2006 Submission:
Hydrogen-Oxygen PEM Regenerative Fuel Cell Development at NASA Glenn Research Center

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Preferred Format: oral

Topic: Testing and Modeling

Subtopic: closed cycle hydrogen-oxygen PEM regenerative fuel cell

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

Glenn Research Center

Power & On-Board Propulsion Technology Division

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

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Prepared for 2006 Fuel Cell Seminar
Honolulu HI

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 H_2 and O_2 reactant gasses
- produce electrical power from stored H_2 and O_2
- system is completely sealed: nothing goes in, nothing escapes other than electrical power and waste heat

Closed loop operation at full power Jun 2004.

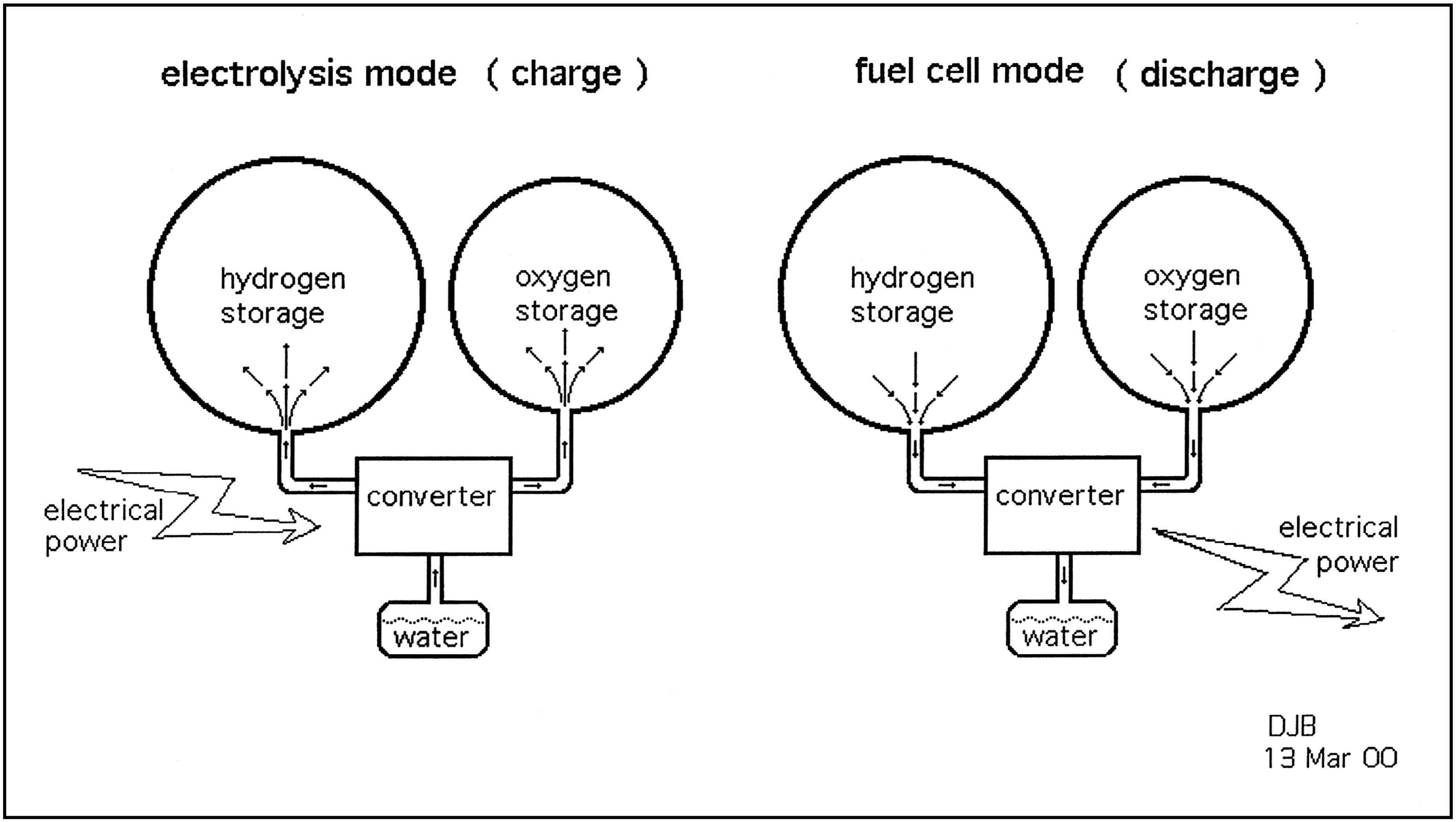
Further development testing July 2004-July 2005

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

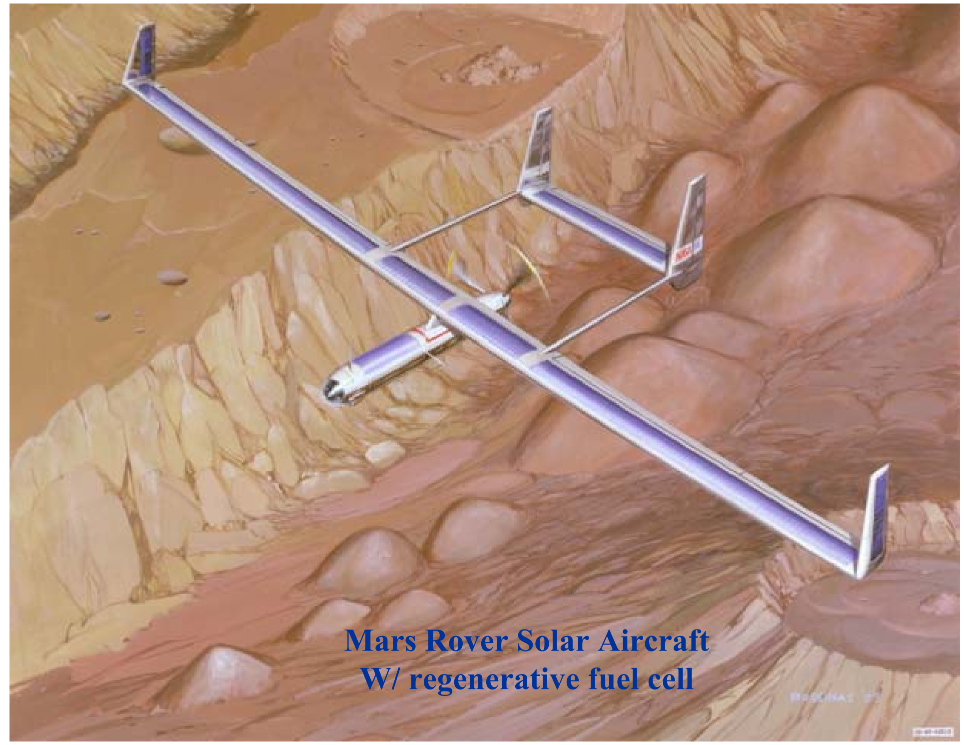
Next step: Complete characterization tests with next generation fuel cell and electrolyser stacks

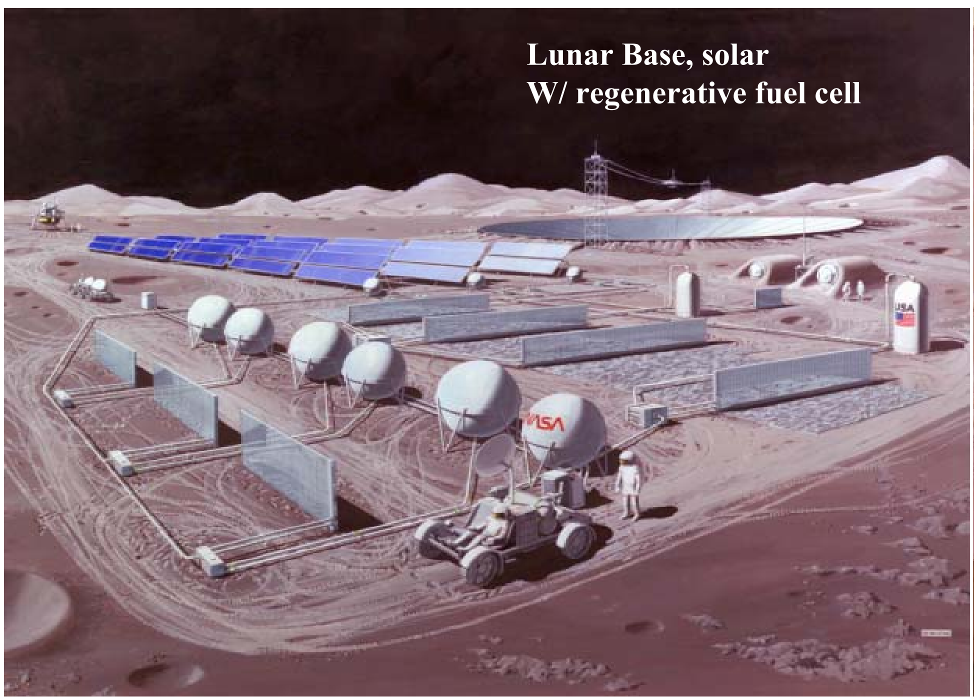
Hydrogen – Oxygen Regenerative Fuel Cell



