AMFC Workshop 2016

AMFC Technical Challenges and Status: From Single Cell to Stack System

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From Single Cell to System – Key Challenges

- AMFC Stack

Selected issues / research needs defined at 2011 AMFC Workshop:

  - Optimize operation conditions (basically effective water management)
  - Solution for carbonation issue
  - Higher anode activity
  - Membrane - operation at T > 80°C; higher water mobility

- Advancement in state of the art 2011 → 2016

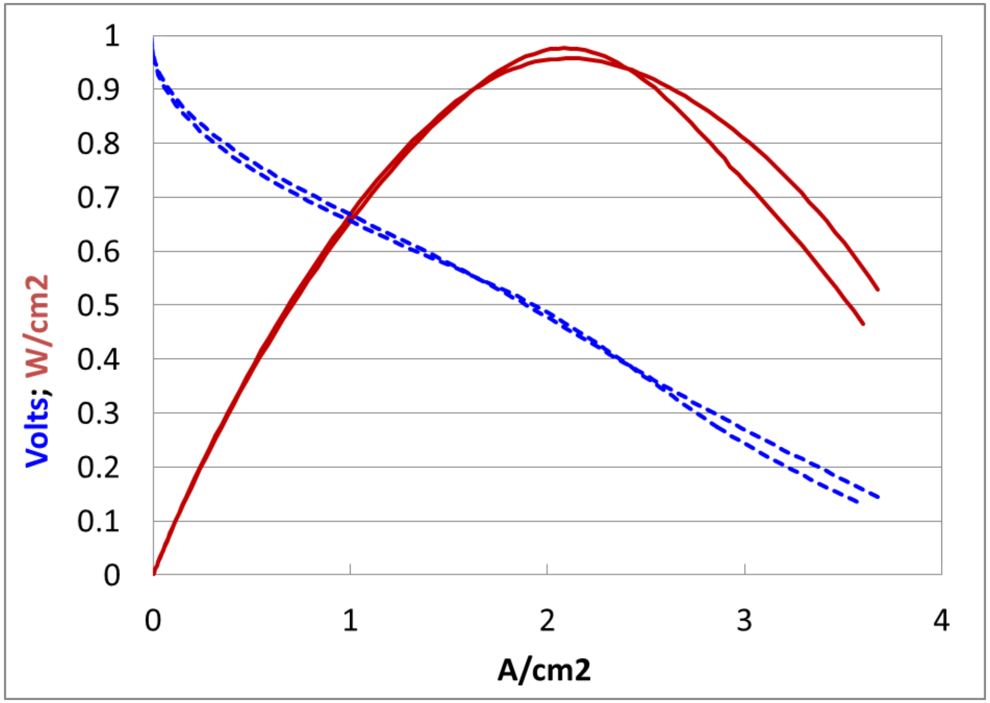
  - 200mW/cm2 MEA @0.5V →
    - 1000mW/cm2 @0.5V (Elbit; [Zhuang *et al*.[1] under O_2])
  - 2kW net stack system →
    - 2kW net system (Cellera 2014)
    - **Presumed 10's of kW system by Daihatsu (albeit KOH-soaked MEA's)**

AMFC Status – Single (well-humidified) Cell

Polarization curve – 5cm2 H_2/Air
Pt-free Ca, Pt-catalyzed An;
CO_2-free air

T_{cell} = T_{air}(humf) = 75°C
P_{air}; P_{H2} = 1;3 bar(g)

30µm thick, polyhydrocarbon membrane



- Performance level of Proton Exchange Membrane (PEM) fuel cells is within reach, however:
  - Air humidification and overall water management are critical
  - CO_2 handling adds to system complexity in operation at lower T_{cell}

Selected Issues & Research Needs

- **Higher anode activity**
- **Membrane - operation at T > 80C / water mobility**

- Anode activity: significant progress has been made
  - Near-Pt activity with Pd-based catalyst [2];
  - Pt-containing bimetallics show activity greater than Pt [3];
  - Advances in fundamental understanding of alkaline HOR [4,5]
- Anode challenge today: also substantially **water management**
- Membrane:
  - Tokuyama A201 – technology of *ca*. 2008 – is still the leading commercial "standard" membrane
  - i.e. *"membrane/ionomer issues" – including the need for higher operation temperature and higher water mobility – have not been adequately resolved!*

KEY BOTTLENECK !

Key System-Level Challenges

- **Water management**
  - *Target :* Operation with no external humidification
  - *Challenge :* Water generation on the fuel side creates propensity for anode flooding and cathode dry-out

