DIRECT METHANOL FUEL CELLS

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Major Contributors to DMFC Effort in FY 2002

Eric Brosha (TSM)	- Ultrasonic spray/freeze dry
John Davey (Tech)	- MEA research; technical support
Christian Eickes (PD)	- Electrocatalysis
Robert Fields (TSM)	- Controls & software
Michael Hickner (GRA)	- Membrane & MEA research
François Le Scornet (GRA)	- Single cell & stack testing
Don McMurry (Tech)	- Controls & software
Bryan Pivovar (TSM)	- Membrane & MEA research
Gerie Purdy (Tech)	- Testing & general support
John Ramsey (GRA)	- Flow & hardware modeling
John Rowley (Tech)	- Technical support
Mahlon Wilson (TSM)	- Cell/stack design & engineering
Christine Zawodzinski (TSM)	- Cell/stack design & engineering
Tom Zawodzinski (TSM)	- Membrane & MEA research
Piotr Zelenay (TSM)	- Project management & electrocatalysis
Yimin Zhu (PD)	- Electrocatalysis

Status by the End of FY 2001

- Composition of anodes with reduced catalyst loading optimized
- 5 gPt/kW successfully demonstrated in a 45-cm^2 five-cell stack with a total Pt loading of 0.53 mg cm^{-2}
- Several membranes with higher selectivity and lower electro-osmotic drag of water identified; improved overall efficiency demonstrated with several alternative membranes
- Fourth-generation 30-cell 80-W DMFC stack delivered and integrated by Ball Aerospace into a complete demonstration system for the military
- Design/modeling study of a ~500 W APU stack initiated

Response to Selected Reviewers' Comments

R ***"Need more emphasis on automotive applications."***

Manufacturing capability resulting from the likely market-entry of DMFCs for portable power applications should reduce the cost and facilitate commercialization of PEM fuel cells for higher power applications, automotive transportation in particular. Portable power-transportation synergy in fuel cell R&D appears to be the best commercialization strategy.

R ***"Not sure that LANL should be developing fuel cell stacks."***

Fundamental research has been and will remain the focus of direct methanol fuel cell program at LANL. Few stack prototypes have been built to prove practical viability of core DMFC technology developed at LANL, identify possible scale-up issues and verify adaptability of the technology to complete systems.

Major Collaborations & Commercial Interactions (C)

R

- Collaboration with <u>Motorola</u> on fundamental DMFC technology and high-temperature RHFC membrane for portable power in final stage of re-instating *via* CRADA; common research to begin in mid-May.

- Partnership with <u>Ball Aerospace</u> in FY 2002:
  - ✓ Complete 60 W (*net power*) DMFC system demonstrated to the military;
  - ✓ Three-year Palm Power research project started in mid-2001, focusing on fundamental research as well as stack development; first 22 W stack delivered to Ball for system integration in March 2002;
  - ✓ Operating conditions for the APU system agreed upon; first stack will be shipped from LANL in the fall of 2002.

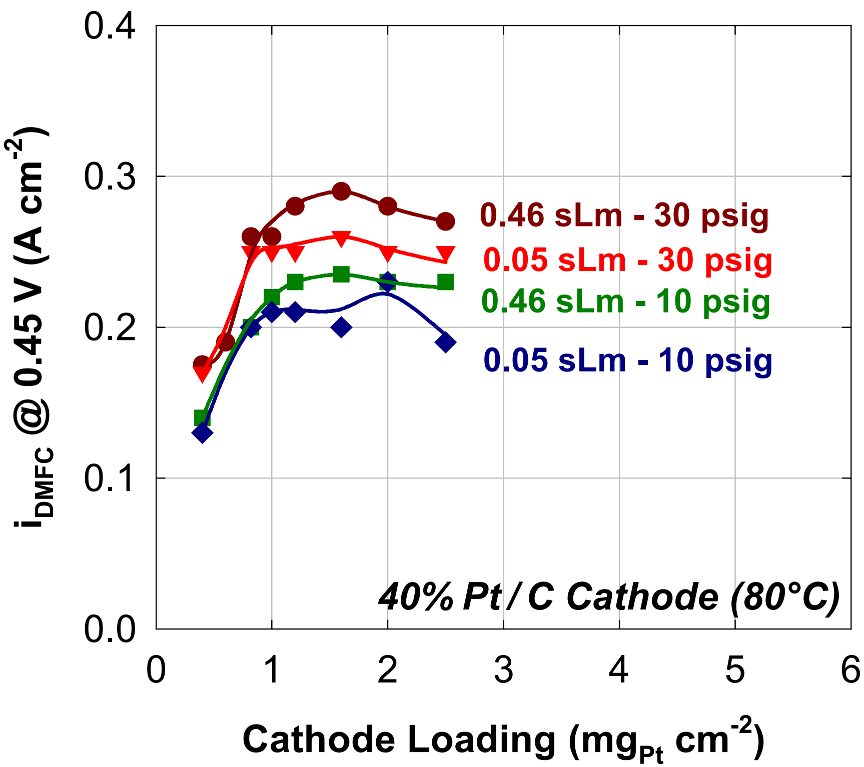
Major Collaborations & Commercial Interactions (II)

