Fuel Cells Systems Analysis

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2015 DOE Hydrogen and Fuel Cells Program Review

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Project ID: FC017

Overview

Timeline

- Start date: Oct 2003
- End date: Open
- Percent complete: NA

Budget

- FY14 DOE Funding: $450K
- Planned DOE FY15 Funding: $555 K
- Total DOE Project Value: $555 K

Barriers

B. Cost

C. Performance

E. System Thermal and Water Management

F. Air Management

J. Startup and Shut-down Time, Energy/Transient Operation

Partners/Interactions

- Eaton, Gore, Ford, dPoint
- SA
- 3M, Ballard, Johnson-Matthey Fuel Cells (JMFC), UTRC, Ballard
- IEA Annexes 22 and 26
- Transport Modeling Working Group
- Durability Working Group
- U.S. DRIVE fuel cell tech team

- This project addresses system, stack and air management targets for efficiency, power density, specific power, transient response time, cold start-up time, start up and shut down energy

Objectives and Relevance

Develop a validated system model and use it to assess design-point, part-load and dynamic performance of automotive and stationary fuel cell systems.

- Support DOE in setting technical targets and directing component development
- Establish metrics for gauging progress of R&D projects
- Provide data and specifications to DOE projects on high-volume manufacturing cost estimation

Impact of FY2015 work

- Established the uncertainties in system performance due to variability in supporting NSTF* cell polarization data: 2-5 $\$/kW_e$ FCS cost, 0.02-0.05 g-Pt/kW_e Pt content, and 10-15% in power density.
- Demonstrated that an alternate Gen-1 catalyst system with conventional high surface area carbon support (d-PtNi/C) has promising performance: 54 $\$/kW_e$ FCS cost and 0.21 g-Pt/kW_e Pt content.
- Identified the dominant NSTF catalyst degradation mechanism and determined the operating conditions for 20% projected voltage loss at rated power density over 5000 h.
- Determined the parasitic power requirements of the Roots air supply system: 12.7 kW_e at 100% flow (9 kW_e target) and 210 W_e at idle (200 W_e target)

NSTF: Nanostructured thin film

Approach

Develop, document & make available versatile system design and analysis tools.

- GCtool: Stand-alone code on PC platform
- GCtool-Autonomie: Drive-cycle analysis of hybrid fuel cell systems

Validate the models against data obtained in laboratories and test facilities inside and outside Argonne.

- Collaborate with external organizations

Apply models to issues of current interest.

- Work with U.S. DRIVE Technical Teams
- Work with DOE contractors as requested by DOE

1	Evaluate the performance of Eaton's integrated air management system with Roots compressor and expander relative to the targets of 8 kW_e power consumption at 92 g/s and 2.5 atm and 200 W_e at idling conditions.	12/14
2	Evaluate the performance of an MEA with an advanced cathode catalyst relative to the targets of 0.44 A/mg-PGM mass activity. 720 $\mu A/cm^2$-PGM specific activity, 1000 mW/cm^2 at rated power, and 300 mA/cm^2 at 800 mV.	03/15
3	Modify the system analysis methodology to incorporate durability considerations relative to the target of 5000 h operating life.	06/15
4	Update the performance and cost of an automotive fuel cell system with an advanced de-alloyed catalyst relative to targets of 60% peak efficiency, $Q/\Delta T$ of 1.45 kW/K, and $40/kW cost.	09/15

Summary: Technical Accomplishments

Validate and document models for pressurized (S1, 2.5-3.0 atm at rated power) and low-pressure (S2, 1.5 atm at rated power) configurations

Stack: Collaboration with 3M, JMFC/UTRC and Ballard in obtaining data to develop validated models for pressures up to 3 atm

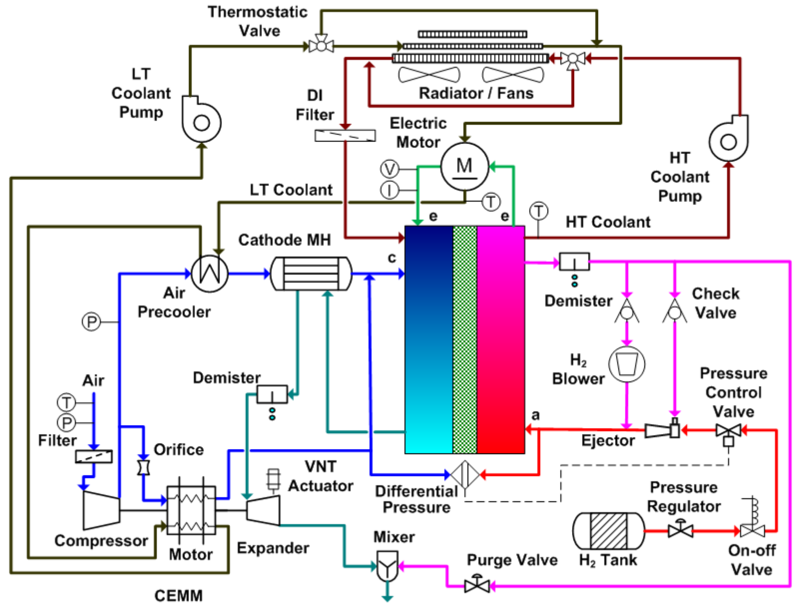
- Ternary PtCoMn/NSTF catalyst system: durability on drive cycles (initial results)
- De-alloyed PtNi/NSTF catalyst system (in progress)
- Dispersed Pt/C and de-alloyed PtNi/C catalyst systems (initial results)

Air Management: Collaborating with Eaton to develop and model Roots compressors and expanders and integrated air management system (ongoing)

Water Management: Collaboration with Gore, dPoint and Ford cross-flow humidifiers (publishing paper)

Fuel Management: Collaboration with 3M and Ford (impurity buildup, ejectors)

Thermal Management: Optimize system performance and cost subject to Q/ΔT constraint (ongoing)

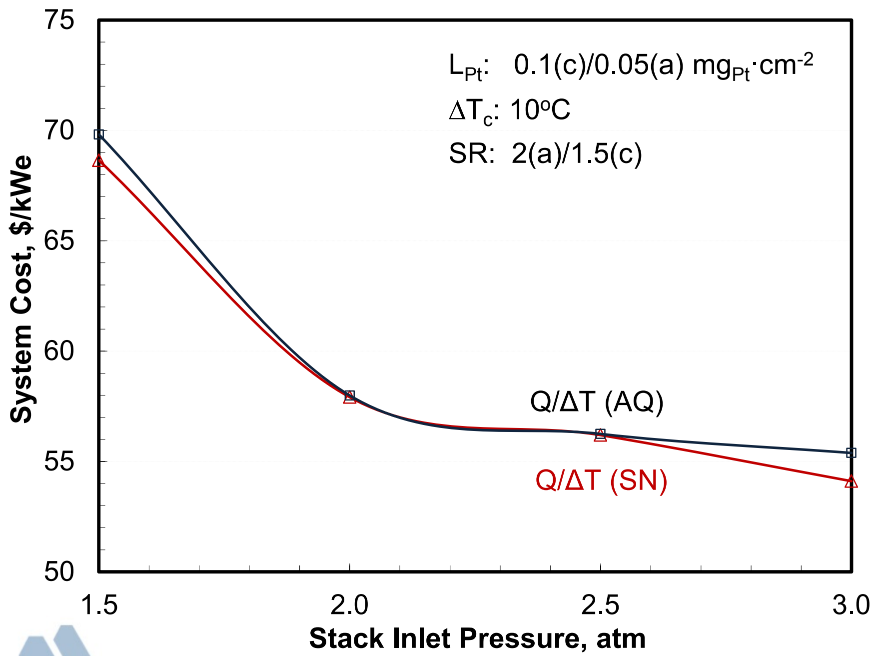


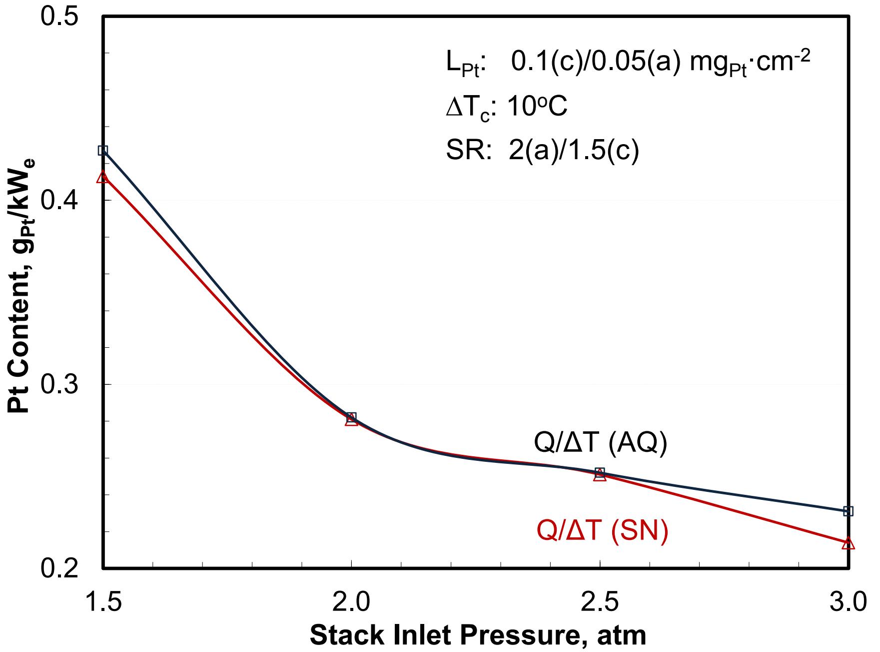
ΔT: Stack coolant exit T – Ambient T

Q/ΔT Study – System Cost and Performance

Study to investigate the effect of stack heat load estimate on the cost and performance of the reference system with NSTF catalyst based MEAs:
$Q/\Delta T$ = 1.45 kW/°C, T_{amb} = 40°C, T_c = 87-94°C (function of P)

- $Q/\Delta T$ (AQ): Actual stack heat load (AQ) considering variable $P(O_2)$, $P(H_2)$, T, current density and water condensation along the flow directions
- $Q/\Delta T$ (SN): Stack heat load estimated using simplified Nernst (SN) potential, independent of operating pressure, temperature, and anode/cathode stoichiometry
- For conditions under which water does not condense in the stack, $Q/\Delta T$ (SN) is an acceptable approximation of $Q/\Delta T$ (AQ)