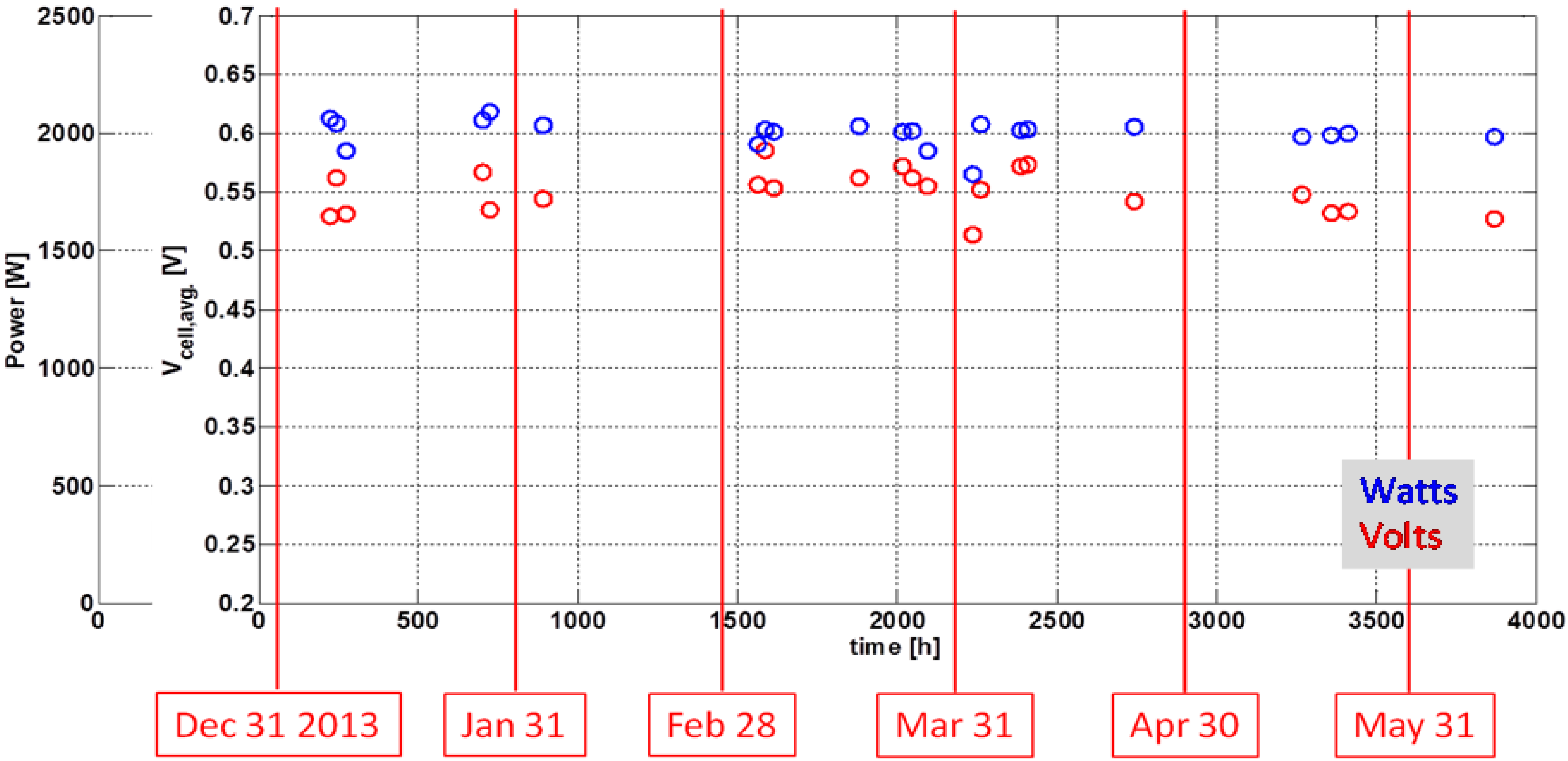
- **CO_2 immunity**
  - *Target :* continuous operation with ambient air feed
  - *Challenge:* direct feed of ambient air causes loss of 50% of the power vs. operation on air free of CO_2

- These challenges have been addressed significantly, nevertheless,
- Substantial room remains for further improvement

Field-tested 2kW AMFC System (Cellera)

- 6-month 2kW H_2/Air stack-system test
- Live site backup capability
- Aluminum hardware; air-cooled
- Cathode water exchanger / dry anode
- Pressure - ambient air / 1.5bar(g) H_2

AMFC Status – Stack operation

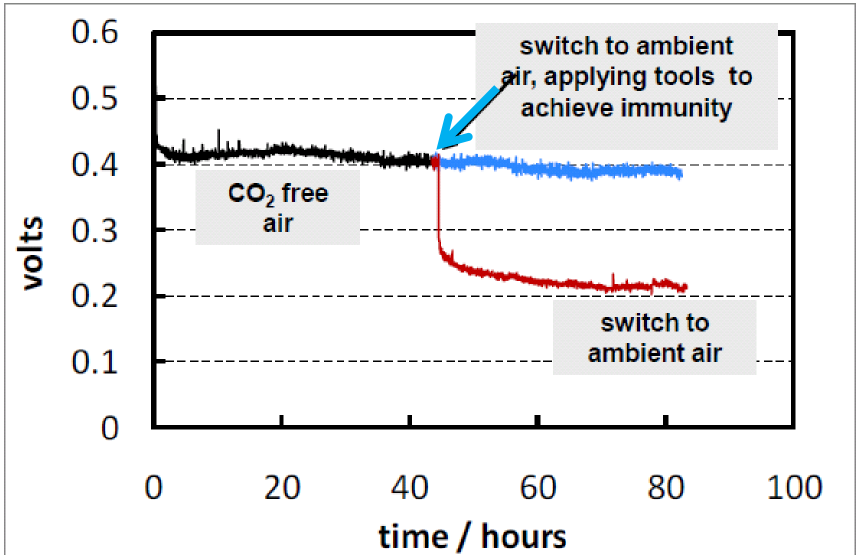


- No measurable degradation over 5000h (intermittent operation)
- Optimized shut-off/restart conditions proved critical