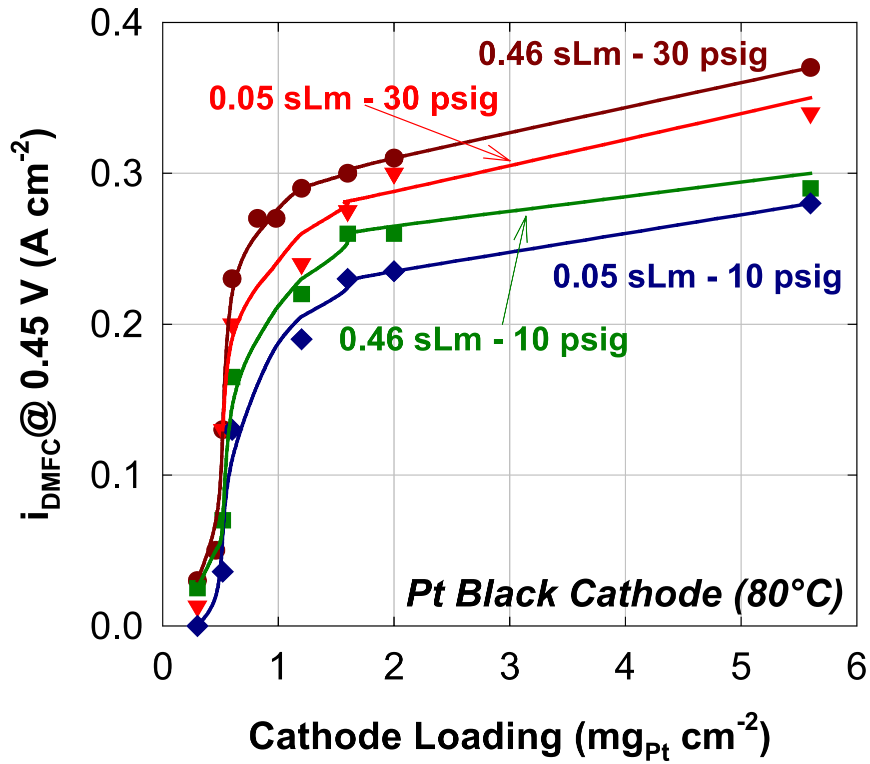
- **Catalyst research:**
  - ✓ **Johnson Matthey – Effect of atomic composition, morphology and crystallography of Pt-Ru blacks on DMFC anode activity;**
  - ✓ **OMG – New carbon-supported cathode catalyst with improved methanol tolerance;**
  - ✓ **Superior MicroPowders – Carbon-supported catalysts for PEM and DMFC cathodes; DMFC MEAs (*planned*).**

- **Membrane/MEA research & development; polymer fabrication:**
  - ✓ **Virginia Tech – Development of alternative polymers (BPSH) and MEAs with significantly improved selectivity;**
  - ✓ **Hydrosize Technologies, Inc. – Fabrication of BPSH initiated; first two batches of BPSH polymer ordered and synthesized; polymer to be shipped to LANL within a week.**

