



Alkaline Anion Exchange Membrane Fuel Cells (AEM-FC) Status

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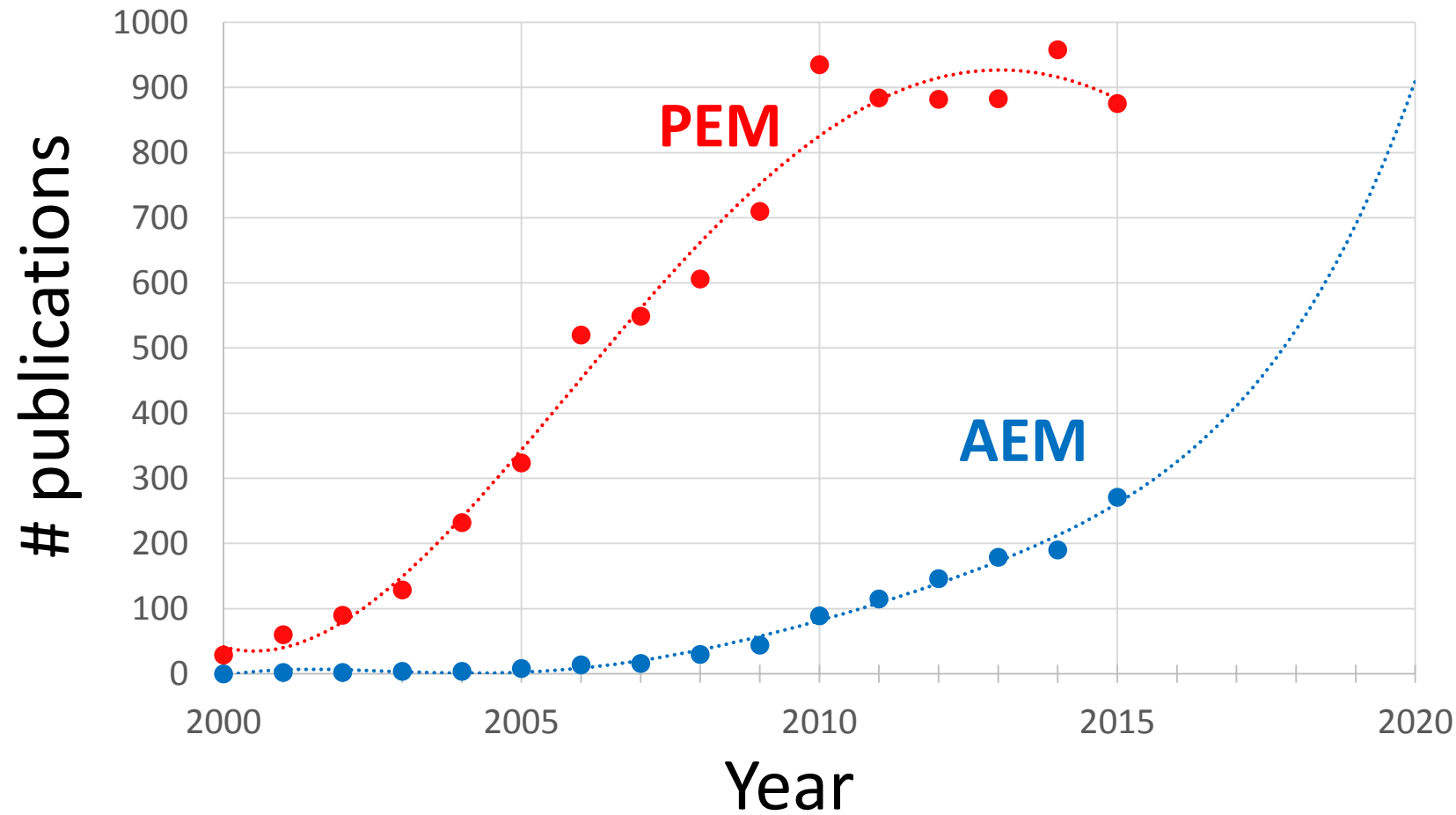