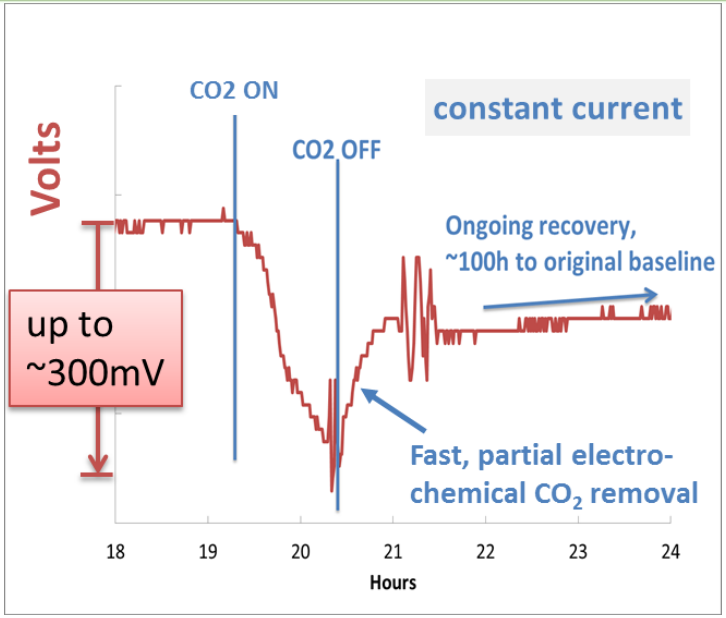
AMFC SYSTEM: CO_2 IMMUNITY

The “CO2 Immunity” Subsystem

- CO_2 sequestration subsystem upstream the cathode developed and demonstrated at Cellera (now Elbit Systems) [6]
  - Two step process; each lowering the CO_2 level by ~10x
  - Thereby reducing CO_2 in the cathode inlet to <5 ppm
  - First step: Thermally regenerated polymeric active material
  - Second step: completes removal of ~99% of CO_2 with a strongly CO_2-bonding inorganic solid



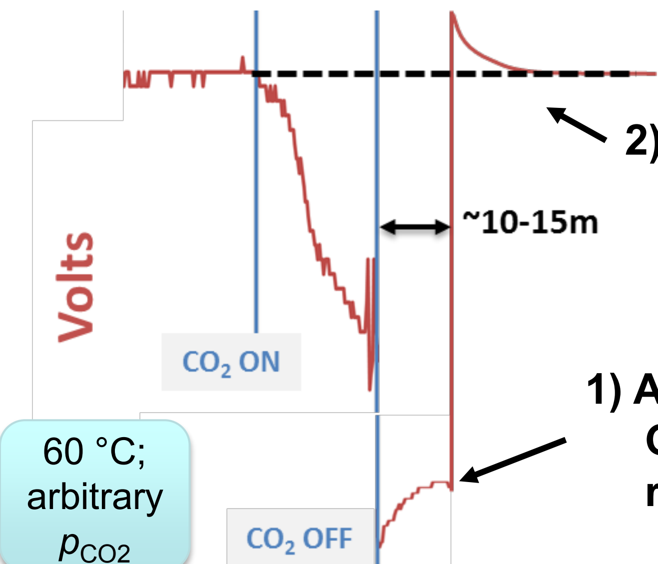
Handling CO2 contamination



Upper plot: Carbonation and de-carbonation (lowering p_{CO2} under same constant current):

- ~100h to full recovery at any given current
- However: **significant partial recovery in 10's of minutes**

- Lower plot: Applying a current well above operation point: → **effective full recovery at the operation point**



2) Return to original current, and voltage returns quickly to original value

1) At "CO_2 OFF", INCREASE CURRENT: Greater proportion of $(H)CO_3^{(2)-}$ replaced at the anode by "new OH^-"

The "CO2 Immunity" Subsystem

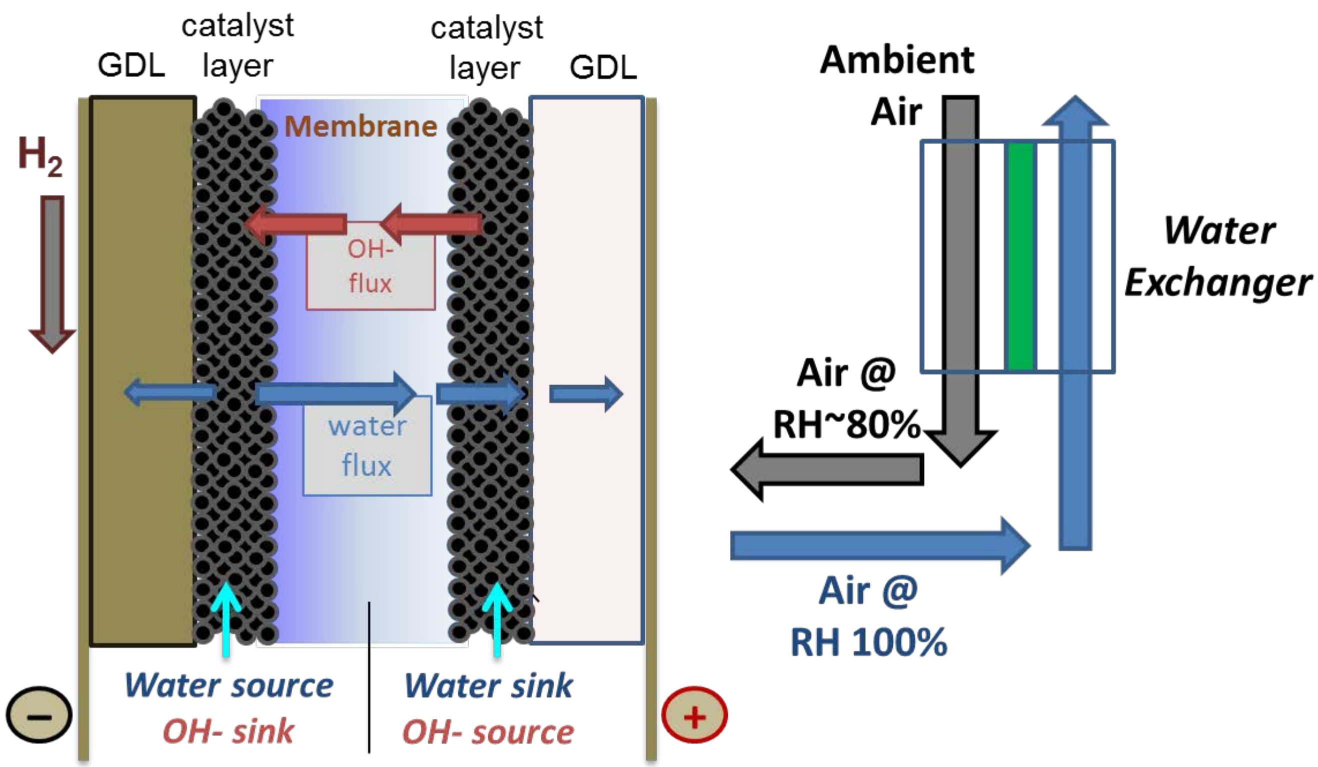
- Corrective measures demonstrated
  - CO_2 sequestration subsystem upstream the cathode
  - De-carbonation within the cell by step of high current

