Non-Flow Through Fuel Cell Power Module Demonstration on the Scarab Rover

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Overview

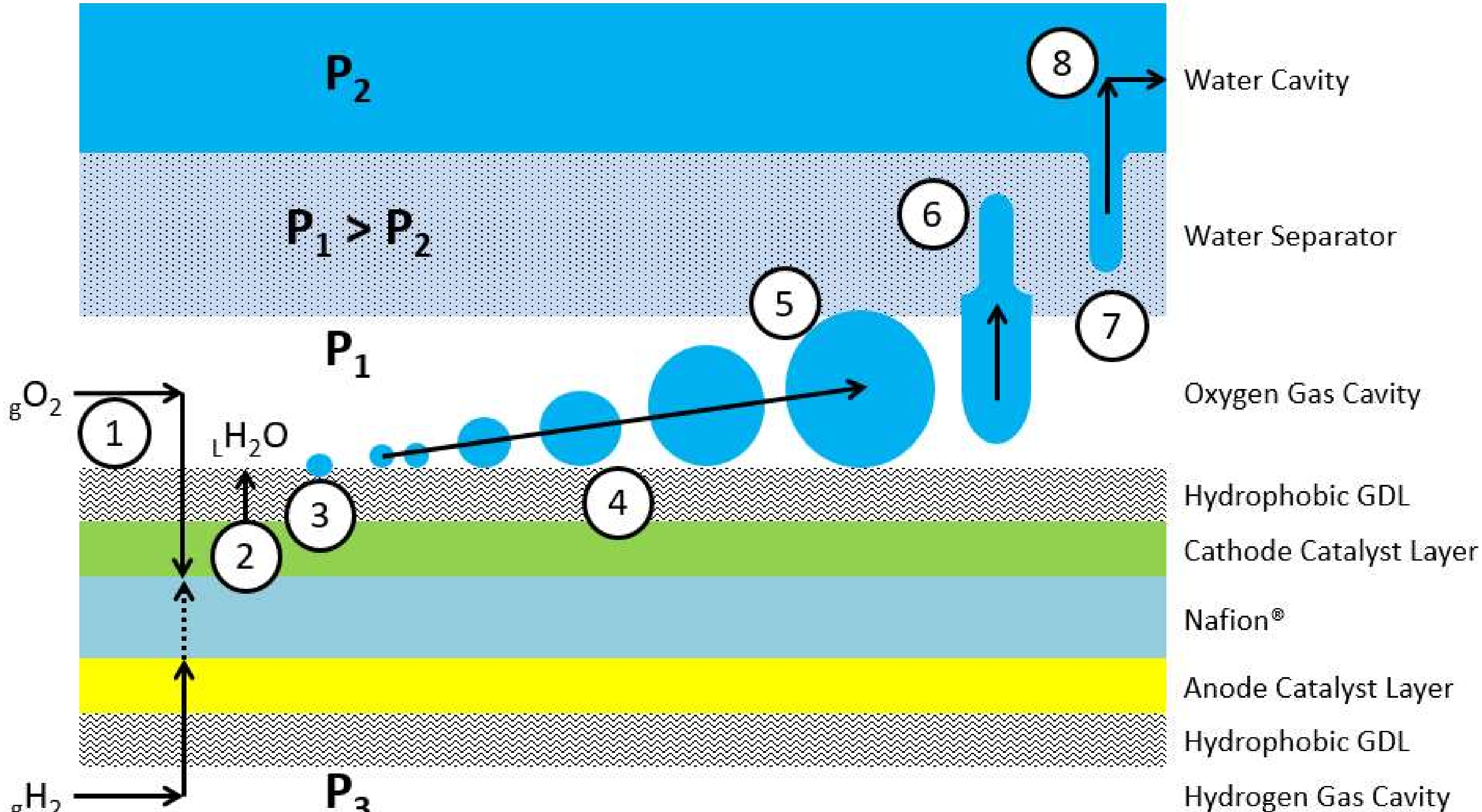
- **Demonstration Scope**
- **Fundamental Technologies**
  - Advanced Product Water Removal (APWR) Non-Flow Through (NFT) Reactant Management
  - Quad-Cell Voltage Monitoring Board (QCVMB)
  - Dust Tolerant Automated Umbilical (DTAU)
- **Power Module**
- **Rover**
- **Integrated Vehicle**
- **Demonstration**
- **Results**
- **Questions?**