2016 Alkaline Membrane Fuel Cell Workshop
Sheraton Grand Phoenix
Phoenix, AZ – April 1, 2016

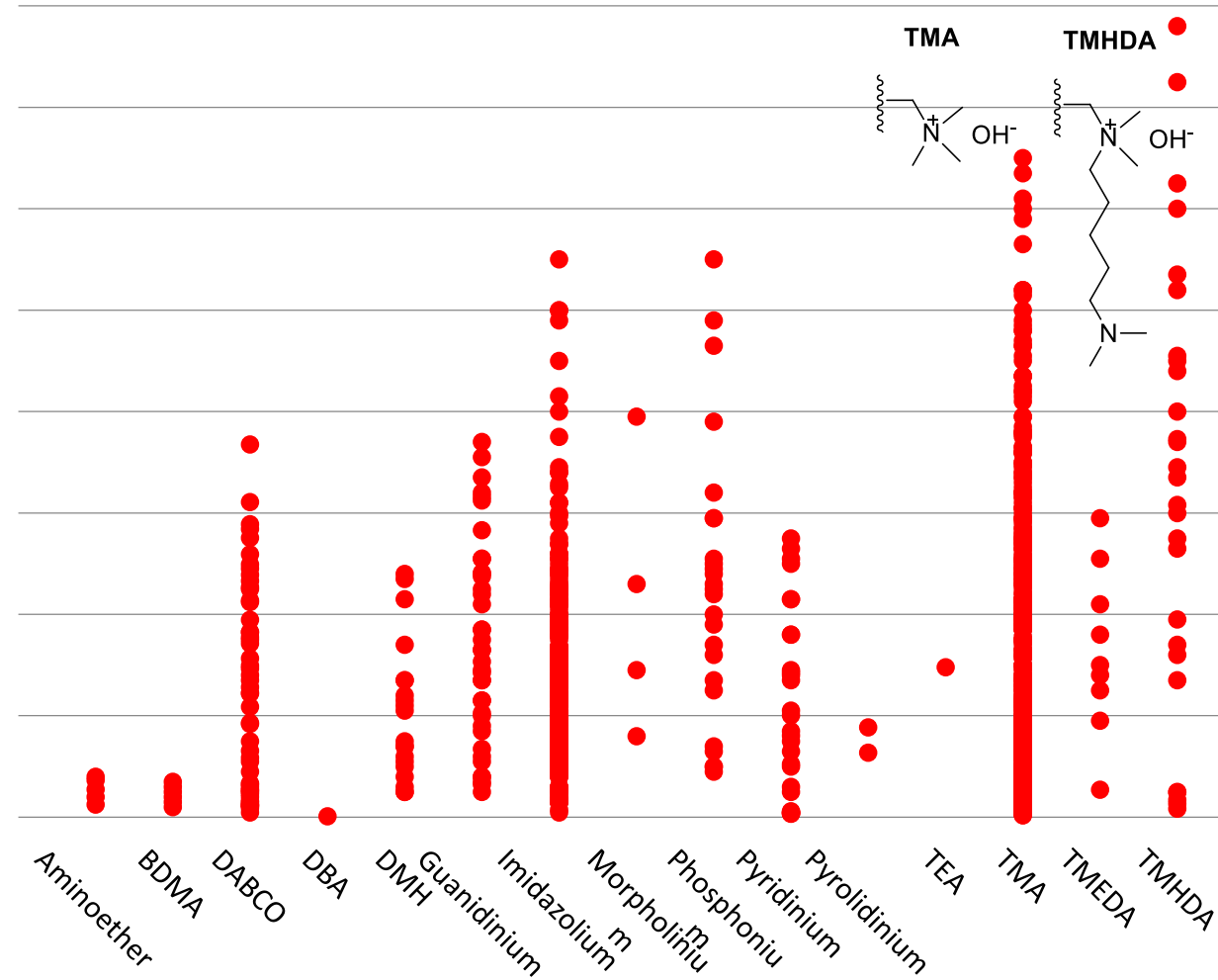
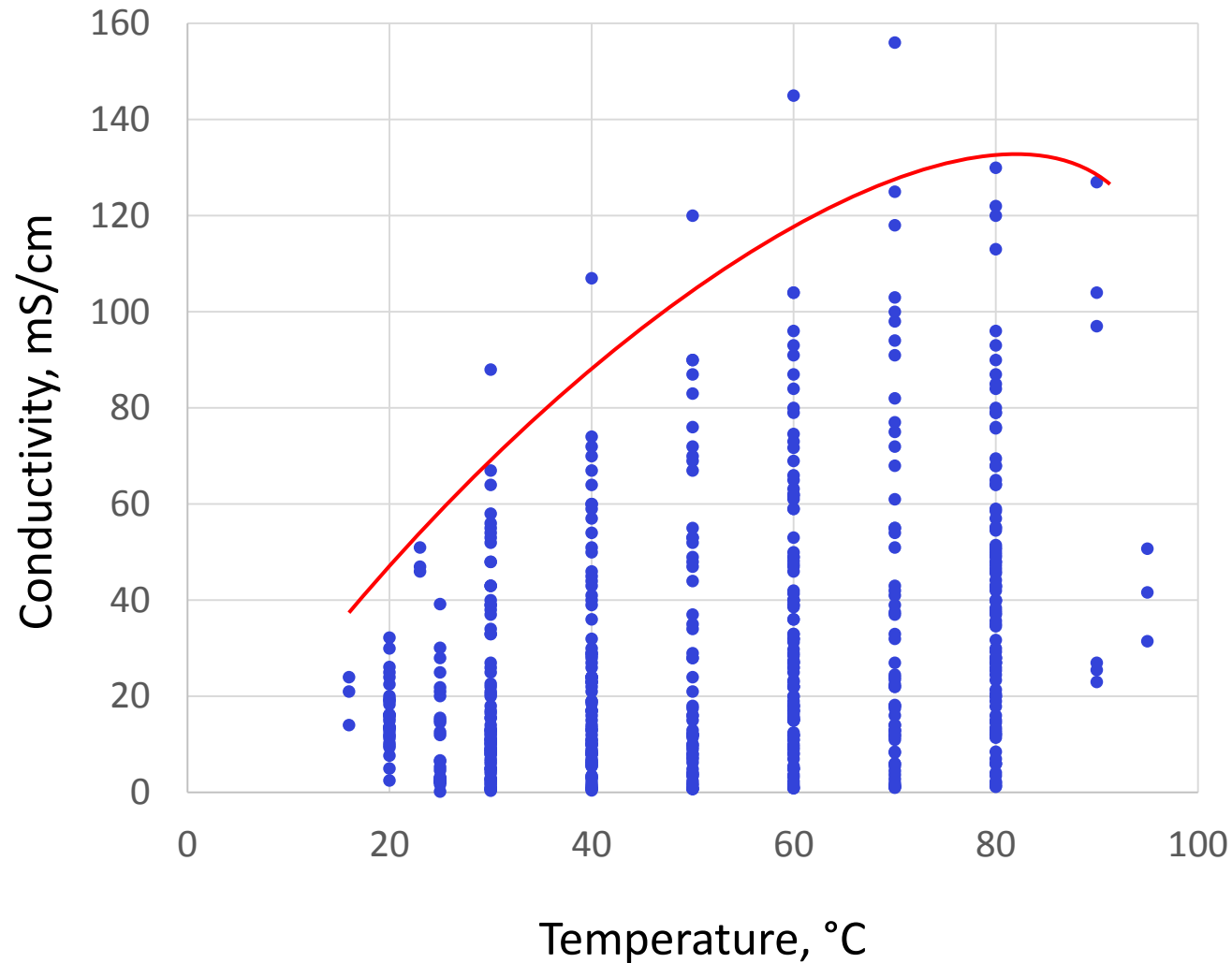