Cathode Research

Carbon-Supported vs. Unsupported Pt Catalysts



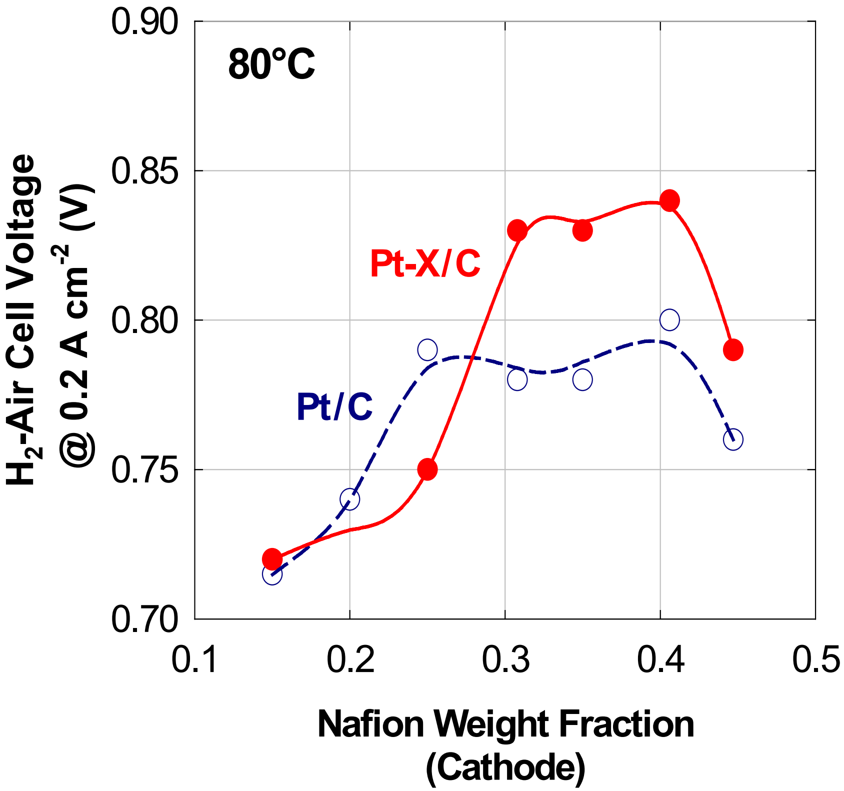


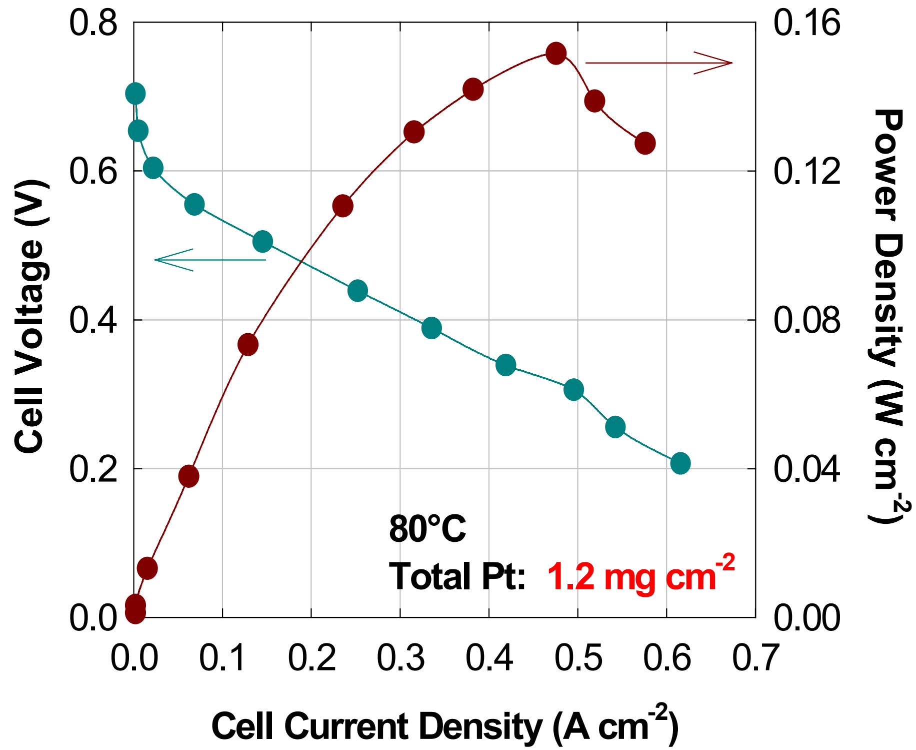
Pt < 1.0 mg cm^{-2} - Pt / C catalyst

Pt > 1.0 mg cm^{-2} - Pt black catalyst

Cathode Research

Nafion Content; Improved Cell Performance with Low Total Pt Loading

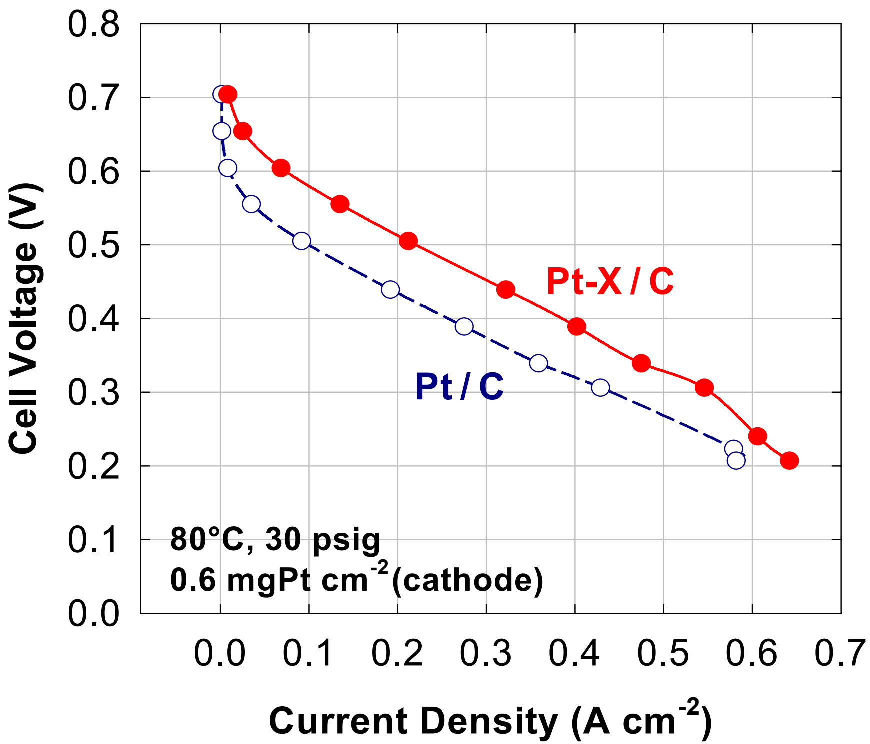


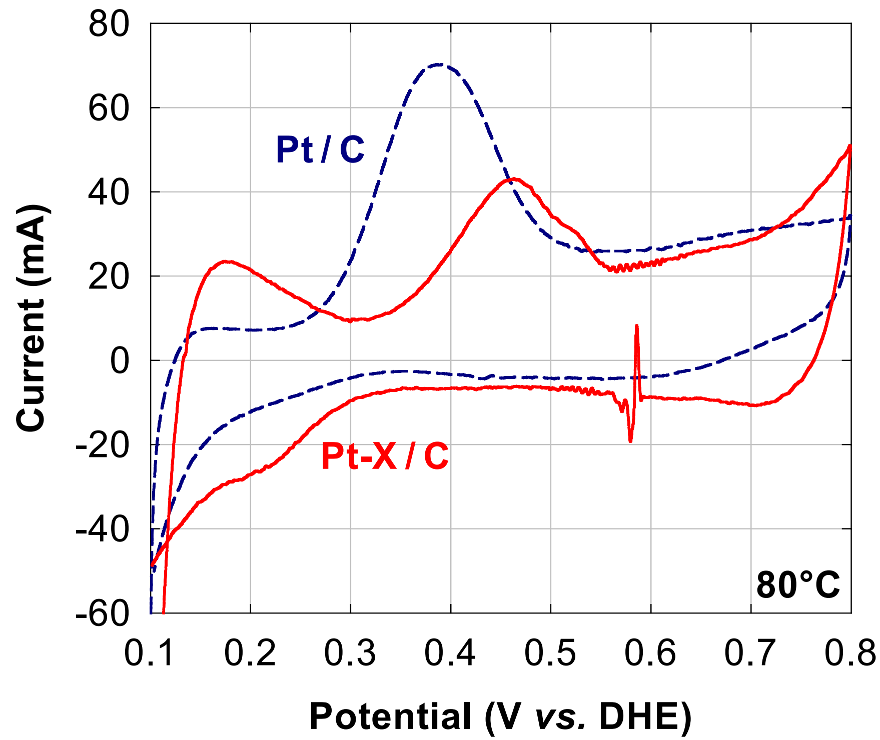


Achievements: (1) Nafion content in the cathode optimized at a low Pt loading (0.6 mg cm^{-2})
(2) Very good performance demonstrated at 80°C with 1.2 mg cm^{-2} total Pt loading

