Fuel Cells Systems Analysis

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2015 DOE Hydrogen and Fuel Cells Program Review

Washington, D.C.
June 8-12, 2015

Project ID: FC017

This presentation does not contain any proprietary, confidential, or otherwise restricted information.
Overview

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

Barriers
B. Cost
C. Performance
E. System Thermal and Water Management
F. Air Management
J. Startup and Shut-down Time, Energy/Transient Operation

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

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

<table>
<thead>
<tr>
<th></th>
<th>Task Description</th>
<th>Date</th>
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<tbody>
<tr>
<td>1</td>
<td>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.</td>
<td>12/14</td>
</tr>
<tr>
<td>2</td>
<td>Evaluate the performance of an MEA with an advanced cathode catalyst relative to the targets of 0.44 A/mg-PGM mass activity. 720 μA/cm²-PGM specific activity, 1000 mW/cm² at rated power, and 300 mA/cm² at 800 mV.</td>
<td>03/15</td>
</tr>
<tr>
<td>3</td>
<td>Modify the system analysis methodology to incorporate durability considerations relative to the target of 5000 h operating life.</td>
<td>06/15</td>
</tr>
<tr>
<td>4</td>
<td>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/ΔT of 1.45 kW/K, and $40/kW cost.</td>
<td>09/15</td>
</tr>
</tbody>
</table>
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 $Q/\Delta T$ constraint (ongoing)

$\Delta T$: Stack coolant exit $T$ – Ambient $T$
Study to investigate the effect of stack heat load estimate on the cost and performance of the reference system with NSTF catalyst based MEAs: \(Q/\Delta T = 1.45\ kW/^\circ\C\), \(T_{\text{amb}} = 40^\circ\C\), \(T_c = 87-94^\circ\C\) (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*
Cell degradation and cell-to-cell performance variability

- Same reference condition (2.5 atm, 85°C, 100% exit RH, SR_c=SR_a=2) visited in four series of tests performed on Cells 23102 (0.1 mg-Pt(c)/cm²) and 23272 (0.15 mg-Pt(c)/cm²)
- 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

<table>
<thead>
<tr>
<th></th>
<th>2.5 atm, 94°C</th>
<th>1.5 atm, 87°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>REP</td>
<td>BOC</td>
</tr>
<tr>
<td>Cell Voltage</td>
<td>mV</td>
<td>662</td>
</tr>
<tr>
<td>Current Density</td>
<td>A/cm²</td>
<td>1.02</td>
</tr>
<tr>
<td>Power Density</td>
<td>mW/cm²</td>
<td>674</td>
</tr>
<tr>
<td>Pt Cost</td>
<td>$/kWe</td>
<td>12.1</td>
</tr>
<tr>
<td>Stack Cost</td>
<td>$/kWe</td>
<td>28.15</td>
</tr>
</tbody>
</table>

*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 H₂-air and H₂-N₂
- ORR kinetics from H₂-O₂ polarization data
- Limiting current density (i_L) and mass transfer overpotentials (η_m) from H₂-air polarization data at high stoichiometries
- Test variables: 1-2.5 atm, 45-90°C, 1-21% O₂, 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/cm²)

- Compared to Pt/C (2 nm)*, d-PtNi/C (5.1-5.8 nm)* has 66% higher specific activity (914 vs. 552 µA/cm²-Pt) but only 17% higher mass activity (0.530 vs. 0.453 A/mg-Pt) because of lower ECSA (58 vs. 82 m²/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 Ni²⁺ 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 Ni²⁺ 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-Pt/kW_e) advantages, especially at lower pressures and temperatures. High surface area Pt/C (~2 nm), however, is unstable under cyclic potentials.

<table>
<thead>
<tr>
<th>Cell</th>
<th>P atm</th>
<th>T °C</th>
<th>Cell Voltage mV</th>
<th>Power Density mW/cm²</th>
<th>Stack Pt Content g_Pt/kW_e</th>
<th>Pt Cost $/kW_e</th>
<th>Stack Cost $/kW_e</th>
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<tbody>
<tr>
<td>d-PtNi/C</td>
<td>2.5</td>
<td>95</td>
<td>661</td>
<td>746</td>
<td>0.190</td>
<td>10.2</td>
<td>25.1</td>
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<tr>
<td></td>
<td>2.0</td>
<td>93</td>
<td>666</td>
<td>650</td>
<td>0.218</td>
<td>11.4</td>
<td>27.5</td>
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<td></td>
<td>1.5</td>
<td>89</td>
<td>684</td>
<td>507</td>
<td>0.280</td>
<td>14.4</td>
<td>33.4</td>
</tr>
<tr>
<td>Pt/C</td>
<td>2.5</td>
<td>95</td>
<td>662</td>
<td>737</td>
<td>0.193</td>
<td>10.3</td>
<td>25.3</td>
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<td></td>
<td>2.0</td>
<td>95</td>
<td>655</td>
<td>655</td>
<td>0.217</td>
<td>11.3</td>
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<td></td>
<td>1.5</td>
<td>91</td>
<td>672</td>
<td>495</td>
<td>0.287</td>
<td>14.7</td>
<td>34.1</td>
</tr>
</tbody>
</table>

BOL: Beginning of life
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.