- CO_2 sequestration technology is advancing independent of AMFC:
  - Isotherms with >30% w/w reversible CO_2 capture [7]
  - Improvements in T swing specs (increasing adsorption T / decreasing desorption T)

- Addressing CO_2 sensitivity - path forward:
  - **Increase operation temperature** to facilitate decarbonation and allow higher "CO_2 slip"

AMFC SYSTEM:
WATER MANAGEMENT

Water in the AMFC

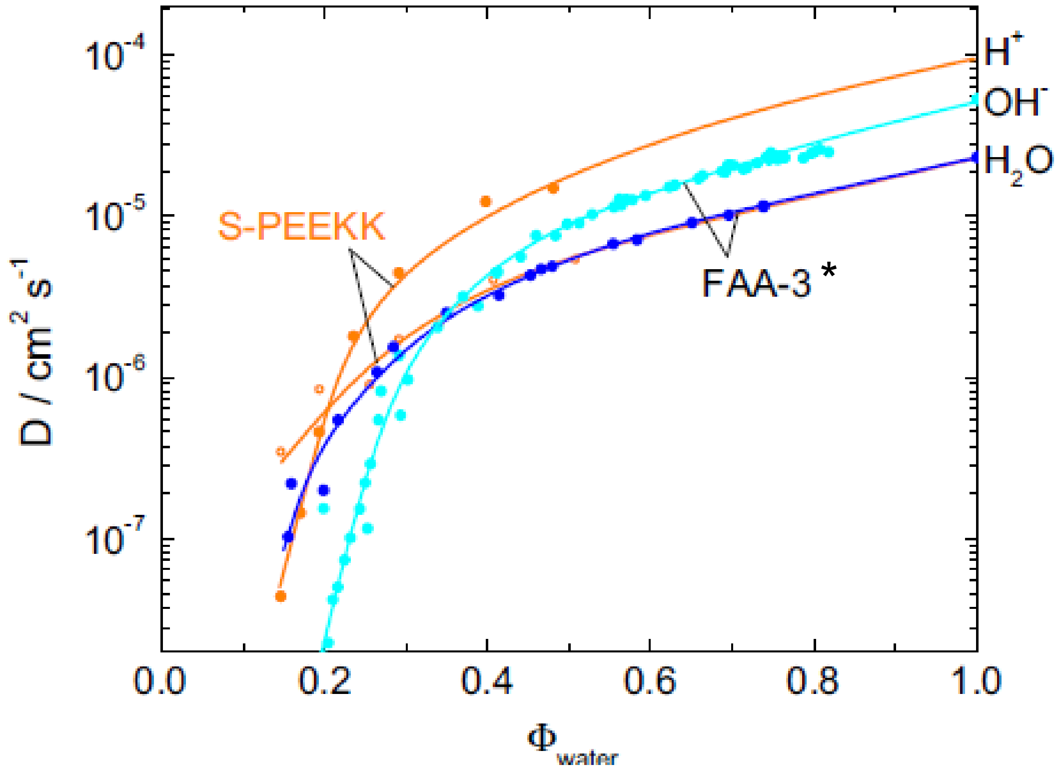


- AMFC Hydration challenge is especially significant because
  - The cathode is actively consuming water and
  - The cathode uses high gas flow (20% O2 @ 2.0 stoichiometry) which causes substantial removal of water from the cell into sub-saturated air

AMFC System: Loss of water of hydration → strong impact on performance

- Diffusivities of H^+ and OH^- in the ionomer drop substantially with drop in the water content [8]

→ **Strong effect of partial dehydration** On conductivity for OH^- ion-conducting ionomers

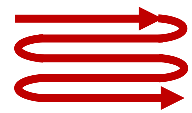


* (FAA-3 membrane by Fumatech)