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





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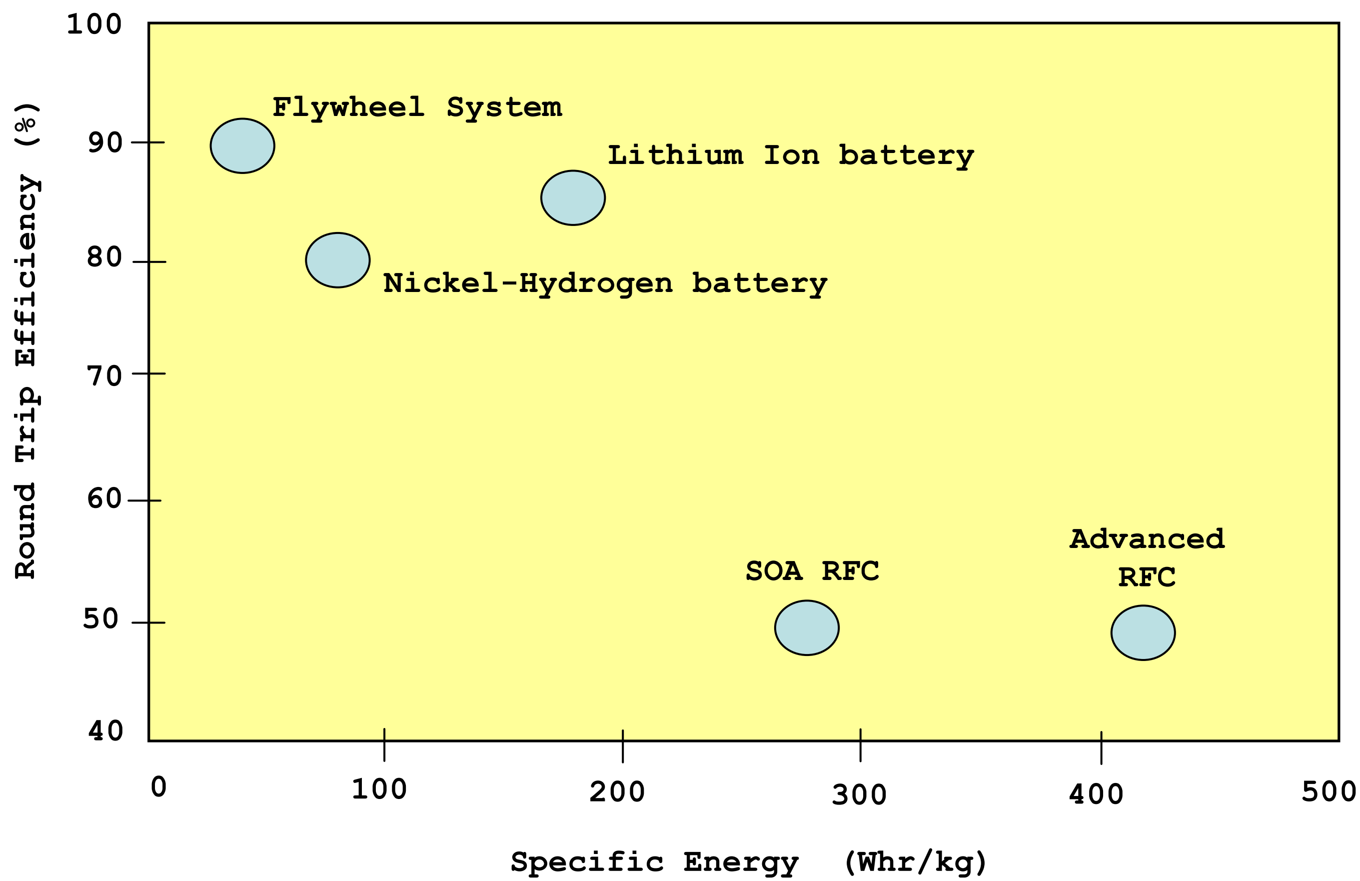
Comparison of Energy Storage Devices (12 hr/12 hr cycle)

Power & On-Board Propulsion Technology Division



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 O_2 and H_2 venting capabilities
6. Provide N_2 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


Closed Loop
Regenerative
Fuel Cell
ERAST Helios
ENERGY STORAGE
NASA Glenn
Research Center
135