<table>
<thead>
<tr>
<th>P (atm)</th>
<th>T (°C)</th>
<th>SR&lt;sub&gt;c&lt;/sub&gt;</th>
<th>Inlet RH (%)</th>
<th>Outlet RH (%)</th>
<th>Cell Voltage (mV)</th>
<th>Power Density (mW/cm&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>FCS Efficiency (%)</th>
<th>Air System ($/kW&lt;sub&gt;e&lt;/sub&gt;)</th>
<th>Fuel System ($/kW&lt;sub&gt;e&lt;/sub&gt;)</th>
<th>Thermal System ($/kW&lt;sub&gt;e&lt;/sub&gt;)</th>
<th>Water System ($/kW&lt;sub&gt;e&lt;/sub&gt;)</th>
<th>Stack ($/kW&lt;sub&gt;e&lt;/sub&gt;)</th>
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<tbody>
<tr>
<td>2.5</td>
<td>95</td>
<td>1.5</td>
<td>82</td>
<td>103</td>
<td>661</td>
<td>746</td>
<td>47.5</td>
<td>11.6</td>
<td>3.6</td>
<td>5.2</td>
<td>1.1</td>
<td>25.1</td>
</tr>
<tr>
<td>2.0</td>
<td>93</td>
<td>1.5</td>
<td>89</td>
<td>93</td>
<td>666</td>
<td>650</td>
<td>48.8</td>
<td>10.4</td>
<td>3.6</td>
<td>4.9</td>
<td>1.5</td>
<td>27.5</td>
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<td>1.5</td>
<td>89</td>
<td>1.5</td>
<td>88</td>
<td>82</td>
<td>684</td>
<td>507</td>
<td>51.1</td>
<td>9.3</td>
<td>3.6</td>
<td>4.5</td>
<td>2.2</td>
<td>33.4</td>
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</tbody>
</table>

L<sub>Pt</sub>: 0.05(a)/0.092(c) mg.cm<sup>-2</sup>
ΔT<sub>c</sub>: 10°C
SR<sub>c</sub>: 1.5
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 H₂O₂ 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 O₂ 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 ($i_0$, $\mu$A.cm$^{-2}$-Pt) correlated with the cumulative fluoride release at cathode (CFR).
- Up to 65 mV increase in kinetic overpotential ($\eta_c$) during the tests.
Mass transfer overpotential ($\eta_m$) 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
- $\eta_m$ is an implicit function of hold potential through CFR and $i_L$
- $\eta_m$ 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 ($\eta_m$) equals 200 mV.
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
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%
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

