DOE Catalysis Working Group Meeting

Arlington, Virginia

Crystal Gateway Marriott Hotel – Monday, June 8, 2015

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Crystal Gateway Marriott Hotel, 1700 Jefferson Davis Highway, Arlington, Virginia

Grand Ballroom Salon A

8:30 - 9:00	*Continental breakfast*
9:00 - 9:05	Welcome - Nancy Garland (DOE) and Piotr Zelenay (LANL),
9:05 - 9:20	*Non-PGM Catalyst Targets: Summary* – Piotr Zelenay (LANL)
9:20 - 9:45	*Designing for High Current Density for Low-PGM Electrode* – Anu Kongkanand (General Motors)
9:45 - 10:10	*Alternative Metal Oxide Supports for Cathode Catalyst Powders in Automotive PEM Fuel Cells* – Jim Waldecker (Ford)
10:00 - 10:35	*Microscopy Studies of Novel Catalyst Structures* – Karren More (ORNL)

Introduction of FCTO-funded Fuel Cell Technologies Incubator and SBIR-STTR Projects

10:35 - 10:50	*Advanced Catalysts and MEAs for Reversible Alkaline Membrane Fuel Cells* – Hui Xu (Giner)
10:50 - 11:05	*Development of Non-PGM Catalysts for Hydrogen Oxidation Reaction in Alkaline Media* – Alexey Serov (University of New Mexico)
11:05 - 11:20	*Innovative Non-PGM Catalysts for CHP Relevant Proton Exchange Membrane Fuel Cells* – Sanjeev Mukerjee (Northeastern University)
11:20 - 11:35	*Proton Energy Systems: Non-Platinum Group Metal OER/ORR Catalysts for Alkaline Membrane Fuel Cells and Electrolyzers* – Nemanja Danilovic (Proton OnSite)
11:35 - 11:50	*Non-Precious Metal Bi-Functional Catalysts* – Paul Matter (PH Matter)
11:50 - 12:00	Wrap-up, action items, discussion of the date, location and topic of the next CWG meeting - Piotr Zelenay (LANL) and Nancy Garland (DOE)
12:00	Adjourn

Non-PGM Catalyst Performance Targets – Summary

Discussion of Non-PGM ORR Catalyst Targets

- **Non-PGM ORR catalyst targets and test protocols discussed extensively at four CWG meetings:**
  - Arlington, VA on May 15th , 2013 (open CWG meeting at AMR)
  - Golden, CO on December 18th , 2013 (joint CWG-DWG meeting; contractors only)
  - Washington, D.C. on June 16th, 2014 (CWG meeting at AMR)
  - Los Alamos, January 21st, 2015 (CWG meeting; contractors only)
- **Comments received from Fuel Cell Tech Team throughout the process**
- **A four-member subcommittee appointed at the Los Alamos meeting to complete targets**
- **Non-PGM targets summarized and provided to FCTO on April 8th, 2015**
- **In general, targets and test protocols aligned with those established for PGM catalysts and PGM-based MEAs**

Non-PGM ORR Electrocatalyst Targets

Characteristic	Unit	2020 Target	Ultimate Target
Voltage at 0.044 A/cm^2 [a]	V	0.87	0.90
Current density loss at target voltage after 30,000 cycles [a, b, c]	%	≤ 40	≤ 40
Loss in high-current-density performance [c, d]	mV	≤ 60 (at 0.8 A/cm^2)	≤ 30 (at 0.8 A/cm^2)
Loss in high-current-density performance [d, e]	mV	≤ 60 (at 0.8 A/cm^2)	≤ 30 (at 1.5 A/cm^2)

[a] Test at 80°C H_2/O_2 in MEA; fully humidified with total outlet pressure of 150 kPa (abs); anode stoichiometry 2; cathode stoichiometry 9.5 (Gasteiger *et al.*, *Applied Catalysis B: Environmental*, **56**, 2005, 9-35.)

[b] Target voltage defined as voltage at which 0.044 mA/cm^2 is measured at the beginning of cycling.

[c] For durability cycling conditions, see U.S. DRIVE Fuel Cell Technical Team Roadmap, June 2013; Appendix A, Table A-1 (Electrocatalyst Cycle and Metrics). http://energy.gov/sites/prod/files/2014/02/f8/fctt_roadmap_june2013.pdf

[d] For polarization protocol, see U.S. DRIVE Fuel Cell Technical Team Roadmap, June 2013; Appendix A, Table A-5. http://energy.gov/sites/prod/files/2014/02/f8/fctt_roadmap_june2013.pdf

[e] For durability cycling conditions, see U.S. DRIVE Fuel Cell Technical Team Roadmap, June 2013; Appendix A, Table A-2 (Catalyst Support Cycle and Metrics). http://energy.gov/sites/prod/files/2014/02/f8/fctt_roadmap_june2013.pdf

