Some considerations when developing non-PGM catalysts

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Fuel Cell Activities

Present to the DOE CWG

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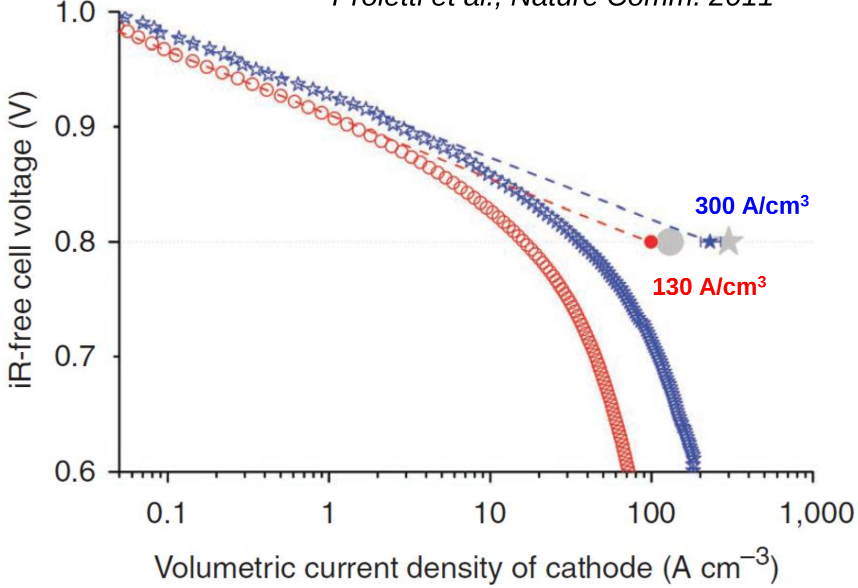
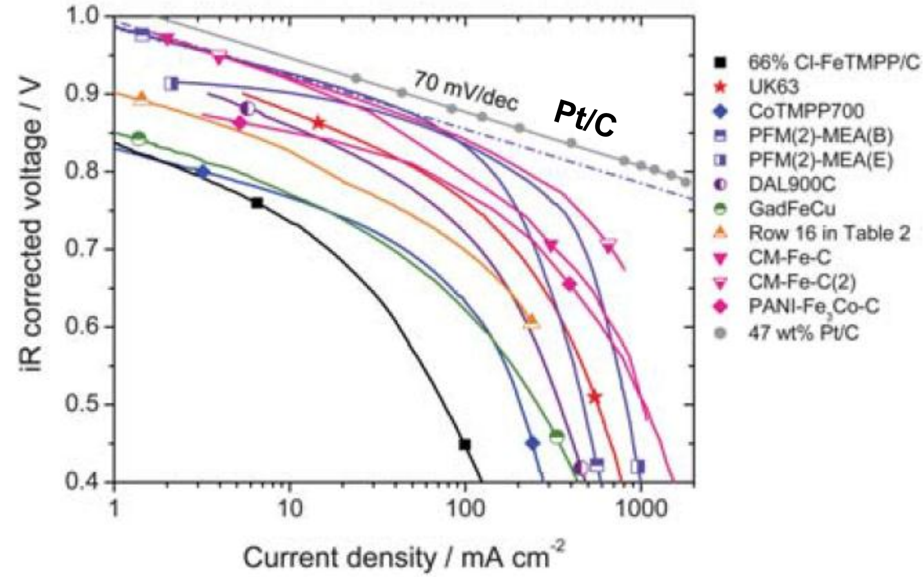
Recent Progresses

Proietti et al., Nature Comm. 2011



Jaouen et al., Ener. Environ. Sci. 2011



- Great progresses in recent years. Mostly achieving kinetic target.
- Does kinetic target need to be adjusted?
- Where do we stands on fuel cell performance and what else needs to be done?