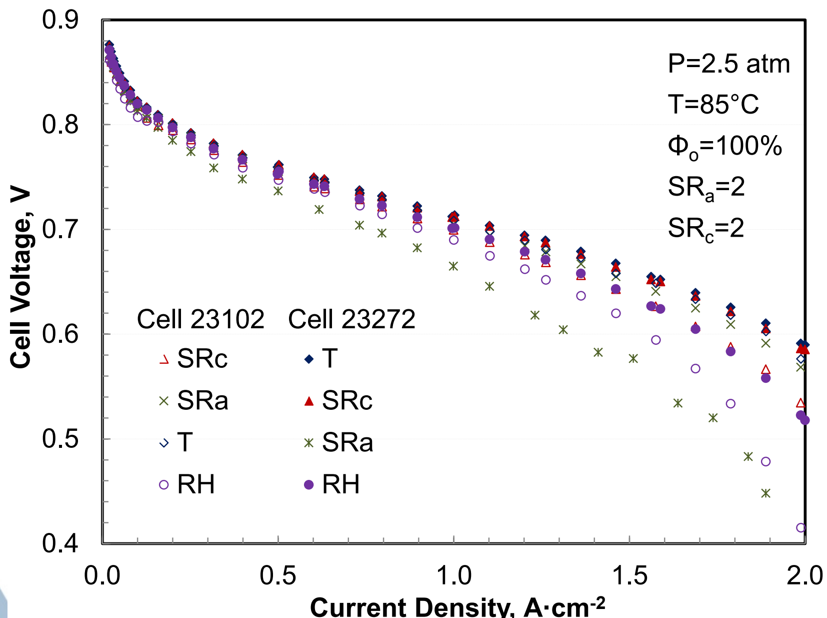


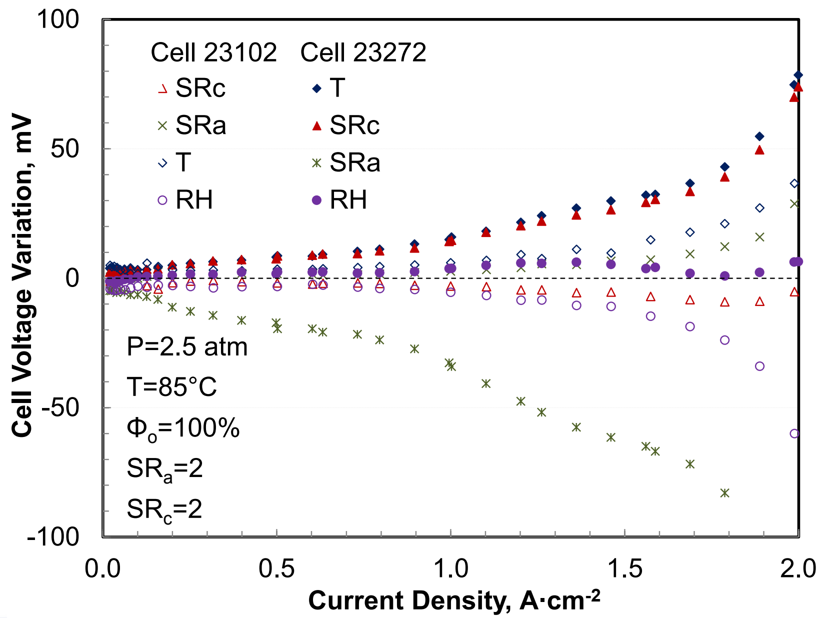
*Cost estimates from SA correlations for high volume manufacturing, $1500/tr-oz Pt price

3M PtCoMn/NSTF Cell ReferenceTests at 2.5 atm

Cell degradation and cell-to-cell performance variability

- Same reference condition (2.5 atm, 85^{o}C, 100% exit RH, SR_c=SR_a=2) visited in four series of tests performed on Cells 23102 (0.1 mg-Pt(c)/cm^2) and 23272 (0.15 mg-Pt(c)/cm^2)
- Cell to cell variability established as deviation from the measured average voltage in the two cells as function of current density
- Cell 23102: Best performance in temperature (T) Series; Recovery from SR_c (cathode stoichiometry) to SR_a (anode stoichiometry) series and from SR_a to T series; Degradation from T to RH series
- Cell 23272: Best performance in T Series; Degradation from T to SR_c series and from SR_c to SR_a series; Recovery from SR_a to RH series



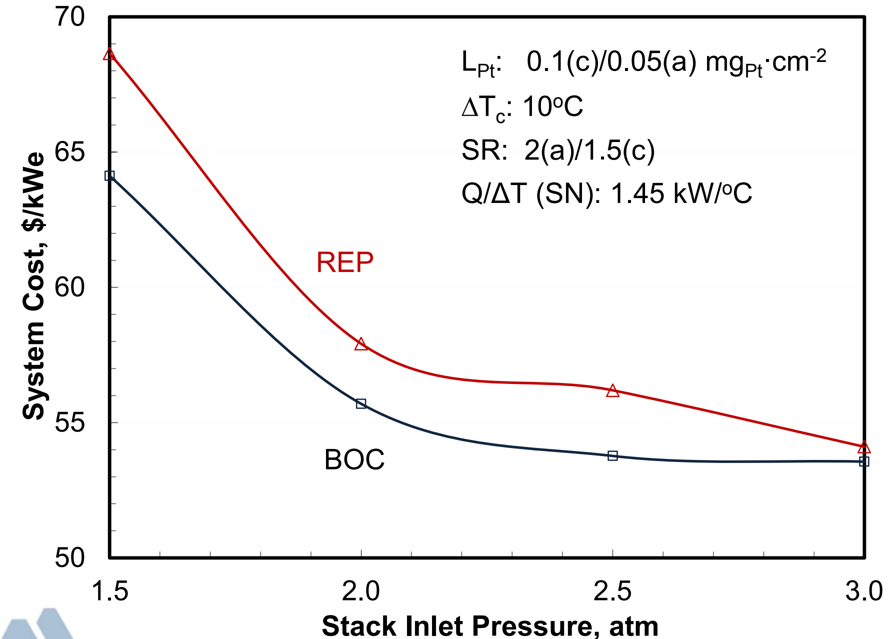


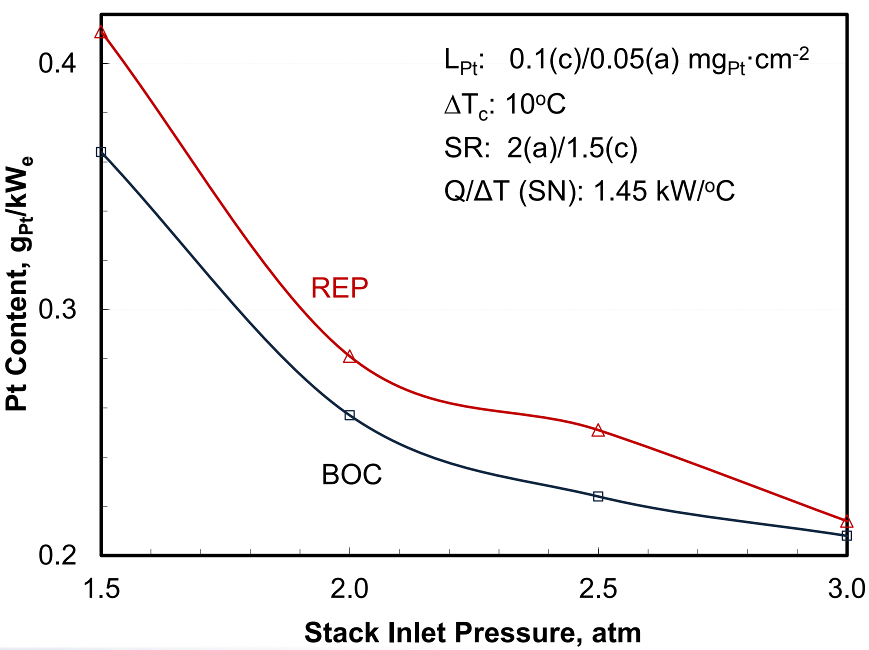
*SR: stoichiometry; Φ: relative humidity (RH)

System Cost and Performance: Variability in Supporting Data

- REP: Performance model based on representative (REP) polarization curves averaged over many runs with identical operating conditions
- BOC: Performance model based on the best of class (BOC) data

		2.5 atm, 94°C		1.5 atm, 87°C	
		REP	BOC	REP	BOC
Cell Voltage	mV	662	662	697	697
Current Density	A/cm^2	1.02	1.14	0.57	0.64
Power Density	mW/cm^2	674	753	394	447
Pt Cost	$/kW_e$	12.1	10.8	19.9	17.5
Stack Cost	$/kW_e$	28.15	25.69	43.10	38.54



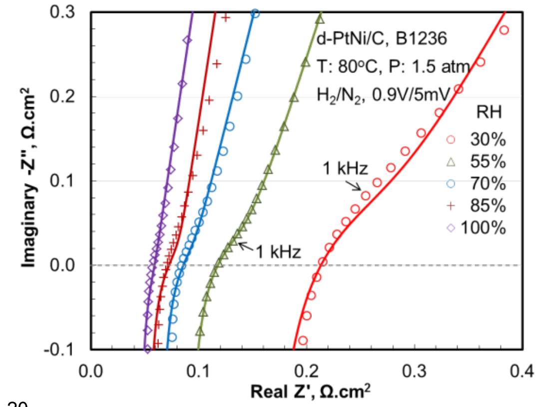


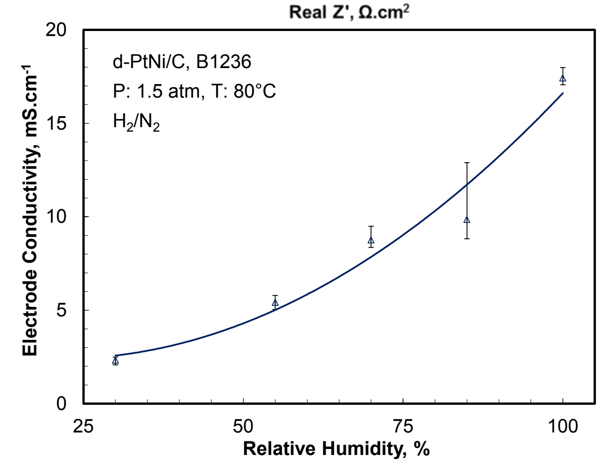
***Cost estimates from SA correlations for high volume manufacturing, $1500/tr-oz Pt price**

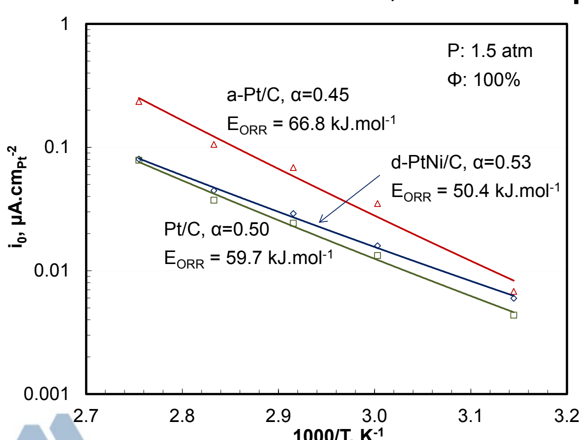
Alternate Catalysts: Model Development

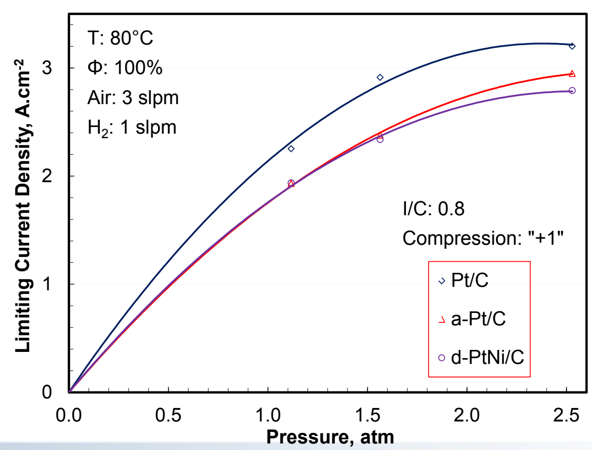
Collaborating with FC106: Rationally Designed Catalyst Layers for PEMFC Performance Optimization

