NASA Fuel Cell and Hydrogen Activities

Presented by: Ian Jakupca
NASA Glenn Research Center

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Overview

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• NASA Near Term Activities
• Energy Storage and Power
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  • Fuel Cells
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• Review
National Aeronautics and Space Administration

Earth

Moon

Mars

In LEO
Commercial & International partnerships

In Cislunar Space
A return to the moon for long-term exploration

On Mars
Research to inform future crewed missions
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# 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
**Primary Fuel Cell**
Discharge Power Only

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

**Discharging**

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

\[\eta_{\text{Cycle}} = \sim 50\%\]

**Discharging**

**Electrolysis**
Chemical Conversion

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

**Charging**

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
Energy Storage Options for Space Applications

- 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)

All images are Artist’s Concepts
Lunar RFC Trade Study Results

10 kW H₂/O₂ RFC Energy Storage System for Lunar Outpost

- RFC specific energy dependent on location.
- Battery specific energy independent of location.

RFCs enable missions to survive the lunar night.
**Venus Power Concept for Variable Altitude Balloon**

- 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).

### Above the clouds
- SOEC recharges H₂ & O₂ from H₂O
- Consumes stored H₂O
- Solar array powers probe

### Below the clouds
- SOFC generates power from H₂ & O₂ to power probe
- Store H₂O byproduct

H₂ from balloon into hydride to descend below the clouds

H₂ from hydride into balloon to ascend above the clouds
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 (O\textsubscript{2} & H\textsubscript{2})

Support Functions/Elements
- ISRU
- Life Support & EVA
- O\textsubscript{2}, H\textsubscript{2}, and CH\textsubscript{4} Storage and Transfer

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

ISRU Resources & Processing

Regolith/Soil Excavation & Sorting

Regolith/Soil Transport

Regolith Crushing & Processing

Water/Volatile Extraction

H\textsubscript{2}O, CO\textsubscript{2} from Soil/Regolith

H\textsubscript{2}O, CO\textsubscript{2} from Mars Atmosphere

CO\textsubscript{2} for O\textsubscript{2} & Metals

Life Support & EVA

Pressurized Rover

Habitats

Modular Power Systems

Solar & Nuclear

Regenerative Fuel Cell

Surface Hopper

Used Descent Stage

Propellant Depot

Lander/Ascent

Consumable Storage

In-Space Construction

In-Space Manufacturing
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
Reactant Processing and Storage

Oxygen
- MOXIE O₂ Generator
- Oxygen Concentrators
- Tank-to-Tank Transfer
- CryoFILL Liquefaction and Storage
- Radio Frequency Mass Gauge (RFMG)

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

Purification and Recovery
- RF analyzer
- Computer
- H₂
- He
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?