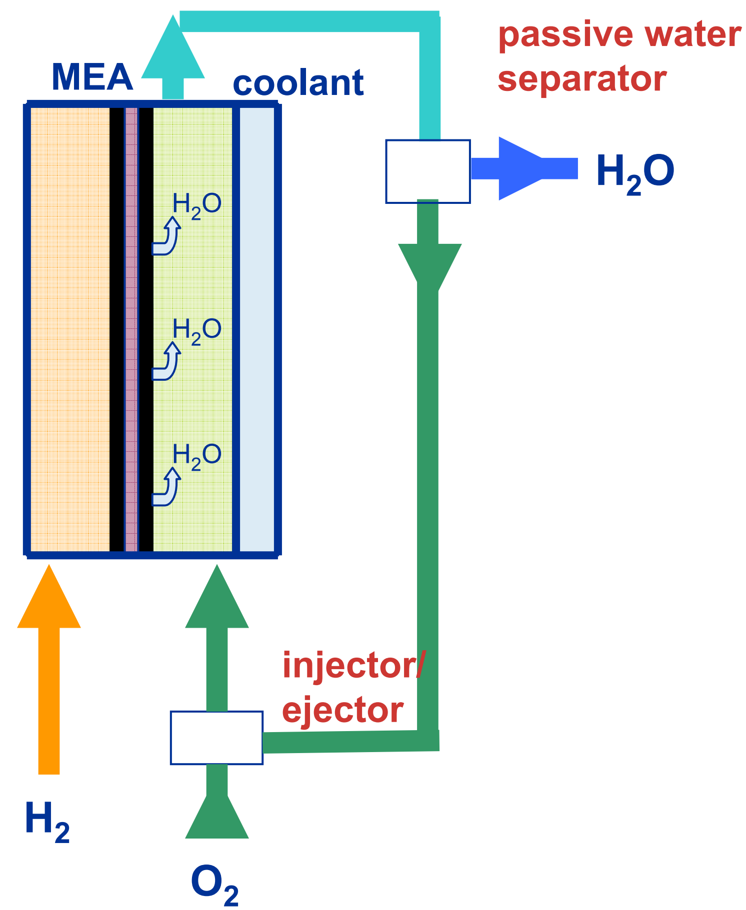
- Teledyne Engineering Model – flow-through system design
- Successful development of fuel cell capable of operation in multiple gravity environments with pure oxygen as oxidant
- Superior fuel cell stack performance
- Balance-of-plant complex, heavy and unreliable
  - Susceptible to active ancillary component failures
- Provides direction for present parallel development efforts
  - Passive components for flow-through system technology
  - Non-flow-through system concepts that eliminate ancillary components

Flow-Through PEM Fuel Cells

Active Ancillary Components



Passive Ancillary Components



Flow-Through PEMFC Development Efforts

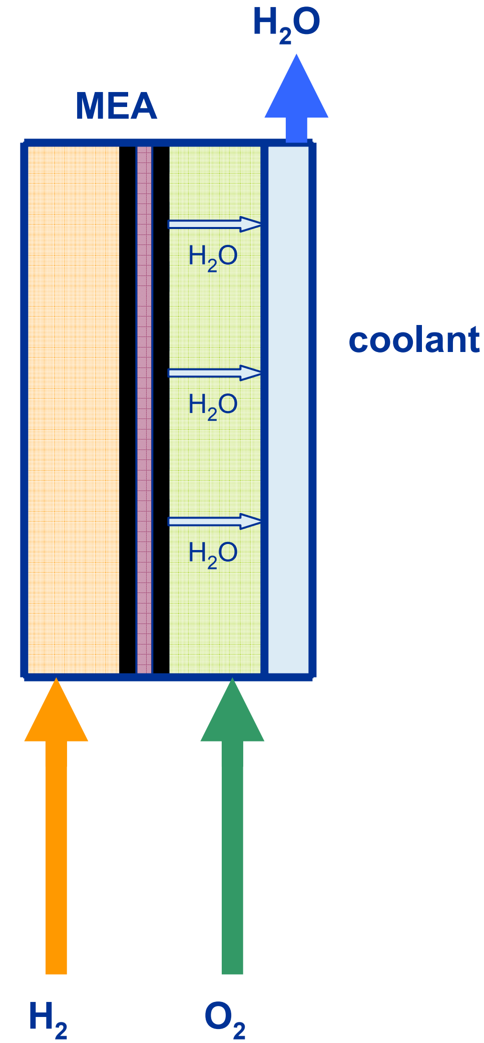
- Replace active components with passive components
  - Four water separation devices under investigation
    - Two membrane separators, meniscus separator, and vortex separator
  - Two reactant recirculation schemes under investigation
    - Water separator upstream or downstream of injector/ejector
- Optimization of multi-kW stack technology
  - Mass
  - Voltage performance
- Downsize for sub-kW mission applications

Replacement of active mechanical ancillary components with passive components is the most critical step in addressing the deficiencies of existing flow-through PEMFC system technology.

Non Flow-Through PEMFC Development Efforts

- Phase II SBIRs
  - Eliminates need for reactant recirculation and separation of product water
  - Several stack deliveries in FY'07
- Parallel NASA in-house balance-of-plant development matched to stack characteristics; results in totally autonomous systems
- Potential to eliminate almost all ancillary components and develop a system with the simplicity of a battery

Non flow-through PEMFC systems offer the most promise for future Exploration missions.



Eliminates ancillary components

Generic PEMFC Development Efforts

- Universally applicable to flow-through, non flow-through, fuel cell and RFC systems
  - High-performance MEA’s with goal of matching or exceeding alkaline fuel cell performance
  - Passive thermal management techniques utilizing flat-plate heat pipes to allow elimination of an additional active component (coolant pump)

PEMFC Funding Challenges

- Existing ETDP funding profiles allow sub-kW fuel cell system development to reach TRL-6 by 2012; multi-kW by 2014
  - Any required acceleration in these need dates will require over-guideline funding augmentation
- Existing ETDP funding profiles do not allow addressing sub-kW RFC system development until FY'10; reaching TRL-6 by 2014
  - Any required acceleration in this need date will also require over-guideline funding augmentation
- As technology need dates shift downstream, the likelihood that non flow-through PEMFC technology will catch up to flow-through PEMFC technology increases
  - Results in lighter weight, simpler, more reliable systems

Fuel Cells for Exploration Missions Summary

- Critical development project needed to ensure the availability of enabling fuel cell and RFC technology for the Vision for Exploration
- Successfully demonstrated operation with pure oxygen in multiple orientations
  - Superior fuel cell stack performance
  - Balance-of-plant active ancillary component limitations
- Present program direction
  - Investigate multiple candidate passive components to replace active components in flow-through PEMFC systems
  - Pursue development of multiple non flow-though PEMFC stack and passive balance-of-plant technology
  - Continue generic PEMFC development in areas of MEAs and passive thermal management techniques