NASA Fuel Cell and Hydrogen Activities

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Department of Energy
Annual Merit Review
30 April 2019
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
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.

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- Gerald (Jerry) Sanders, Lead for In-Situ Resource Utilization (ISRU) System Capability Leadership Team

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## Electrochemical System Definitions

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### Description
- **Primary Power**: Energy conversion system that supplies electricity to customer system. Operation limited by initial stored energy.
- **Energy Storage**: Stores excess energy for later use. Supplies power when baseline power supply (e.g. PV) is no longer available. Tied to external energy source.
- **Commodity Generation**: Converts supplied chemical feedstock into useful commodities. Requires external energy source (e.g. thermal, chemical, electrical, etc.).

### Examples
- **Primary Power**: Nuclear (e.g. RTG, KiloPower), Primary Batteries, Primary Fuel Cells.
- **Energy Storage**: Rechargeable Batteries, Regenerative Fuel Cells.
- **Commodity Generation**: ISS Oxygen Generators (OGA, Elektron), ISRU Propellant Generation.

### NASA Applications
- **Primary Power**: 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**: Satellites (PV + Battery), ISS (PV + Battery), Surface Systems (exploration platforms, ISRU, crewed), Platforms to survive Lunar Night.
- **Commodity Generation**: Oxygen Generation, Propellant Generation, Material Processing, Recharging Regenerative Fuel Cells.

### 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

\[ \Delta P \]

\[ Q \]

\[ \Delta P \]

\[ TH \]

\[ \Delta P \]

\[ Q_{TH} \]

\[ Q_{ELE} \]

Discharging

Charging

**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 $O_2$
  - Different internal flow characteristics
- No space-qualified high-pressure electrolyzer exists
  - ISS $O_2$ 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.
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

ISRU Resources & Processing
- Regolith/Soil Excavation & Sorting
- Regolith/Soil Transport
- Regolith Crushing & Processing
- Water/Volatile Extraction
- H₂O, CO₂ from Soil/Regolith
- CO₂ from Mars Atmosphere
- CH₄, O₂, H₂O

Life Support & EVA
- Pressurized Rover
- Habits
- CO₂ & Trash/Waste

Modular Power Systems
- Solar & Nuclear
- Regenerative Fuel Cell
- Surface Hopper
- Lander/Ascent
- Propellant Depot
- Used Descent Stage

Consumable Storage
- Lander/Ascent

In-Space Construction
- Civil Engineering, Shielding, & Construction

In-Space Manufacturing
- Parts, Repair, & Assembly
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

Maintenance & Repair

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 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

**Reactants**
- Oxygen
- Hydrogen
- Zero Boil-Off Tank (ZBOT)

**Equipment**
- CO₂ Feed
- CO₂ Exhaust
- O₂ Exhaust
- Endplate (-)
- Midplate (+/-)
- Endplate (+)
- 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
Thank you for your attention.

Questions?