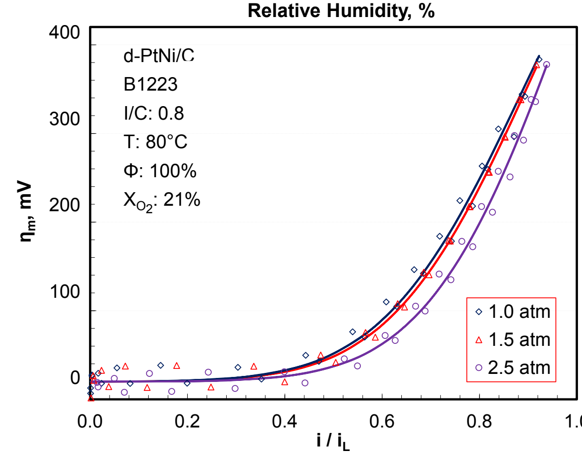
- Data from UTRC using MEAs supplied by JMFC: 1st-generation (Gen-1) de-alloyed PtNi/C, dispersed Pt/C, annealed Pt/C (a-Pt/C)
- Electrode and membrane conductivities from impedance data in H_2-air and H_2-N_2
- ORR kinetics from H_2-O_2 polarization data
- Limiting current density (i_L) and mass transfer overpotentials (η_m) from H_2-air polarization data at high stoichiometries
- Test variables: 1-2.5 atm, 45-90°C, 1-21% O_2, 30-100% RH, 0.1-3 slpm air









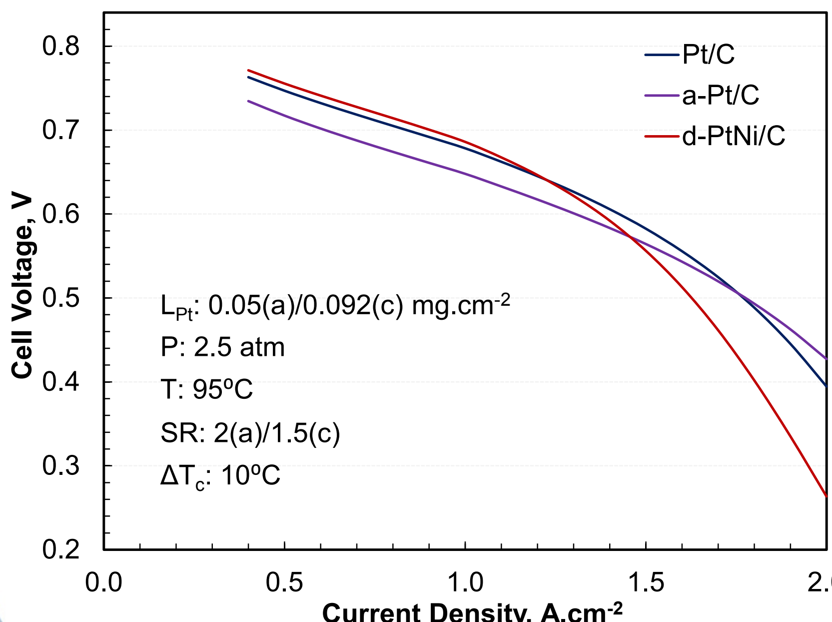


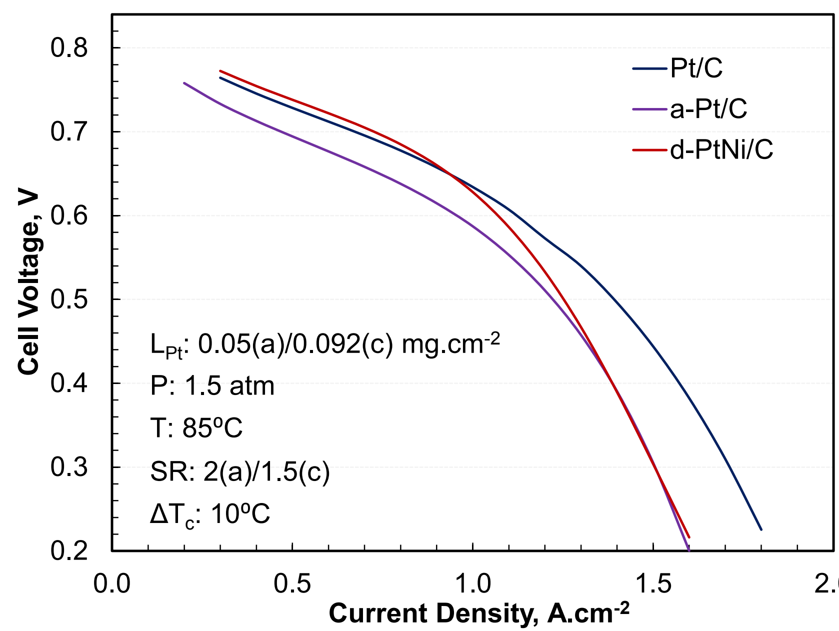
i_L defined as the reference current density at which the mass transfer overpotential (η_m) equals 450 mV

Performance of Alternate Catalyst System – De-alloyed PtNi/C MEAs

Modeled polarization curves* for conditions required to satisfy Q/ΔT constraint at 100% exit RH (inclusive of 10 mV cell to stack voltage loss at 1 A/cm^2)

- Compared to Pt/C (2 nm)*, d-PtNi/C (5.1-5.8 nm)* has 66% higher specific activity (914 vs. 552 μA/cm^2-Pt) but only 17% higher mass activity (0.530 vs. 0.453 A/mg-Pt) because of lower ECSA (58 vs. 82 m^2/g-Pt); Pt/C = 0.3, I/C = 0.8
- Above a critical (cross-over) current density, the advantage of higher mass activity of d-PtNi/C is offset by higher mass transfer overpotentials because of smaller surface area of Pt (and Ni^{2+} contamination). Further optimization and improvement of d-PtNi/C catalyst structure is ongoing in FC-106 and at JMFC.
- d-PtNi/C more durable because the annealing step grows Pt particles to ~5.1-5.8 nm (~2 nm for Pt/C) in spite of Ni^{2+} leaching out (FC087)



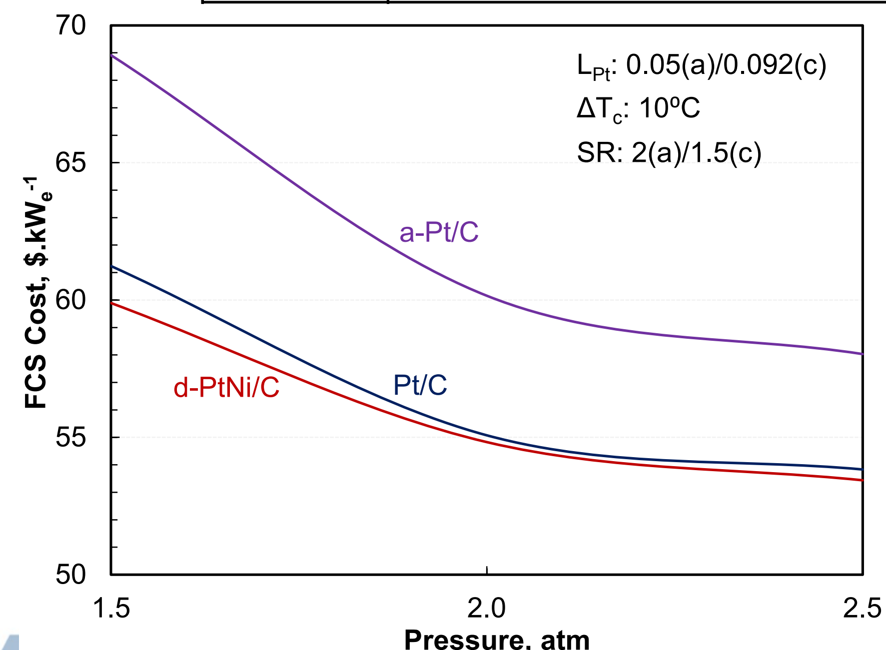


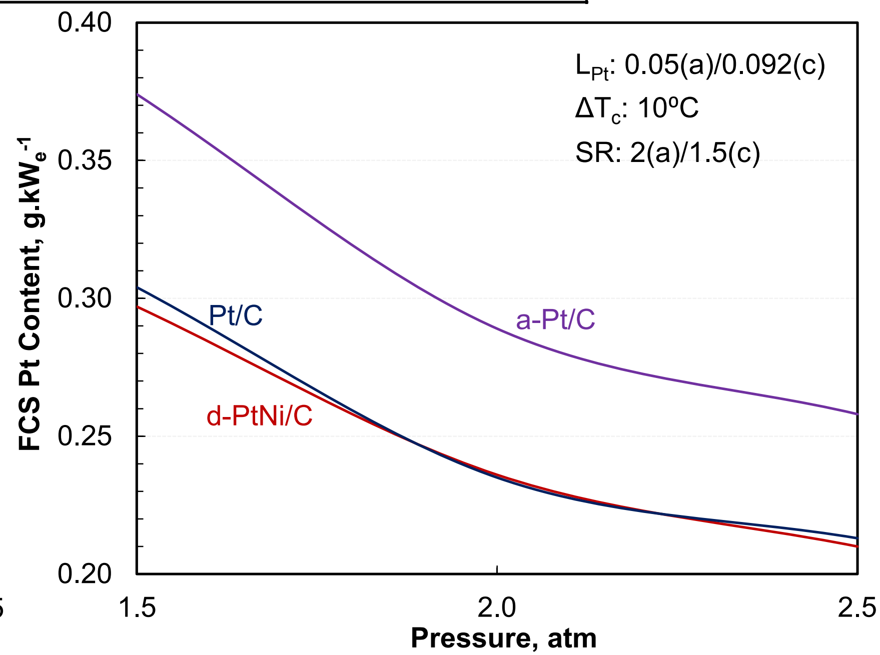
***Design-point performance at fixed P, T, SR(c), mass velocity in gas channel**

Comparative BOL Performance: d-PtNi/C vs. Pt/C

- Gen-1 d-PtNi/C has slight cost ($\$/kW_e$) and performance ($g\text{-}Pt/kW_e$) advantages, especially at lower pressures and temperatures. High surface area Pt/C (~2 nm), however, is unstable under cyclic potentials.