AEM-FCs in the literature

AEM-FC – a blooming field. Most of the papers are focused on development of anion conducting polymers for AEMs



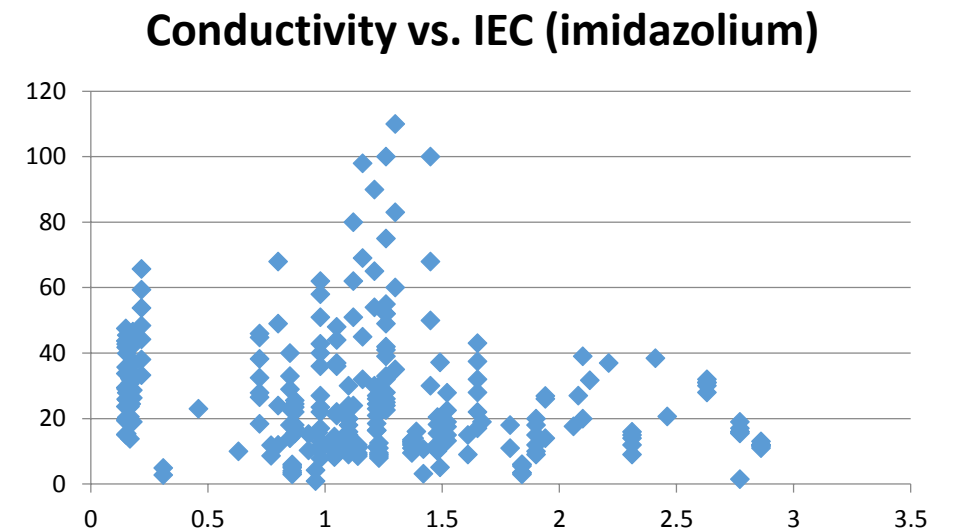
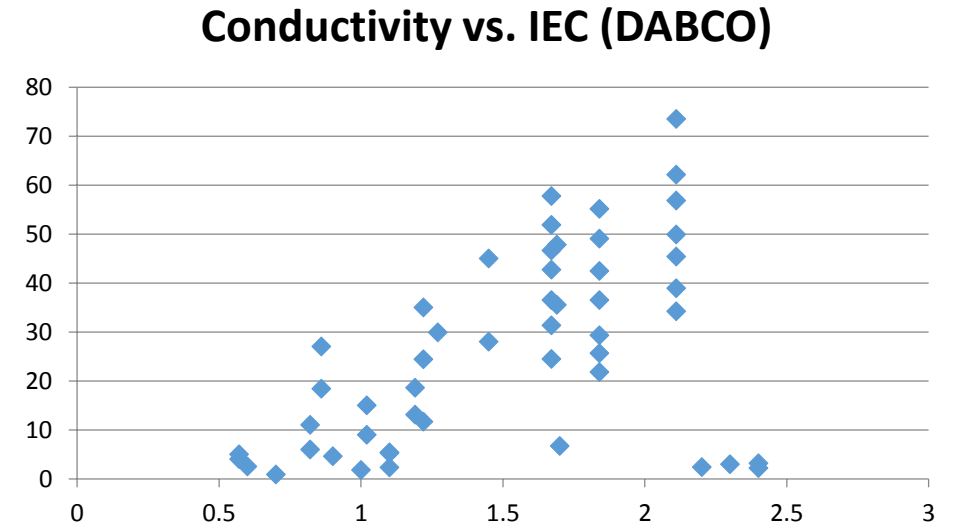
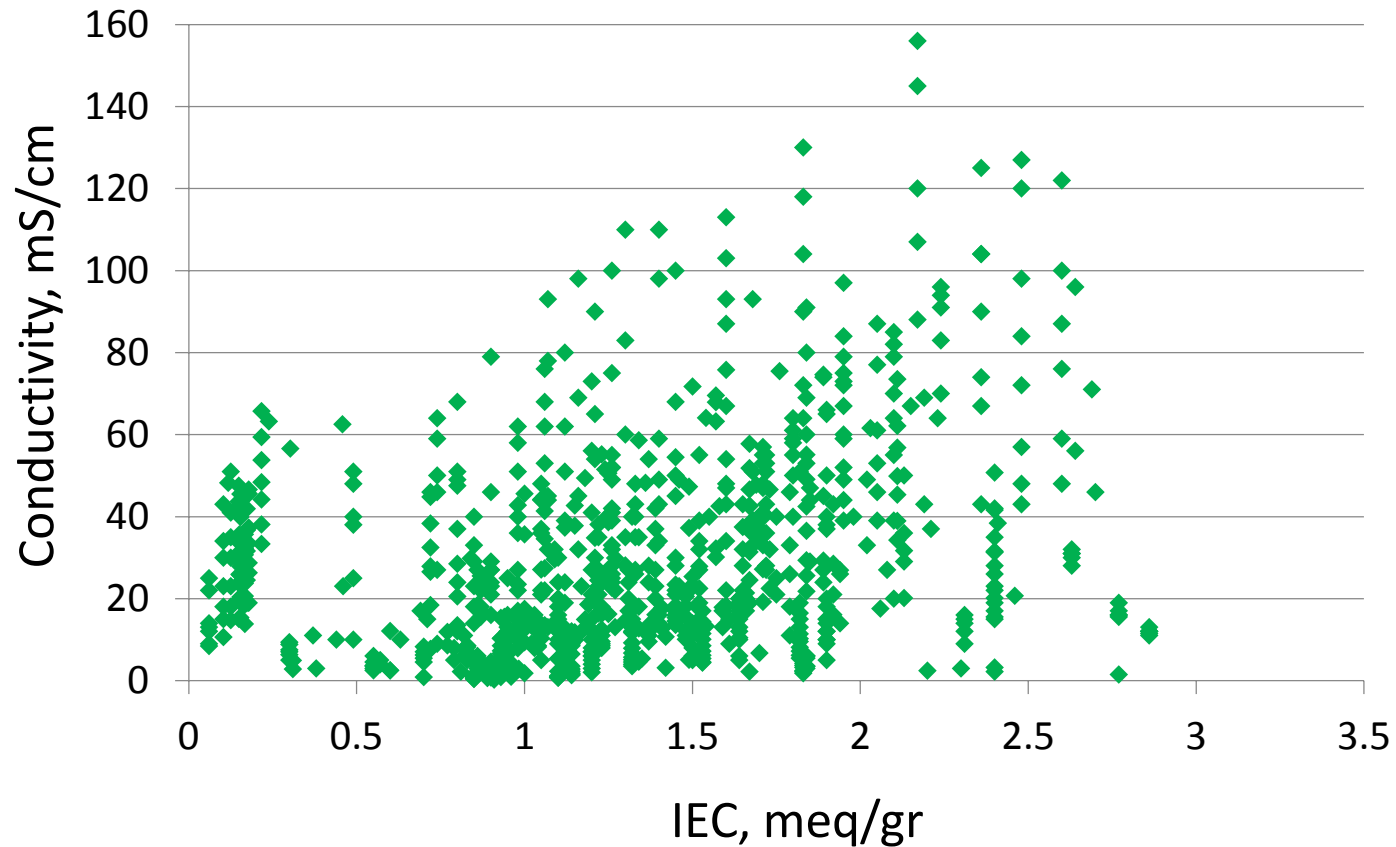
Breaking conductivity barriers in AEMs