Demonstration Scope

- **Provide tangible evidence illustrating that the Advanced Product Water Removal (APWR) Non-Flow Through (NFT) Reactant Management fuel cell technology has matured to TRL 5**
  - Flight-qualified H_2/O_2 fuel cell hardware is not currently available
  - The most recent flight-qualified hardware was de-commissioned at the end of the Space Shuttle program
- **Package APWR NFT fuel cell stack into a modular power system**
  - Design to allow for implementation onto multiple platforms without modifications
  - Validate packaged fuel cell stack performance equivalent to laboratory performance
- **Power a mobile platform using modular power system**
  - Validate full vehicle operational capability when powered by modular power system
  - Validate that the fuel cell stack and modular power system are unaffected by disturbances (mechanical, electrical, thermal, etc.) imposed by the vehicle during mobile operations

Non-Flow-Through (NFT) Fuel Cell Technology

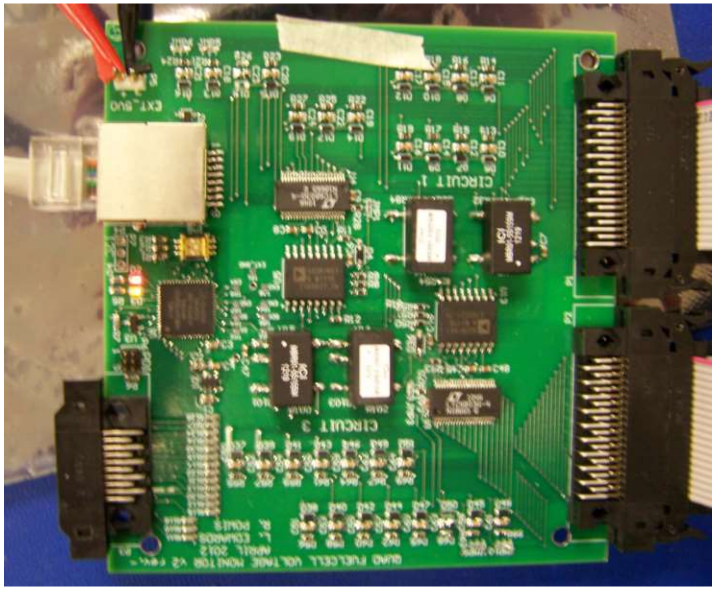
- **Advanced Product Water Removal (APWR) water management technology achieves Non-Flow Through (NFT) reactant control**
  - Surface tension and capillary forces passively “wick” water from each cell to a low-pressure water cavity
  - Eliminates need for external water removal (reduces mass, increases reliability)



For Illustrative Purposes only - Not to Scale

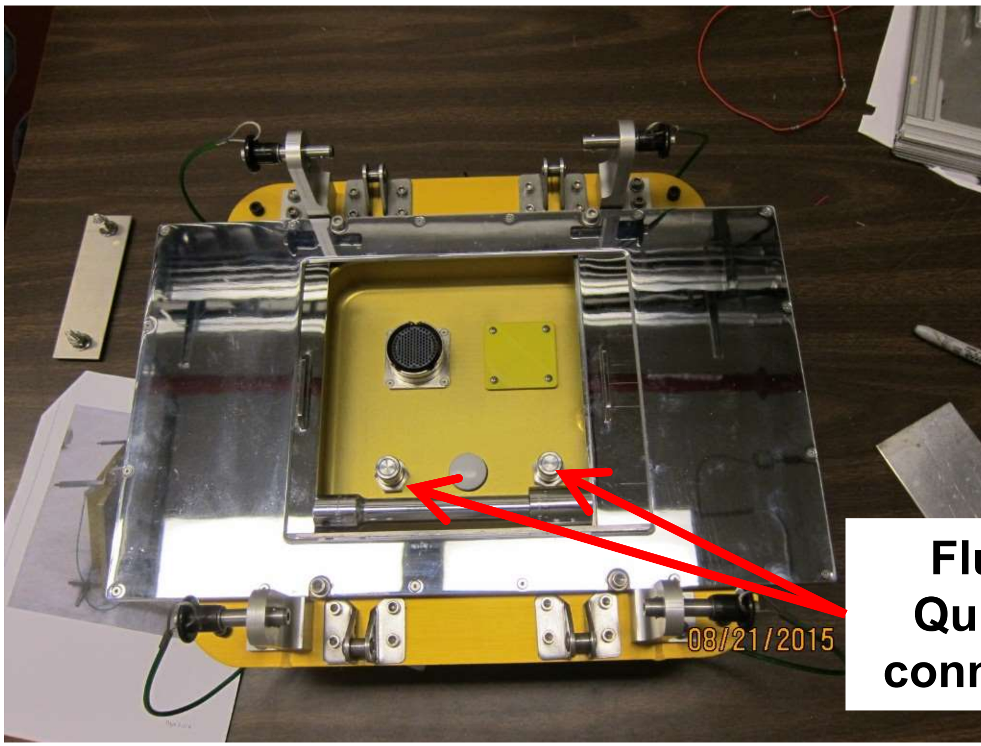
Quad-Cell Voltage Monitoring Board (QCVMB)

