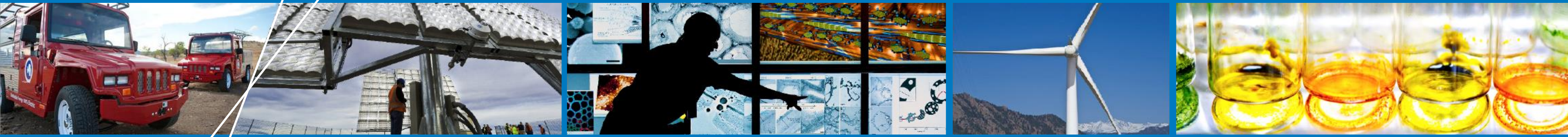
Establishing baselines/protocols/targets relevant for PEM electrolysis



Bryan Pivovar

National Renewable Energy Laboratory

Advanced Water Splitting Workshop

Stanford

April 12, 2016

PEM FC Protocols

- **Learn/Follow examples of PEM FC**
  - FC Protocols/Targets established/continuously updated for components, MEAs and cells
  - Different protocols for different organizations US DOE, US DRIVE, FCCJ, JARI tend to have similarities.
  - Pt stability, carbon corrosion, membrane stability/durability, MEA performance and durability.
  - Which of these areas have unique concerns for electrolysis vs. PEM.

APPENDIX E – TESTING PROTOCOLS

Table E1 Electrocatalyst Cycle and Metrics

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 s	
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[a]	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 [b]	After 0, 1k, 5k, 10k, and 30k cycles	$\leq$30 mV loss at 0.8 A/cm^2
ECSA/Cyclic Voltammetry[c]	After 10, 100, 1k, 3k, 10k, 20k and 30k cycles	$\leq$40% loss of initial area

a. Mass activity in A/mg @ 150 kPa abs backpressure at 857 mV iR-corrected on 6% H_2 (balance N_2)/O_2 {or equivalent thermodynamic potential}, 100% RH, 80°C normalized to initial mass of catalyst and measured before and after test.
b. Polarization curve per protocol in Table E3.
c. Sweep from 0.05 to 0.6 V at 20 mV/s, 80°C, 100% RH.

US DEPARTMENT OF ENERGY (DOE), Funding Opportunity Announcement (FOA) Number: DE-FOA-0001224

PEM FC vs PEM Electrolysis

- **Contrasting PEM automotive FC vs electrolysis**
  - Highly oxidizing, high potential oxygen electrode, typically higher pressure operation, duty cycle and number or operating hours required, cost targets.
- **HOR vs HER**
  - low loadings Pt/C possible, low over potentials, modest impacts between 50 mV and -50 mV vs RHE, carbon corrosion concerns (start up/shut down)?, gas generation vs consumption?
- **Membranes**
  - Similar materials, FCs have higher concerns with RH cycling, decreased concerns relative to cross-over (selectivity) and pressure drop (creep/mechanical properties).
- **MEAs/cell performance**
  - FC targets/protocols specific for application. Electrolysis can be intermittent or continuous, very different potential impacts.
- **Bipolar Plates**
  - Higher cell potentials, increased pressure drops.
- **ORR vs OER**
  - Pt vs Ir, 0.6-1 V operation versus 1.4-2V operation. Supported vs unsupported or non-carbon supported catalysts, diffusion layers (on oxygen side).

All need discussion. ORR vs OER is clearly an area where changing conditions have a strong impact on established knowledge base/approach.

Need for baselines – Standards for Comparison

		Ref	1.45 V	1.48 V	1.51 V	1.53 V	1.55 V	1.60 V	$i/i_{Ir\text{-}Ni}$
Ir-Ni	NREL	[1]	42	186	635	1317	2372	9363	**0.86**
Ir-Ni Acid	NREL	[1]	55	218	741	1578	2771	11001	**1.00**
Ir-Co	NREL	[1]	44	182	625	1327	2469	10010	**0.89**
Ir-Co Acid	NREL	[1]	40	158	540	1182	2115	9038	**0.76**
Ir	NREL	[1]	3	11	58	146	295	1006	**0.11**
Ir-Ni	Strasser et al.	[4]	–	–	–	370	–	–	**0.23**
Ir-Ni	Strasser et al.	[5]	–	38	–	–	–	–	**0.17**
Ir-Ni	Strasser et al.	[6]	–	–	88	–	–	–	**0.12**
Ir	Strasser et al.	[7]	–	–	70	–	–	–	**0.09**
Ir	Chen et al.	[8]	–	–	–	–	–	572	**0.05**
Ir-Nb-Ti	Chen et al.	[9]	–	–	–	–	–	537	**0.05**
Ir	Shao et al.	[10]	–	–	–	–	–	475	**0.04**
Ir	Shao-Horn et al.	[11]	–	3	–	–	–	–	**0.02**
Ir-Bi	Walton et al.	[12]	–	–	–	6	–	–	**0.00**
Ru-Co	Strasser et al.	[13]	–	205	–	–	–	–	**0.94**
Ru	Shao-Horn et al.	[11]	–	14	–	–	–	–	**0.07**
Ru-Ir	Mayousse et al.	[14]	2	–	–	–	–	–	**0.03**

Comparison References

[1] NREL in preparation work.

[4] Reier, T.; Pawolek, Z.; Cherevko, S.; Bruns, M.; Jones, T.; Teschner, D.; Selve, S.; Bergmann, A.; Nong, H. N.; Schlögl, R.; Mayrhofer, K. J. J.; Strasser, P. *Journal of the American Chemical Society* **2015**.

[5] Nong, H. N.; Gan, L.; Willinger, E.; Teschner, D.; Strasser, P. *Chemical Science* **2014**, *5*, 2955.

[6] Nong, H. N.; Oh, H. S.; Reier, T.; Willinger, E.; Willinger, M. G.; Petkov, V.; Teschner, D.; Strasser, P. *Angewandte Chemie International Edition* **2015**, *54*, 2975.

[7] Oh, H.-S.; Nong, H. N.; Reier, T.; Gliech, M.; Strasser, P. *Chemical Science* **2015**, *6*, 3321.

[8] Hu, W.; Wang, Y.; Hu, X.; Zhou, Y.; Chen, S. *Journal of Materials Chemistry* **2012**, *22*, 6010.

[9] Hu, W.; Chen, S.; Xia, Q. *International Journal of Hydrogen Energy* **2014**, *39*, 6967.

[10] Zhang, G.; Shao, Z.-G.; Lu, W.; Li, G.; Liu, F.; Yi, B. *Electrochemistry Communications* **2012**, *22*, 145.

[11] Lee, Y.; Suntivich, J.; May, K. J.; Perry, E. E.; Shao-Horn, Y. *The Journal of Physical Chemistry Letters* **2012**, *3*, 399.

[12] Sardar, K.; Ball, S. C.; Sharman, J. D.; Thompsett, D.; Fisher, J. M.; Smith, R. A.; Biswas, P. K.; Lees, M. R.; Kashtiban, R. J.; Sloan, J. *Chemistry of Materials* **2012**, *24*, 4192.

[13] Forgie, R.; Bugosh, G.; Neyerlin, K.; Liu, Z.; Strasser, P. *Electrochemical and Solid-State Letters* **2010**, *13*, B36.

[14] Mayousse, E.; Maillard, F.; Fouda-Onana, F.; Sicardy, O.; Guillet, N. *International Journal of Hydrogen Energy* **2011**, *36*, 10474.