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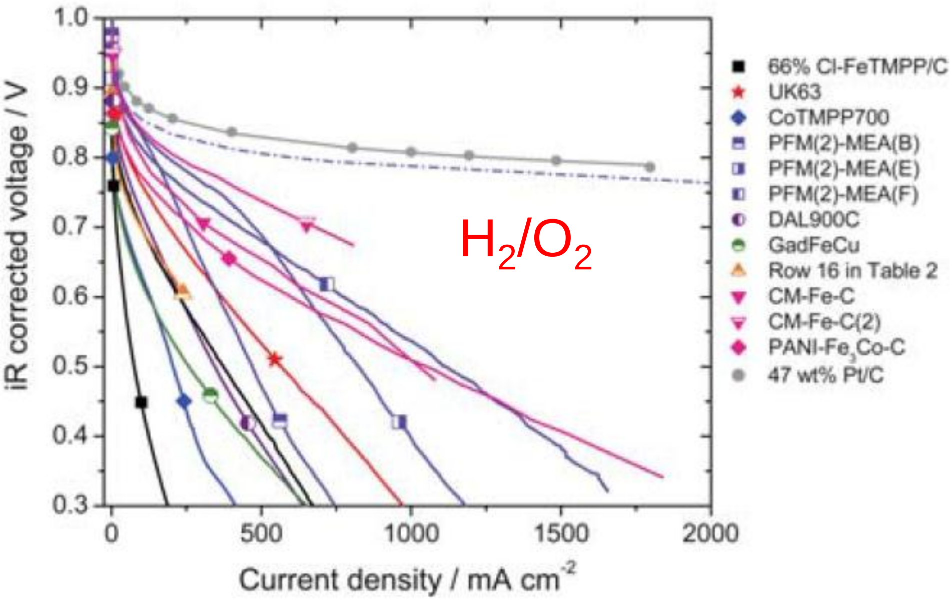
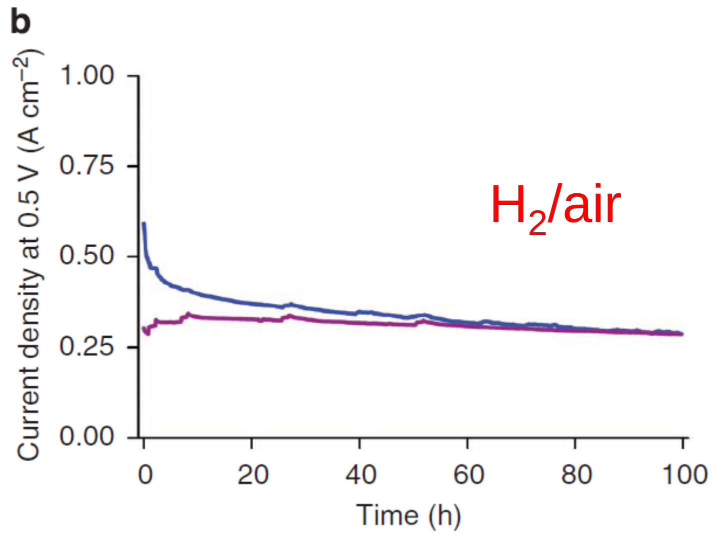
Obvious Issues

Jaouen et al., Ener. Environ. Sci. 2011



Proietti et al., Nature Comm. 2011



- Serious transport loss above 0.1 A/cm^2_{MEA}.
- Cause of loss is unclear but likely due to flooding and poor proton conduction in the catalyst's micropores.
- Stability is very poor, especially for the most active catalysts.

Usable Power?

From FCTT Roadmap, June 2013

Table 3. Technical Targets for MEAs

Characteristic	Units	Status	2020 Target
$Q/\Delta T_i$ [a]	kW/°C	1.9[b]	1.45
Cost	$/kW	17[c]	14
Durability with cycling [d, e]	Hours	9,000[f]	5,000
Performance @ 0.8 V[g]	mA/cm^2	311	300
	mW/cm^2	248	250
Performance @ rated power [e]	mW/cm^2	845[h]	1,000

$$Q/\Delta T_i = \frac{\text{Stack power (90 kW) x} \left(\frac{E_{th,LHV}\text{ (1.25 V) – Voltage at rated power}}{\text{Voltage at rated power}} \right)}{\text{Stack temperature – Ambient temperature (40°C)}}$$

- For automotive application, size of the radiator (heat rejection) determine the maximum useable power (rated power).
- As a rule of thumb, V lower than 0.56 V is *not* usable. (raw voltage, H_2/air)
- In addition, power density targets prevent us for going to lower current density to maintain high voltage.