Cathode Research

New Binary Catalyst with Improved O_2 Activity & Methanol Tolerance





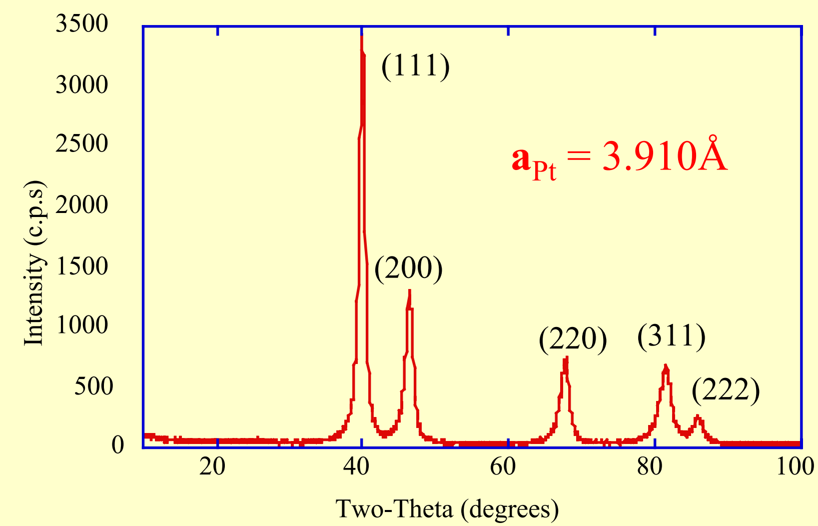
Achievement: **Even at low a Pt loading of ~ 0.6 mg cm^{-2}, the new binary Pt-X / C catalyst shows significantly better activity in oxygen reduction and improved methanol-tolerance over commercial Pt / C catalyst (E-Tek).**

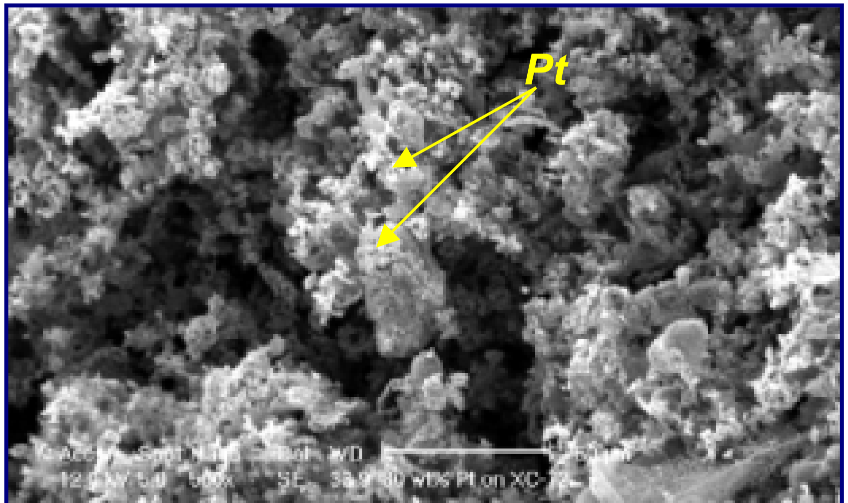
Ⓒ *Collaboration with OMG (formerly Degussa-dmc^2)*

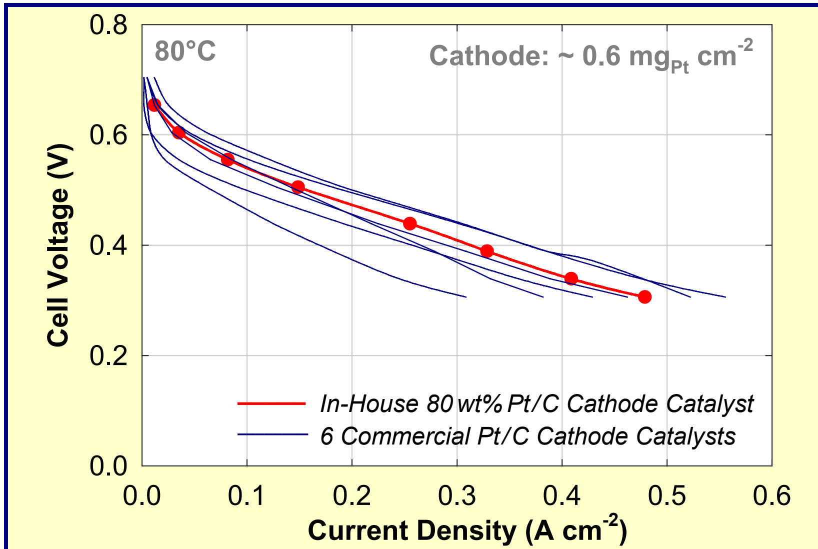
In-House Catalyst Effort

New Carbon-Supported Pt Catalyst: 80wt%Pt/C

- ✓ Ultrasonic-spray / free-dry method
- ✓ 10-µm droplets quickly frozen in LN_2
- ✓ 6.1 nm Pt particle size determined by whole-profile fitting of XRD data
- ✓ Pt very well dispersed Pt (SEM)
- ✓ ***DMFC performance very close to that of best cathode catalysts commercially available!***