Cell	P atm	T °C	Cell Voltage mV	Power Density mW/cm^2	Stack Pt Content g_{Pt}/kW_e	Pt Cost $\$/kW_e$	Stack Cost $\$/kW_e$
d-PtNi/C	2.5	95	661	746	0.190	10.2	25.1
	2.0	93	666	650	0.218	11.4	27.5
	1.5	89	684	507	0.280	14.4	33.4
Pt/C	2.5	95	662	737	0.193	10.3	25.3
	2.0	95	655	655	0.217	11.3	27.4
	1.5	91	672	495	0.287	14.7	34.1



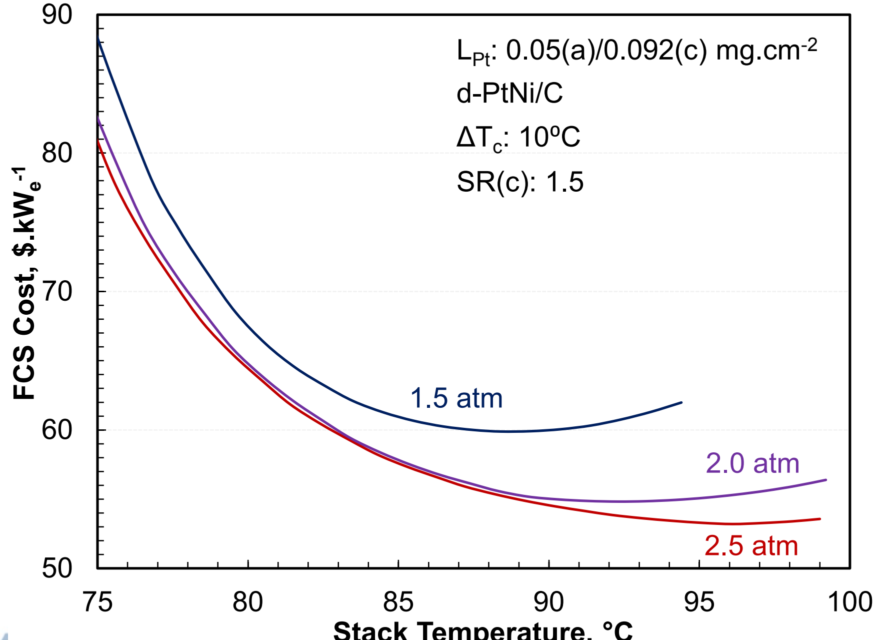


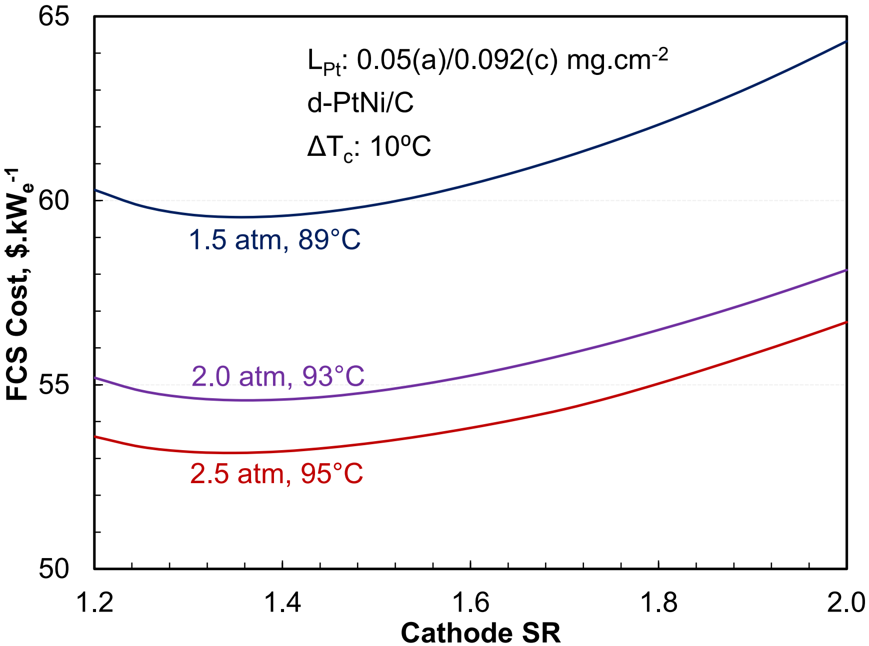
BOL: Beginning of life

Cost and Performance of FCS with d-PtNi/C MEAs

- Under optimum conditions, d-PtNi/C runs drier at 1.5 atm (88% RH at cathode inlet, 82% at cathode outlet) than at 2.5 atm (82% RH at cathode inlet, 103% at cathode outlet)
- Further improvement in cost and performance expected from ongoing efforts to optimize d-PtNi/C catalyst structure

P atm	T °C	SR_c	Inlet RH %	Outlet RH %	Cell Voltage mV	Power Density mW/cm^2	FCS Efficiency %	Air System $\$/kW_e$	Fuel System $\$/kW_e$	Thermal System $\$/kW_e$	Water System $\$/kW_e$	Stack $\$/kW_e$
2.5	95	1.5	82	103	661	746	47.5	11.6	3.6	5.2	1.1	25.1
2.0	93	1.5	89	93	666	650	48.8	10.4	3.6	4.9	1.5	27.5
1.5	89	1.5	88	82	684	507	51.1	9.3	3.6	4.5	2.2	33.4

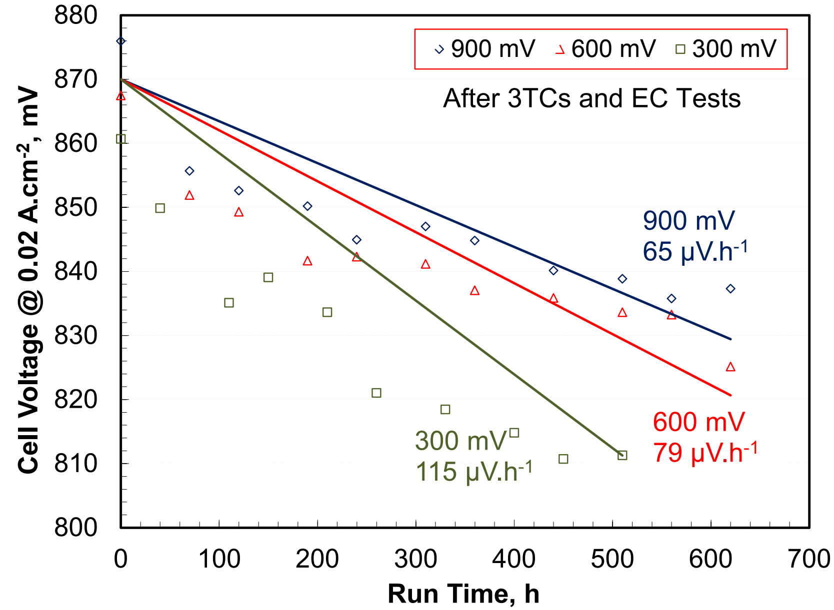


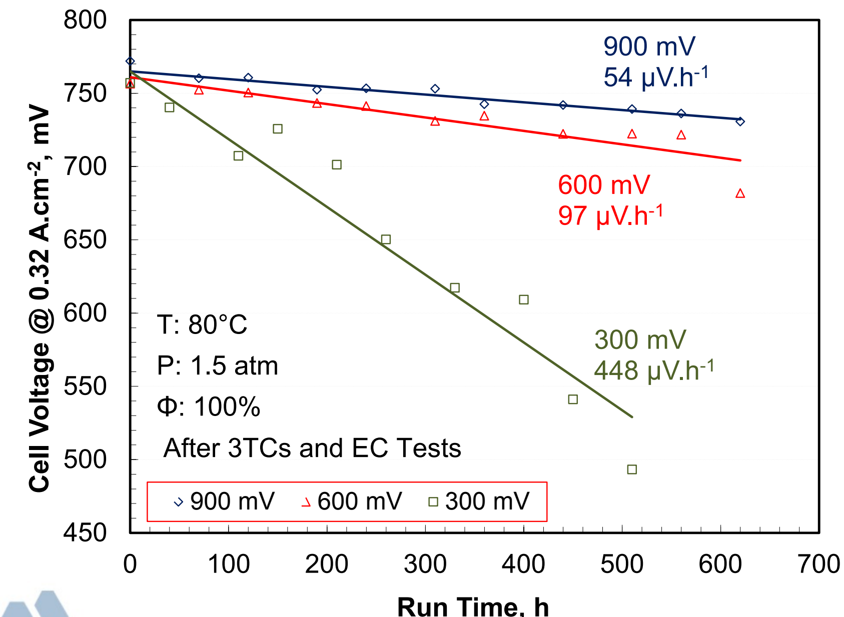


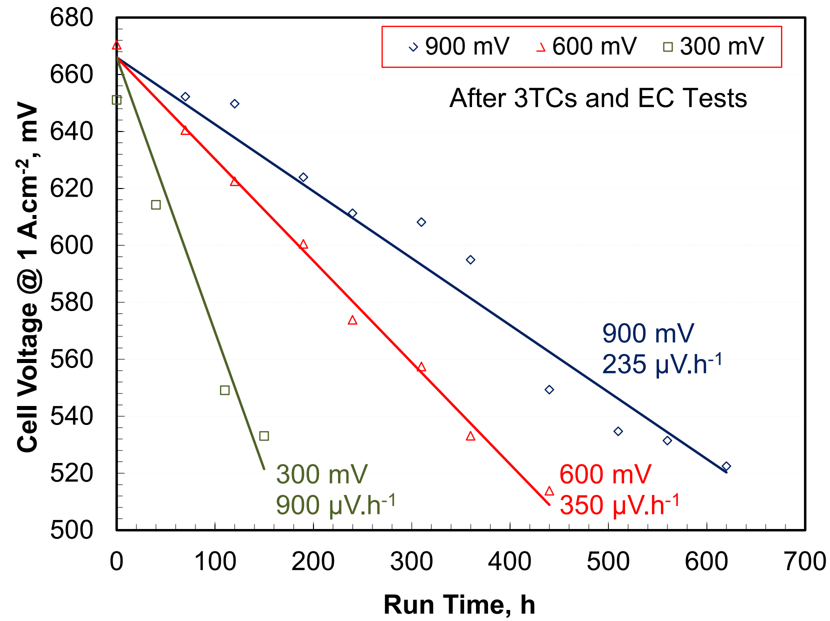
Durability of NSTFC MEAs: Irreversible Degradation

Long holds at low potentials identified as the dominant degradation mechanism in NSTF catalysts

- Three tests run at 3M to expose ternary NSTF catalysts* at 0.3, 0.6 and 0.9 V at 90°C, 100% RH, constant SR(c) = 2
- Irreversible degradation defined as loss in cell voltage after normal recovery method: three thermal-conditioning (TC) cycles plus electrochemical characterization (EC) tests
- Voltage losses from polarization curves at 1.5 atm, 80°C, 100% RH





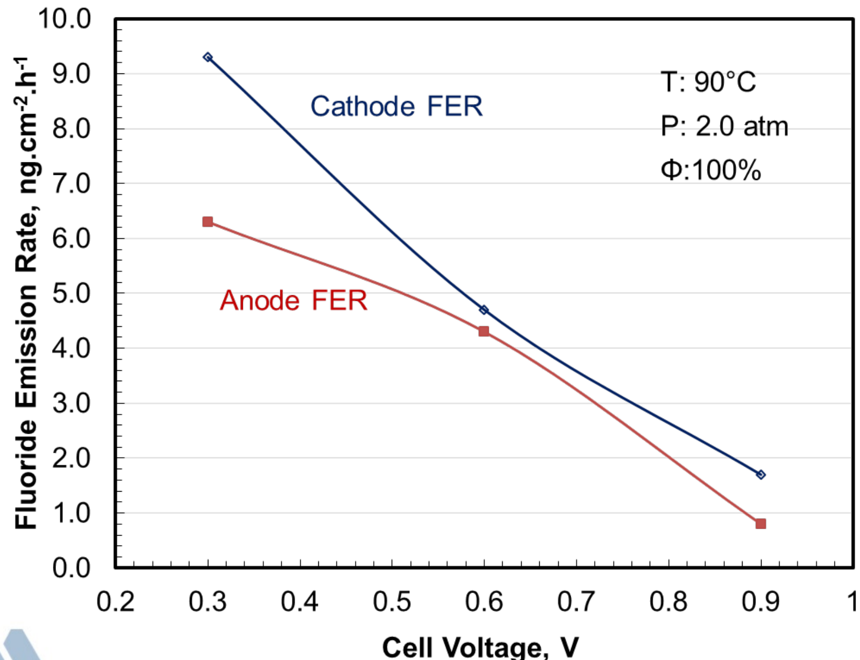


*Pt loading in PtCoMn/NSTF catalysts: 0.15(c)/0.05(a) mg/cm²

Fluoride Release Rates

Fluoride release measured by ion chromatography of collected water samples

- F^- concentrations are very low: 20 ppb or less
- Although concentrations are the same, F^- generation rate increases with decreasing cell V (higher current density) due to higher effluent water flow rate (production + supplied)
- Measured fluoride emission rates (FER) higher on cathode than on anode
- Both cathode and anode FER are higher at lower cell voltages
- Fluoride release rates for NSTF catalysts are an order-of-magnitude smaller than for dispersed Pt/C catalysts with chemically stabilized and mechanically reinforced membranes

