The closed-cycle hydrogen-oxygen PEM regenerative fuel cell (RFC) at NASA Glenn Research Center has demonstrated multiple back to back contiguous cycles at rated power, and round trip efficiencies up to 52 percent. It is the first fully closed cycle regenerative fuel cell ever demonstrated (entire system is sealed: nothing enters or escapes the system other than electrical power and heat). During FY2006 the system has undergone numerous modifications and internal improvements aimed at reducing parasitic power, heat loss and noise signature, increasing its functionality as an unattended automated energy storage device, and in-service reliability. It also serves as testbed towards development of a 600 W-hr/kg flight configuration, through the successful demonstration of lightweight fuel cell and electrolyser stacks and supporting components.

This paper updates the FY2006 experimental effort and highlights the performance achieved to date. Continuing test operations focus on:

1.) Increasing the number of contiguous uninterrupted charge discharge cycles
2.) Increasing the performance envelope boundaries
3.) Operating the RFC as an energy storage device on a regular basis
4.) Characterizing system performance with smaller and lighter weight basic components
5.) Instrumentation and in situ fluid sampling strategies to monitor health and anticipate breakdowns
6.) Continued development of fully automated operation and system health monitoring

The RFC has demonstrated its potential as an energy storage device for aerospace solar power systems such as solar electric aircraft, lunar and planetary surface installations; any airless environment where minimum system weight is critical. Its development process continues on a path of risk reduction for the flight system NASA will eventually need for the manned lunar outpost.

END OF ABSTRACT
Hydrogen-Oxygen PEM Regenerative Fuel Cell Development at NASA Glenn Research Center

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PEM Hydrogen-Oxygen Regenerative Fuel Cell at NASA Glenn Research Center

Built up at NASA GRC during FY 2002 - 2003
First closed loop demonstration Sep. 2003
Coordinated operation of fuel cell and electrolyser subsystems as integrated electrical energy storage system
generate and store H2 and O2 reactant gasses
produce electrical power from stored H2 and O2
system is completely sealed: nothing goes in, nothing escapes other than electrical power and waste heat
Closed loop operation at full power Jun 2004.
Further development testing July 2004-July 2005
Demonstrated 5 contiguous back to back charge-discharge cycles at full power without breakdown or degradations under semi autonomous control July 2005.
New reactant recirculation loop pumps, thermal control improvements made during FY2006, unattended operation demonstrated April 2006
Next step: Complete characterization tests with next generation fuel cell and electrolyser stacks
Hydrogen – Oxygen Regenerative Fuel Cell

fuel cell mode (discharge)

electrolysis mode (charge)

Converter

Hydrogen storage

Oxygen storage

Water

Electrical power
Why RFC’s offer promise

• Key technology that enables future NASA missions
  – Solar energy storage of choice for day/night cycles > 4 hr
• Technical performance appears achievable
Comparison of Energy Storage Devices
(12 hr/12 hr cycle)

- Flywheel System
- Lithium Ion battery
- Nickel-Hydrogen battery
- SOA RFC
- Advanced RFC

Specific Energy (Whr/kg)

Round Trip Efficiency (%)

Specific Energy (Whr/kg)
Design Groundrules for Closed Loop Regenerative Fuel Cell Test Rig

1. Meet or exceed national safety standards for systems utilizing pressurized Hydrogen and Oxygen
2. Use commercial off-the-shelf and fabricated components to build working rig initially.
3. Provide flexibility to incorporate flight-like components later
4. Include additional sensors for data collection.
5. Provide O2 and H2 venting capabilities
6. Provide N2 purging and vacuum charging as service interfaces not part of the rig.
7. Provide capability for collecting gas and water grab samples.
Storage Tank - Hydrogen

Oxygen

Blg 135  Regenerative Fuel Cell Test Site
Lynntech Gen4 Hydrogen-Oxygen PEM Fuel Cell Stack