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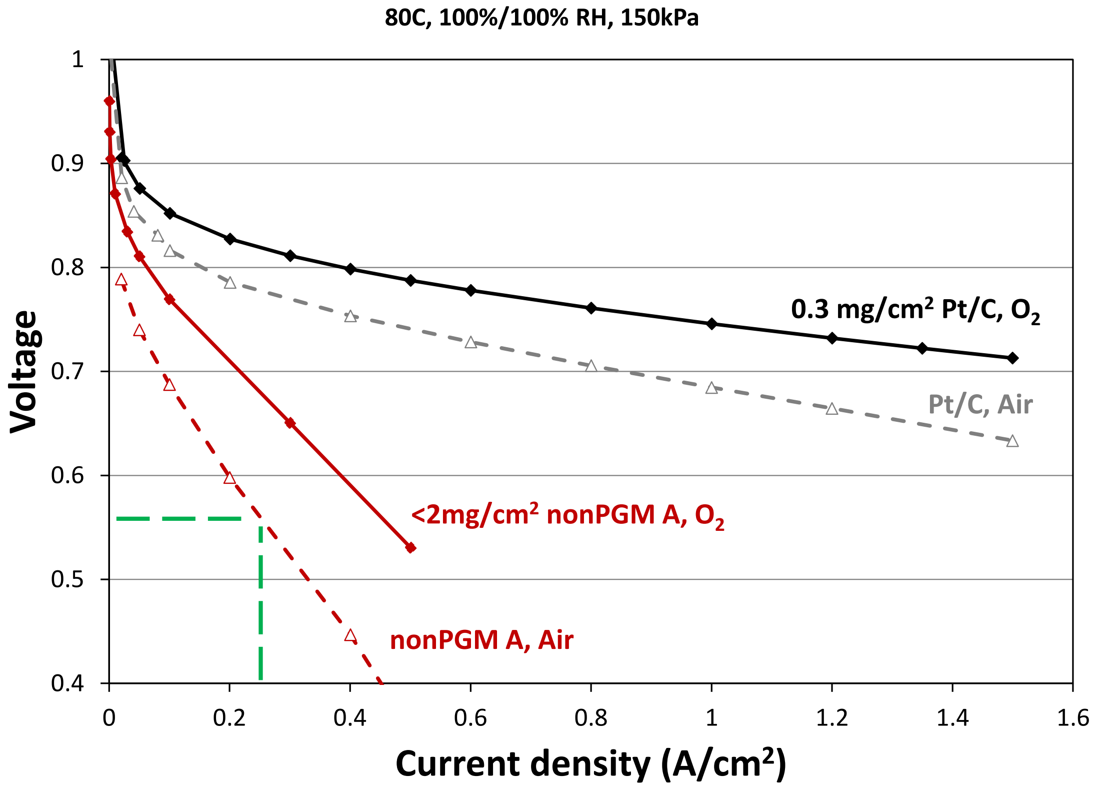
