Scope Title

Reversible Proton Exchange Membrane (PEM) Cells for High-Pressure Oxygen and Hydrogen

Scope Description

Objective: Develop a PEM cell design that stably and efficiently operates in both electrolysis and fuel cell modes at high pressures with pure oxygen and hydrogen.

NASA needs energy storage technologies with very high specific energies (W·hr/kg) to maximize the intended science and exploration payloads. Packaged state-of-the-art lithium ion battery systems have a packaged specific energy of ~180 W·hr/kg. Regenerative fuel cell systems have the theoretical potential to more than double this specific energy, depending on the mission specifics and mission energy requirements. Current regenerative fuel cell (RFC) energy storage systems include a significant balance of plant to manage the discrete stack architecture necessitated by the water management requirements of the hydrogen-oxygen-water reaction triad. Detailed research into potential electrolyte chemistries for high-efficiency/low-mass RFC systems strongly indicates that the PEM technology includes the necessary ionic conductivity to support required reaction rates as well as the mechanical durability to survive the high pressures and dynamic thermal and mechanical environments. A unitized fuel cell that supports both the power-producing fuel cell reaction and the energy-storing electrolysis reaction has the potential to reduce the complexity of the RFC balance of plant. Recent developments by academia, Government, and industry have produced these unitized PEM cells for use in hydrogen/air systems. NASA operates in environments without access to air and must use pure oxygen. This call seeks to leverage the existing developments in the unitized PEM cell design that support high-pressure unitized PEM cell operation in air to utilize pure oxygen. As this application is critically limited by available power and mass, preference is given to solutions with lower parasitic power and mass.

- Working fluids: Oxygen, hydrogen, water.
- Operational life: >170 cycles (~10-yr life + flight qualification testing).
- Minimum round-trip efficiency: >48% based on higher heating value (HHV) when measured at 500 mA/cm² in fuel cell mode, 1,500 mA/cm² in electrolysis mode.
- Operation in fuel cell mode:
  - Minimum = 3 hr.
  - Target = 366 hr.
- Operation in electrolysis mode:
  - Minimum = 3 hr.
  - Target = 366 hr.
• Maximum time to cycle between modes: 3 min (lower preferred).
• Process fluid pressure range (oxygen and hydrogen):
  - Minimum = 35 to 250 psia.
  - Target = 35 to 2,500 psia.

Expected TRL or TRL Range at completion of the Project

2 to 4

Primary Technology Taxonomy

Level 1
TX 03 Aerospace Power and Energy Storage

Level 2
TX 03.2 Energy Storage

Desired Deliverables of Phase I and Phase II

- Research
- Prototype
- Hardware
- Analysis

Desired Deliverables Description

Phase I Deliverables:

1. Final report.
2. Testing up to 250 psia with both reactants.
3. Engineering data package including supporting analyses, design drawings, test plans, and reports.

Phase II:

1. Final report.
2. Testing up to 2,500 psia with both reactants.
3. Engineering data package including supporting analyses, design drawings, test plans, and reports.
4. Prototype reversible fuel cell stack of at least five cells with an active area of at least $50 \text{ cm}^2$ for testing at a NASA center.

State of the Art and Critical Gaps

Current regenerative fuel cell designs utilize discrete (separate) electrochemical stacks for the fuel cell and electrolysis reactions. A unitized cell has the possibility of significantly reducing the mass of a system by eliminating up to a third of the system components by incorporating both reactions within a single electrochemical stack. The Department of Energy has supported development of unitized cells for hydrogen/air systems. However, these cell designs utilize catalysts and other materials unsuitable for the $\text{H}_2/\text{O}_2$ systems required by space applications.

Relevance / Science Traceability

This technology would support any lunar or Mars mission that requires an energy storage system with a specific energy higher than the $\sim180 \text{ W\cdothr/kg}$ offered by packaged lithium ion battery systems. This includes Science Mission Directorate (SMD) lunar sensor arrays or crewed lunar outposts.
References

The literature contains a large number of papers on the challenges associated with reversible PEM cells. These challenges include catalyst selectivity, amphiphilic/hydrophilic/hydrophobic surface treatments, and fluid versus electrode reversibility. Since the bulk of the recent research in this area was funded by the Department of Energy (DOE), see the DOE Reversible Fuel Cell Targets ([https://www.hydrogen.energy.gov/pdfs/20001-reversible-fuel-cell-targets.pdf](https://www.hydrogen.energy.gov/pdfs/20001-reversible-fuel-cell-targets.pdf)) for the current terrestrial performance and life targets.

Scope Title

High-Efficiency Reversible Dehumidification Technology

Scope Description

Objective: Develop a desiccant material or other technical solution to manage dew point of bulk gases and recover separated water for later use.

Water management is a major concern on the lunar surface, and operational systems on the lunar surface need to conserve water whenever possible. Power-limited in situ resource utilization (ISRU) and regenerative fuel cell (RFC) energy storage systems generate water-saturated hydrogen and oxygen gases that need to be dehumidified prior to storing the gases. Nonregenerative desiccants or technologies that require dumping absorbed water overboard constitute unacceptable water-loss rates for ISRU and RFC systems. As this application is critically limited by available power and mass, preference is given to solutions with lower parasitic power and mass.

- Bulk fluid 1: Oxygen, saturated with water (noncondensing) at flow rates up to 50 SLPM.
- Bulk fluid 2: Hydrogen, saturated with water (noncondensing) at flow rates up to 100 SLPM.
- Target dew point: <-40 °C.
- Recovery rate (%): >99.3% per cycle.
- Operational life: >100 cycles (~6-yr life + flight qualification testing).
- Process fluid pressure range: 35 to 2,500+ psia.
- Process fluid temperature range: 4 to 85 °C.

Special notes:

- Desiccant materials to be compatible with bulk fluids.
- No slipstreams (any fluids that leave the system through a slipstream represent a loss of system capacity).
- Cannot release particulates to the system that could contaminate the electrochemical hardware.

Expected TRL or TRL Range at completion of the Project

3 to 5

Primary Technology Taxonomy

Level 1

TX 03 Aerospace Power and Energy Storage

Level 2

TX 03.2 Energy Storage

Desired Deliverables of Phase I and Phase II
Desired Deliverables Description

Phase I Deliverables:

1. Final report.
2. Engineering data package including supporting analyses, design drawings, test plans, and reports.

Phase II Deliverables:

1. Final report.
2. Engineering data package including supporting analyses, design drawings, test plans, and reports.
3. Two prototype sets of hydrogen and oxygen humidification control system for testing at a NASA Center.

State of the Art and Critical Gaps

Based on current research, there exists a gap for regenerative humidity regulation solutions for hydrogen and oxygen gas systems with long-term operation that exclude venting water or gases overboard.

Relevance / Science Traceability

This technology can apply to any NASA mission that produces hydrogen and oxygen from water. Examples include ISRU and power applications and, to a much lesser extent, life support applications.

References