- PC-104 Industry Standard Module size (3.6” x 3.8”)
- 48 Individual Cell Voltages (0-2.5V_{DC})
- 12 bit ADC enables ±10 mV cell voltage accuracy
- 33 Hz measurement rate (each cell voltage)
- 0 and 1 V_{DC} reference voltages for in situ real-time calibration checks
- 600 V_{DC} Isolation between signals and board
- On-board MCU 4 DIO; USB, UART, I^2C communication
- Programmable *in-situ* fault detection/health monitoring tables
- 16 Single Ended (or 8 differential) 0-1 V_{DC} range inputs with 12 bit ADC; 33 Hz measurement rate
- 6 LED status indicators
- 1.5 watt consumption on a 5 V_{DC} bus
- Up to 8 boards can be interfaced simultaneously to the control processor (384 cells)



Dust Tolerant Automated Umbilical (DTAU)

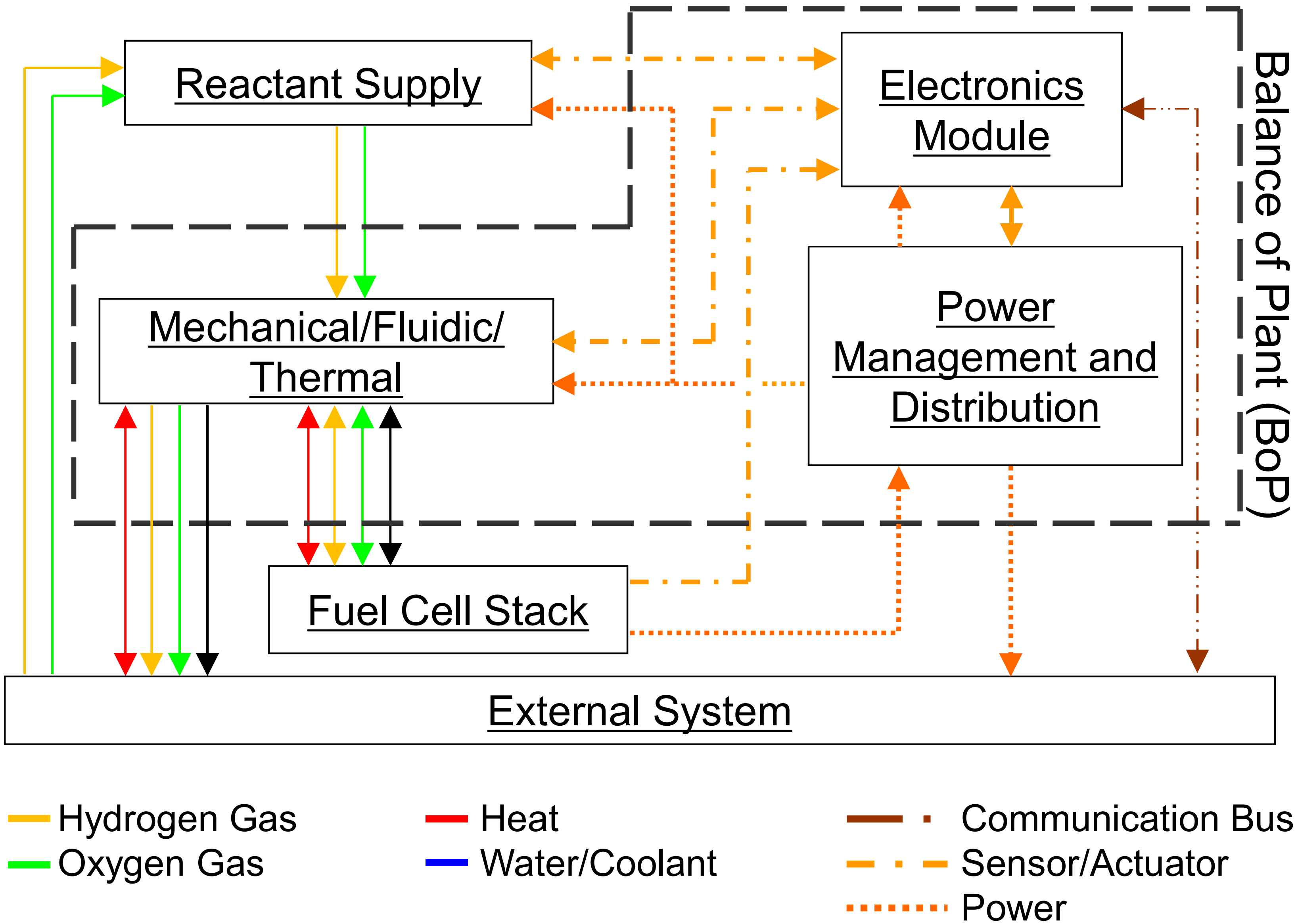
- Prototype hardware with COTS quick connects (QCs) in a dust-resistant enclosure
- Halves are manually latched and a motorized drive brings the QCs together
- Encoder detects when QCs are fully mated
- Box and QC compartment are purged with GN2
- Procedures to confirm that QCs are mated and leak-proof
- H2 detector monitors purge gas