D. Dekel et al., to be submitted (2016)

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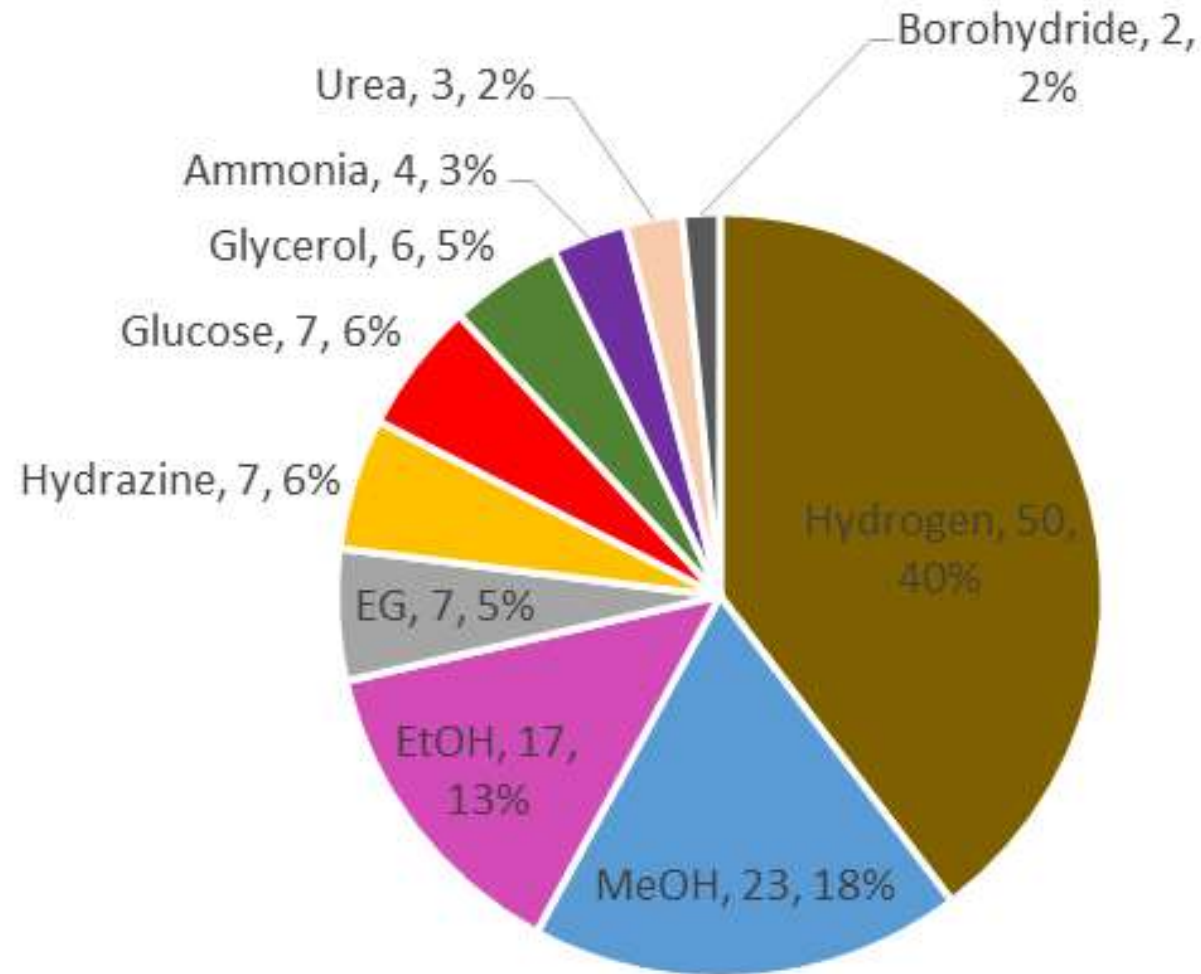
Breaking conductivity barriers in AEMs



D. Dekel et al., *to be submitted* (2016)

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AEM-FC tests in the literature – fuel diversity