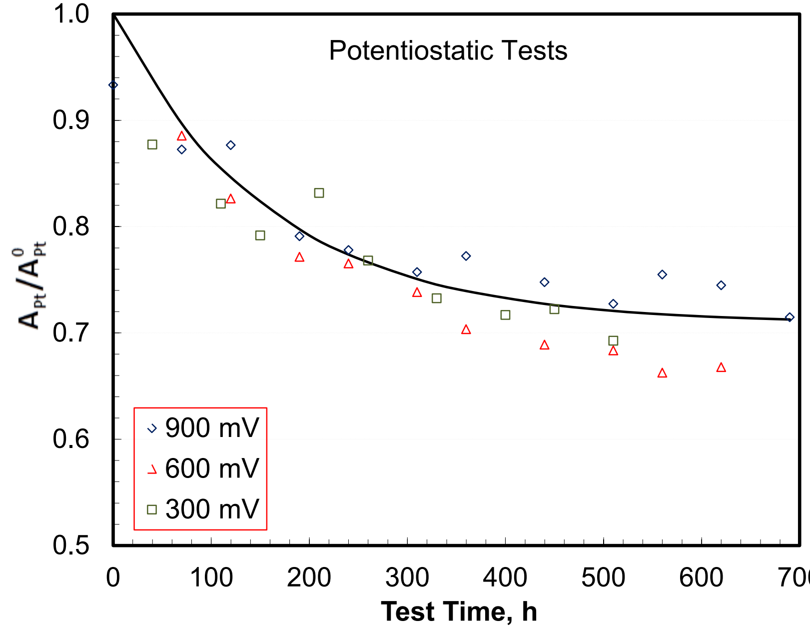


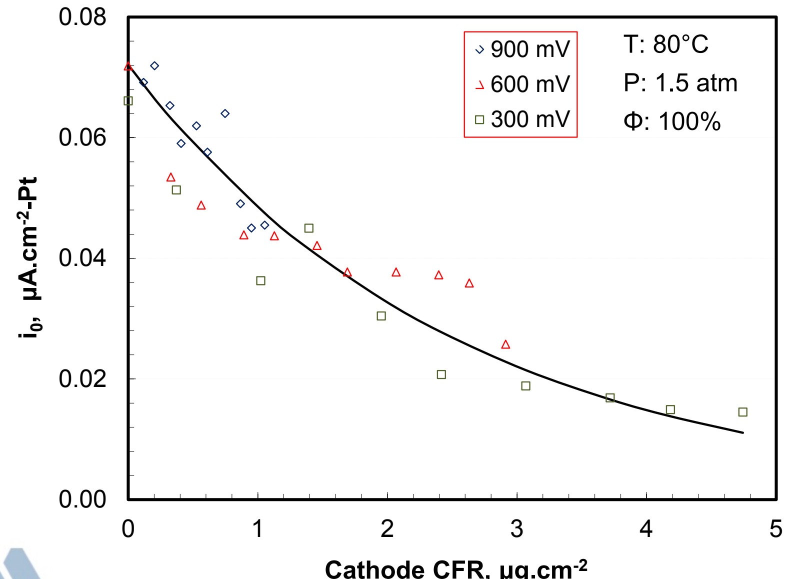
Some observations concerning FER

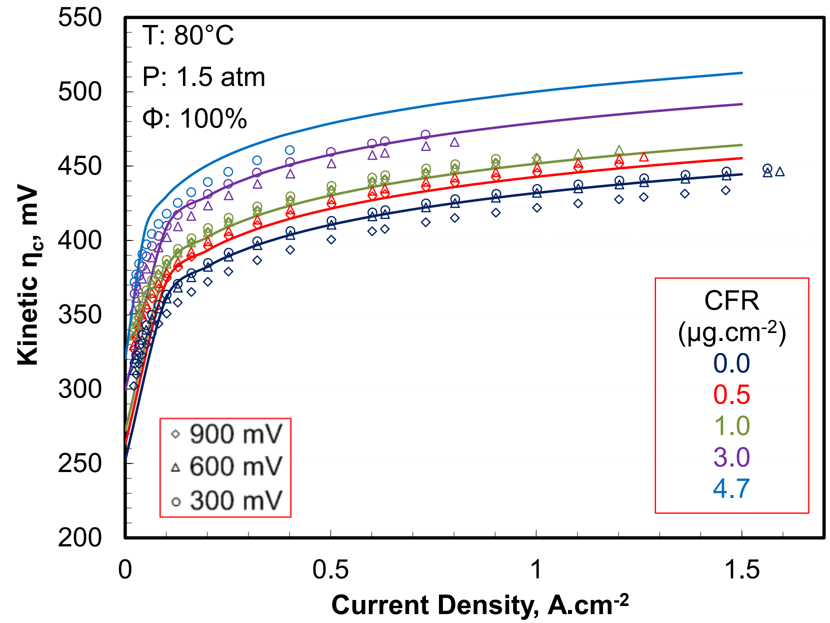
- Measured cathode FER increasing with decreasing cell voltage is consistent with the observed dependence of H_2O_2 production on potential in RRDE tests
- Anode FER correlates with cell voltage rather than anode potential. This may be related to the cell-voltage dependence of the net O_2 crossover to anode from cathode.

Correlation for Irreversible Increase in Kinetic Losses

- ECSA (A_{Pt}) loss is due to smoothening of whiskerettes. Under potentiostatic conditions, it only a function of time and not hold potential
- ORR specific activity also decreased, more degradation at 0.3 V than at 0.6 V or 0.9 V
- Exchange current density (i_0, μA.cm^{-2}-Pt) correlated with the cumulative fluoride release at cathode (CFR)
- Up to 65 mV increase in kinetic overpotential (η_c) during the tests



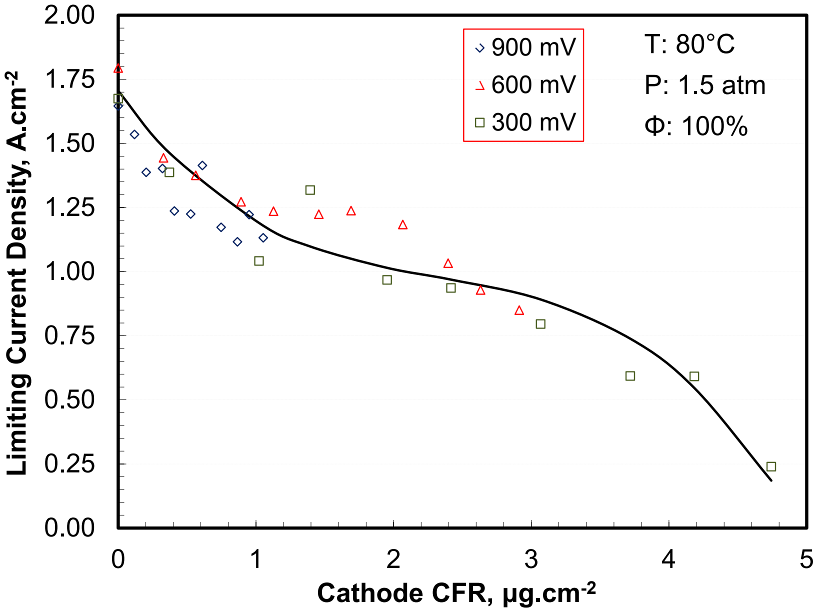


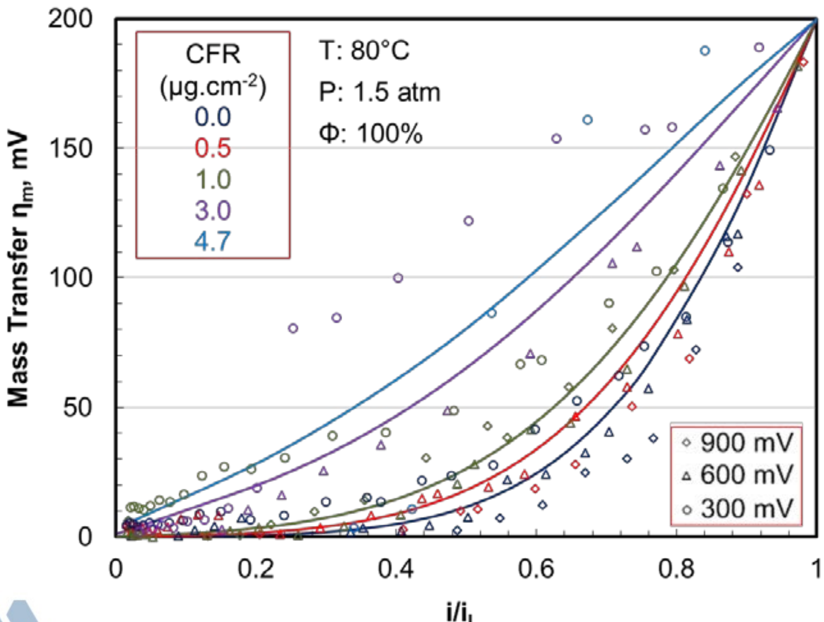


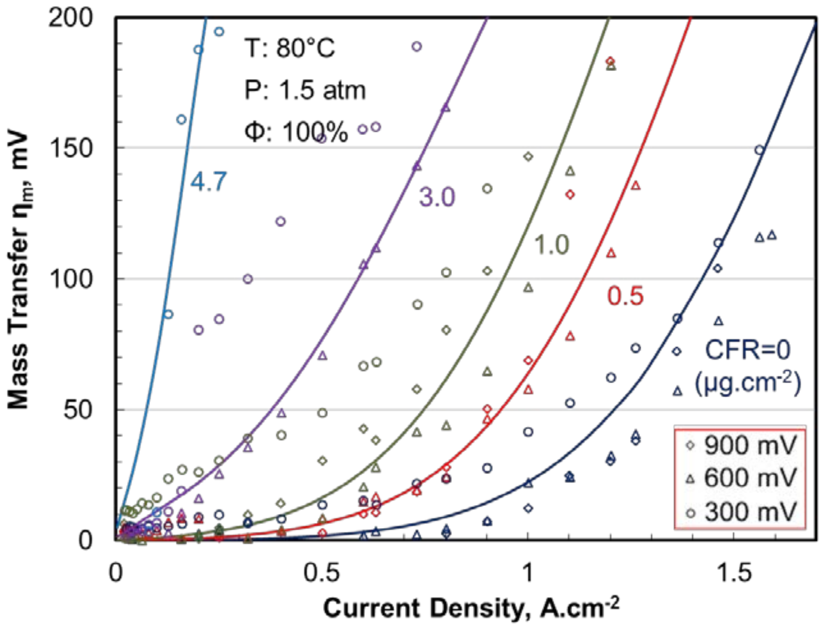
Correlation for Irreversible Increase in Mass Transfer Overpotentials