Passive half mounted on Scarab

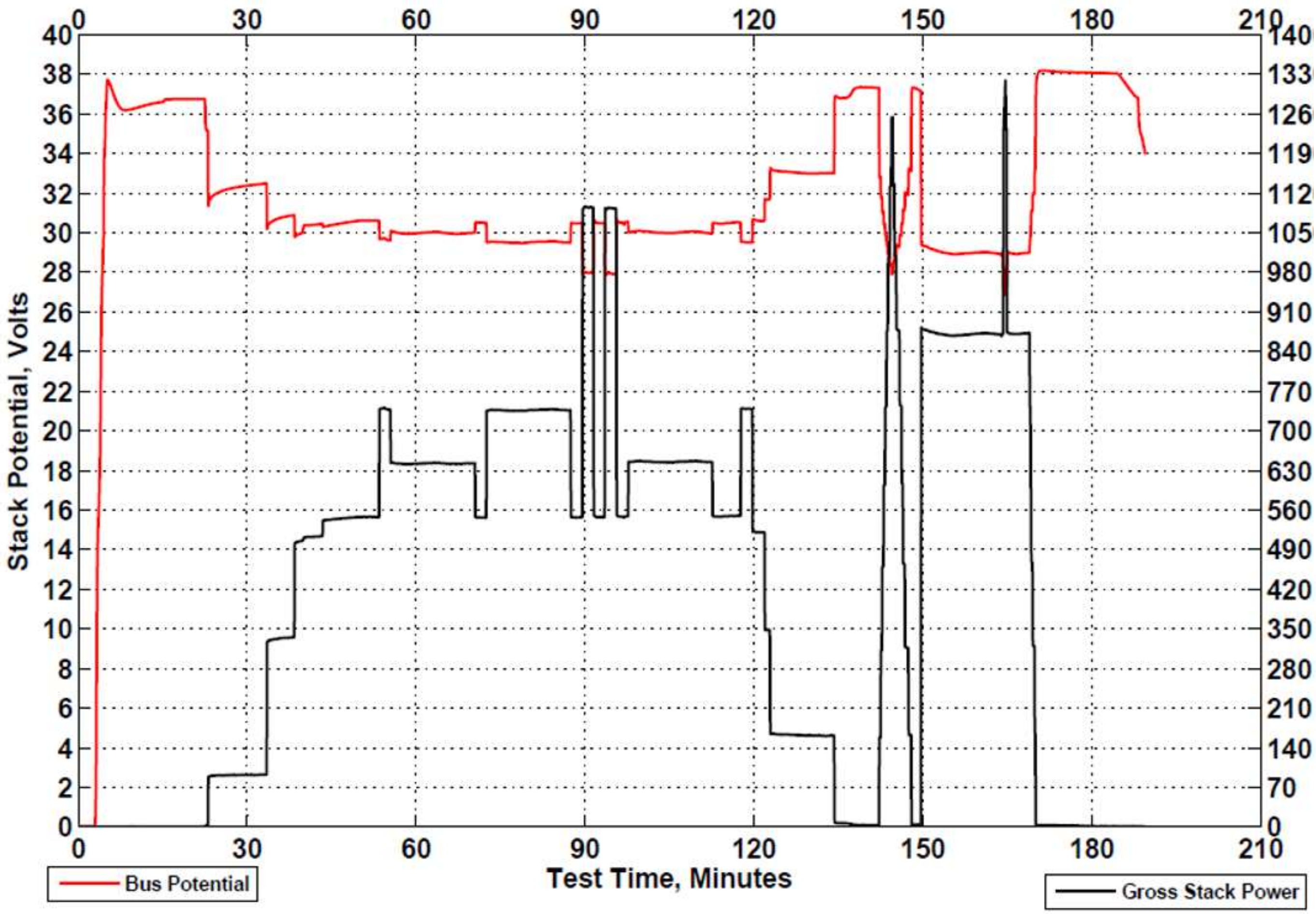
Active half manually latched to passive half for fluid transfer