Lynntech Gen4 Hydrogen-Oxygen PEM Fuel Cell Stack

Power output: 5.25 kW

Active Area: 200 cm^2

Efficiency*: 70%

Pressure: 50-400 psi

Weight: 40.2 lbs

Dimensions: 10” Ø, 20”L

Power Density: 131 W/lb

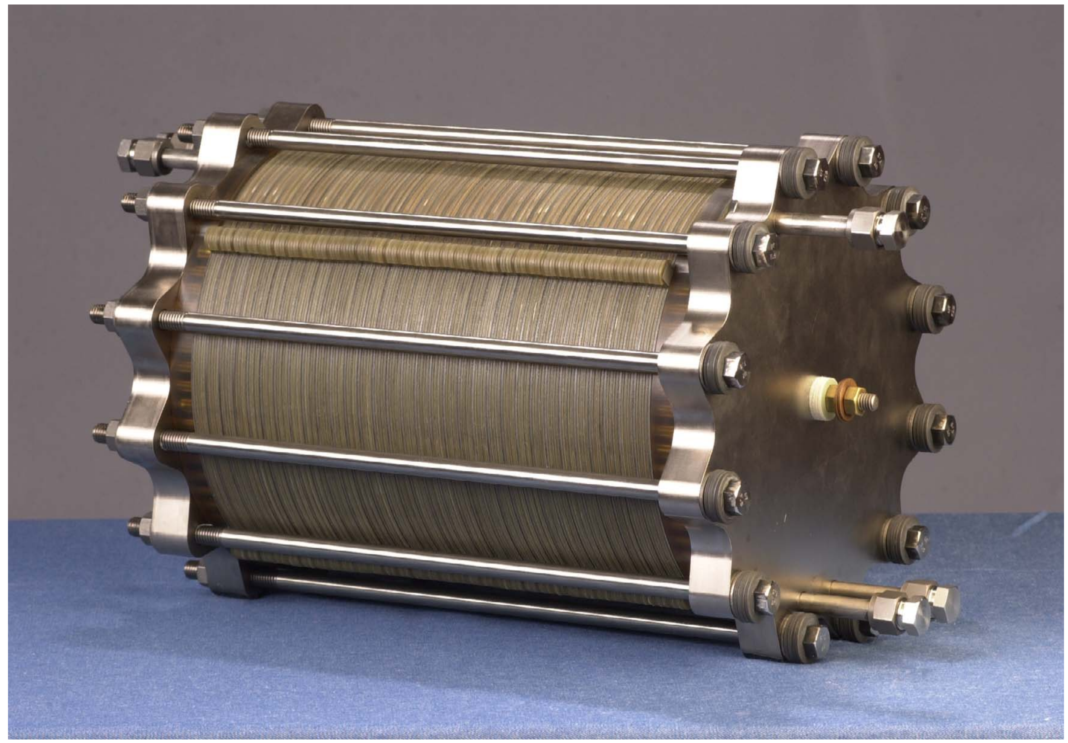
Number of Cells: 64

Output Voltage: 50-54 V

Current: 100 A

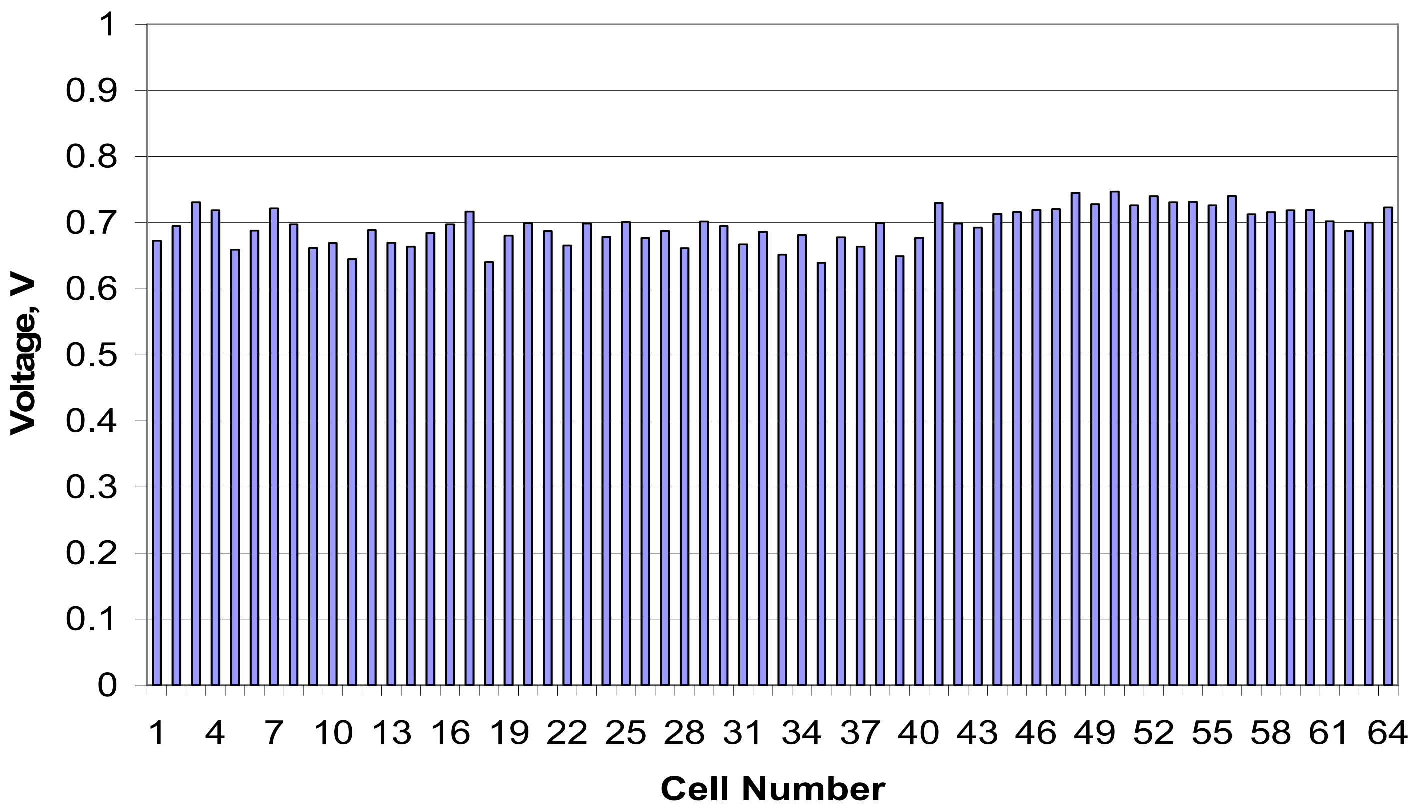
H_2 Consumption: 45 SLM

O_2 Consumption: 22.5 SLM



*Efficiency is calculated based upon LHV of H_2

Fuel Cell Individual Cell Performance at 100A, 65 psig and 135^{o}F



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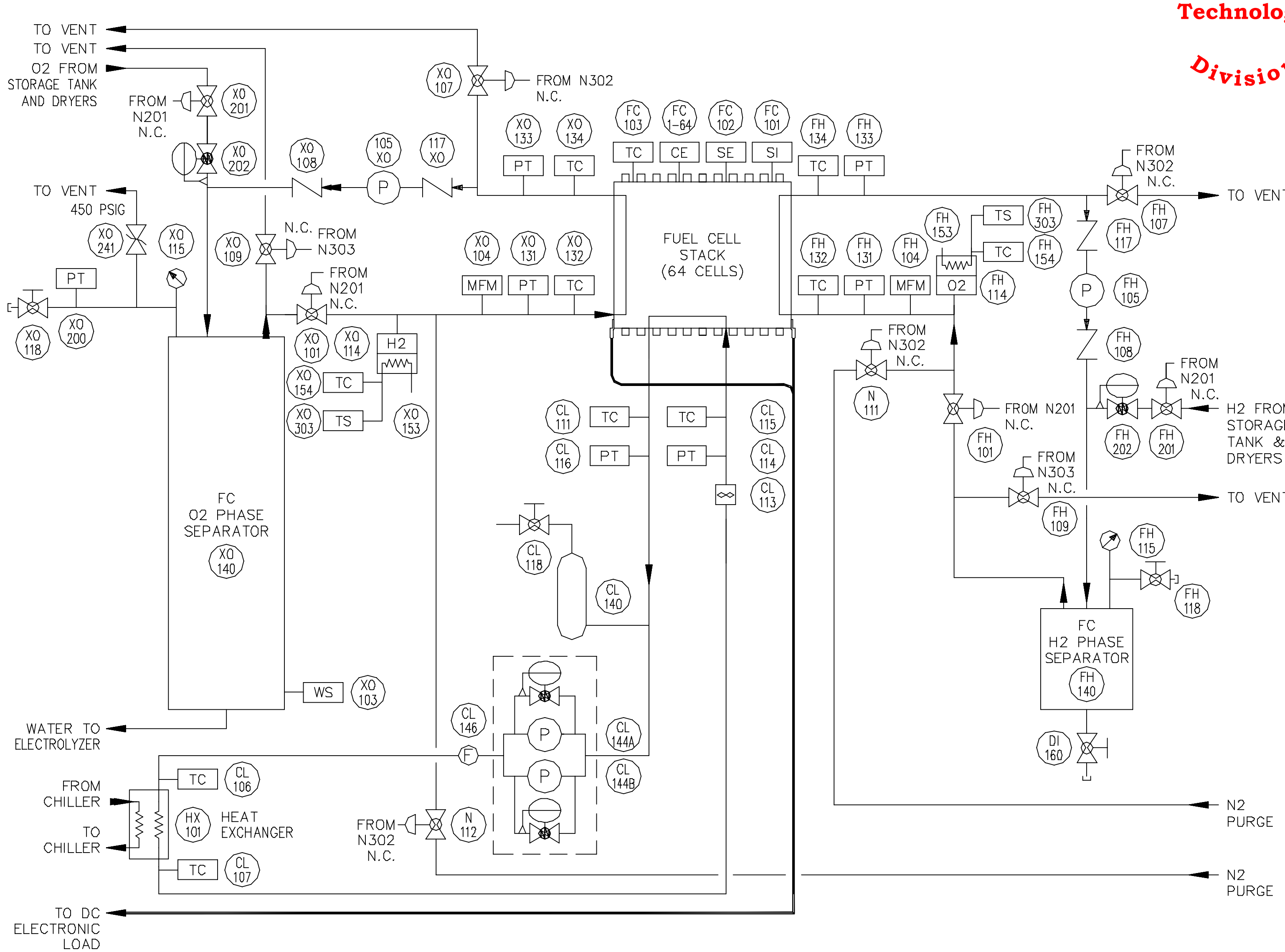
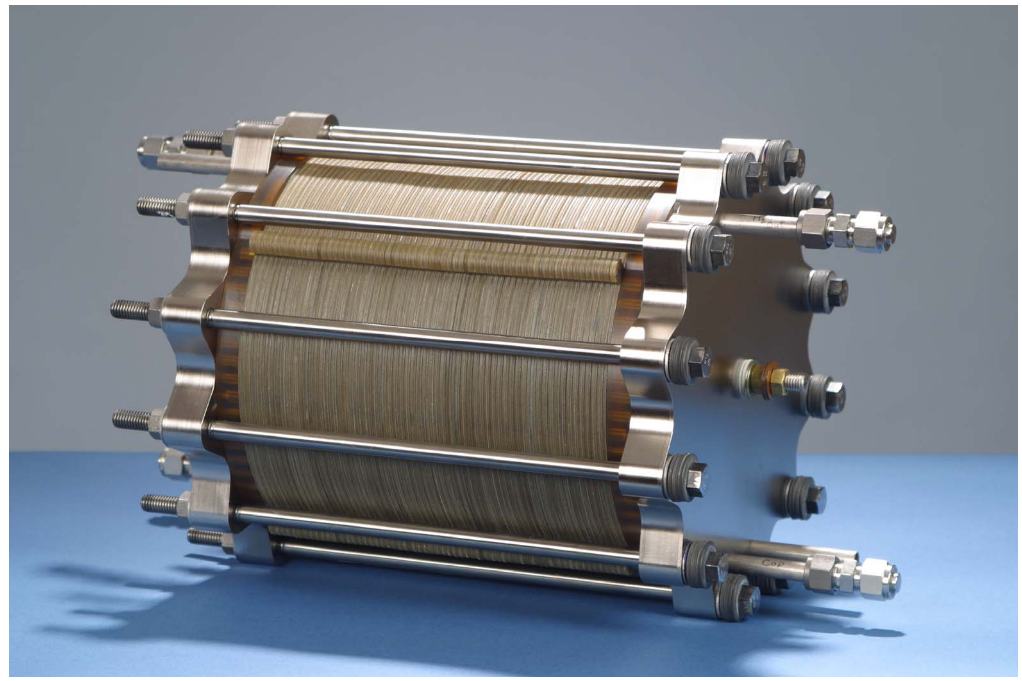


Regenerative Fuel Cell - Fuel Cell Stack and Reactant Recirculation Loops

Lynntech Gen4 PEM Electrolyzer Stack

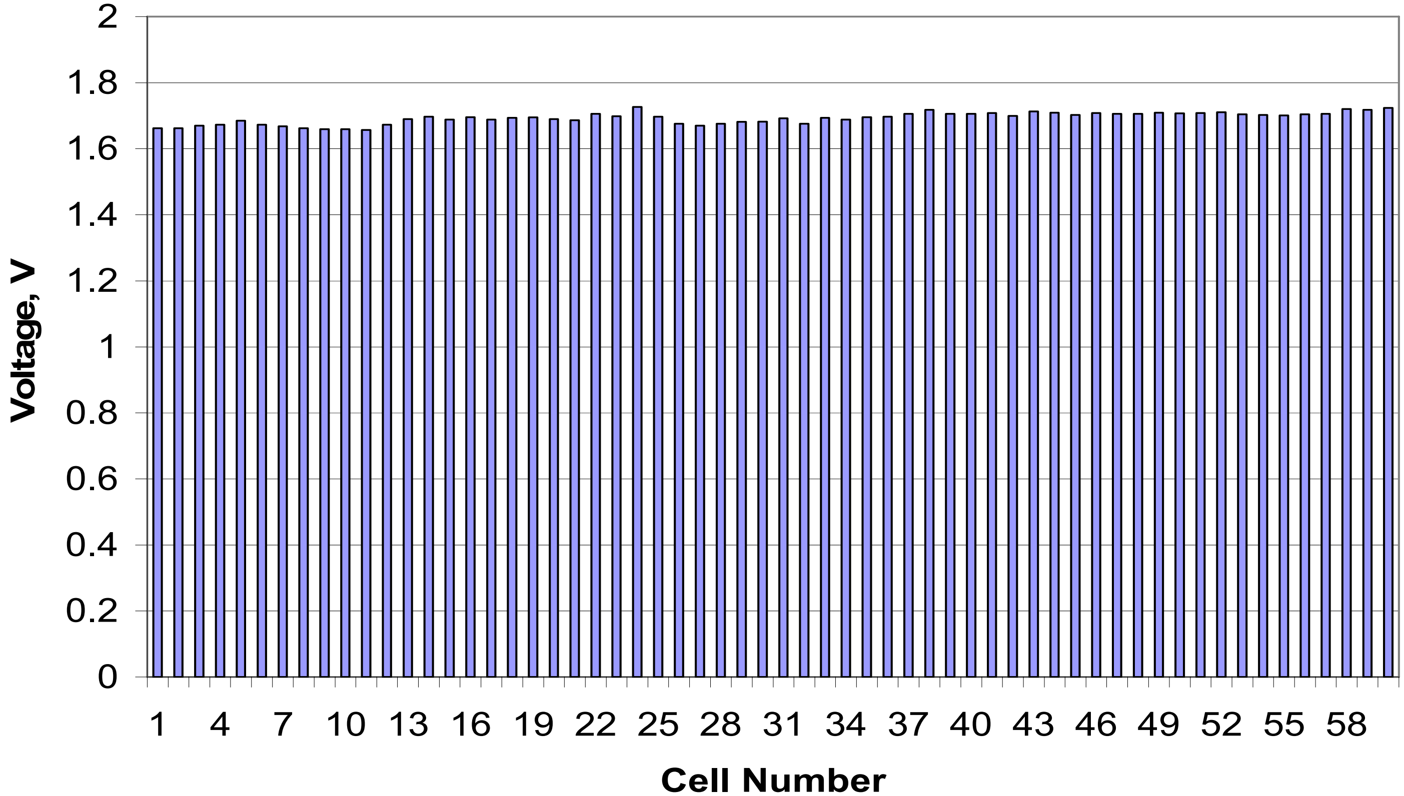
Power Input: 15 kW
Active Area: 200 cm^2
Efficiency*: 71%
Output Pressure: 0-400 psi
Weight: 31.7 lbs
Dimensions: 10" Ø, 14"L
Power Density: 492 W/lb
Number of Cells: 60
Applied Voltage: 104 V
Current: 150 A
H_2 Production: 60 SLM
O_2 Production: 30 SLM