Mass transfer overpotential (η_m) correlated with i/i_L and the cumulative fluoride release at cathode (CFR)

- i_L correlates with CFR and decreases as more fluoride is released
- η_m is an implicit function of hold potential through CFR and i_L
- η_m is primarily a function of CFR and current density for 300 and 600 mV hold potentials





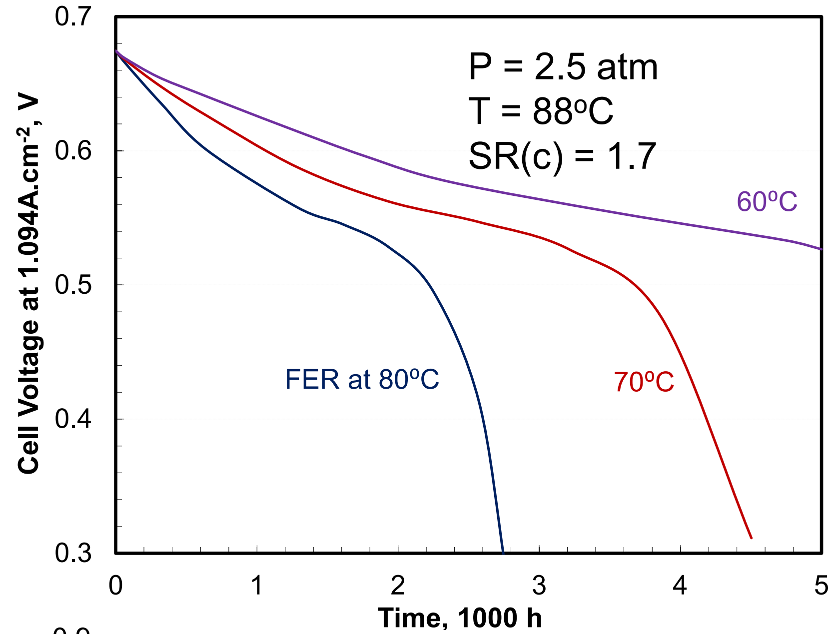


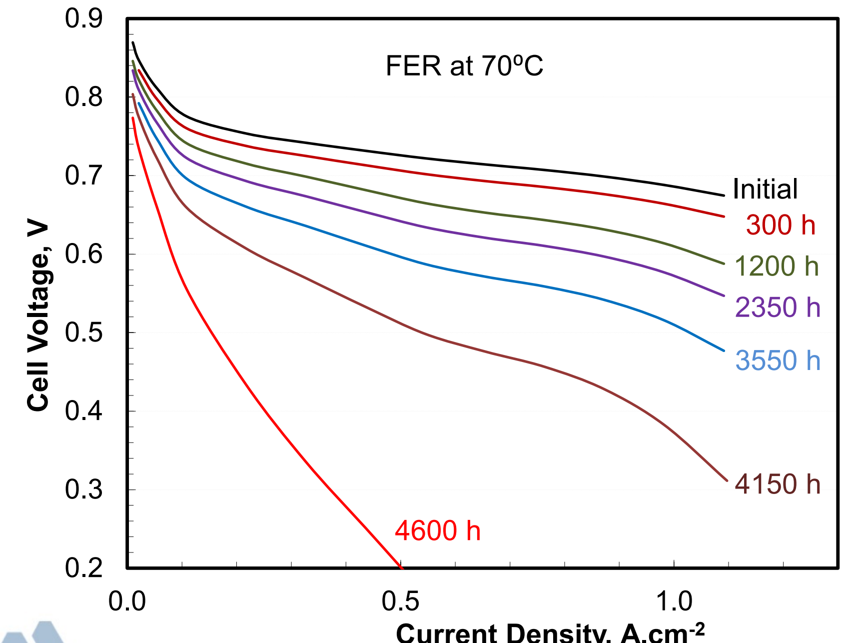
i_L defined as the reference current density at which the mass transfer overpotential (η_m) equals 200 mV

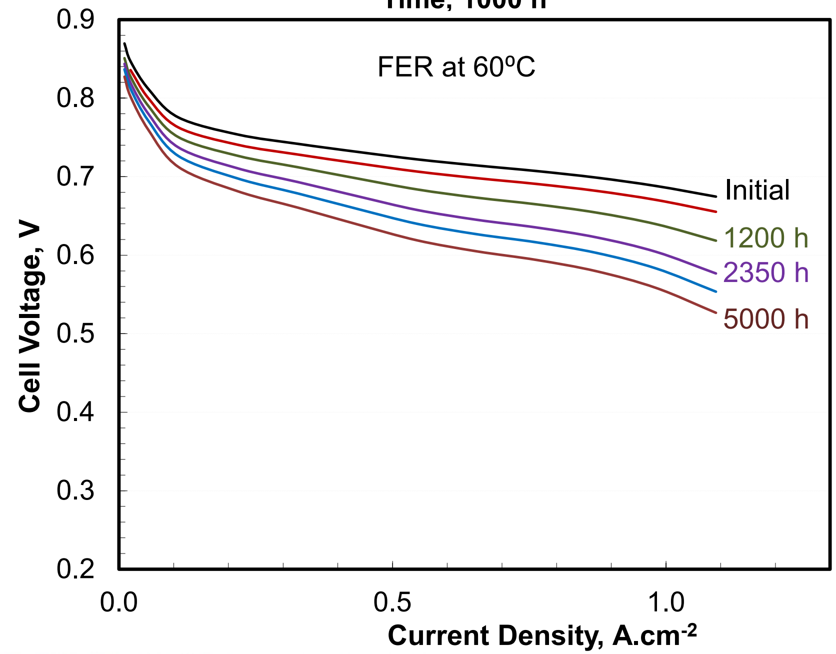
Durability of Stacks with NSTF Catalysts: Preliminary Results

Projected durability over lifetime represented as repeated FUDS and FHDS cycles

- Steady-state polarization curves to determine % time and temperature at potential
- Assumed FER in NSTF* has the same temperature dependence as DuPont™ XL membrane with Pt/C electrodes (50 kJ/mol)
- Projected decrease in cell voltage at rated current density with FER at 60°C : 7% after 1000 h, 13% after 2000 h, 22% after 5000 h





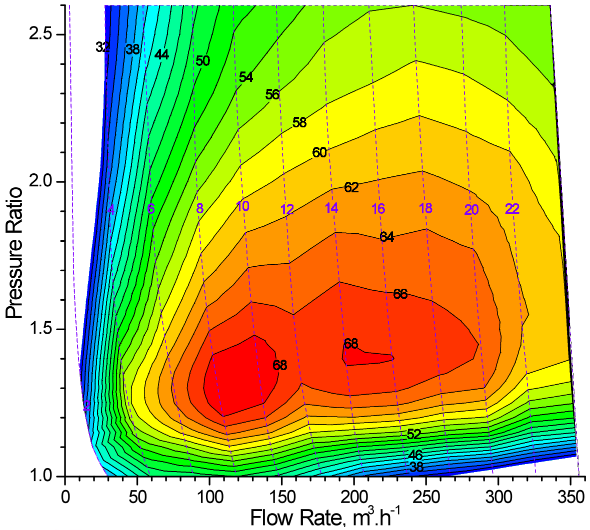


FUDS (FHDS): Federal urban (highway) drive schedule; *Temperature dependence of FER for NSTF TBD

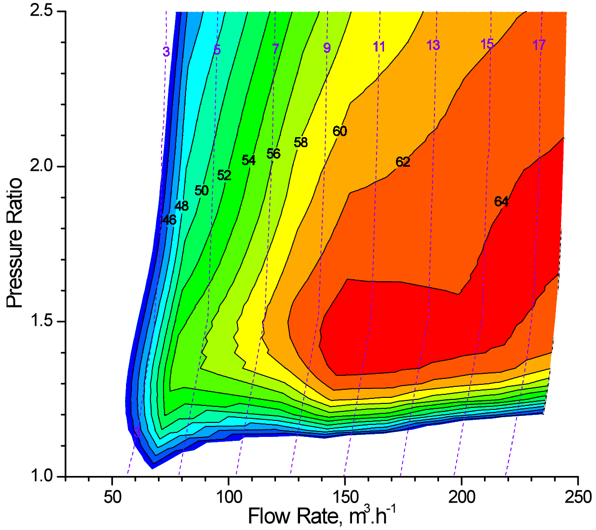
Roots Air Management System with Integrated Expander

Argonne is collaborating with Eaton-led team to model and analyze Roots air management system and optimize it for use in Ballard fuel cell module

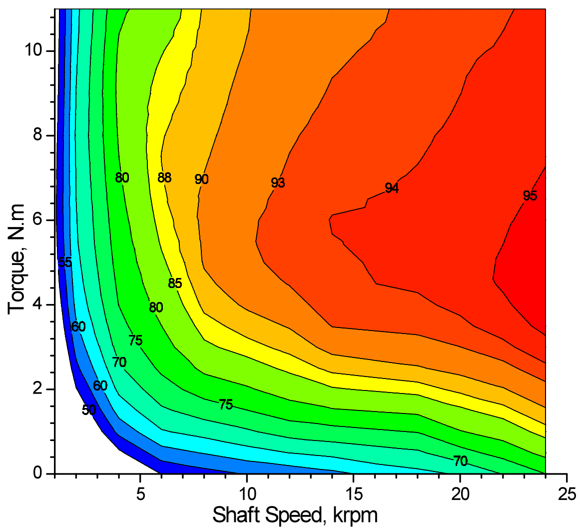
- Developed performance maps for V250 Twin Vortices Series Roots compressor, Gen2 three-lobe V210 Roots expander, and 30-kW motor and motor-controller
- Compared with the status numbers, the isentropic efficiency of V250 compressor is lower at 100% flow and is comparable at 25% flow
- Compared with the status numbers, the isentropic efficiency of the V210 expander is lower in part due to the nature of the Roots expansion process
- Combined efficiency of motor/motor-controller is higher than 80% over a wide range of torque (> 2 N.m) and shaft speed (> 8,000 rpm); peak efficiency can exceed 95%