FCTT Roadmap: Electrocatalyst Testing (Table A-1)

Table A-1. Electrocatalyst Cycle and Metrics
Table Revised March 2, 2010

Cycle	Triangle sweep cycle: 50 mV/s between 0.6 V and 1.0 V. Single cell 25-50 cm^2	
Number	30,000 cycles	
Cycle time	16 seconds	
Temperature	80°C	
Relative humidity	Anode/cathode 100/100%	
Fuel/oxidant	Hydrogen/N_2 (H_2 at 200 sccm and N_2 at 75 sccm for a 50 cm^2 cell)	
Pressure	Atmospheric pressure	
Metric	**Frequency**	**Target**
Catalytic mass activity*	At beginning and end of test minimum	≤40% loss of initial catalytic activity
Polarization curve from 0 to ≥1.5 A/cm^2**	After 0, 1k, 5k, 10k, and 30k cycles	≤30 mV loss at 0.8 A/cm^2
ECSA/cyclic voltammetry***	After 10, 100, 1k, 3k, 10k, 20k, and 30k cycles	≤40% loss of initial area

* Mass activity in A/mg @ 150 kPa abs, backpressure at 857 mV iR-corrected on 6% H_2 (bal N_2)/O_2 (or equivalent thermodynamic potential), 100% RH, 80°C normalized to initial mass of catalyst and measured before and after test.

** Polarization curve per Fuel Cell Tech Team Polarization Protocol in Table A-5.

*** Sweep from 0.05 to 0.60 V at 20 mV/s, 80°C, and 100% RH.

FCTT Roadmap: Support Testing (Table A-2)

Table A-2. Catalyst Support Cycle and Metrics
Table Revised January 14, 2013

Cycle	Triangle sweep cycle: 500 mV/s between 1.0 V and 1.5 V; run polarization curve and ECSA; repeat for total 400 h. Single cell 25-50 cm^2	
Number	5,000 cycles	
Cycle time	2 seconds	
Temperature	80°C	
Relative humidity	Anode/cathode 100/100%	
Fuel/oxidant	Hydrogen/nitrogen	
Pressure	Atmospheric	
Metric	**Frequency**	**Target**
Catalytic activity*	At beginning and end of test, minimum	$\leq$40% loss of initial catalytic activity
Polarization curve from 0 to $\geq$1.5 A/cm^2**	After 0, 10, 100, 200, 500, 1k, 2k, and 5k cycles	$\leq$30 mV loss at 1.5 A/cm^2 or rated power
ECSA/cyclic voltammetry***	After 0, 10, 100, 200, 500, 1k, 2k, and 5k cycles	$\leq$40% loss of initial area

* Mass activity in A/mg @ 150 kPa abs, backpressure at 857 mV iR-corrected on 6% H_2 (bal N_2)/O_2 (or equivalent thermodynamic potential), 100% RH, 80°C normalized to initial mass of catalyst and measured before and after test.

** Polarization curve per Fuel Cell Tech Team Polarization Protocol in Table A-5.

*** Sweep from 0.05 to 0.6 V at 20 mV/s, 80°C, and 100% RH.

FCTT Roadmap: Polarization Plot Protocol (Table A-5)

Table A-5. Fuel Cell Tech Team Polarization Protocol

Test Point #	Current Density [A/cm^2]	Anode Inlet H_2% (balance N_2) inlet/dry	Anode H_2 Stoich [-]	Anode Dewpoint Temp [°C]	Anode Inlet Temp [°C]	Anode Pressure Outlet [kPaabs]	Cathode Inlet O_2% inlet/dry	Cathode Inlet N_2% inlet/dry	Cathode O_2 Stoich [-]	Cathode Dewpoint Temp [°C]	Cathode Inlet Temp [°C]	Cathode Pressure Outlet [kPaabs]	Cell/ Stack Control Temp [°C]	Temp pt. Run Time min	Set Point Transit Time s
Break-in															
B1	0.6	100%	1.5	59	80	150	21%	79%	1.8	56	80	150	80	20	0
Reduction															
R1	0	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	1	0
R2	0	100%	1.5	59	80	150	0%	100%	1.8	59	80	150	80	Until V>0.1V	0
Polarization curve															
P1	0.2	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P2	0.4	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P3	0.6	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P4	0.8	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P5	1	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P6	1.2	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P7	1.4	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P7	1.6	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P8	1.8	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P9	2	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P10	1.8	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P11	1.6	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P12	1.4	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P13	1.2	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P14	1	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P15	0.8	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P16	0.6	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P17	0.4	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P18	0.2	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P19	0.1	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P20	0.05	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P21	0.02	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P22	0.05	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P23	0.1	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0
P24	0.2	100%	1.5	59	80	150	21%	79%	1.8	59	80	150	80	3	0