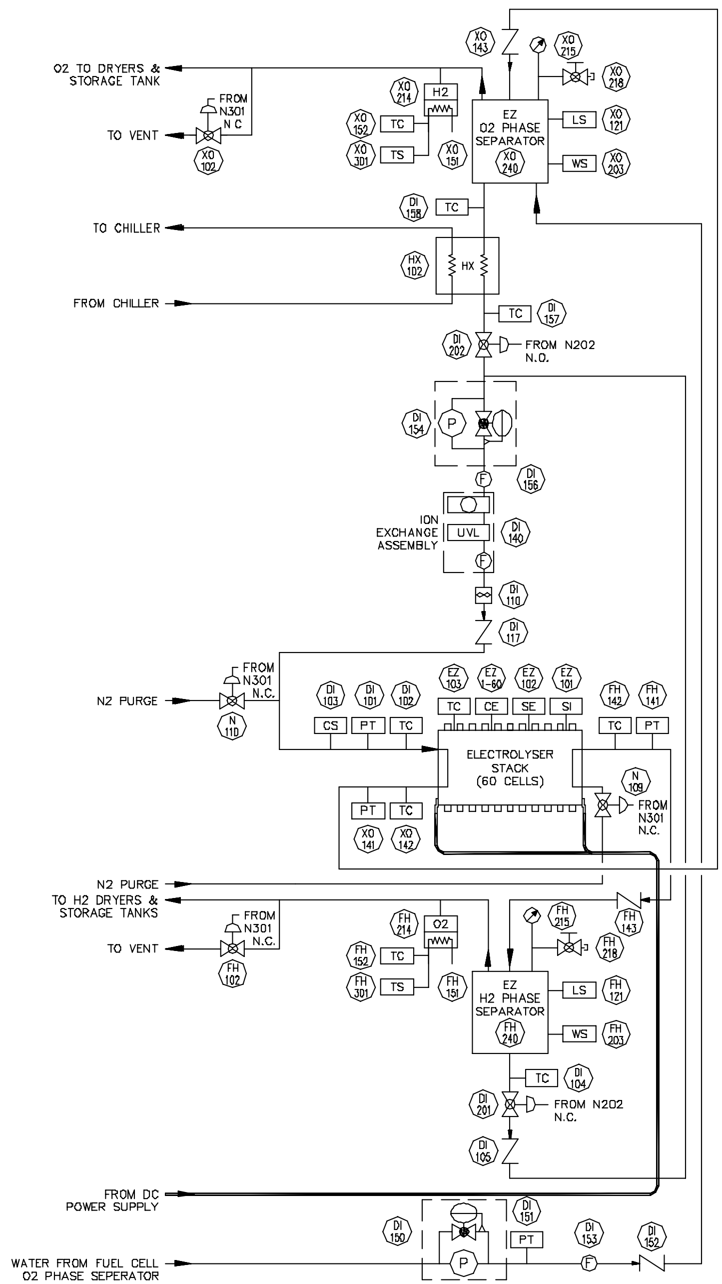


*Efficiency is calculated based on the LHV of H_2

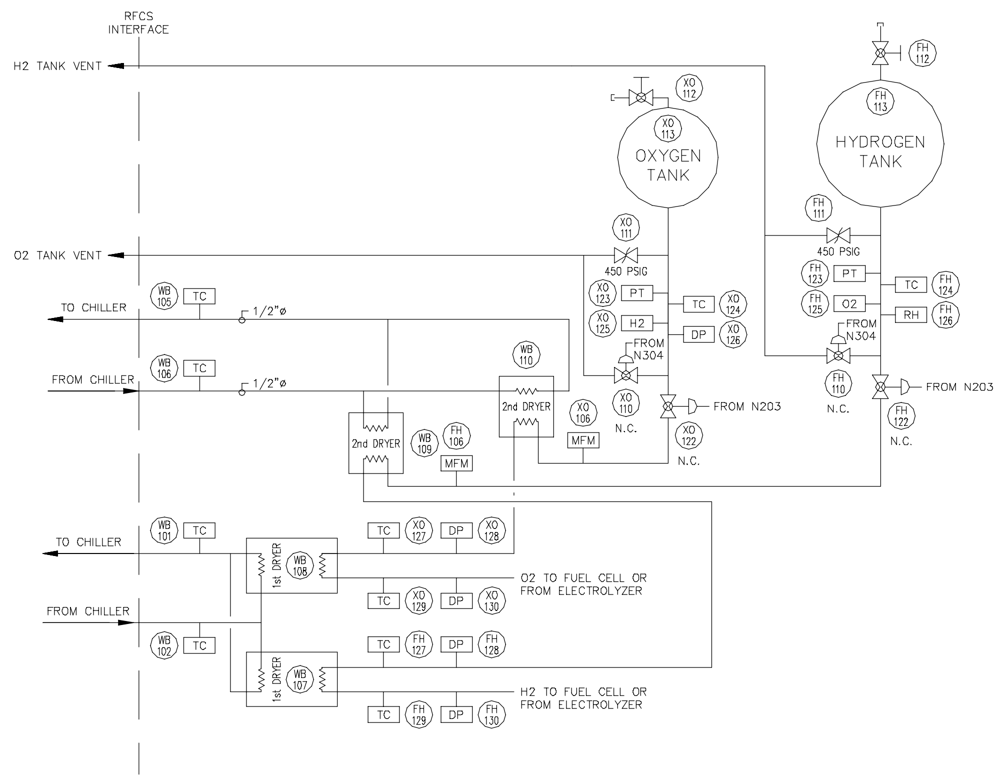
Electrolyzer Individual Cell Performance

at 150 A, 245 psig and 140^{o}F





Regenerative Fuel Cell - Electrolyser / Reactant Regeneration



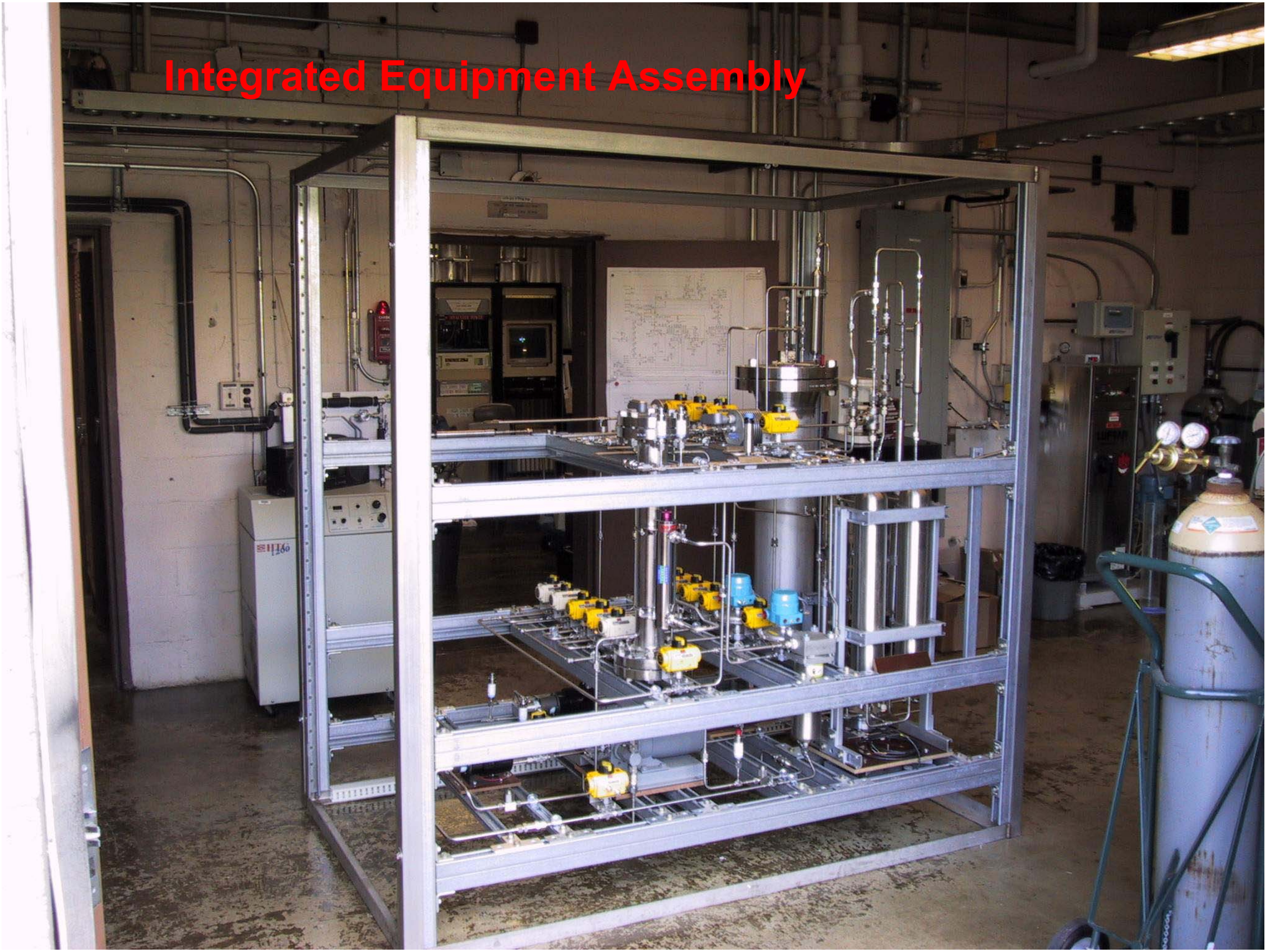
Regenerative Fuel Cell - Reactant Gas Dryers and Storage