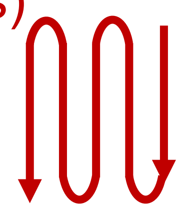
240 cm2 Single-cell: Water Imaging

- Neutron Imaging "through-plane" (limited to single cell, giving a full lateral water distribution image)

- Horizontal single channels used for serpentine anode flow field



- Multi-serpentine (11 channels, 5 passes) flow field on cathode side



- Dry H_2; humidified air (80% RH); Cell T = 60°C

Yellow indicates "dry"; **more water → more blue**

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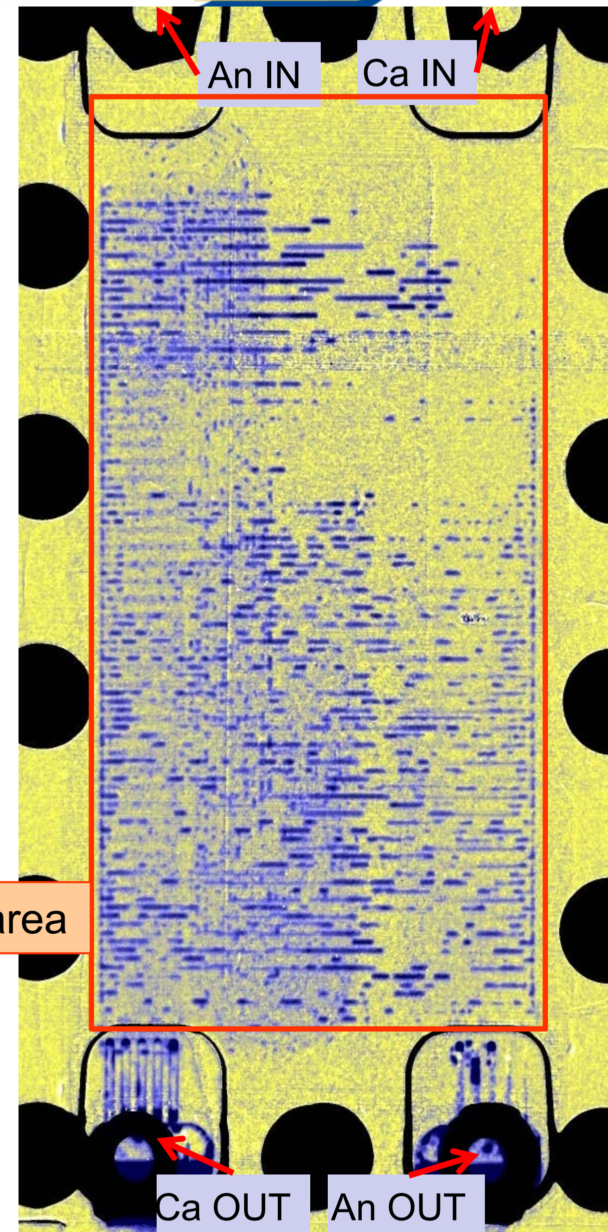
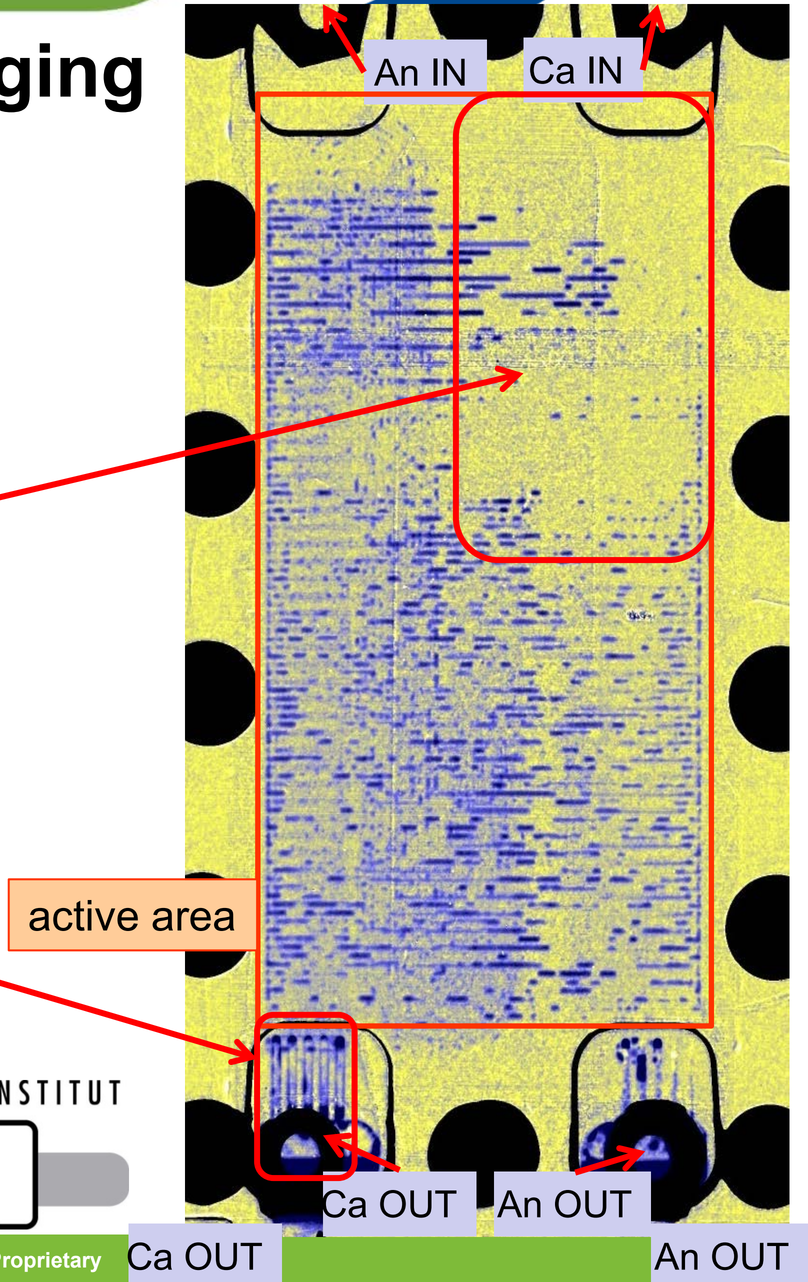