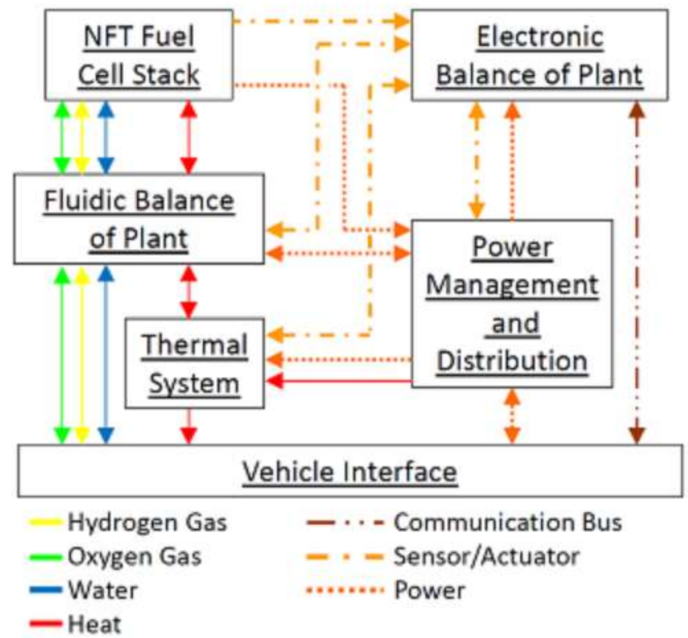
Overview of a Fuel Cell Power System



AMPS 1kW APWR NFT PFC Power Module

Advanced Modular Power Systems 1 Kilowatt Advanced Product Water Removal Non-Flow-Through Primary Fuel Cell Power Module





		Power Module
Mass	kg	149
	lb	329
Vol.	Liter	267
	ft^3	9.44

The "Dunes"

Outdoor test field for large scale vehicle demos and extended cross-slope testing

- 100 ft. X 80ft. graded area covered with 6 in. of sand
- Large hill with 3 sides of different slope angles: 10, 15, and 20 deg.
- Obstacle course consisting of boulders (~2-3 ft.), moguls, and small hills
- Controls in place to limit vegetation and erosion and allow for drainage
- Vehicle/trailer entrance

Scarab Rover

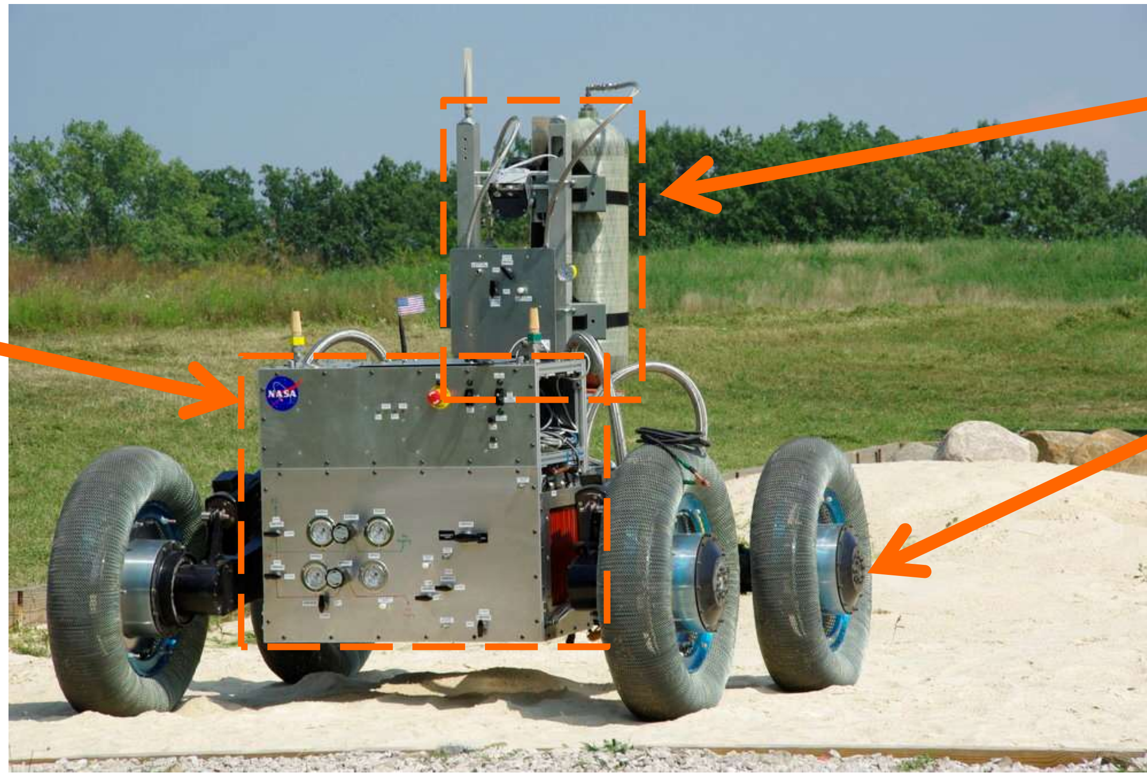
Scarab Specifications	
Unloaded Mass	300 kg
Maximum Locomotion Speed	5 cm/s
Wheelbase	0.8 – 1.4 m
Track width	1.4 m
CG height	0.48 – 0.74 m
Wheel diameter	66 – 81 cm