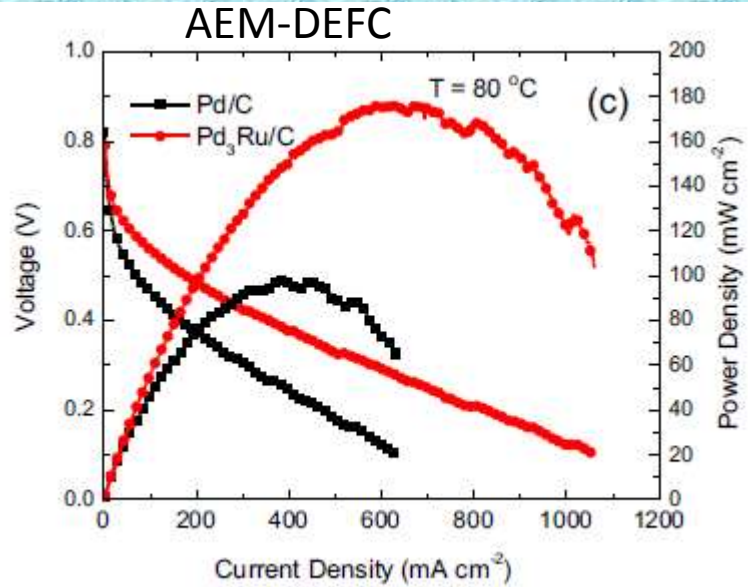


(accumulated) publications showing AEM-FC performance tests

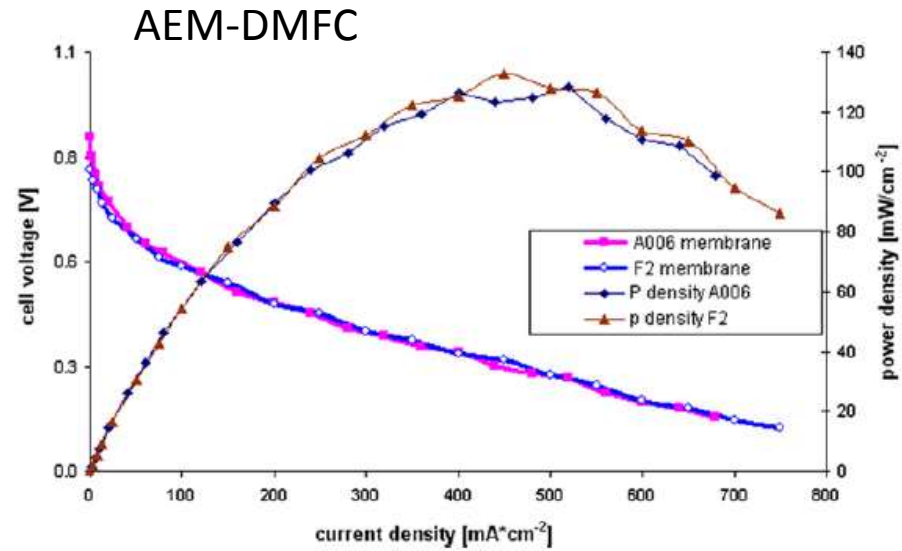
D. Dekel et al., *to be submitted* (2016)

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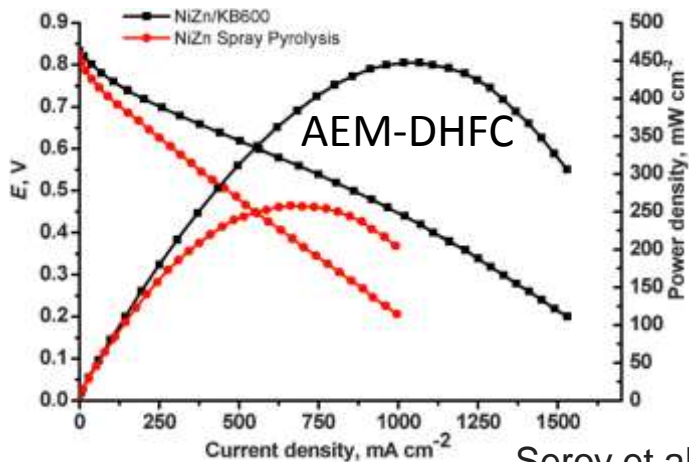
Performance of AEM-FCs: liquid fuels



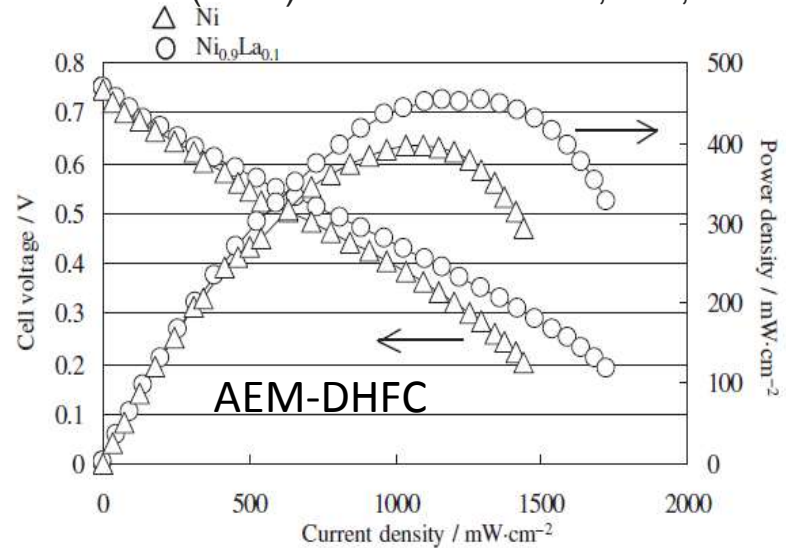
Ma et al. (2013) *J. Power Sources*, 241, 696