240 cm2 single-cell: Water Imaging

- **Operation with dead-ended anode and periodic gas purge (3s per 3 mins)**

“Dry” section of MEA propagating from Cathode inlet

Excess water removal at Ca exhaust



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Consequences

- Water exchanger on the cathode side is a key component of the AMFC water-management subsystem, **targeting highest dew point** for the cathode inlet

- Fast **rate of water transport** across the cell membrane into the cathode is critical for high AMFC performance

RESEARCH NEEDS

Membrane/ionomer upgrade is a key system requirement

- [increase T_{cell}] x [decrease t_{mem}] x [increase σ_{ion}]

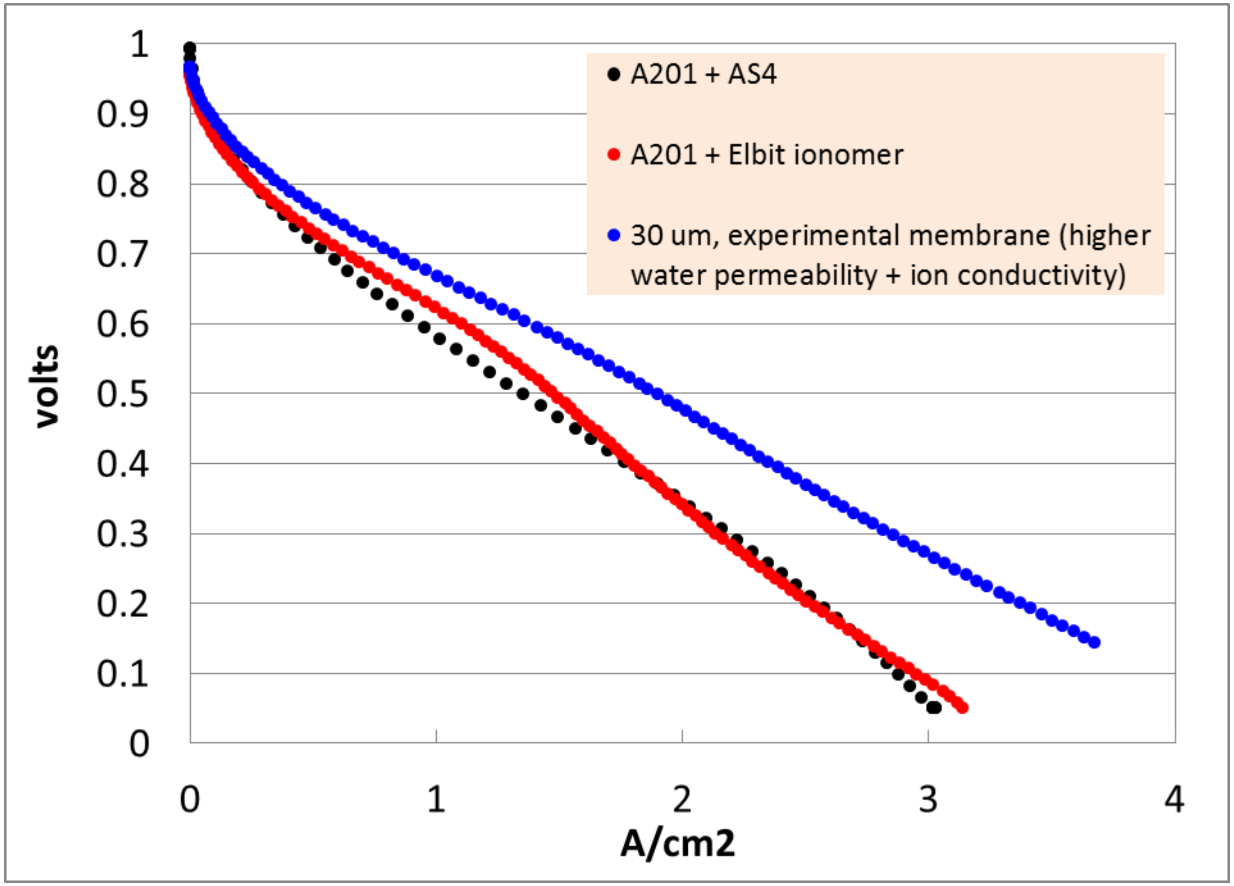
- With the main (system) benefits being:
  - **Facilitated water management**
  - **Reduced CO_2 filtration requirements**

- Obtained by
  - </= ~15 μm thick membranes of good mechanical integrity
  - Higher ionomer/membrane stability at 80 °C+

Influence of the membrane on AMFC performance

- Performance increase from optimized membrane properties (IEC/ion conductivity, water transport):

