Objectives

• The overall objective is to determine membrane degradation mechanisms and how to prevent or mitigate them.
  _ Determine changes in membrane materials properties as degradation occurs
  _ Determine if any electrical properties can act as a signature of developing degradation.
  _ Investigate the potential of advanced control systems to prevent degradation problems
The overall objective is to determine membrane degradation mechanisms and how to prevent or mitigate them.

- Determine changes in membrane materials properties as degradation occurs
- Determine if any electrical properties can act as a signature of developing degradation.
- Investigate the potential of advanced control systems to prevent degradation problems
• Total Funding: $1,022,521
• DOE Share: $804,836
• Match: $217,685
• FY03 Funding: $281,694
• DOE Technical Barrier for Fuel Cell Components
  _ P. Durability

• DOE Technical Target for Fuel Cell Stack System for 2010
  _ Durability 5000 hours
Approach

• Develop a system for monitoring current and voltage output for each individual membrane in a stack.
  _ High sampling rate and permanent storage of data

• Develop characterization techniques that can reveal changes in materials properties that occur upon degradation.
  _ Magnetic Resonance microimaging
  _ Synchrotron based x-ray microimaging
• Hydrogen gas monitoring and containment - plexiglass box with a sensitive hydrogen leak detector to identify dangerous concentrations of $\text{H}_2$. 
Year 1:
- Dynamic terminal characteristic models developed for fuel cells
- Data acquisition system designed for fully instrumented fuel cells including development of A/D card that runs under LINUX
- Developed a single cell PEM FC to allow *in situ* synchrotron x-ray measurements of the cell in operation
- First MRI data of PEM’s obtained using chemical treatment protocols from literature and replication of bulk NMR data in literature with spatial resolution
- PI Seymour Attended North American Membrane Society Meeting initiating contact with PEM research community
- Ordered high magnetic field gradient coil for measuring small displacements and integration into Electrophoretic NMR probe

Year 2:
- Fully instrumented 2 separate 80 membrane PEM fuel cells
- Performed initial test runs to debug hardware and software in preparation for long term testing
- Performed initial x-ray analysis on degraded membranes
- Concluding study reproducing bulk NMR study of Nafion 117 solvent mobility dependence on MeOH concentration, manuscript preparation in progress
- Initiating MRI studies of PEM’s after failure during Fuel Cell operation by other components of project
- Initiating combined sequential MRI and X-Ray analysis of membranes
- Construction of ENMR probe with M. Holz visiting MSU during summer or fall

Year 3:
- Run long term degradation by exercising fuel cells with real world load transients
- Integration of MRI and ENMR to attempt spatial resolution of proton transport under load conditions
- Perform spatially resolved x-ray and MRI analysis of membranes at various stages of degradation as identified by electrical characterization
- Investigate control strategies that may help reduce degradation
# Temperature Measurement For Dynamic Thermal Model

Omega SMCJ thermocouple to analog converter

Advantech PCI-1710 12-bit data acquisition card

Computer

Thermocouple near membrane gas diffusion layer measures temperature

Outlet Air Passage

K-type Thermocouple

Fuel Cell Cartridge

Location of K-type thermocouple in SR-12 fuel cell stack

SR-12 output voltage

Max

Min

PEM stack current

# An accurate and simple physically motivated electrical terminal model for PEM fuel cell.

# Accurate prediction of steady-state SR-12 stack voltage as a function of stack current.
# Cross validation predicted SR-12 output voltage (dark line is the predicted response). Dynamic models are needed for design of multi-source and distributed power systems that incorporate fuel cells to ensure good system performance and prevent degradation.

S. Pasricha, M. Keppler and S. R. Shaw, “A Dynamic PEM Fuel Cell Model”.
Technical Progress

Ongoing Experiments

• 80 membranes/FC enclosure
• Measure voltage for each individual membrane, current and temperature at a 2000 Hz rate.
• Total of 224,000 data points per second will be stored to provide a permanent
• Data permanently stored to two 1.4 Terabyte RAID-5 hot-swap arrays.
• Provides a record of performance of each individual membrane over its entire life span.
Example of high resolution temporal data acquired from system. Spikes are due to FC system switching membranes on & off.

**Water Translational Self-Diffusion**

- $5.77 \times 10^{-10} \text{ m}^2/\text{s}$
  - $\pm 0.5 \times 10^{-10}$
- $5.59 \times 10^{-10} \text{ m}^2/\text{s}$
  - $\pm 0.4 \times 10^{-10}$
- $2.33 \times 10^{-9} \text{ m}^2/\text{s}$
- $\Delta = 10 \text{ ms}$
- $0 \text{ m}^2/\text{s}$
Technical Progress

- Students Supported: James C. Mabry, Daniel Howe MS ChE
- Publications / Presentations:
- Related proposals funded: None

T<sub>1</sub> relaxation maps showing depth distribution of mobility-high T<sub>1</sub> high molecular mobility; Note PEM swelling and increased mobility of MeOH relative to H2O

T<sub>1</sub> maps of Nafion® 117

- Water: 2178 ± 57 ms
- Methanol: 2527 ± 34 ms
- 237 ± 16 ms
- 766 ± 30 ms
T<sub>1</sub> Weighted 'H Intensity Images Nafion®

in supernatant H<sub>2</sub>O

in air
Technical Progress

• Students Supported
  - Two masters candidates, a PhD candidate, and two undergraduates have been supported in this work

• Publications / Presentations
  - The paper "Instrumentation for PEM Fuel Cell Degradation Monitoring was written, submitted, and accepted.
Membrane performance degradation with repeated severe hydration/drying cycles showing a nearly 50% reduction in maximum deliverable power.
• Time-dependent I-V response curves of abrupt loading of the fuel cell suggest that degradation is due to reduced hydrogen diffusion through the membranes.

• Spatially resolved X-ray characterization of the before and after membranes, show no change in chemical make-up, although a small sulfur peak with nearly uniform spatial distribution was found.
Technical Progress

• This program supported a graduate student and two REU (research experience for undergraduates)


Future Work

• Compare spatially resolved x-ray studies with spatially resolved MRI data for new and degraded (by thermal, humidity, and load cycling) membranes to determine hydrogen diffusion variability.