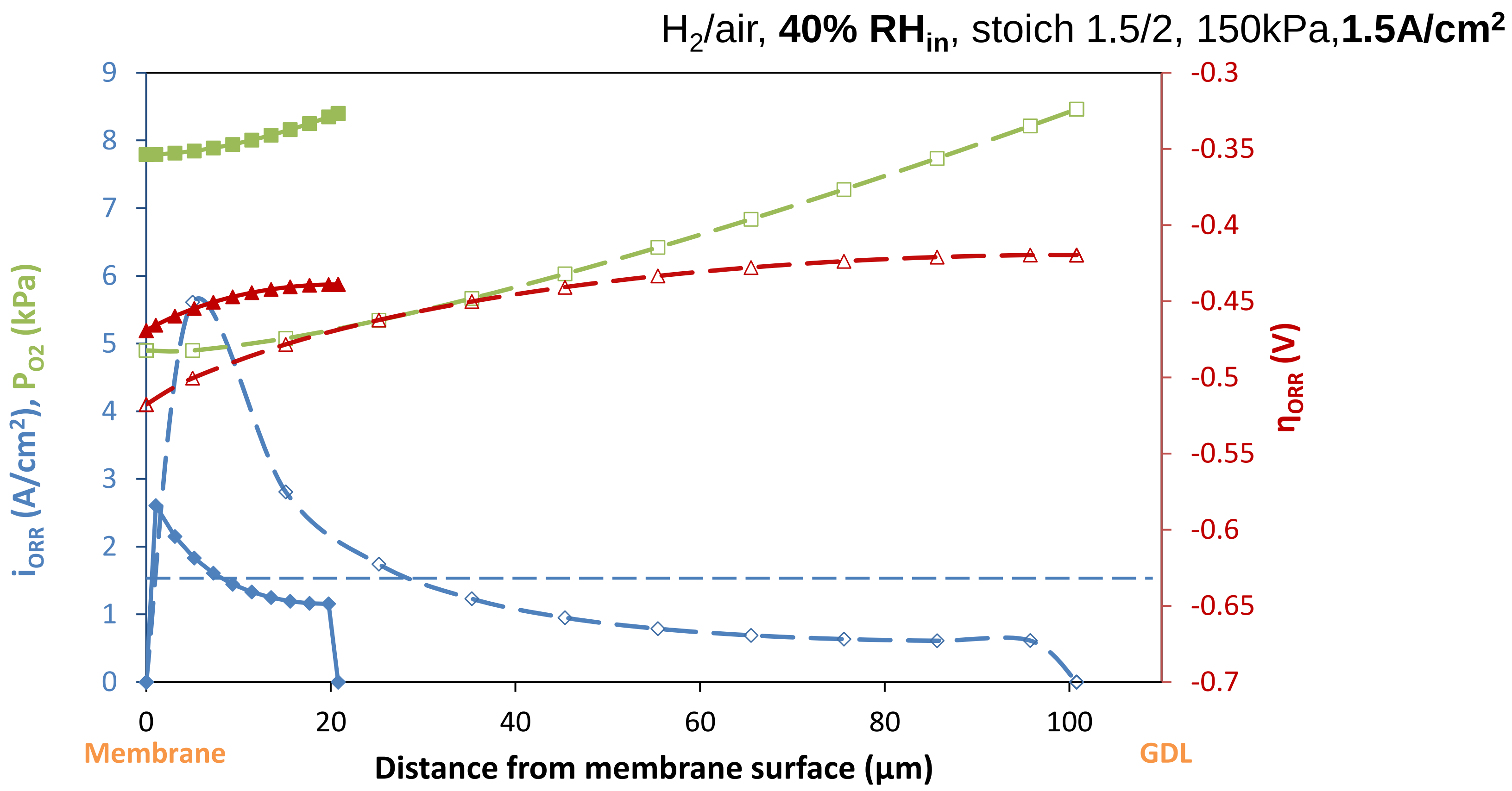
Reality check: H_2/air performance