Power output: 5.25 kW
Active Area: 200 cm²
Efficiency*: 70%
Pressure: 50-400 psi
Weight: 40.2 lbs
Dimensions: 10” Ø, 20”L
Power Density: 131 W/lb
Number of Cells: 64
Output Voltage: 50-54 V
Current: 100 A
H₂ Consumption: 45 SLM
O₂ Consumption: 22.5 SLM

*Efficiency is calculated based upon LHV of H₂
Fuel Cell Individual Cell Performance at

100A, 65 psig and 135°F
Regenerative Fuel Cell - Fuel Cell Stack and Reactant Recirculation Loops
Lynntech Gen4 PEM Electrolyzer Stack

Power Input: 15 kW
Active Area: 200 cm²
Efficiency*: 71%
Output Pressure: 0-400 psi
Weight: 31.7 lbs
Dimensions: 10” Ø, 14”L
Power Density: 492 W/lb
Number of Cells: 60
Applied Voltage: 104 V
Current: 150 A
H₂ Production: 60 SLM
O₂ Production: 30 SLM

*Efficiency is calculated based on the LHV of H₂
Electrolyzer Individual Cell Performance

at 150 A, 245 psig and 140°F
Regenerative Fuel Cell - Electrolyser / Reactant Regeneration
Regenerative Fuel Cell - Reactant Gas Dryers and Storage
Ice Catcher

Ice-catcher Before Preliminary Testing

Ice-catcher After Preliminary Testing
Integrated Equipment Assembly
Integrated Equipment Assembly inside Blg 135
Integrated Equipment Assembly: Fuel Cell and
CONTROL / MONITOR INSTRUMENTATION

Instrument data collection, most control actuation through National Instruments Field Point I / O modules

Ethernet Bus and multiport switching hubs accommodate Field Point I / O and RS232 / RS485 serial connections.

Fiber optic data link control room to test site

PC-based National Instruments <Lab View> controller 3 redundant controller PC’s, master-slave hierarchy “RFC Day Cycle” program

Critical safety functions hard-wired / relay logic
Two extended day / night cycles, with interruptions.
• Closed loop operation at full power > 4 hrs operation - June 2004.

• Two (2) day/night cycles closed loop with SOA hardware (Short Stack) - April 2005.

• One day/night (charge/discharge) cycle at full power closed loop with SOA hardware - May 2005.

• Five (5) contiguous day/night cycles at full power closed loop with SOA hardware - June 2005.
Problems Solved

• Mode Transition Pressure Swings due to Reactant Recombination
  – Scheduled control valves, volumes, and orifices

• Individual Cell Dropoff, Cell Dryout, Cell Flooding
  – Controlled temperatures, pressures, reactant recirculation

• Rapid Power Transitions Via Fuzzy Logic
  – Faster than a human operator

• Water Balance
  – Completely sealed, closed loop system

• Inert Contaminants
  – Venting / purging reduced to zero as reactants are refined over many cycles.
RFC round trip efficiency demonstration

Electrolyzer Polarization
68 - 115 F
70 psig

Operating point for RTE test.
RFC round trip efficiency demonstration
RFC round trip efficiency demonstration

Hydrogen and Oxygen Reactant Storage Pressure Profile

- H2 Pressure
- O2 Pressure

Pressure (psig) vs. Elapsed Time (hrs)
RFC round trip efficiency demonstration

Electrolyzer Cell Voltage and Efficiency Profile

- EZ11 (L)
- EZ24 (H)
- EZ Avg CV
- EZ Eff

350 mA/cm²
140 F
RFC round trip efficiency demonstration

Fuel Cell Voltage and Efficiency Profile

- FC39
- FC50
- FCavg
- Efficiency

300 mA/cm²
60 psig
140 F
Summary

• First Ever, Fully Closed Cycle Hydrogen-Oxygen Regenerative Fuel Cell

• Completed Multiple Contiguous Day / Night Closed Loop Cycles at Full Power with SOA Hardware

• 50 PCT Round Trip Efficiency demonstrated
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