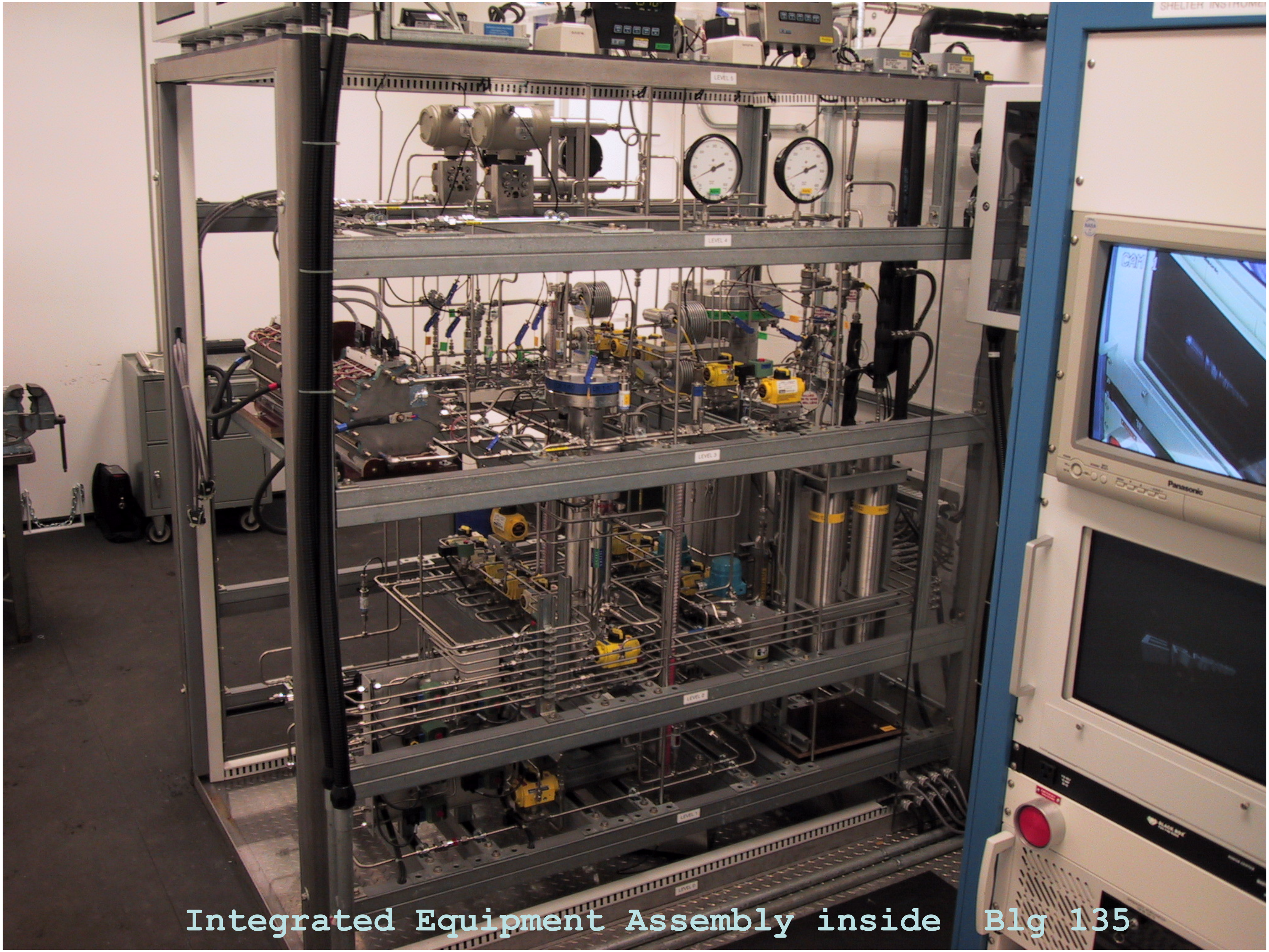
Ice Catcher

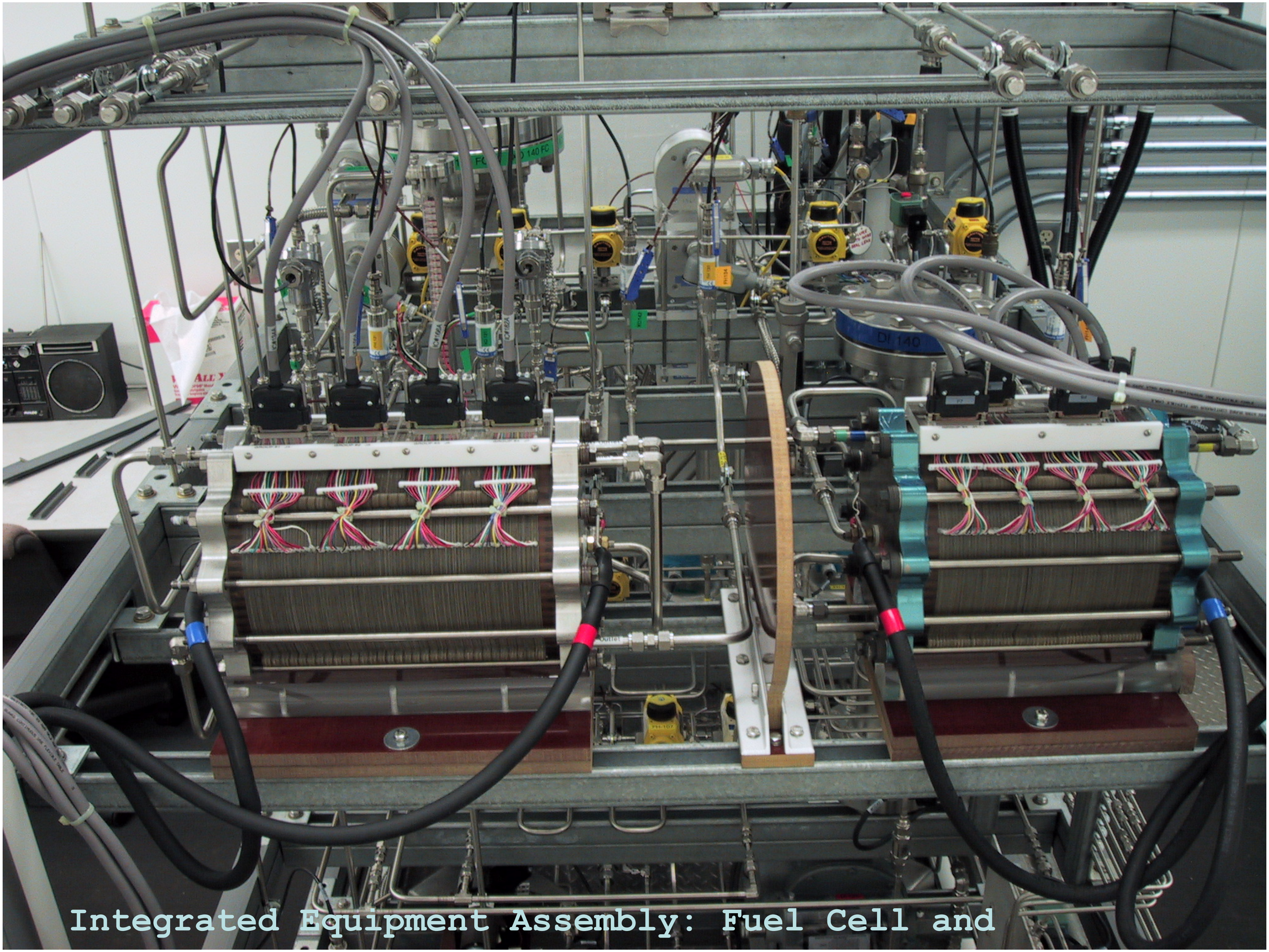
Ice-catcher Before
Preliminary Testing

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.