- Performance in H_2/air is rarely reported. (Understandable, but please do so.)
- From limited available data (GM and few literature), usable power is only ~0.2 A/cm^2.
  (0.1 W/cm^2 vs target of 1 W/cm^2)
- Can we pack more catalyst into the electrode to compensate? *It's so cheap!!*

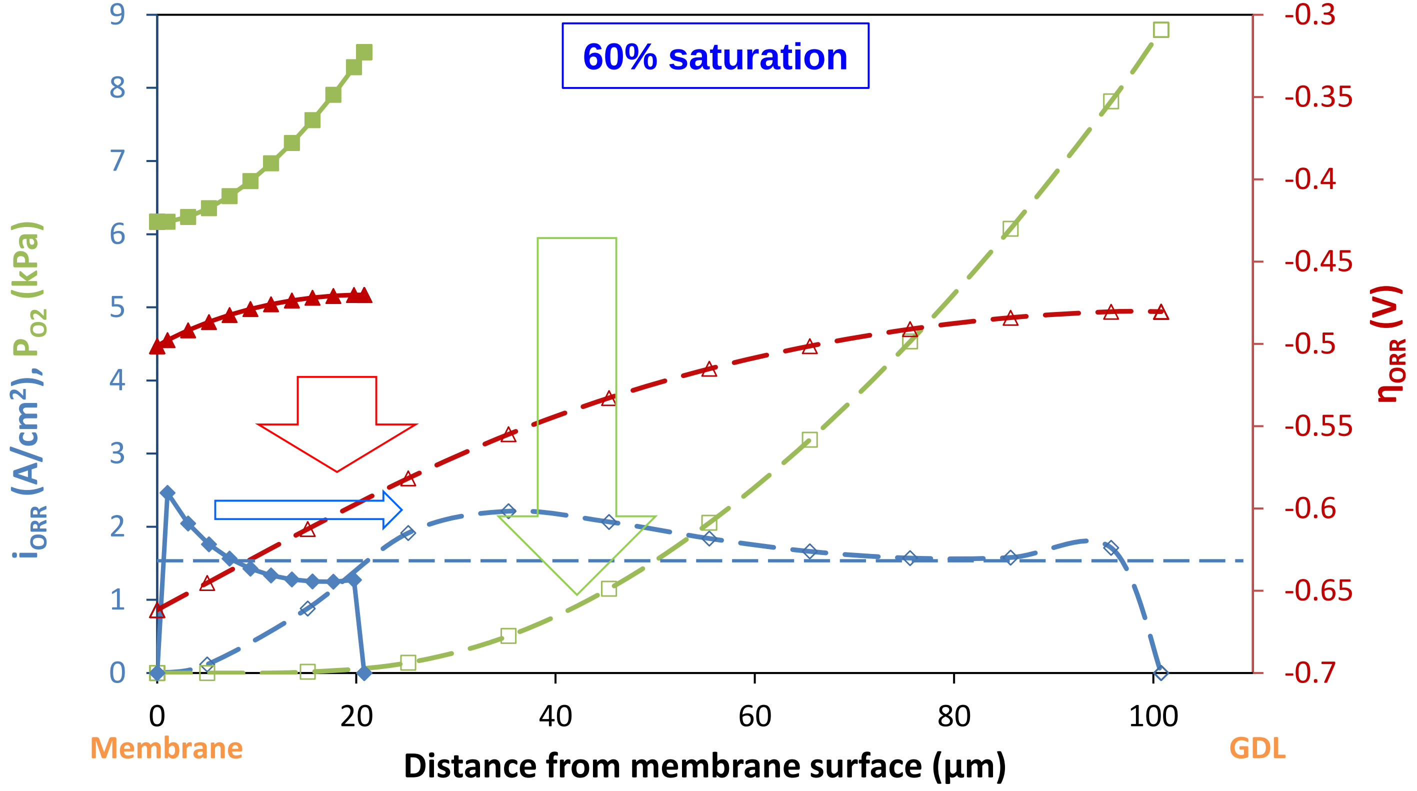
Thick vs Thin electrodes. Both have same kinetics.



- Modeling using Pt/C-like electrode properties (likely the best case scenario).
- Thick electrode leads to large proton and O_2 transport losses (~50mV).