V250 Compressor



V210 Expander



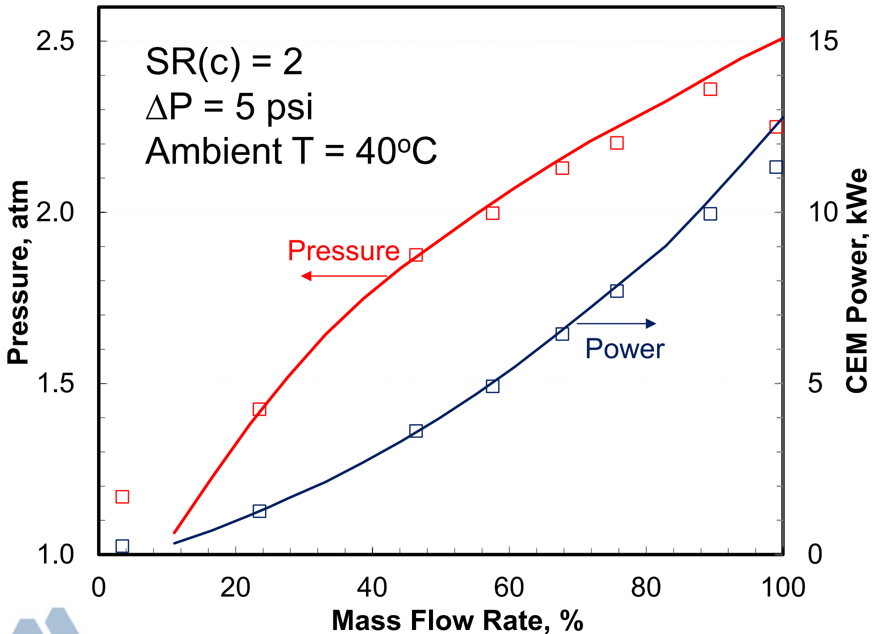
Motor/Motor-Controller

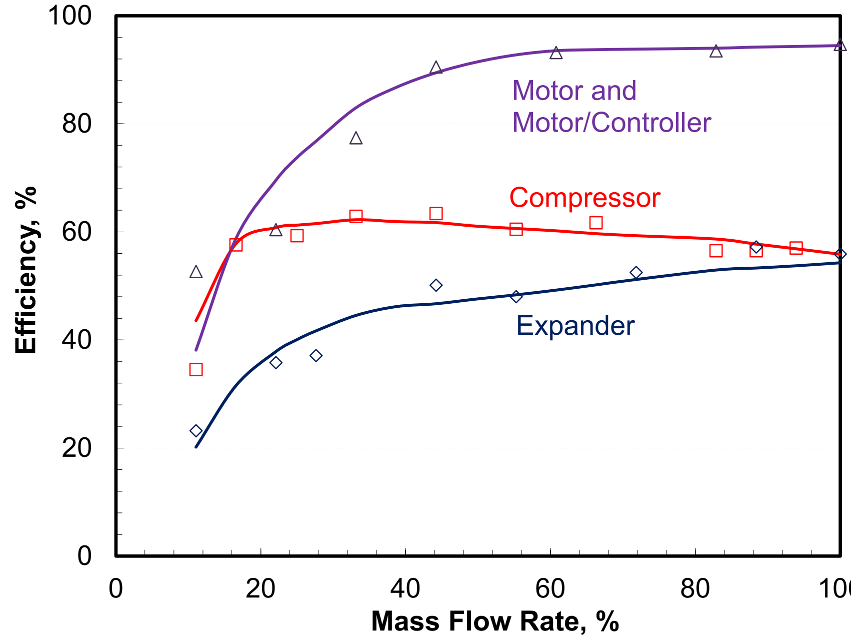
Projected Performance of Roots Air Management System

Validated the integrated two-shaft model using Eaton dyno data with simulated expander map

- Input power (12.7 kW) higher than target at 100% flow
- Input power (1.5 kW) approaching targets at 25% flow
- Input power (210 W) matching targets at idle, albeit at lower pressure

Characteristic	Units	2011 Status	2017 Target	Roots - CEM
Input power at full flow (with / without expander)	kW_e	11.0 / 17.3	8 / 14	12.7 / 16.5
Compressor Discharge Pressure (Flow Rate)	atm (g/s)	2.5 (92)	2.5 (92)	2.5 (92)
Combined motor/motor-controller efficiency at full flow	%	80	90	94.9
Compressor / expander adiabatic efficiency at full flow	%	71 / 73	75 / 80	58.3 / 56.3
Mechanical efficiency at full flow	%			95.8 / 96.3
Compressor / expander isentropic efficiency at full flow	%		67.5 / 80	55.9 / 54.3
Input power at 25% flow (with / without expander)	kW_e	2.3 / 3.3	1.0 / 2.0	1.5 / 2.0
Compressor Discharge Pressure (Flow Rate)	atm (g/s)	1.5 (23)	1.5 (23)	1.45 (23)
Combined motor/motor-controller efficiency at 25% flow	%	57	80	70.2
Compressor / expander adiabatic efficiency at 25% flow	%	62 / 64	65 / 70	64.3 / 40.8
Mechanical efficiency at 25% flow	%			95.3 / 98.2
Compressor / expander isentropic efficiency at 25% flow	%		58.5 / 70	61.2 / 40.1
Turndown ratio (max/min flow rate)		20	20	10
Input power at idle (with / without expander)	W_e	600 / 765	200 / 200	210 / 210
Compressor Discharge Pressure (Flow Rate)	atm (g/s)	1.2 (4.6)	1.2 (4.6)	1.05 (9.1)
Combined motor/motor-controller efficiency at idle	%	35	70	32
Compressor / expander adiabatic efficiency at idle	%	61 / 59	60 / 60	56.4 / 21.9
Mechanical efficiency at idle	%			72.2 / 81.9
Compressor / expander isentropic efficiency at idle	%	61 / 59	54 / 60	40.7 / 17.9

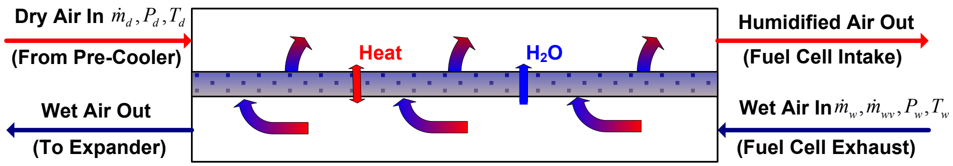




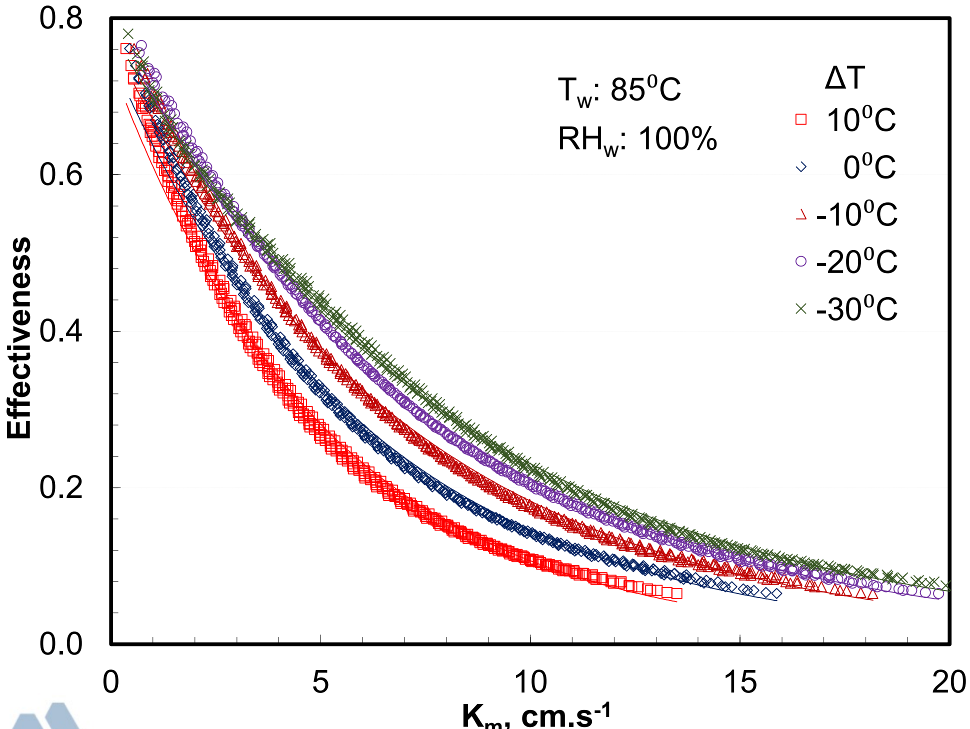
ΔP: Pressure drop between compressor discharge and expander inlet at 100% flow

Humidifier Performance

Publishing a joint paper with Gore, dPoint and Ford on the performance of planar humidifiers with high-flux vapor transport (composite) membranes



Developed mass transfer effectiveness (ε) correlation for SA's cost analysis: Fraction of water vapor in the wet stream ($\dot{m}_{wv}$) that is transferred to the dry stream ($J_m A_m$)



Correlation Variables

Tw: Wet In T

RH_w: RH wet in

ΔT: Wet In T – Dry In T

ρ_{wv}: Wet in vapor density

A_m: Membrane area (calculated)

K_m: Mass transfer coefficient (calculated)

$$\varepsilon = \frac{J_m A_m}{\dot{m}_{wv}}$$

$$K_m = \frac{\dot{m}_{wv}}{A_m \rho_{wv}}$$

$$\epsilon_r(\Delta T, K_m) = \varepsilon_{0r}(\Delta T) e^{-\varphi_{2r}(\Delta T) K_m}$$

$$\epsilon(T_w, \Delta T, K_m) = \varepsilon_r(\Delta T, K_m)\varphi_1(T_w, \Delta T) e^{-\varphi_2(T_w, \Delta T) K_m}$$

Separate correlations for ε_{0r}, φ_{2r}, φ_1, and φ_2

Collaborations

Air Management	Eaton: Roots Air Management System with Integrated Expander (FC103)
Stack	3M: High Performance, Durable, Low Cost Membrane Electrode Assemblies for Transportation (FC104) Ballard/Eaton: Roots Air Management System with Integrated Expander (FC103) JMFC and UTRC: Rationally Designed Catalyst Layers for PEMFC Performance Optimization (FC106)
Water Management	Gore, Ford, dPoint: Materials and Modules for Low-Cost, High-Performance Fuel Cell Humidifiers (FC067)
Thermal Management	Honeywell Thermal Systems
Fuel Management	3M, Ford
Fuel Economy	ANL (Autonomie)
H_2 Impurities	3M, ISO-TC-192 WG
System Cost	SA: Manufacturing Cost Analysis of Fuel Cell Systems and Transportation Fuel Cell System Cost Assessment (FC018)
Dissemination	IEA Annex 22 and 26, Transport Modeling Working Group

- Argonne develops the fuel cell system configuration, determines performance, identifies and sizes components, and provides this information to SA for high-volume manufacturing cost estimation
- Conducting joint life-cycle cost studies with SA

Future Work

1. Support DOE development effort at system, component, and phenomenological levels
2. Support SA in high-volume manufacturing cost projections, collaborate in life-cycle cost studies
   - Optimize system parameters considering costs at low-volume manufacturing
   - Life cycle cost study for fuel cell electric buses (work with Ballard, Eaton, SA)
3. Alternate MEAs with advanced alloy catalysts
   - De-alloyed PtNi on NSTF (3M collaboration)
   - De-alloyed PtNi on high surface-area carbon support (ANL catalyst project with JMFC and UTRC as partners), calibrate/validate model on larger area cells
4. System architecture and balance-of-plant components
   - Air management system with Roots compressors and expanders (Eaton collaboration)
   - Fuel and water management systems: anode gas recirculation trade-off study
   - Bipolar plates and flow fields for low pressure drops and uniform air/fuel distribution, cell to stack performance differentials
5. Incorporate durability considerations in system analysis
   - System optimization for cost, performance, and durability on drive cycles (NSTF and d-PtNi/C catalyst systems)

