NASA Fuel Cell and Hydrogen Activities

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Overview

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• NASA Near Term Activities
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NASA has many development activities supported by a number of high quality people across the country. This list only includes the most significant contributors to the development of this presentation.

**Headquarters**
- Lee Mason, Space Technology Mission Directorate, Deputy Chief Engineer
- Gerald (Jerry) Sanders, Lead for In-Situ Resource Utilization (ISRU) System Capability Leadership Team

**Jet Propulsion Laboratory**
- Erik Brandon, Ph.D, Electrochemical Technologies
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**Marshall Space Flight Center**
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**Kennedy Space Center**
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**Glenn Research Center**
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- Wesley L. Johnson, Cryogenic and Fluid Systems
- Lisa Kohout, Photovoltaic and Electrochemical Systems
- Dianne Linne, ISRU Project Manager
- Phillip J. Smith, Photovoltaic and Electrochemical Systems
- Tim Smith, Chief, Space Technology Project Office
# Electrochemical System Definitions

## Primary Power
Discharge Power Only

**Description**
- Energy conversion system that supplies electricity to customer system
- Operation limited by initial stored energy

**Examples**
- Nuclear (e.g. RTG, KiloPower)
- Primary Batteries
- Primary Fuel Cells

**NASA Applications:**
Missions without access to continuous power (e.g. PV)
- All NASA applications require electrical power
- Each primary power solution fits a particular suite of NASA missions

## Energy Storage
Charge + Store + Discharge

**Description**
- Stores excess energy for later use
- Supplies power when baseline power supply (e.g. PV) is no longer available
- Tied to external energy source

**Examples**
- Rechargeable Batteries
- Regenerative Fuel Cells

**NASA Applications:**
Ensuring Continuous Power
- Satellites (PV + Battery)
- ISS (PV + Battery)
- Surface Systems (exploration platforms, ISRU, crewed)
- Platforms to survive Lunar Night

## Commodity Generation
Chemical Conversion

**Description**
- Converts supplied chemical feedstock into useful commodities
- Requires external energy source (e.g. thermal, chemical, electrical, etc.)

**Examples**
- ISS Oxygen Generators (OGA, Elektron)
- ISRU Propellant Generation

**NASA Applications:**
Life-support, ISRU
- Oxygen Generation
- Propellant Generation
- Material Processing
- Recharging Regenerative Fuel Cells
Electrochemical System Definitions

**Primary Fuel Cell**
Discharge Power Only

\[ 2H_2 + O_2 \rightarrow 2H_2O + 4e^- + \text{Heat} \]

**Regenerative Fuel Cell**
Charge + Store + Discharge

\[ \Delta P \]

**Electrolysis**
Chemical Conversion

\[ 2H_2O + 4e^- \rightarrow 2H_2 + O_2 + \text{Heat} \]

Regenerative Fuel Cell = Fuel Cell + Interconnecting Fluidic System + Electrolysis
Each power technology contributes to an integrated Regenerative Fuel Cells (RFCs) for Lunar Exploration

- Batteries meet energy storage needs for low energy applications
- RFCs address high energy storage requirements where nuclear power may not be an option (in locations near humans)
- Nuclear and radio isotope power systems provide constant power independent of sunlight
Current energy storage technologies are insufficient for NASA exploration missions.

Availability of flight-qualified fuel cells ended with the Space Shuttle Program.

Terrestrial fuel cells not directly portable to space applications.
- Different wetted material requirements (air vs. pure O₂)
- Different internal flow characteristics

No space-qualified high-pressure electrolyzer exists.
- ISS O₂ Generators are low pressure electrolyzers
- Terrestrial electrolyzers have demonstrated >200 ATM operation.
Battery Activities in Support of NASA Missions

- Low temperature electrolytes to extend operating temperatures for outer planetary missions
- High temperature batteries for Venus missions
- Non-flammable separator/electrolyte systems
- Solid-state high specific energy, high power batteries
- Li-air batteries for aircraft applications
  - Improved cathode and electrolyte stability in Lithium-Oxygen batteries
- Multi-functional load-bearing energy storage
- X-57 Maxwell distributed electric propulsion flight demonstration
- Safe battery designs and assessments for aerospace applications
Energy Storage System Needs for Future Planetary Missions

**Primary Batteries/Fuel Cells for Surface Probes:**
- High Temperature Operation (> 465°C)
- High Specific Energy (>400 Wh/kg)
- Operation in Corrosive Environments

**Rechargeable Batteries for Aerial Platforms:**
- High Temperature Operation (300-465°C)
- Operation in Corrosive Environments
- Low-Medium Cycle Life
- High Specific Energy (>200 Wh/kg)
- Operation in High Pressures

**Primary Batteries/Fuel cells for planetary landers/probes:**
- High Specific Energy (> 500 Wh/kg),
- Long Life (> 15 years),
- Radiation Tolerance & Sterilizable by heat or radiation

**Rechargeable Batteries for flyby/orbital missions:**
- High Specific Energy (> 250 Wh/kg)
- Long Life (> 15 years)
- Radiation Tolerance & Sterilizable by heat or radiation.