Scarab Power Demands, Watts

Motion	Motion Power	Total Power
Hotel Loads	175	175
Stationary (Elevation Hold)	6	181
Transit, Level hard ground	85	255
Transit, Level loose sand	120	305
Point Turn	200	375
Elevating Body	225	400
Peak Transient	590	765

Integrated Scarab Rover with Power Module

Advanced Modular Power Systems 1 Kilowatt Advanced Product Water Removal Non-Flow-Through Primary Fuel Cell Power Module



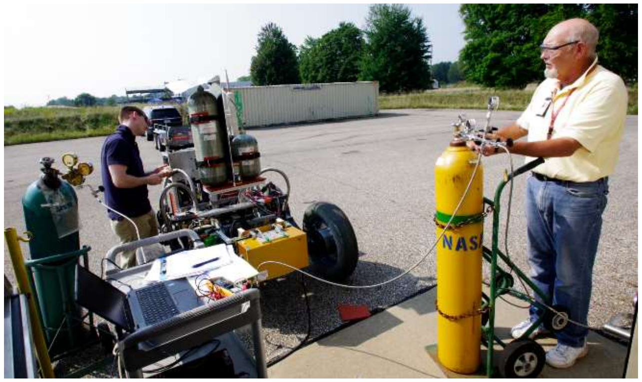
Integrated System Metrics For Power Module with $_gH_2$ & $_gO_2$ Reactant Storage		
Specific Energy	W•hr/kg	208
	kJ/kg	749
Energy Density	W•hr/L	86
Power Density	W/L	2.26

		Power Module	Reactant System	Total System
Mass	kg	149	34	183
	lb	329	75	404
Vol.	Liter	267	175	442
	ft^3	9.44	6.19	15.6
Stored Energy	kW•h	N/A	N/A	38
	MJ	N/A	N/A	137

Demonstration Success Criteria

Success Criteria	Priority
Power Module delivers at least 1 kW nominal power output within the voltage range of 24-36 VDC	High
SCARAB rover can start and idle with all power provided by the fuel cell power module (no power from additional external sources)	High
SCARAB rover can achieve forward, unidirectional motion on flat terrain at maximum speed with all power provided by the fuel cell power module	High
SCARAB rover can turn in place on flat terrain with all power provided by the fuel cell power module	High
SCARAB rover can utilize “inching” method of propulsion on flat terrain with all power provided by the fuel cell power module	Medium
SCARAB rover can climb a slope of at least 5 degrees with all power provided by the fuel cell power module	Medium
SCARAB rover can climb a slope up to 20 degrees with all power provided by the fuel cell power module	Low
SCARAB rover can climb a slope at a crossing angle with all power provided by the fuel cell power module	Low
SCARAB rover can navigate and climb small boulders and other obstacles at The Dunes test site with all power provided by the fuel cell power module	Low