Project Summary

Relevance:	Independent analysis to assess design-point, part-load and dynamic performance of automotive and stationary FCS
Approach:	Develop and validate versatile system design and analysis tools Apply models to issues of current interest Collaborate with other organizations to obtain data and apply models
Progress:	Established the uncertainties in system performance due to variability in supporting NSTF cell polarization data: 2-5 $/kW$_e$ FCS cost, 0.02-0.05 g-Pt/kW$_e$ Pt content, and 10-15% in power density. Demonstrated that an alternate Gen-1 catalyst with conventional high surface area carbon support (d-PtNi/C) has promising performance: 54 $/kW$_e$ FCS cost and 0.21 g-Pt/kW$_e$ Pt content. Identified the dominant NSTFC degradation mechanism and determined the operating conditions for 20% projected voltage loss at rated power density over 5000 h. Determined the parasitic power requirements of the Roots air supply system: 12.7 kW$_e$ at 100% flow (9 kW$_e$ target) and 210 W$_e$ at idle (200 W$_e$ target)
Collaborations:	3M, dPoint, Eaton, Ford, Gore, JMFC, SA, UTRC, ANL (Autonomie)
Future Work:	Fuel cell systems with emerging de-alloyed catalysts Alternate balance-of-plant components System analysis with durability considerations on drive cycles

Technical Back-Up Slides

Publications and Presentations

Journal Publications

R. K. Ahluwalia, X. Wang, W. B. Johnson, F. Berg, and D. Kadylak, "Performance of a Cross-Flow Humidifier with a High Flux Water Vapor Transport Membrane," accepted for publication in Journal of Power Sources, 2015.

D. D. Papadias, R. K. Ahluwalia, J. K. Thomson, H. M. Meyer III, M. P. Brady, H. Wang, R. Mukundan, and R. Borup, "Degradation of SS316L Bipolar Plates in Fuel Cell Environment: Corrosion Rate, Barrier Film Formation Kinetics and Contact Resistance," Journal of Power Sources, Vol. 273, pp. 1237-1249, 2015.

T. Q. Hua, R. K. Ahluwalia, L. Eudy, G. Singer, B. Jermer, N. Asselin-Miller, S. Wessel, T. Patterson, and J. Marcinkoski, "Status of Hydrogen Fuel Cell Electric Buses Worldwide," Journal of Power Sources, Vol. 269, pp. 975-993, 2014.

Conference Presentations

D. Myers, N. Kariuki, J. Hammons, R. Ahluwalia, X. Wang, J-K Peng, and D. Fongalland, "Dealloyed Pt-Ni Polymer Electrolyte Fuel Cell Cathodes: Effects of Catalyst-Ionomer Ink Composition on Structure and Performance," 227th ECS Meeting, Chicago, IL, May 24-28, 2015.

X. Wang, J-K Peng, R. Ahluwalia, D. Myers, and Z. Yang, "Mass Transfer Overpotentials in Dispersed Pt/C and De-Alloyed PtNi/C Polymer Electrolyte Fuel Cell Cathodes," 227th ECS Meeting, Chicago, IL, May 24-28, 2015.

R. K. Ahluwalia, X. Wang, T. Q. Hua, and D. Myers, "Fuel Cell Systems for Transportation: Recent Developments in U.S.A.," IEA Annex 26 Meeting, Meeting, CEA, Grenoble, France, Dec. 3, 2014.

R. K. Ahluwalia, and N. Garland, "Report from the Annexes: Annex 26.," IEA AFC ExCo 49th Meeting, CEA, Grenoble, France, Dec. 4-5, 2014.

R. K. Ahluwalia and Wang, X., "Fuel Cells Systems Analysis," US Drive Fuel Cell Tech Team Meeting, Southfield, MI, July 16, 2014.

Meetings Organized

R. K. Ahluwalia, "IEA Advanced Fuel Cells Annex 26: Fuel Cells for Transportation," CEA, Grenoble, France, Dec. 3, 2014.

Reviewers' Comments

Generally favorable reviews with recommendations to

- Include supplemental slides describing model inputs and calibration process
- More emphasis on end-of-life (EOL) parameters and EOL trade-offs
- Incorporate degradation and durability considerations in system analysis
- Assess the effect of variability and noise in input data for various components
- Place less priority on high-volume cost, more on market introduction volumes
- Expand work on alternate catalysts and conventional supports
- Prioritize work on choice of advanced catalysts

Work scope consistent with above recommendations

√ Included more supplemental slides on model input parameters and calibration

√ Collaborated with 3M to identify the dominant degradation mechanism, conduct long-duration tests, and develop durability model

√ Presented initial results on projected performance degradation on drive cycles

√ Presented results on the effect of variability in the input data on system performance (BOC vs. REP)

√ Working with Eaton and Ballard on the state-of-the-art fuel cell systems for electric buses

√ Prioritized work on advanced catalysts, emphasizing de-alloyed PtNi/C catalyst, and presented initial results on FCS performance with this catalyst

√ On-going discussions with SA and DOE to consider costs at lower volumes

Critical Assumptions and Issues

PEFC Stack

- 1.5-3 atm at rated power
- 40-67% O_2 utilization (SR_c: 1.5-2.5)
- 50% H_2 consumption per pass
- Cell voltage at rated power: TBD
- 24-µm 3M membrane at TBD temperature
- 3M ternary alloy: 0.05/0.1 mg-Pt/cm^2 on anode/cathode
- GDL: 235-µm non-woven carbon fiber with MPL
- 1.1-mm metal bipolar plates, each with cooling channels
- 17 cells/inch

Fuel Management System

- Hybrid ejector-recirculation pump
- 35% pump efficiency
- 3 psi pressure drop at rated power

Air Management System

- Compressor-expander module
- Liquid-cooled motor
- Efficiencies at rated power: 71% compressor, 73% expander, 89.5% motor, 89.5% controller
- Turn-down: 20
- 5 psi pressure drop at rated power

Heat Rejection System

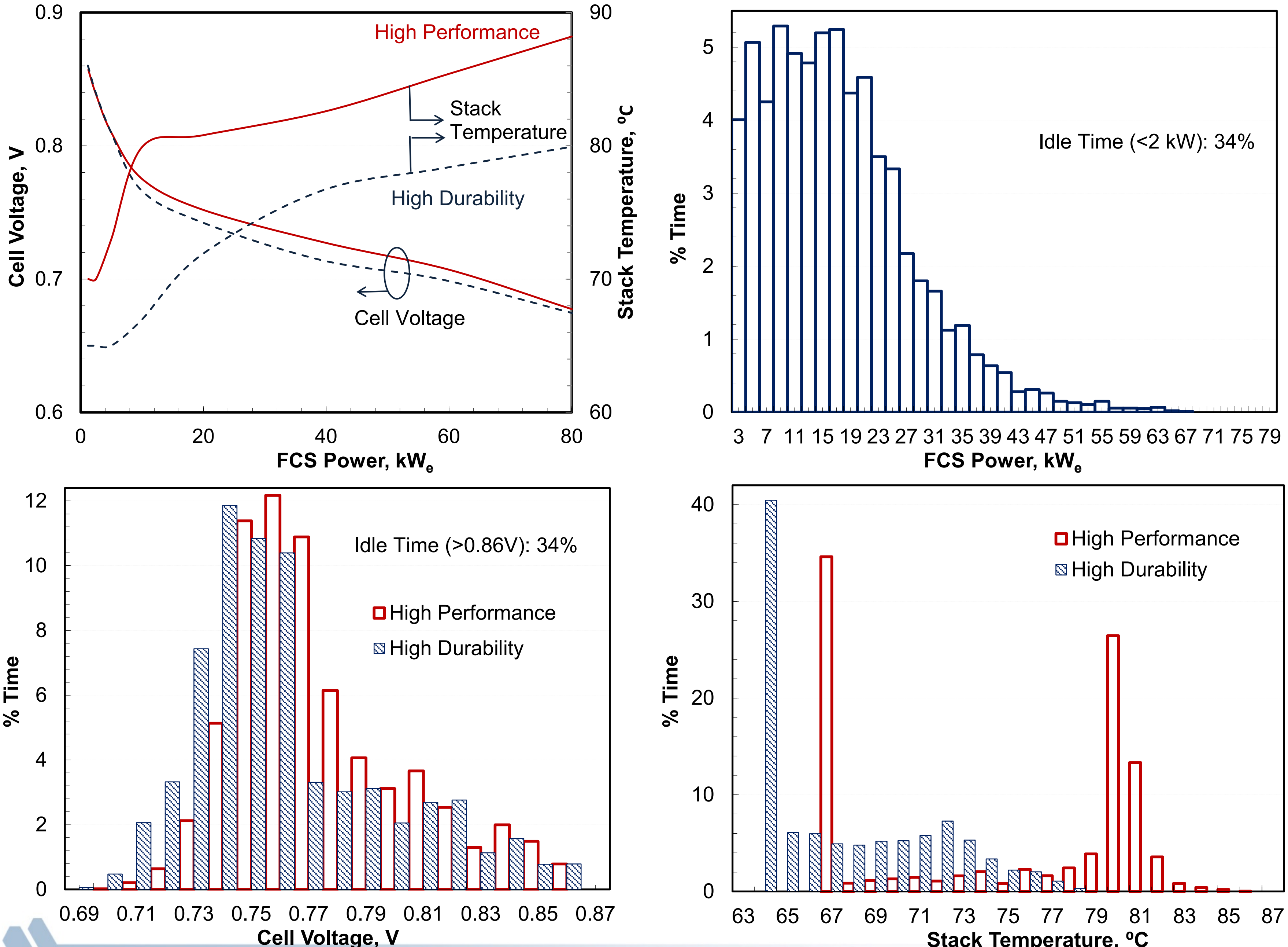
- Two circuits: 75-95°C HT, 10°C ΔT
  65°C LT coolant, 5°C ΔT
- 55% pump + 92% motor efficiency
- 45% blower + 92% motor efficiency
- 10 psi pressure drop in stack and 5 psi in radiator

Water Management System

- Membrane humidifier, TBD dew-point temperature at rated power

Stack T permitted to rise to 95°C for short durations under some driving conditions

Polarization Curves: Trade-Off Study



FCS power demand of a modeled SUV on FUDS and FHDS

Test Plan

Degradation Conditions

- $90^{o}C$ cell, 100/100% RH, 100/100 kPag H_2/Air
- Potentiostatic hold at 0.9, 0.6, or 0.3 V
- Constant flow based on CS 2/2 @ J estimated at BOL hold potential

Cyclic Tests

- Repeatedly degrade for 10 h with periodic F- collection and partial recondition cycles (1 TC)
- Every 20 h, measure H_2/Air pol curve
- Every 40-80 h of degradation, recondition more fully (3 TC cycles), and measure cathode ORR activity, cathode ECSA, H_2 crossover, shorting resistance, and H_2/Air pol curve.

MEA

- Anode: 0.05PtCoMn/NSTF
- Cathode: 0.15PtCoMn/NSTF
- PEM: 3M 825EW 20 µm, unsupported, w/ additive
- GDLs: 3M 2979/2979, 10% strain
- 50 cm² test cell; quad serpentine FF