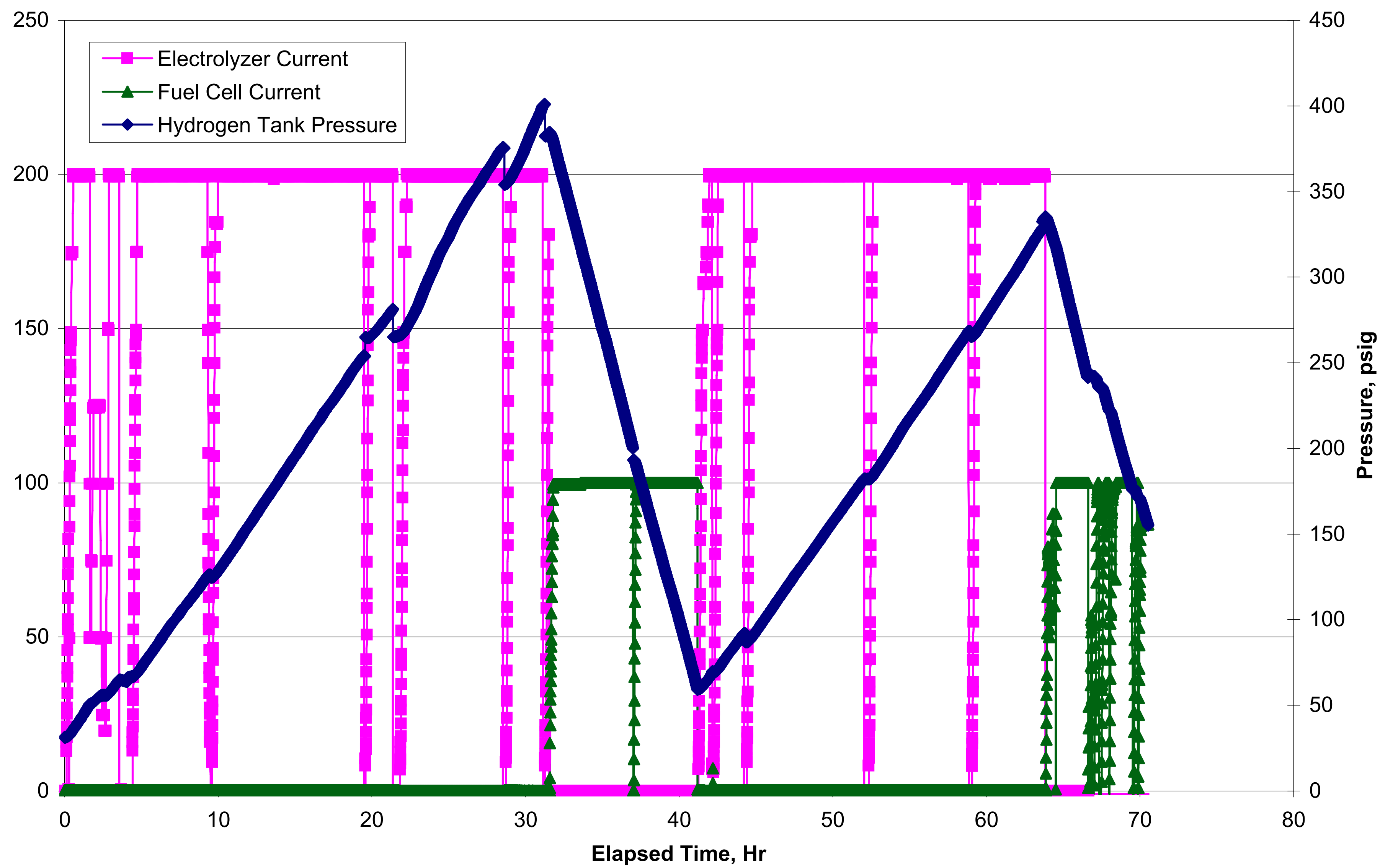
Fiber optic data link control room to test site

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

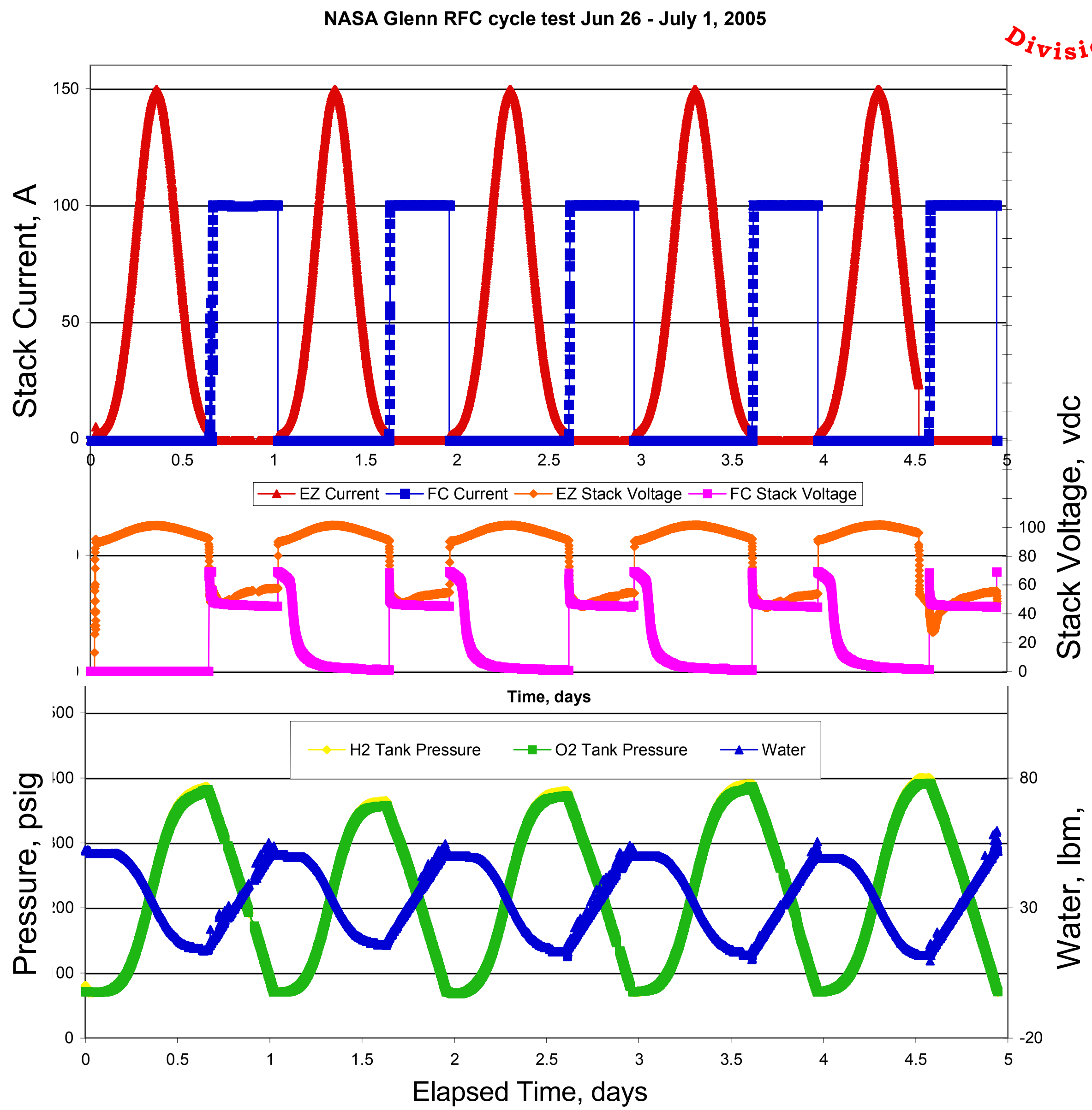

NASA Glenn
Regenerative Fuel Cell Test Rig
Mode Transition Control
Normal Modes
Purge
Shutdown
EZ Mode
FC MODE
Timing Information
Cyclic Operation Criteria
Initiate
Panasonic

Two extended day / night cycles, with interruptions



Regenerative Fuel Cell @ NASA GRC

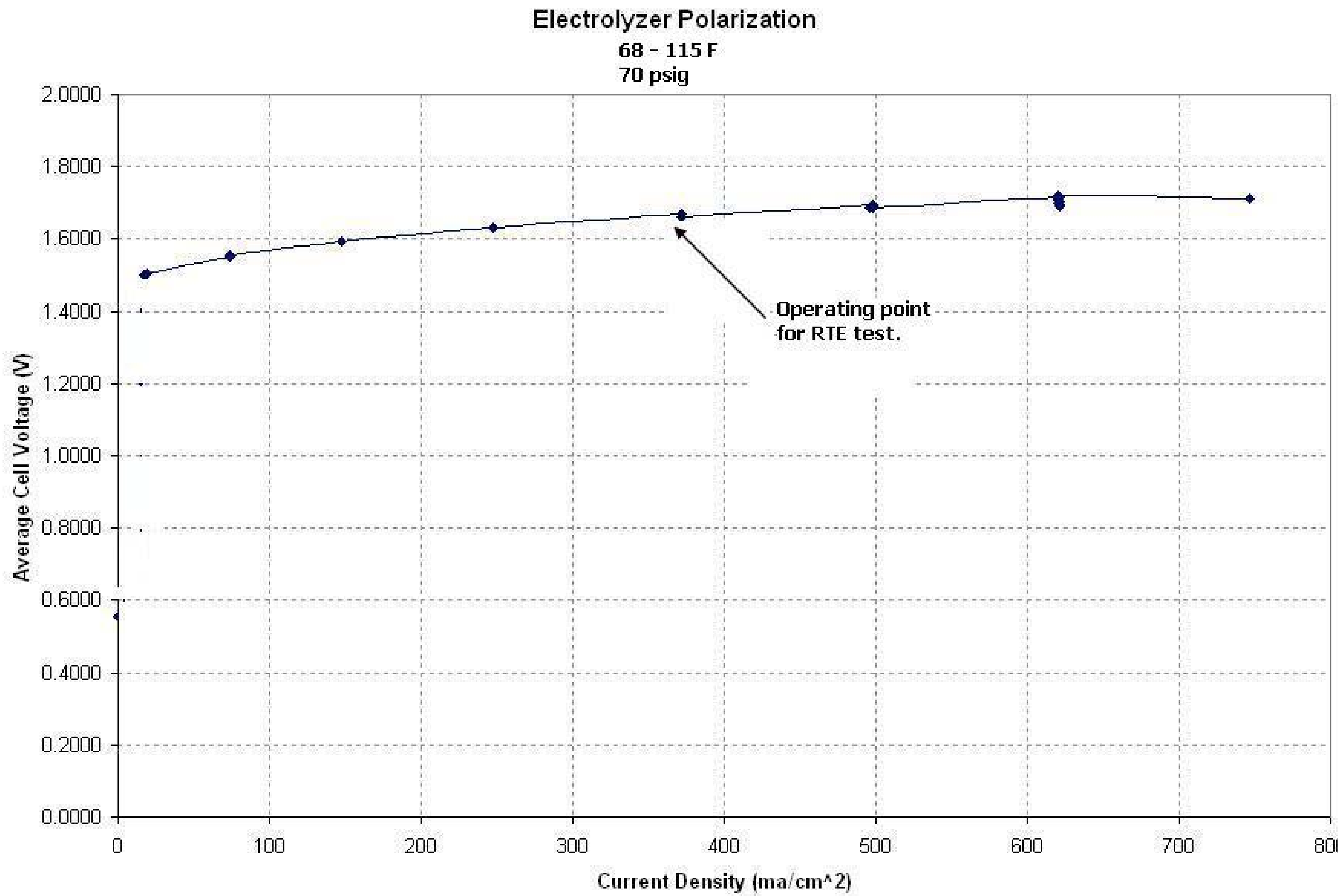
- Closed loop operation at full power > 4 hrs operation - June 2004.
- Two (2) day/night cycles closed loop with SOA hardware (Short Stack) - April 2005.
- One day/night (charge/discharge) cycle at full power closed loop with SOA hardware - May 2005.
- Five (5) contiguous day/night cycles at full power closed loop with SOA hardware - June 2005