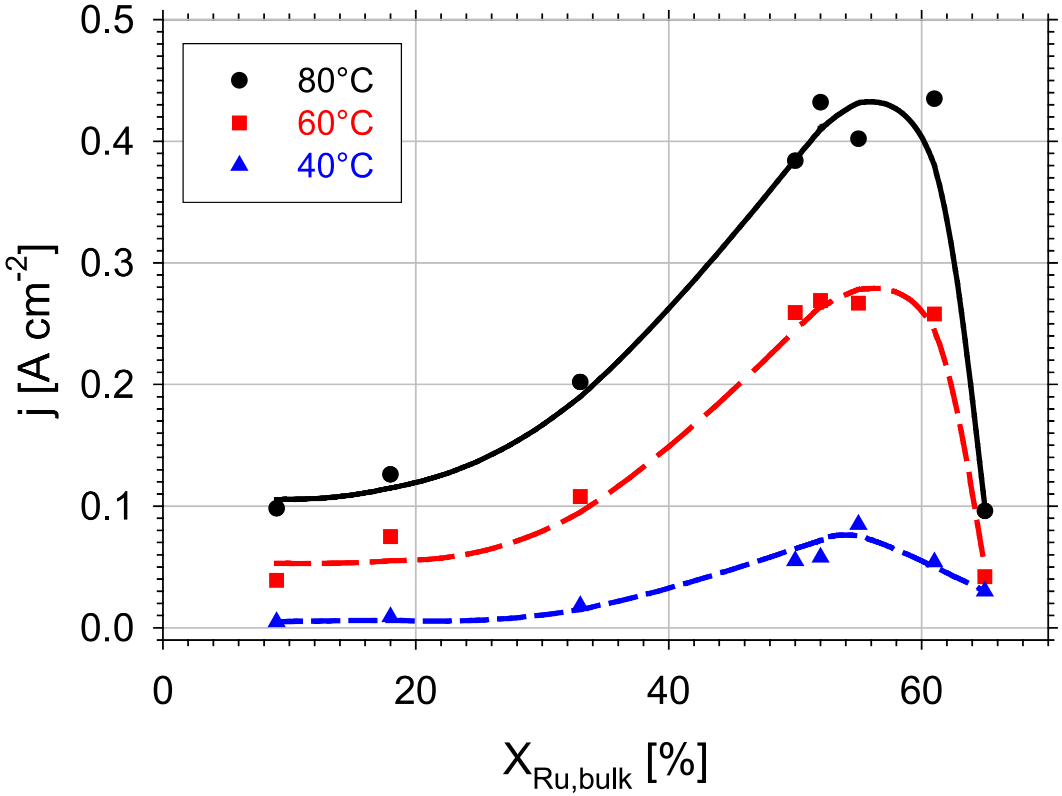






Anode Research

Pt-Ru Blacks: Catalytic Activity vs. Atomic *Ratio*



Achievement: **Optimum bulk composition of the anode catalyst found to be 55 ± 5 at% Ru, regardless of temperature.**

C *Collaboration with Johnson Matthey*

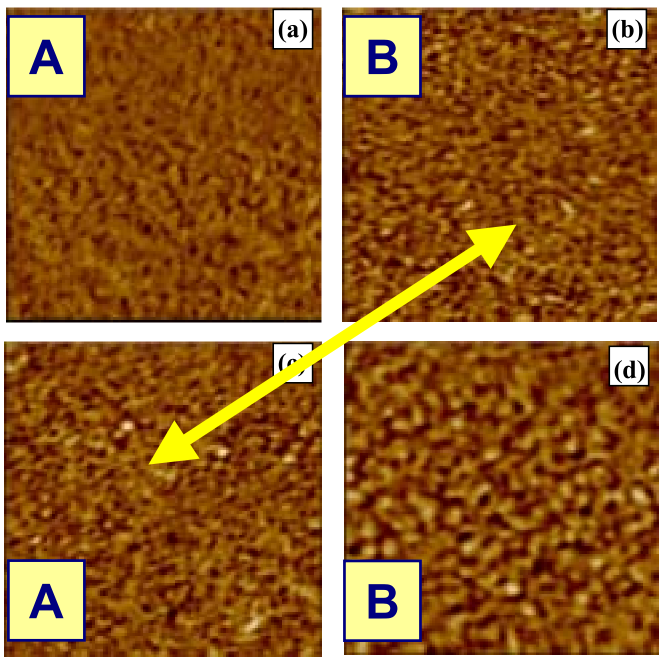
Membrane / MEA Research

Effect of Processing on Membrane Performance

Membrane	MeOH Permeability 10^6 (cm2/s)	Conductivity mS/cm	Selectivity 10^-6 mS s/cm3	Relative Selectivity	E_D
N117	*2.73*	*84.7*	*31.0*	*1.0*	*~3.3*
BPSH-40 (A)	0.50	38.5	76.3	2.5	~1.5
BPSH-35 (B)	0.81	43	53.1	1.7	1.3
BPSH-40 (B)	1.40	38.1	27.2	0.9	2.7