Demonstration



Charging the reactant gas tanks using the DTAU

Integrated Vehicle Being Prepared for Checkout Testing on Level Surface

Integrated Vehicle Driving Across the 20° Slope

Success Criteria	Priority	
PM delivers ≥1 kW nominal power within 24-36 VDC	High	√
Scarab, when powered by Fuel Cell Power module:		
- Starts and idles	High	√
- Moves forward, unidirectional motion on flat terrain at max speed	High	√
- Turns in place on flat terrain	High	√
- Utilizes "inching" method of propulsion on flat terrain	Medium	√
- Climbs a slope of at least 5 degrees	Medium	√
- Climbs a slope up to 20 degrees	Low	√
- Climbs a slope at a crossing angle	Low	√
- Climbs small boulders and other obstacles at The Dunes test site	Low	√

Front View of the Integrated Vehicle

Review

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National Aeronautics and Space Administration
Questions?
www.nasa.gov/exploration

BACK-UP SLIDES

AMPS Major Objectives

Advanced Modular Power Systems (AMPS)

Domain: Vehicle Systems

Lead Center: GRC

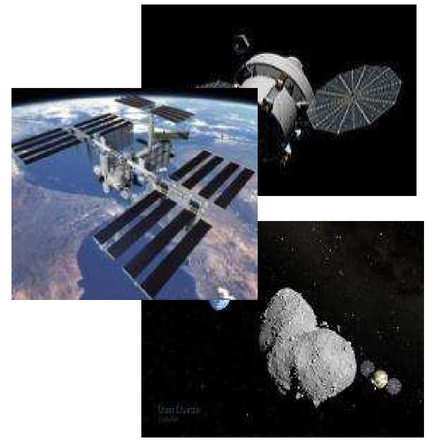
PM: Karin Bozak

Chief Technologist: Jim Soeder

- AMPS will infuse new technology into power systems and components and prove their capabilities on exploration based ground demonstrations

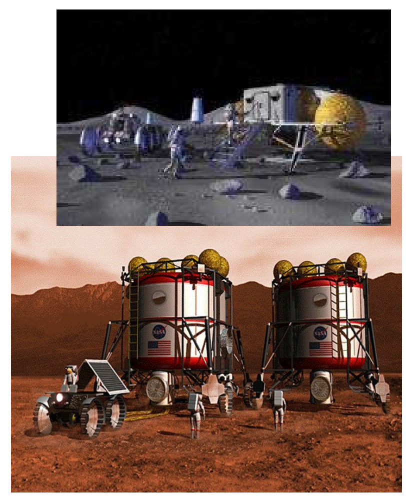
- AMPS will develop modular power units which, when combined with standardized interfaces can provide commonality across a variety of exploration vehicles