\[ SR(c) = 2 \]
\[ \Delta P = 5 \text{ psi} \]
Ambient T = 40°C

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units</th>
<th>2011 Status</th>
<th>2017 Target</th>
<th>Roots - CEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input power at full flow (with / without expander)</td>
<td>kW_e</td>
<td>11.0 / 17.3</td>
<td>8 / 14</td>
<td>12.7 / 16.5</td>
</tr>
<tr>
<td>Compressor Discharge Pressure (Flow Rate)</td>
<td>atm (g/s)</td>
<td>2.5 (92)</td>
<td>2.5 (92)</td>
<td>2.5 (92)</td>
</tr>
<tr>
<td>Combined motor/motor-controller efficiency at full flow</td>
<td>%</td>
<td>80</td>
<td>90</td>
<td>94.9</td>
</tr>
<tr>
<td>Compressor / expander adiabatic efficiency at full flow</td>
<td>%</td>
<td>71 / 73</td>
<td>75 / 80</td>
<td>58.3 / 56.3</td>
</tr>
<tr>
<td>Mechanical efficiency at full flow</td>
<td>%</td>
<td>95.8 / 96.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressor / expander isentropic efficiency at full flow</td>
<td>%</td>
<td>67.5 / 80</td>
<td>55.9 / 54.3</td>
<td></td>
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<tr>
<td>Input power at 25% flow (with / without expander)</td>
<td>kW_e</td>
<td>2.3 / 3.3</td>
<td>1.0 / 2.0</td>
<td>1.5 / 2.0</td>
</tr>
<tr>
<td>Compressor Discharge Pressure (Flow Rate)</td>
<td>atm (g/s)</td>
<td>1.5 (23)</td>
<td>1.5 (23)</td>
<td>1.45 (23)</td>
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<tr>
<td>Combined motor/motor-controller efficiency at 25% flow</td>
<td>%</td>
<td>57</td>
<td>80</td>
<td>70.2</td>
</tr>
<tr>
<td>Compressor / expander adiabatic efficiency at 25% flow</td>
<td>%</td>
<td>62 / 64</td>
<td>65 / 70</td>
<td>64.3 / 40.8</td>
</tr>
<tr>
<td>Mechanical efficiency at 25% flow</td>
<td>%</td>
<td>95.3 / 98.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressor / expander isentropic efficiency at 25% flow</td>
<td>%</td>
<td>58.5 / 70</td>
<td>61.2 / 40.1</td>
<td></td>
</tr>
<tr>
<td>Turndown ratio (max/min flow rate)</td>
<td></td>
<td>20</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Input power at idle (with / without expander)</td>
<td>W_e</td>
<td>600 / 765</td>
<td>200 / 200</td>
<td>210 / 210</td>
</tr>
<tr>
<td>Compressor Discharge Pressure (Flow Rate)</td>
<td>atm (g/s)</td>
<td>1.2 (4.6)</td>
<td>1.2 (4.6)</td>
<td>1.05 (9.1)</td>
</tr>
<tr>
<td>Combined motor/motor-controller efficiency at idle</td>
<td>%</td>
<td>55</td>
<td>70</td>
<td>32</td>
</tr>
<tr>
<td>Compressor / expander adiabatic efficiency at idle</td>
<td>%</td>
<td>61 / 59</td>
<td>60 / 60</td>
<td>56.4 / 21.9</td>
</tr>
<tr>
<td>Mechanical efficiency at idle</td>
<td>%</td>
<td>72.2 / 81.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressor / expander isentropic efficiency at idle</td>
<td>%</td>
<td>61 / 59</td>
<td>54 / 60</td>
<td>40.7 / 17.9</td>
</tr>
</tbody>
</table>

\[ \Delta P: \text{Pressure drop between compressor discharge and expander inlet at 100\% flow} \]
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 ($\varepsilon$) correlation for SA’s cost analysis: Fraction of water vapor in the wet stream ($\dot{m}_{wv}$) that is transferred to the dry stream ($J_mA_m$)

Correlation Variables
- $T_w$: Wet In T
- $\Delta T$: Wet In T – Dry In T
- $\rho_{wv}$: Wet in vapor density
- $A_m$: Membrane area (calculated)
- $K_m$: Mass transfer coefficient (calculated)

Separate correlations for $\varepsilon_0r$, $\varphi_2r$, $\varphi_1$, and $\varphi_2$
### Collaborations

<table>
<thead>
<tr>
<th>Category</th>
<th>Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Management</td>
<td>Eaton: Roots Air Management System with Integrated Expander (FC103)</td>
</tr>
</tbody>
</table>
| 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                                                            |
| 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

<table>
<thead>
<tr>
<th>Relevance:</th>
<th>Independent analysis to assess design-point, part-load and dynamic performance of automotive and stationary FCS</th>
</tr>
</thead>
</table>
| 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
Journal Publications


Conference Presentations


Meetings Organized

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% O₂ utilization (SRc: 1.5-2.5)
- 50% H₂ 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/cm² 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 temperature permitted to rise to 95°C for short durations under some driving conditions.
FCS power demand of a modeled SUV on FUDS and FHDS
Test Plan

Degradation Conditions
- 90°C cell, 100/100% RH, 100/100 kPag H₂/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 H₂/Air pol curve
- Every 40-80 h of degradation, recondition more fully (3 TC cycles), and measure cathode ORR activity, cathode ECSA, H₂ crossover, shorting resistance, and H₂/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

<table>
<thead>
<tr>
<th>Pre ORR: 3 Recondition Cycles</th>
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<tbody>
<tr>
<td>Measure ORR Activity</td>
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<tr>
<td>Measure shorting and crossover</td>
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<tr>
<td>Measure ECSA</td>
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<tr>
<td>Time Buffer</td>
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| 1 Recondition Cycle          |
| H₂/Air Pol Curve             |
| Degrade (10 h)               |
| 1 Recondition Cycle(s)       |

| Degradate (10 h) and F- Collection |
| 1 Recondition Cycle(s) |

Repeat for 300-400 h
Repeat 2-3 x