Katzfuß et al. (2013) *J. Membrane Sci.*, 425, 131



Serov et al., *Angewandte Chemie Intern. Ed.*, 53 (2014) 10336

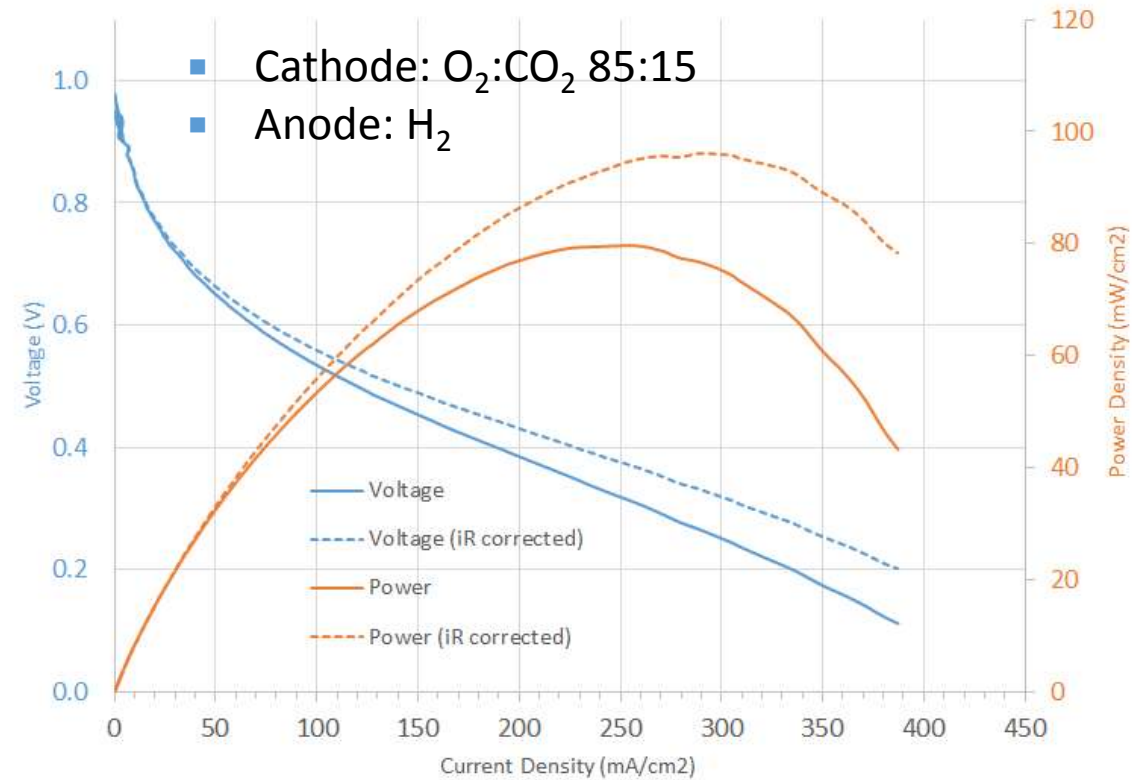
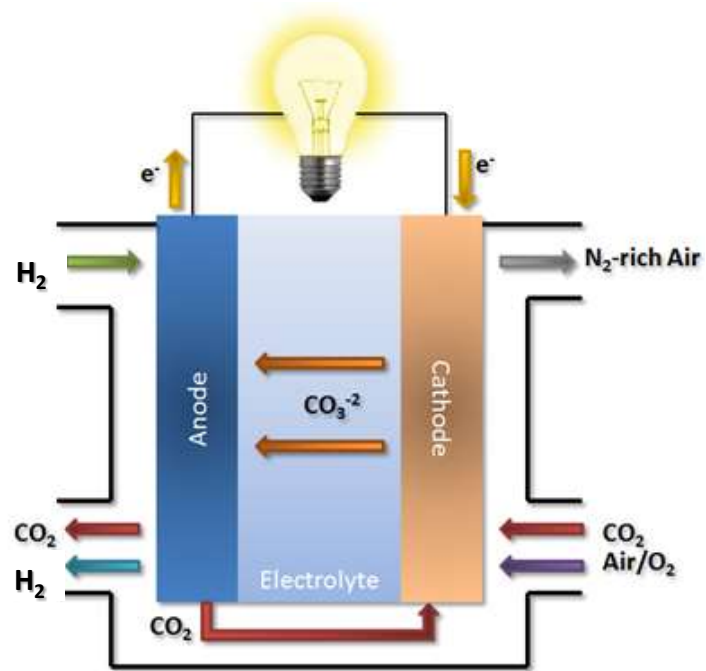


Sakamoto et al. (2013),
J. Power Sources, 234, 252

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Performance of AEM-FCs: carbonate/O₂ oxidant