Applications



Exploration Missions

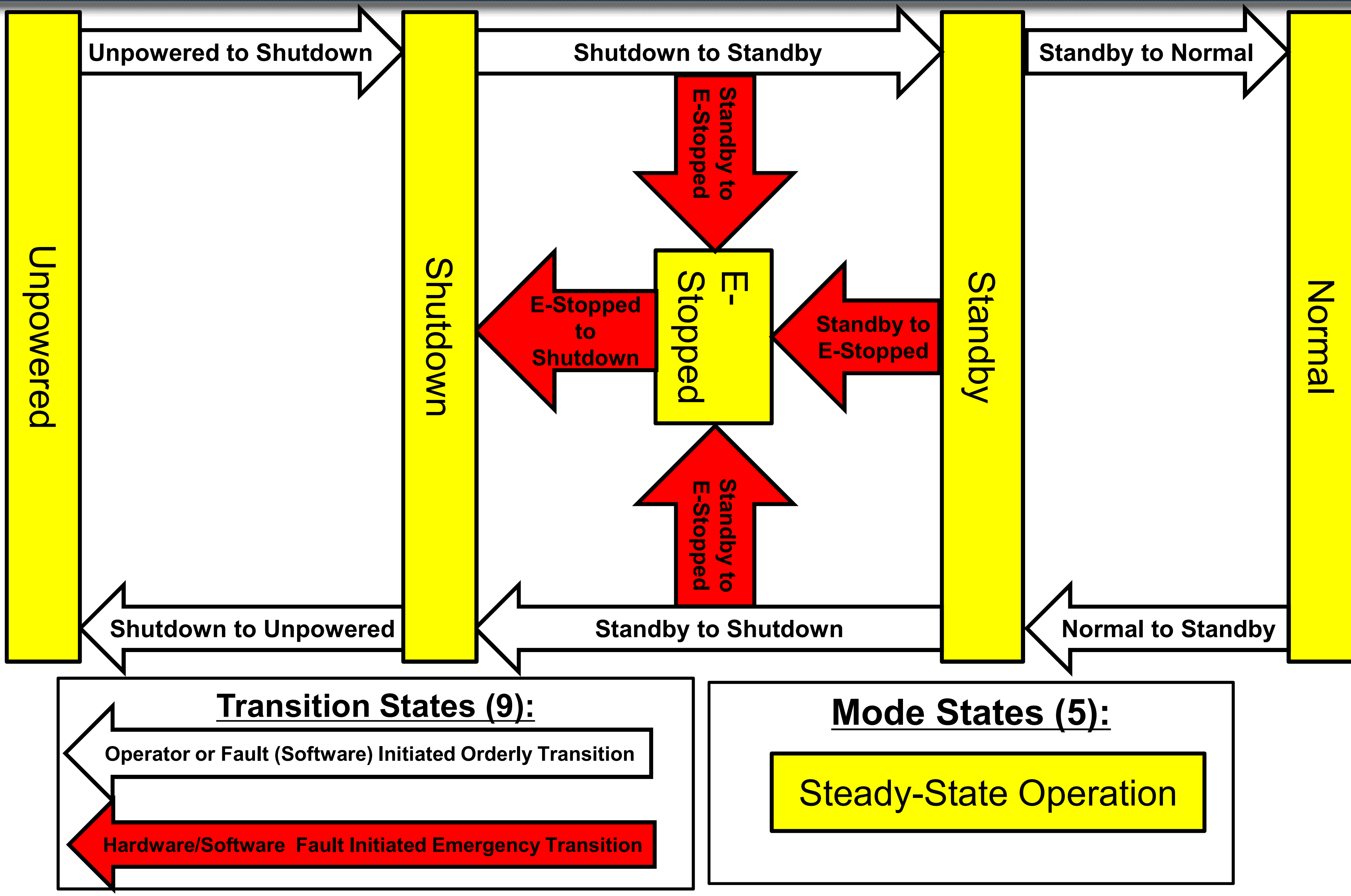
Mars / Lunar Rovers



Planetary Outposts

EVA Suits

NFT Operational Definitions



Demonstration Test Matrix

Activity	Details	Preparation/Equipment Required	# of Runs	Time / Run (min)	Total Time with setup (min)	Required ? (Y/N)
Driving on flat terrain	Scarab driven forwards and backwards.	Leveling soil	3	20	90	Y
Turn in place	Turned in place on tilt-bed (more space). Loads measured at various angles.	None	3	5	45	Y
Elevate body	Scarab elevated from lowest to highest positions.	None	3	5	45	Y
Slope climbing	Scarab driven up various slope angles (5, 10, 15, 20 deg). Angles may change. Repeated if needed.	Loosening and leveling soil.	4	30	150	Y
Cross-slope climbing	Repeat of slope climbing tests but with Scarab leaning and driving across the slope. Lower slope angles not needed.	Loosening and leveling soil.	3	30	120	N
Obstacle course	Scarab driven through obstacles which consists of sand moguls, small hill, rocks, and boulders. Tests can be focused on specific obstacles of interest.	None	3	10	60	N
Inching	Repeat of driving of flat terrain but using "inching" mode of travel.	Leveling soil	3	20	90	N
			Total Time (hr) =		***10***	

Demonstration Test Plan

Day	Location	Time of Day	Task	Time (min)
Day 1	The Dunes	Morning	Start up Scarab and fuel cell	45
			Check-out system	60
			Test out stationary/hotel loads	15
			Flat terrain tests	120
		Afternoon	Turn in place tests	45
			Elevate body tests	45
			Inching Tests	90
			Shut down Scarab and fuel cell	45
Day 2	The Dunes	Morning	Start up Scarab and fuel cell	45
			Check-out system / verify hotel loads	15
			Repeat turn in place, inching tests at minimal level	60
			Start slope-climbing tests (up to 20 deg)	75
		Afternoon	Continue slope-climbing tests	75
			Cross-slope climbing tests (up to 20 deg)	120
			Shut down Scarab and fuel cell	45
			Total Time (hr) =7.25	
Day 4 – "Media Day"	The Dunes (weather permitting)	Morning	Transfer Scarab and equipment to Dunes	60
			Start up Scarab and fuel cell	45
			Check-out system / verify hotel loads	15
			Slope-climbing tests/demos	90
		Afternoon	Cross-slope climbing tests (10, 15, and 20 deg)	60
			Demonstrate turning/elevating/inching	60
			Obstacle course demos	60
			Shut down Scarab and fuel cell	45
			Transfer Scarab and equipment to bldg. 334	45
			Total Time (hr) =8	