- Improved membrane characteristics play a significant role

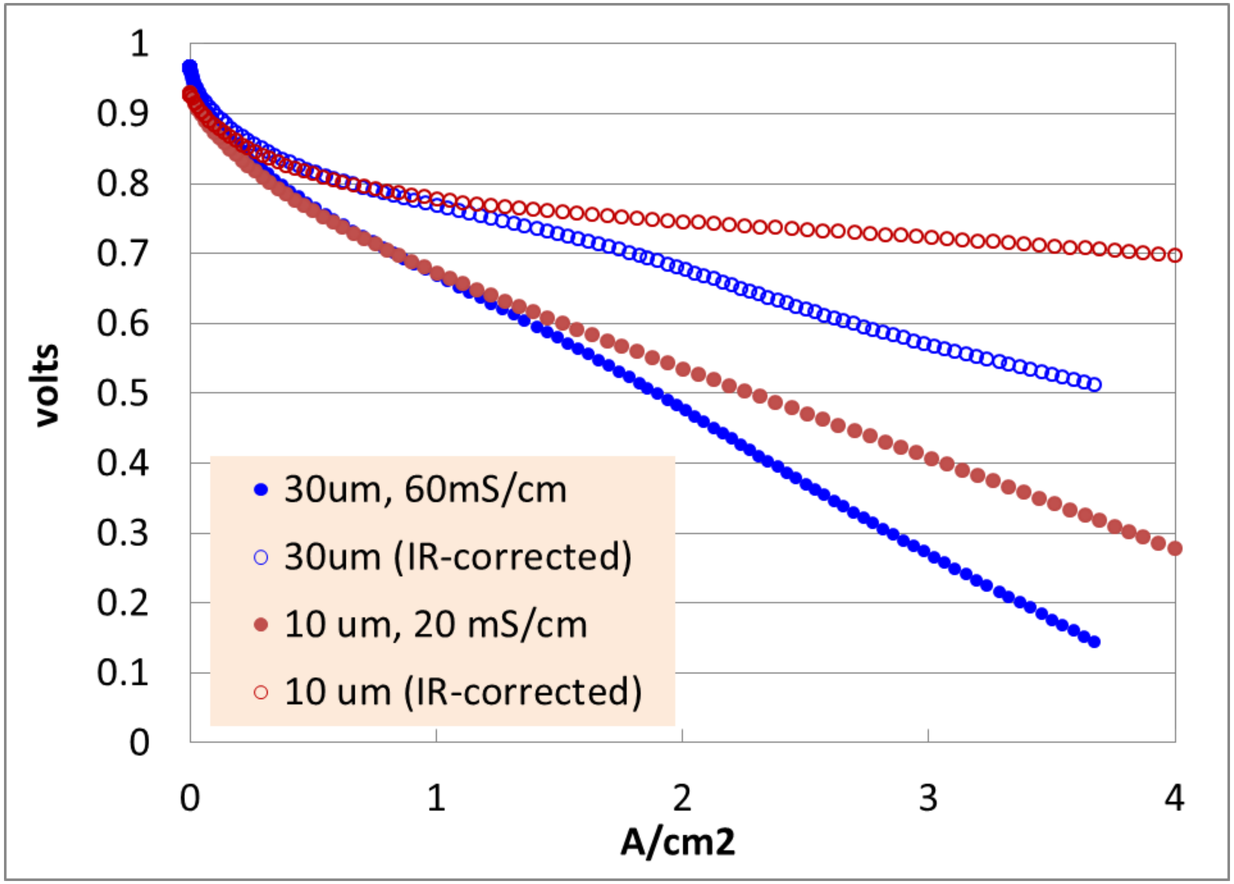


- **Single cell / 5cm2**
- **Full Ca humidification**
- **75C**

Influence of the membrane on AMFC performance

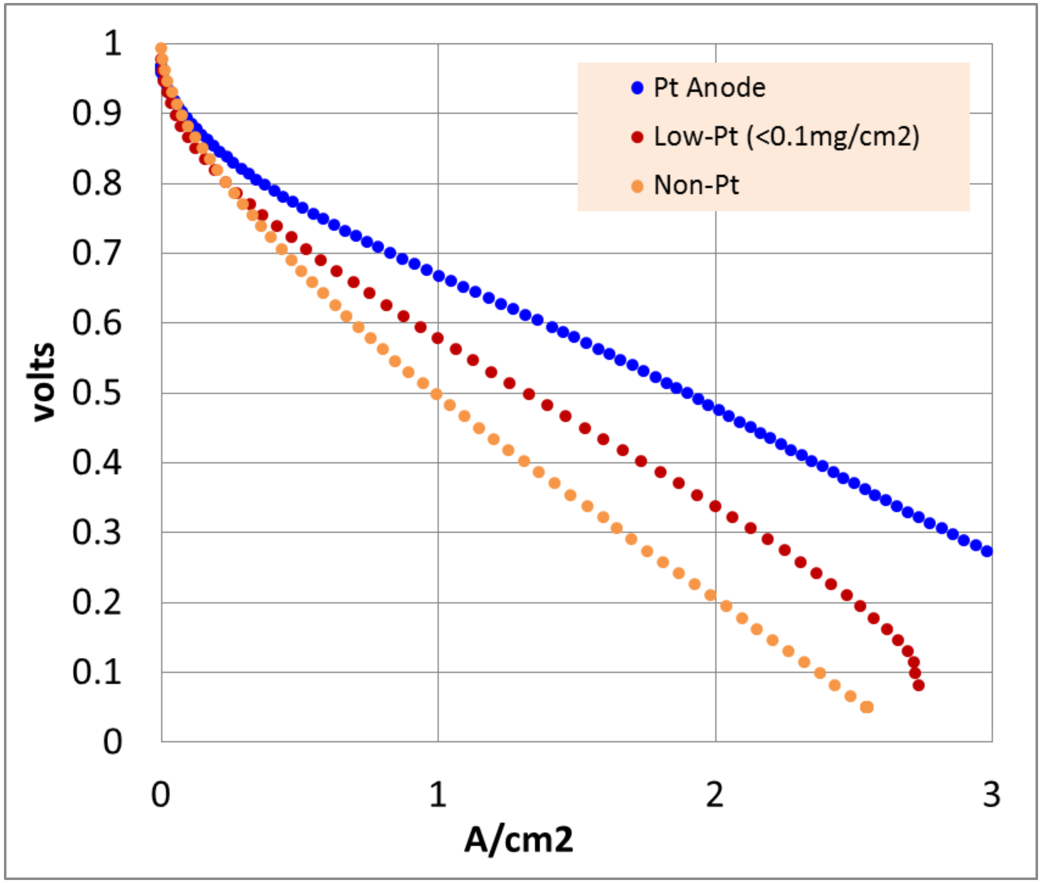
- 30 micron membrane, ~60 mS/cm (OH- at 75C)
- 10 micron membrane, ~20 mS/cm (OH- at 75C)