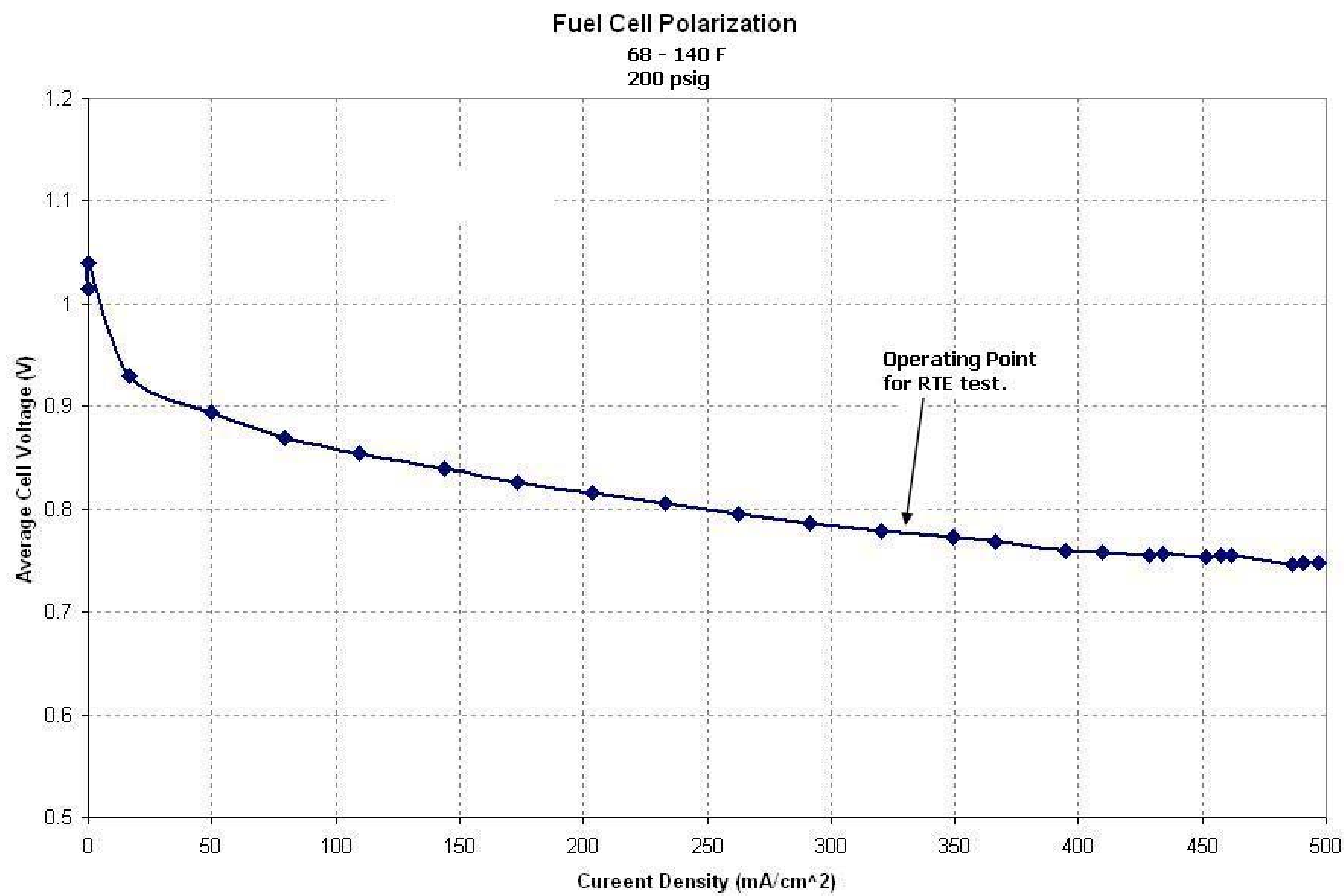
Problems Solved

- **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



RFC round trip efficiency demonstration



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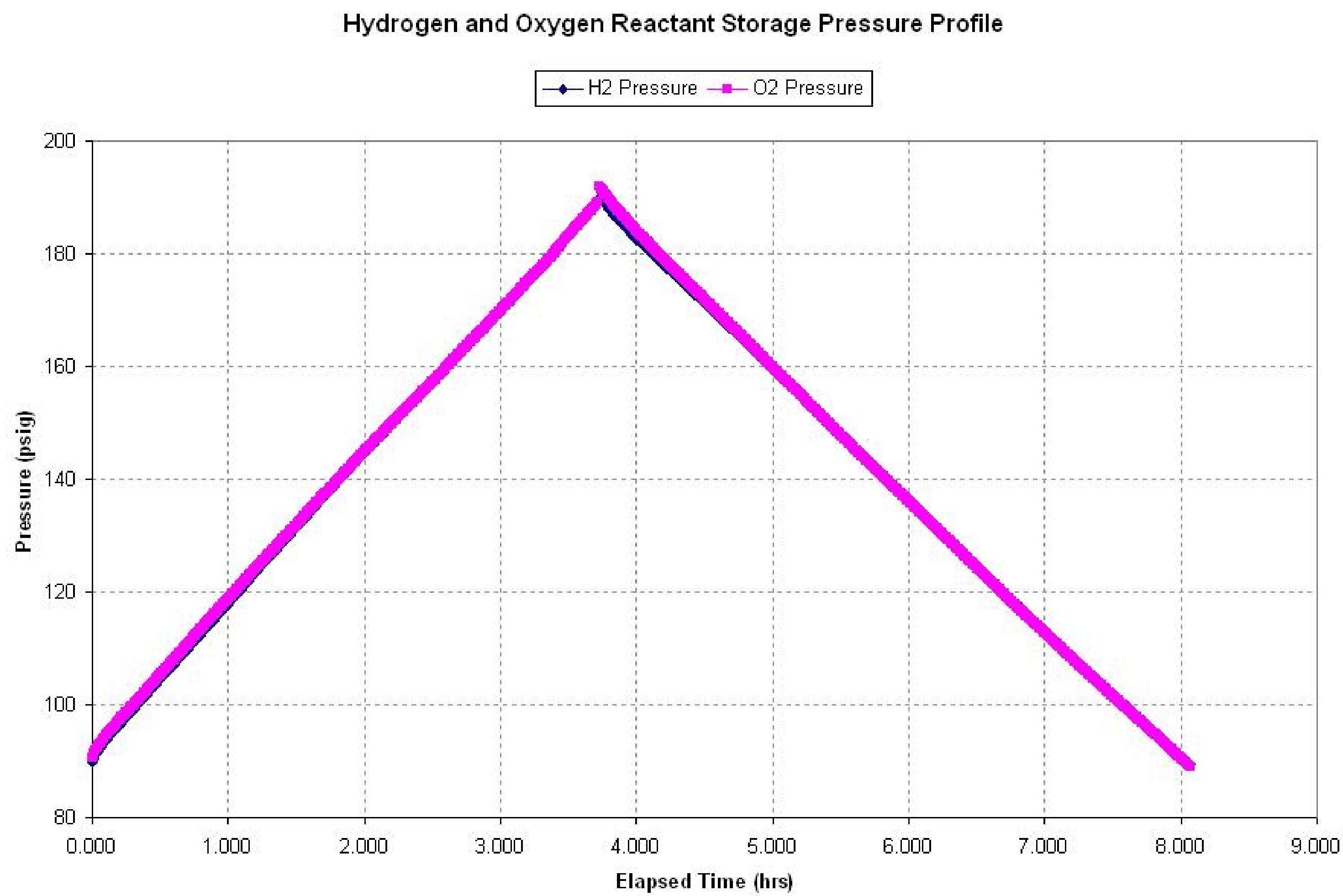
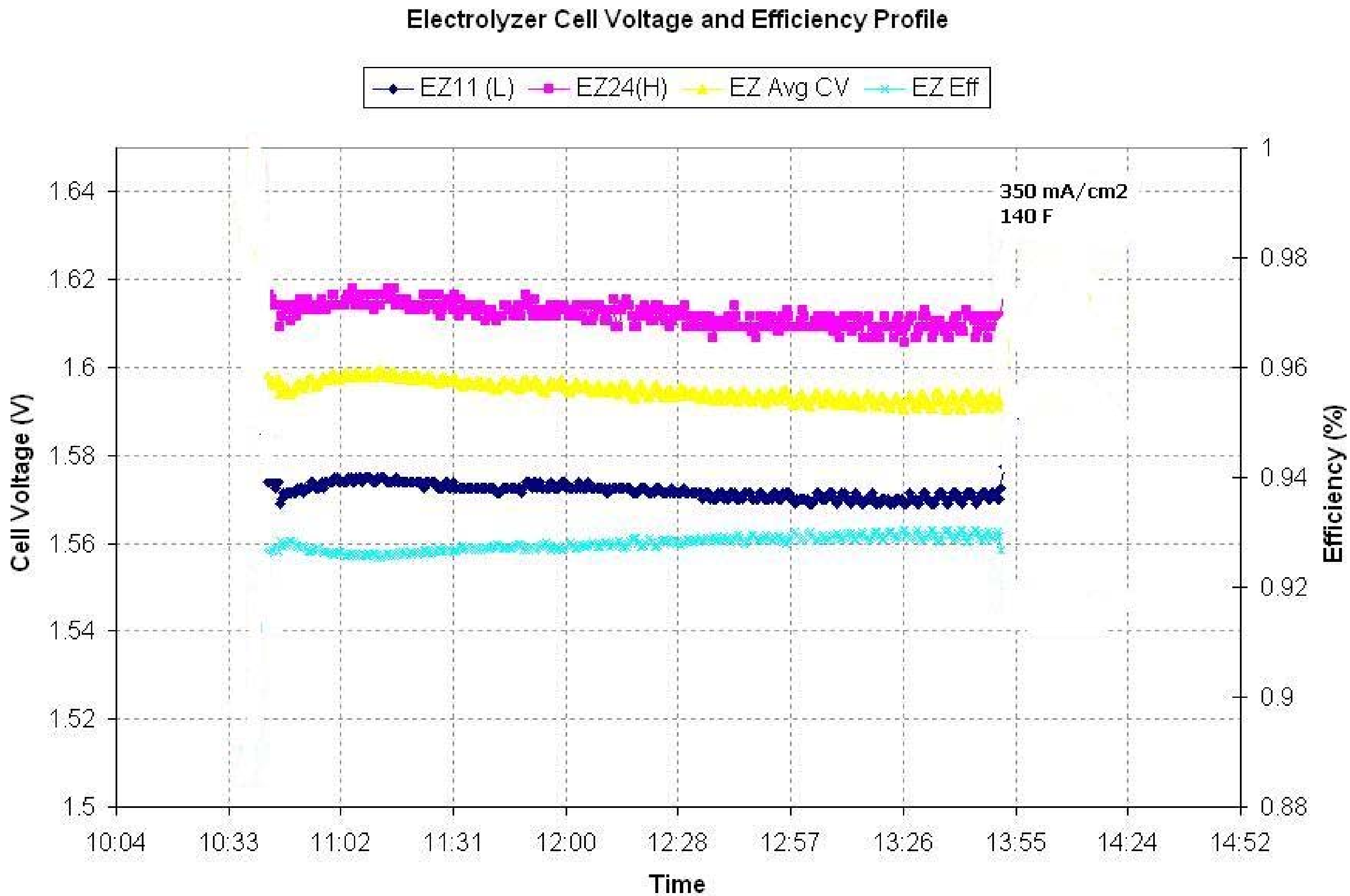