BPSH-35

BPSH-40

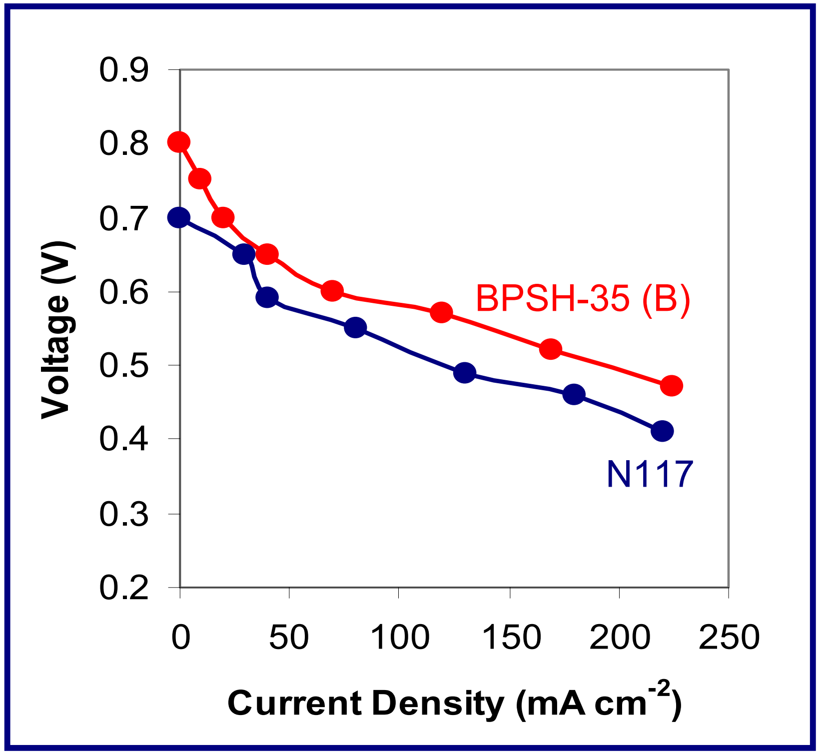


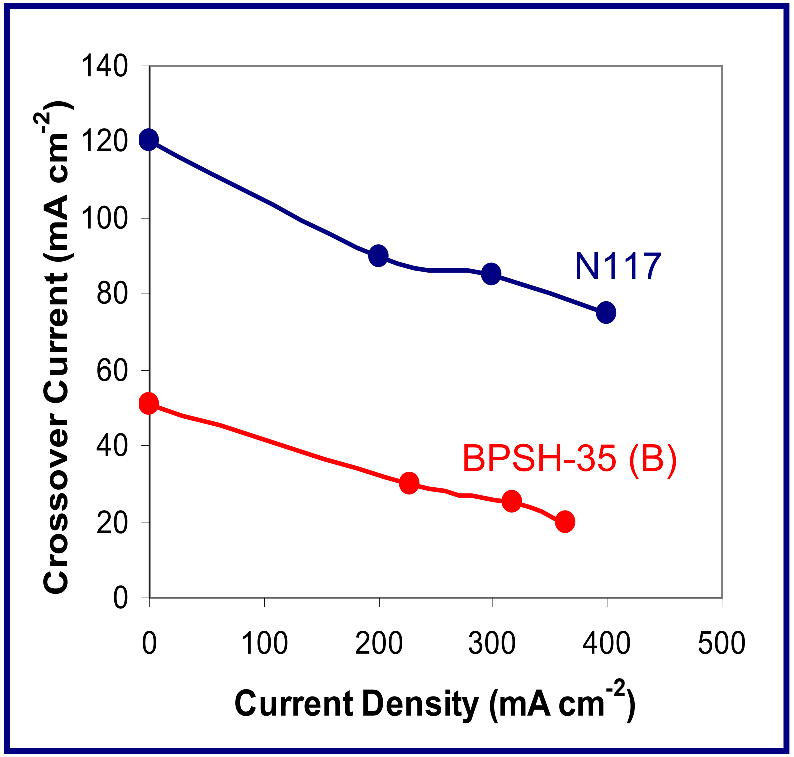
A – *Membrane before processing*
B – *Membrane after processing*

Processing greatly affects BPSH polymer properties and morphology; after processing, BPSH-35 (B) becomes similar to BPSH-40 (A).

Membrane / MEA Research

DMFC MEAs with Alternative Polymers





Achievement: In short-term testing, with ambient air at 80°C and 1.0 M MeOH anode feed, BPSH-35 (B) offers significantly reduced methanol crossover and comparable performance to Nafion 117.