Stoichs for points below 0.2A/cm^2 at 0.2A/cm^2 equivalent flow

Non-PGM MEA/Stack Targets

Characteristic	Unit	2020 Target	Ultimate Target
Voltage at high power [f]	V	0.66 (at 0.75 A/cm^2)	0.66 (at 1.5 A/cm^2)
Cost (guideline)	$/kW$_e$	14	10
Durability [g, h]	hours	5,000	5,000

[f] For polarization protocol, see U.S. DRIVE Fuel Cell Technical Team Roadmap, June 2013; Appendix A, Table A-5. http://energy.gov/sites/prod/files/2014/02/f8/fctt_roadmap_june2013.pdf. Ultimate target for high power is calculated to achieve Q/ΔTi of 1.45 assuming 90 kW stack gross power operating at 95°C stack temperature and 40°C ambient temperature.

[g] Based on the protocol for determining cell/stack durability in U.S. DRIVE Fuel Cell Technical Team Roadmap, June 2013; Appendix A, Table A-6 (≤ 10% drop in rated power after test). http://energy.gov/sites/prod/files/2014/02/f8/fctt_roadmap_june2013.pdf

[h] Need to meet or exceed at temperatures of 80°C up to peak temperature, measured using the polarization curve protocol found in Table A-5 of Appendix A.

FCTT Roadmap: Cell/Stack Durability Protocol (Table A-6)

Table A-6. Protocol for Determining Cell/Stack Durability

Test Point #	Current Density [A/cm^2]	Anode Inlet H_2% (balance N_2) inlet/dry	Anode H_2 Stoich [-]	Anode Dew point Temp [°C]	Anode Inlet Temp [°C]	Anode Pressure outlet [kPaabs]	Cathode Inlet O_2% inlet/dry	Cathode Inlet N_2% inlet/dry	Cathode O_2 Stoich [-]	Cathode Dew point Temp [°C]	Cathode Inlet Temp [°C]	Cathode Pressure Outlet [kPaabs]	Cell/ Stack control Temp [°C]	Test pt. Run Time min	Set Point Transition time s	Worst-Case Response Transition Time s
Wet w/load cycling																
RH1	0.02	80%	96	83	85	101.3	21%	79%	108	83	85	101.3	80	0.5	0	2
RH2	1.2	80%	1.6	83	85	101.3	21%	79%	1.8	83	85	101.3	80	0.5	0	2
RH3	0.02	80%	96	83	85	101.3	21%	79%	108	83	85	101.3	80	0.5	0	2
RH4	1.2	80%	1.6	83	85	101.3	21%	79%	1.8	83	85	101.3	80	0.5	0	2
RH5	0.02	80%	96	83	85	101.3	21%	79%	108	83	85	101.3	80	0.5	0	2
RH6	1.2	80%	1.6	83	85	101.3	21%	79%	1.8	83	85	101.3	80	0.5	0	2
RH7	0.02	80%	96	83	85	101.3	21%	79%	108	83	85	101.3	80	0.5	0	2
RH8	1.2	80%	1.6	83	85	101.3	21%	79%	1.8	83	85	101.3	80	0.5	0	2
RH9	0.02	80%	96	83	85	101.3	21%	79%	108	83	85	101.3	80	0.5	0	2
RH10	1.2	80%	1.6	83	85	101.3	21%	79%	1.8	83	85	101.3	80	0.5	0	2
Trans1	0.6	80%	2	70	80	101.3	21%	79%	2	70	80	101.3	80	2	0	30 (dew point)
Dry w/load cycling																
RH11	0.1	80%	5	53	80	101.3	21%	79%	5	53	80	101.3	80	0.5	0	30 (dew point)
RH12	0.02	80%	25	53	80	101.3	21%	79%	25	53	80	101.3	80	0.5	0	2
RH13	0.1	80%	5	53	80	101.3	21%	79%	5	53	80	101.3	80	0.5	0	2
RH14	0.02	80%	25	53	80	101.3	21%	79%	25	53	80	101.3	80	0.5	0	2
RH15	0.1	80%	5	53	80	101.3	21%	79%	5	53	80	101.3	80	0.5	0	2
RH16	0.02	80%	25	53	80	101.3	21%	79%	25	53	80	101.3	80	0.5	0	2
RH17	0.1	80%	5	53	80	101.3	21%	79%	5	53	80	101.3	80	0.5	0	2
RH18	0.02	80%	25	53	80	101.3	21%	79%	25	53	80	101.3	80	0.5	0	2
RH19	0.1	80%	5	53	80	101.3	21%	79%	5	53	80	101.3	80	0.5	0	2
RH20	0.02	80%	25	53	80	101.3	21%	79%	25	53	80	101.3	80	5	0	2

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