NASA Fuel Cell and Hydrogen Activities

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Overview

• National Aeronautic and Space Administration
• Definitions
• NASA Near Term Activities
• Energy Storage and Power
  • Batteries
  • Fuel Cells
  • Regenerative Fuel Cells
  • Electrolysis
• ISRU
• Cryogenics
• Review
National Aeronautics and Space Administration

Earth
- ISS
- Commercial launch Vehicles
- Commercial & International partnerships

Moon
- Orion
- SLS
- Robotic Surface Missions
- Commercial Lunar Lander
- Lunar Orbital Platform - Gateway
- PPE: Habitat - Airlock - Logistics

Mars
- Mars robotic exploration, technology development
- Research to inform future crewed missions

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
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
- Ratnakumar Bugga, Ph.D, Electrochemical Technologies

**Marshall Space Flight Center**
- Kevin Takada, Environmental Control Systems

**Kennedy Space Center**
- Erik Dirschka, PE, Propellant Management

**Glenn Research Center**
- William R. Bennett, Photovoltaic and Electrochemical Systems
- Fred Elliott, Space Technology Project Office
- Ryan Gilligan, Cryogenic and Fluid Systems
- 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
2H₂ + O₂ → 2H₂O + 4e⁻ + Heat

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

\[ \text{Discharging} \]

\[ \text{Charging} \]

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

**Electrolysis**
Chemical Conversion
2H₂O + 4e⁻ → 2H₂ + O₂ + 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
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)
Lunar RFC Trade Study Results

10 kW H$_2$/O$_2$ 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
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**

**ISRU Resources & Processing**
- Resource & Site Characterization
- Regolith/Soil Excavation & Sorting
- Regolith/Soil Transport
- Water/Volatile Extraction
- Regolith Crushing & Processing
- CO₂ from Mars Atmosphere
- H₂O, CO₂ from Soil/Regolith

**Life Support & EVA**
- Pressurized Rover
- Habitations
- Regenerative Fuel Cell
- Surface Hopper
- Used Descent Stage
- Propellant Depot
- Lander/Ascent

**Modular Power Systems**
- Solar & Nuclear
- Consumable Storage
- Lander/Ascent
Lunar ISRU Mission Capability Concepts

- Resource Prospecting – Looking for Polar Ice
- Excavation & Regolith Processing for $O_2$ Production
- Thermal Energy Storage Construction
- Carbothermal Processing with Altair Lander Assets
- 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

- Maintenance & Repair

- Logistics Management

- Living Quarters & Crew Support Services

- Construction and Emplacement

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

- Roads
Reactant Processing and Storage

**Oxygen**
- MOXIE $\text{O}_2$ Generator
- Oxygen Concentrators

**Hydrogen**
- Zero Boil-Off Tank (ZBOT) Experiment

CryoFILL Liquefaction and Storage

Radio Frequency Mass Gauge (RFMG)

Purification and Recovery

- $\text{H}_2$
- 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?