C *Collaboration with Virginia Tech*

Membrane / MEA Research

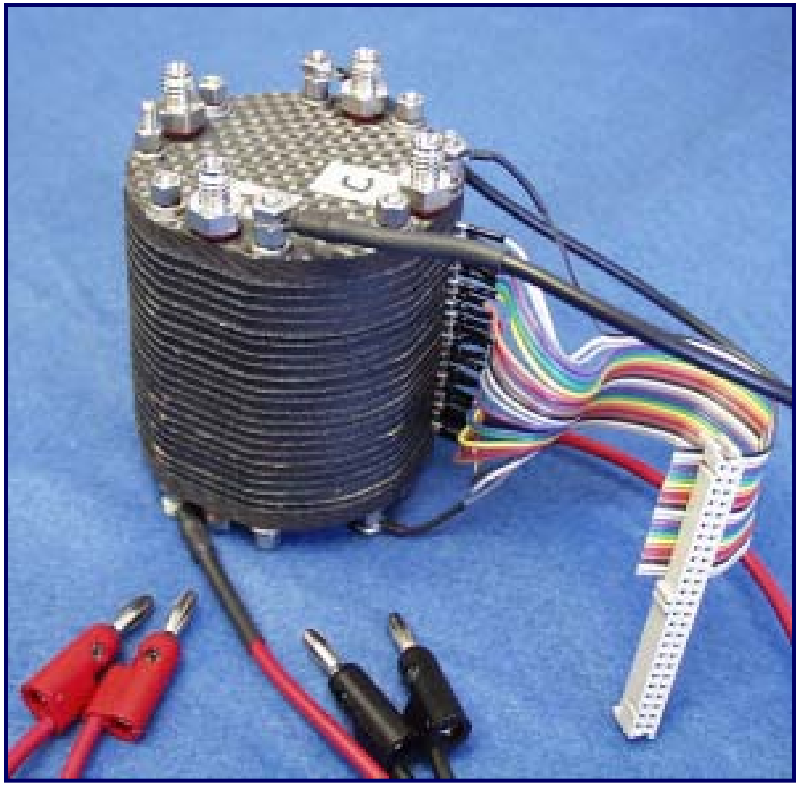
MEA Issues Critical to Further Progress

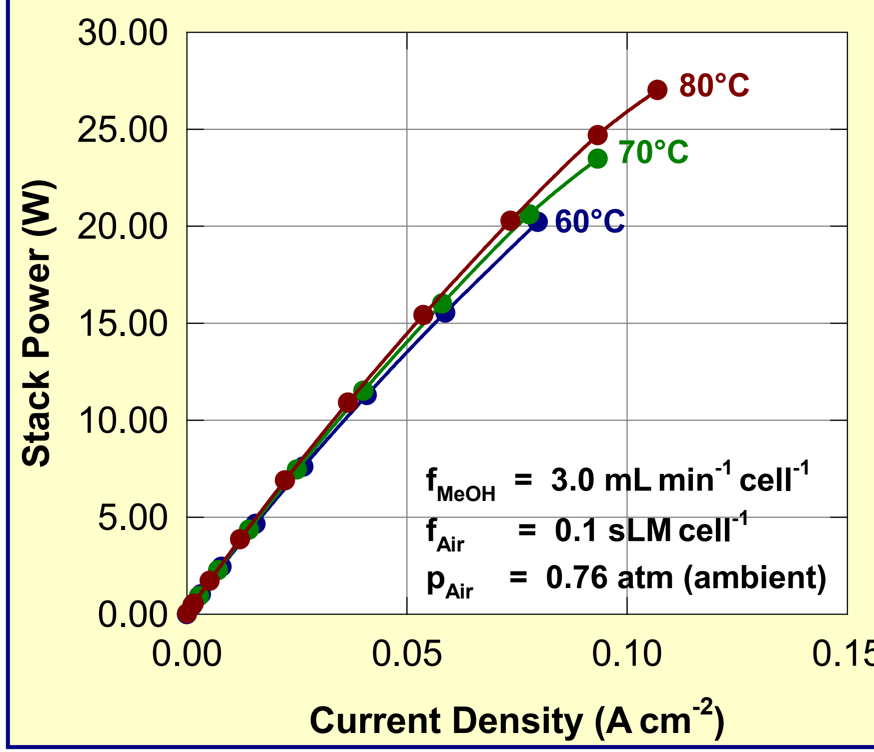
Membrane	Fuel Cell Conductivity (mS cm^{-1})	Membrane Conductivity (mS cm^{-1})	Fuel Cell Relative Selectivity	Membrane Relative Selectivity
Nafion 117	*85*	*110*	*1.0*	*1.3*
BPSH-40 (A)	38	80	2.5	4.4
BPSH-50 (A)	40	100	1.3	3.8
BPSH-60 (A)	52	170	1.1	2.5
Ion Clad	26	130 *Tricoli*	1.5	5.7

- **Based on membrane properties alone, relative selectivity of “alternative” MEAs should be higher than observed in DMFC testing.**
- **“Fuel cell conductivity” needs to be improved.**
- **More research required - with Nafion-free catalyst layers in particular.**

22 W DMFC Stack for Portable Power

High Efficiency, Ambient Pressure & Low Cathode Air Flow



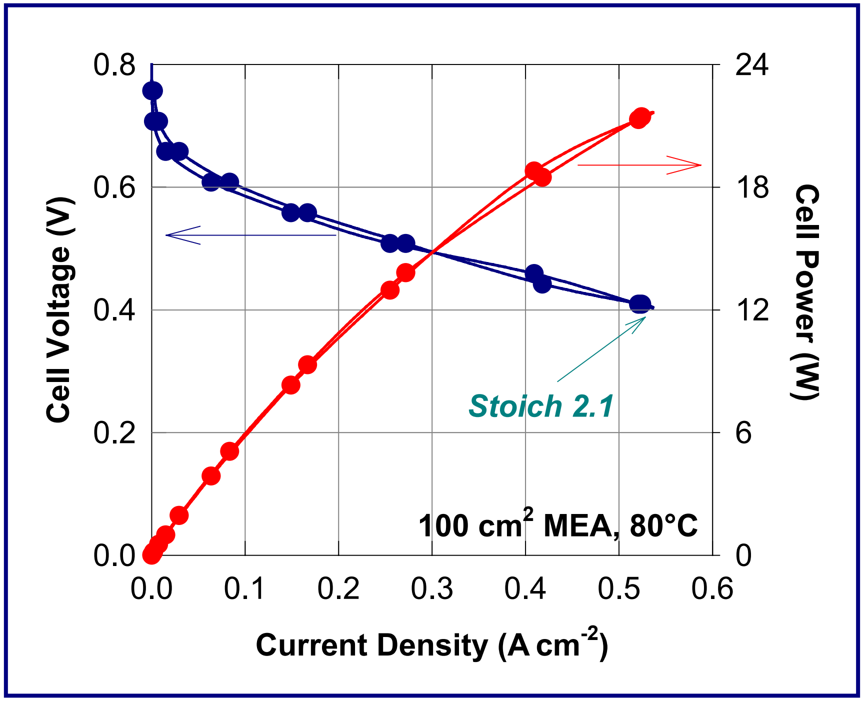


Achievement: Very good performance demonstrated at ambient cathode pressure (0.76 atm), low air flow ($\lambda < 3$) and relatively high stack voltage of ~12 V (0.55 V cell^{-1}).