**Low temperature Batteries for Probes and Landers:**
- Low Temperature Primary batteries (< -80°C)
- Low Temperature Rechargeable Batteries (< -60°C)
Lunar RFC Trade Study Results

10 kW H$_2$/O$_2$ RFC Energy Storage System for Lunar Outpost

- RFC System Mass: kg
- RFC System Specific Energy: W-hr/kg
- Batteries

RFCs enable missions to survive the lunar night.

RFC specific energy dependent on location.
Battery specific energy independent of location.
• A solar array powers the probe at high altitude and generates H₂ and O₂ with Solid Oxide Electrolysis Cell (SOEC) using water carried from ground as a closed-system.
• Metal hydride H₂ storage and compressed gas O₂ storage
• Solid Oxide Fuel Cell (SOFC) will powers the probe at low altitudes from the stored H₂ and O₂.
• H₂-filled balloon will be used for buoyancy and altitude control (60-15 km).
Electrolysis within NASA

**Fundamental Process**
- Electrochemically dissociating water into gaseous hydrogen and oxygen
- Multiple chemistries – Polymer Electrolyte Membrane (PEM), Alkaline, Solid Oxide
- Multiple pressure ranges
  - ISRU & Life support = low pressure
  - Energy storage = high pressure

**Life Support**: Process recovered H₂O to release oxygen to source breathing oxygen
- Redesign ISS Oxygen Generator assembly for increased safety, pressure, reliability, and life
- Evaluate Hydrogen safety sensors

**Energy Storage**: Recharge RFC system by processing fuel cell product H₂O into H₂ fuel and O₂ oxidizer for fuel cell operation

**ISRU**: Process recovered H₂O to utilizing the resulting H₂ and O₂
- Hydrogen Reduction – Hydrogen for material processing
- Life Support – Oxygen to source breathing oxygen
- Propellant Generation – Oxygen for liquefaction and storage
In-situ Resource Utilization (ISRU)

Modular Power Functions/Elements
- Power Generation
- Power Distribution
- Energy Storage (O₂ & H₂)

Support Functions/Elements
- ISRU
- Life Support & EVA
- O₂, H₂, and CH₄ Storage and Transfer

Shared Hardware to Reduce Mass & Cost
- Solar arrays/nuclear reactor
- Water Electrolysis
- Reactant Storage
- Cryogenic Storage
- Mobility

In-Space Construction

In-Space Manufacturing

Life Support & EVA
- Pressurized Rover
- Regenerative Fuel Cell

Modular Power Systems
- Solar & Nuclear
- Surface Hopper

CO₂ & Trash/Waste
- Used Descent Stage
- Lander/Ascent

CO₂, O₂, H₂, and CH₄

H₂O, CO₂ from Soil/Regolith

H₂O from Mars Atmosphere

Regolith Crushing & Processing

Regolith/Soil Transport

Regolith/Soil Excavation & Sorting

Resource & Site Characterization

Water/Volatile Extraction

ISRU Resources & Processing
Lunar ISRU Mission Capability Concepts

- Resource Prospecting – Looking for Polar Ice
- Excavation & Regolith Processing for O₂ Production
- Carbothermal Processing with Altair Lander Assets
- Thermal Energy Storage Construction
- Landing Pads, Berm, and Road Construction
- Consumable Depots for Crew & Power
ISRU is Similar to Establishing Remote Mining Infrastructure and Operations on Earth

Communications
- To/From Site
- Local

Transportation to/from Site:
- Navigation Aids
- Loading & Off-loading Aids
- Fuel & Support Services

Power:
- Generation
- Storage
- Distribution

Planned, Mapped, and Coordinated Mining Ops:
Areas for: i) Excavation, ii) Processing, and iii) Tailings

Maintenance & Repair

Living Quarters & Crew Support Services

Construction and Emplacement

Roads

Logistics Management
Reactant Processing and Storage

**Oxygen**
- MOXIE O₂ Generator
- Oxygen Concentrators
- CryoFILL Liquefaction and Storage

**Hydrogen**
- Zero Boil-Off Tank (ZBOT) Experiment
- Purification and Recovery

**Radio Frequency Mass Gauge (RFMG)**
- Tank-to-Tank Transfer
Zero Boil-off Cryogenics

Zero Boil-Off Tank (ZBOT) Experiment: Hardware in MSG Aboard ISS

1g (1W), 90%, Self-Pressurization

Micro-g (0.5W), 70%, Self-Pressurization

ZBOT Experiment During Jet Mixing
Thank you for your attention.

Questions?