- **Thin membrane is potentially more beneficial** than simple increase in conductance



AMFC performance recorded with different anode catalysts

- Consequences of advancing to the low-cost AMFC anode – arising from low anode catalyst activity together with low catalyst utilization [9] and limited rate of H_2 access in a "flooded" anode*



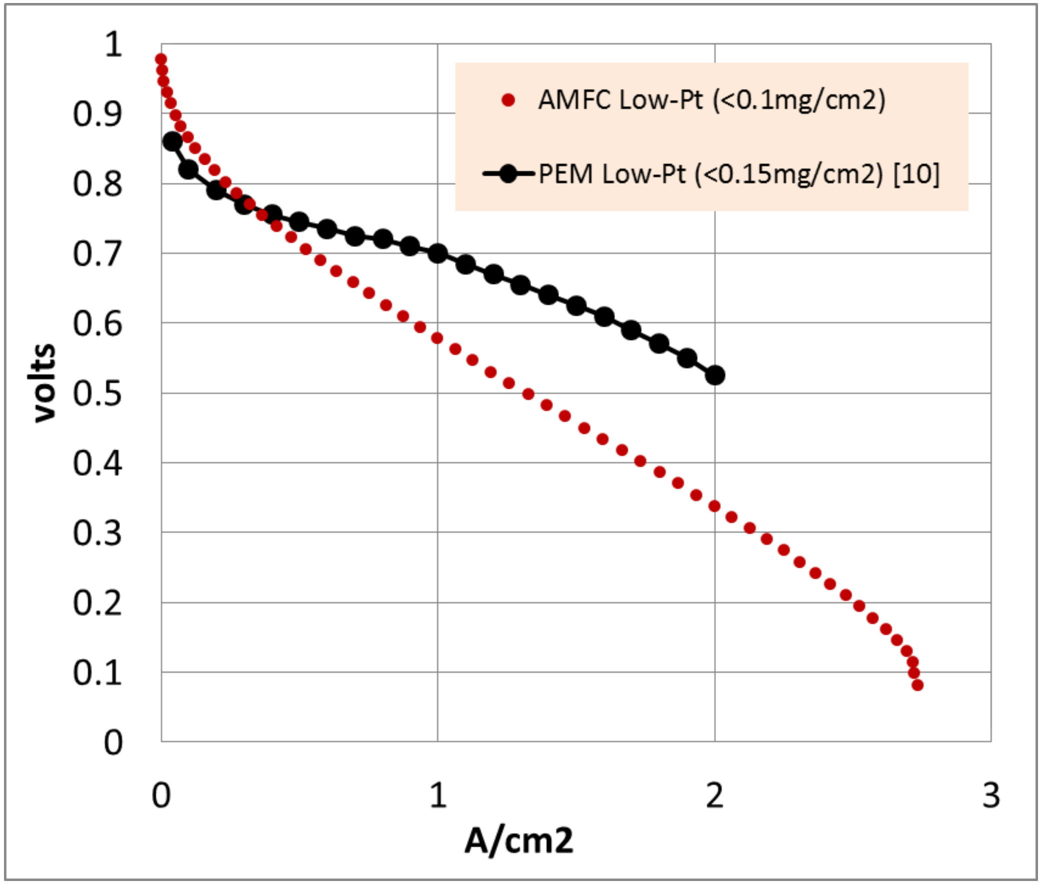
- **Single cell / 5cm2**
- **Full Ca humidification**
- **75C**
- **30 micron membrane**

* Reminder: 2x water generation rate

Present performance of AMFC and PEMFC of low cell Pt loading

- Performance boost still needed to match low-Pt PEM cells

- Membrane improvements can certainly help, but improved intrinsic activity and novel catalyst layer structures are clearly required



Concluding Remarks

- Primary goal today *from the system point of view* is: **Minimize the complexity and cost of applying system fixes to problems caused by materials properties limitations**
- Reduce cathode dry-out losses through better internal water transport characteristics
- Allow higher temperature operation with advanced membranes which combine high T tolerance, water permeability and conductivity

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