C *Collaboration with Ball Aerospace*

500 W Prototype Stack / System Development for APU

On Track with Stack Deliverable in Fall 2002



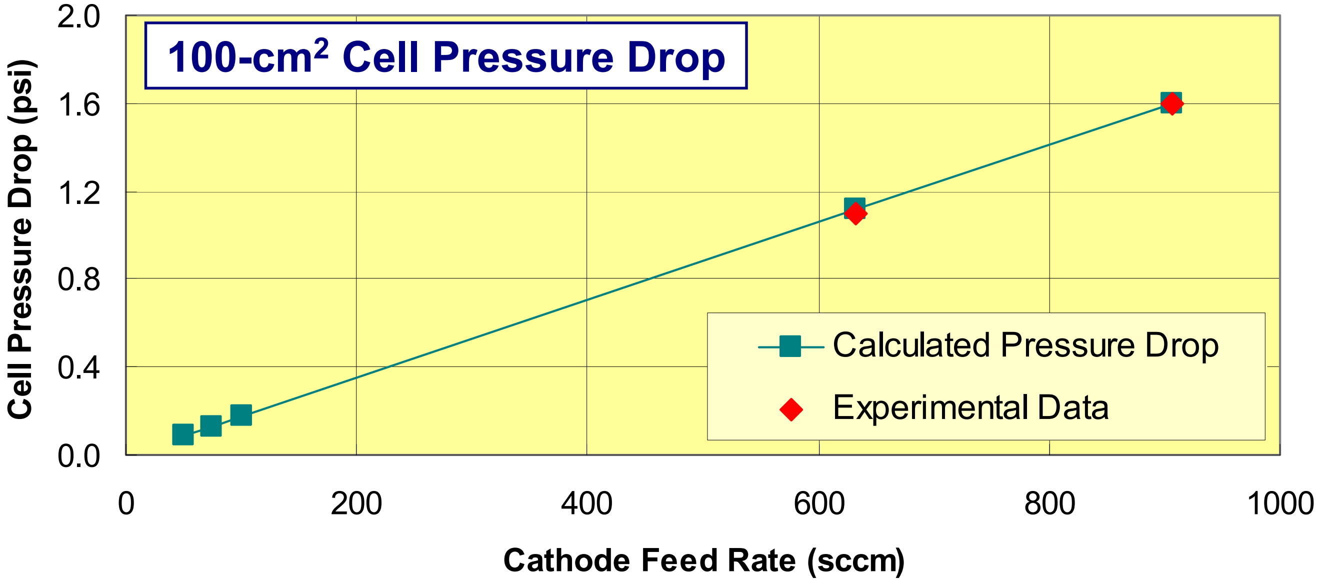
APU Stack: High-conductivity 100-cm^2 graphite hardware used in the first-generation APU cell. Performance recorded:

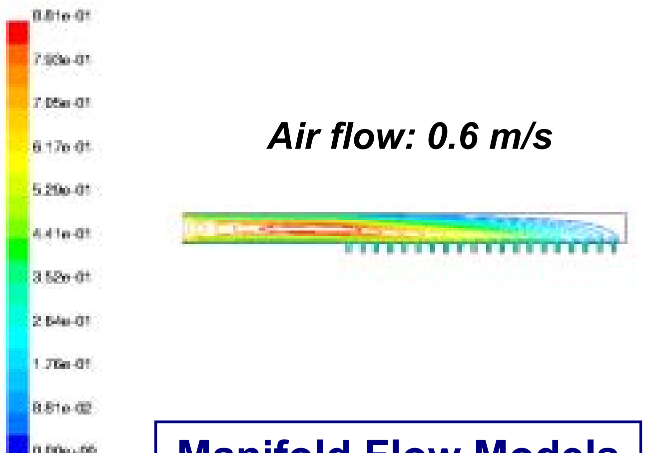
2.1 air stoich, 30 psig cathode back pressure: **~ 21 W**

1.3 air stoich, ambient cathode pressure: **~ 11 W**

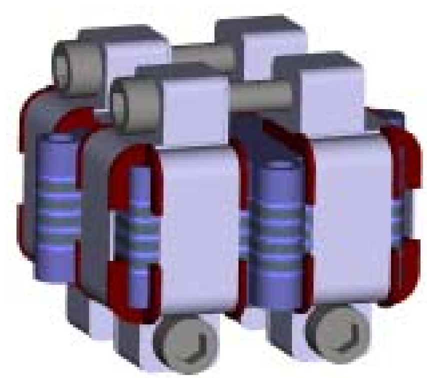
APU Hardware & Flow Modeling

Pressure Drop – Air Flow – Stack Hardware





Manifold Flow Models



Alternative Compression Approach

FY 2002: Summary

Reduction in Catalyst Loading:

- ✓ **Composition of cathodes with reduced Pt loading optimized; good performance with a total precious metal loading of 1.2 mg cm^{-2} demonstrated at 80°C – *task completed***

Catalyst Research:

- ✓ **Alternative Pt-X cathode catalyst identified (*patent pending*)**
- ✓ **In-house catalyst fabrication capability established; system used to make - commercially unavailable - 80 wt% Pt/C cathode catalyst**
- ✓ **Study of the effect of Pt-to-Ru atomic ratio on anode performance at different cell operating temperatures – *task completed***

FY 2002: Summary (II)

Membrane Research:

- ✓ **Well-performing BPSH (sulfonated poly(arylene ether sulfone)) MEAs with significantly reduced methanol crossover demonstrated – *task completed***
- ✓ **Demonstration of short stack with 3× better selectivity – *pending***

Stack R&D:

- ✓ **Components for 22 W DMFC stack for portable power applications designed, fabricated and optimized in single-cell and short-stack testing; first 22 W stack built and delivered to Ball Aerospace**
- ✓ **Components for 500 W stack for auxiliary power applications under development; single cell operation of 100-cm^2 hardware demonstrated with good results – *task on schedule*** *(stack delivery planned for the fall of 2002)*

FY 2003 Plans

- **Continue fundamental research and development in electrocatalysis of methanol oxidation and oxygen reduction; improve performance by optimizing hydrophilic/hydrophobic properties of the cathode** *(Sep 03)*
- **Study and report on the effect of sulfonation on performance of BPSH membranes in direct methanol fuel cells; narrow the gap between bench-top and fuel-cell selectivity of alternative membranes to no more than 30%** *(May 03)*
- **Demonstrate for at least 500 hours durability of Nafion and alternative MEAs (no more than 15% performance loss)** *(May 03)*
- **Demonstrate for at least 100 hours sustained operation of a "portable power" DMFC stack with air stoich below two** *(May 03)*
- **Investigate composition of the DMFC cathode exhaust as a function of cell operating conditions** *(Sep 03)*