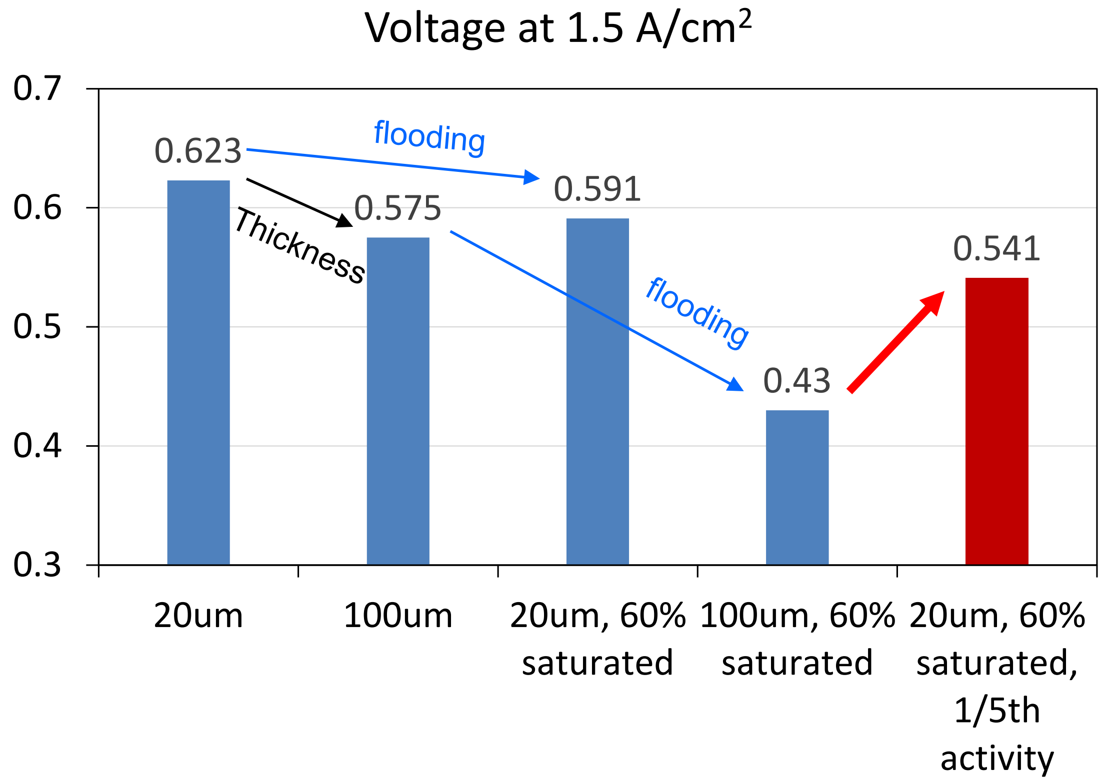
Real problem starts when flooded

H_2/air, **40% RH$_{in}$**, stoich 1.5/2, 150kPa,**1.5A/cm^2**



- Water in thick electrodes tend to reach saturation earlier than in thin electrodes. (as early as 40% RH$_{in}$)
- And when thick electrode floods, the effect is far more severe.

Prediction of voltage at 1.5 A/cm^2



- In this example, increase in thickness causes ~50mV and ~160mV losses when electrode is dry and when water accumulation occurs, respectively.
- In fact, it is better to sacrifice kinetic activity by reducing the catalyst loading down to 1/5th (20 µm thick).
- Think twice before go thick! Even with a new highly-conductive ionomer, significant challenge remains in water management.

Future Foci

- Increase volumetric activity.
  - → Thick electrodes are unrealistic. Prefer ~20 µm cathode (600 A/cm^3@0.8V, ~22 A/cm^3@0.9V)
- Eliminate use of Fenton catalyst metals such as Fe and Cu.
- Improve stability.
- Develop catalyst to give more usable power
  - → As a starter, let's report H_2/air performance
  - → Do not recommend MEA optimization at this stage.
  - → Recommend catalyst design to improve oxygen transport.
  - → Do we need a high-power target? (should be driven by current Q/ΔT & Stack power density targets)
  - → At this stage, hybridizing with PGM catalyst does not give significant benefit. However, this will change if usable power of the non-PGM improves.
  - → In that sense, catalysts that give high usable power but low kinetics are better than those with high kinetics but low usable power.