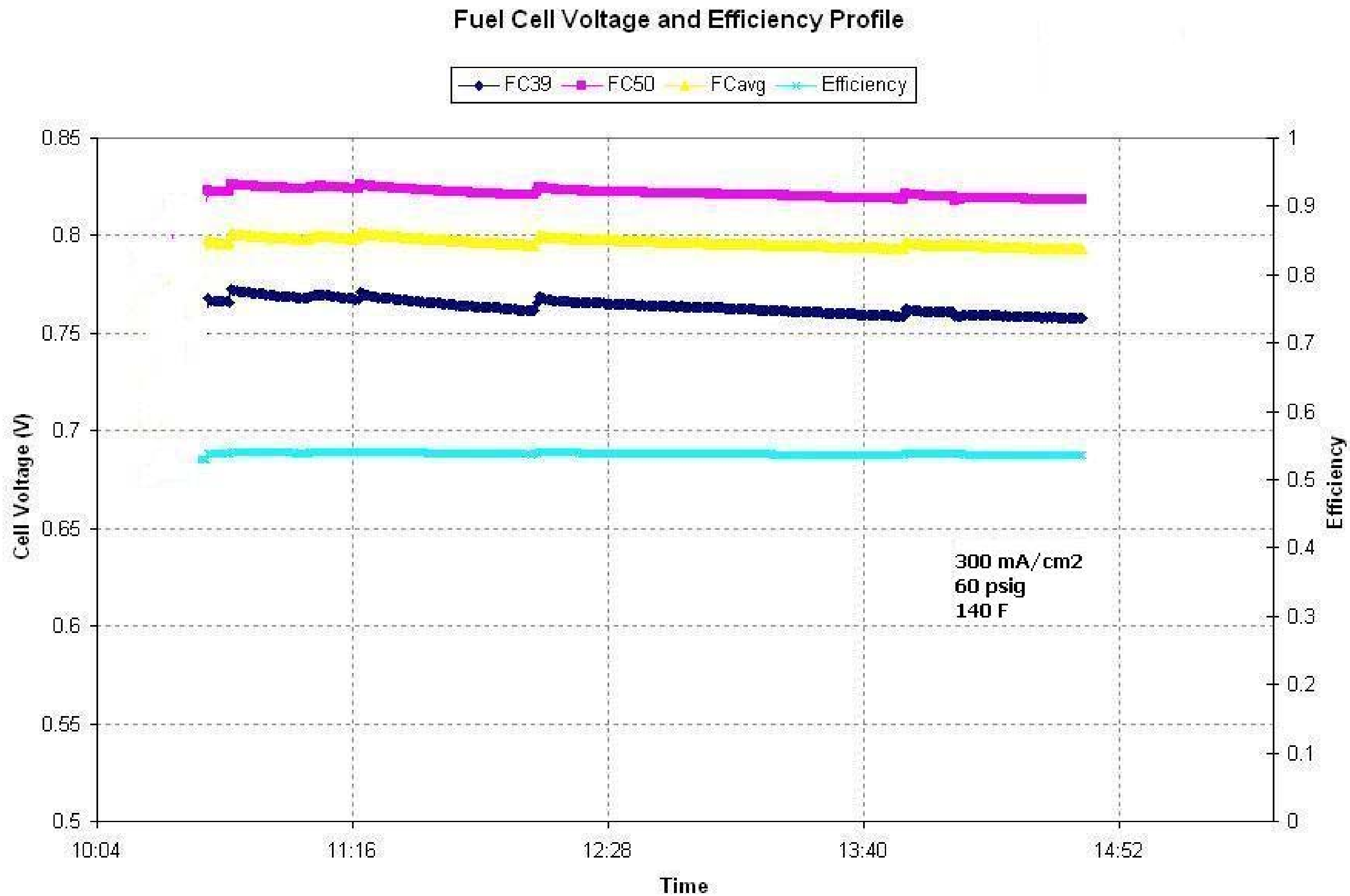


RFC round trip efficiency demonstration



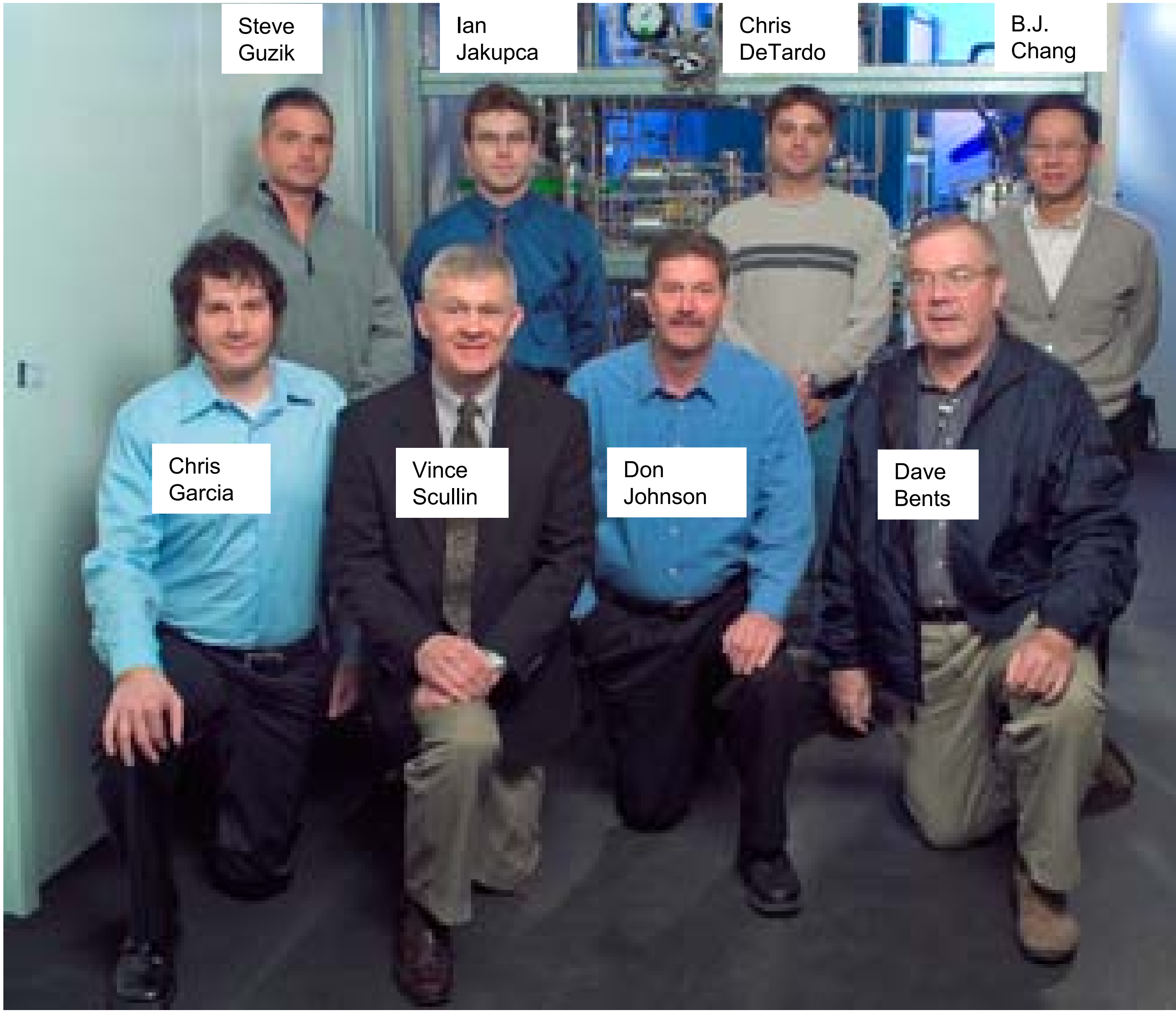
RFC round trip efficiency demonstration



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

Acknowledgements



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