Carbonate AEM-FC*



*received from W. Mustain



W. Rigdon, T. Omasta, C. Lewis and W.E. Mustain, *ECS Trans*, 69(33) (2015) 1-9.

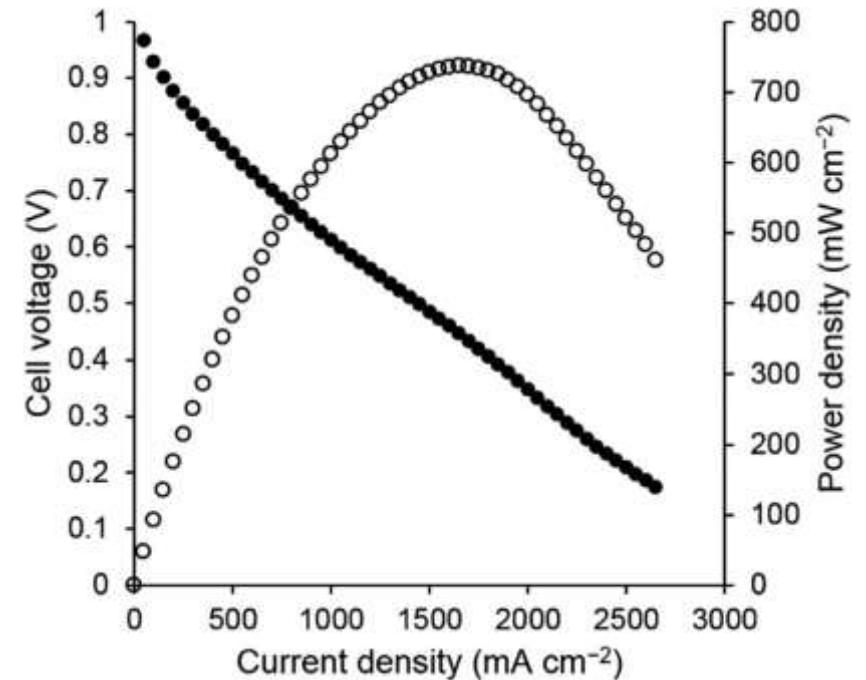
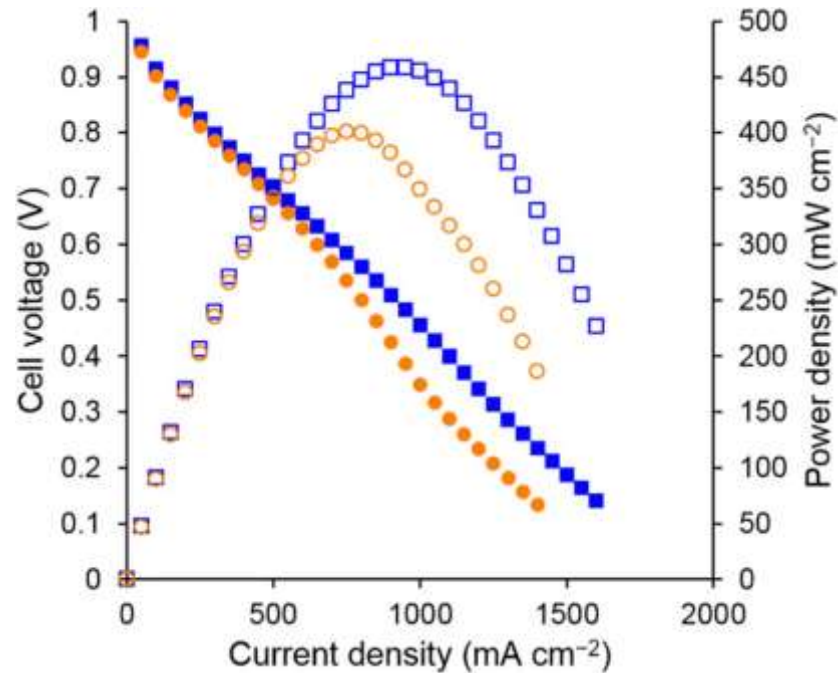
N. Spinner, W. Mustain, *J. Electrochem. Soc.*, 160 (2013) F1275.

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Performance of AEM-FCs: hydrogen fuel



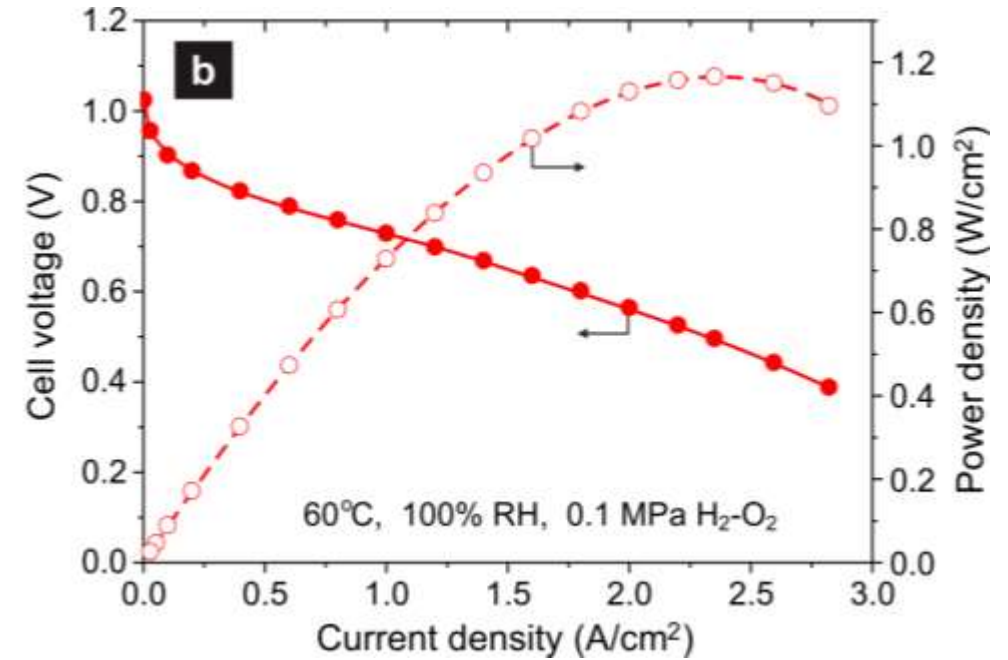
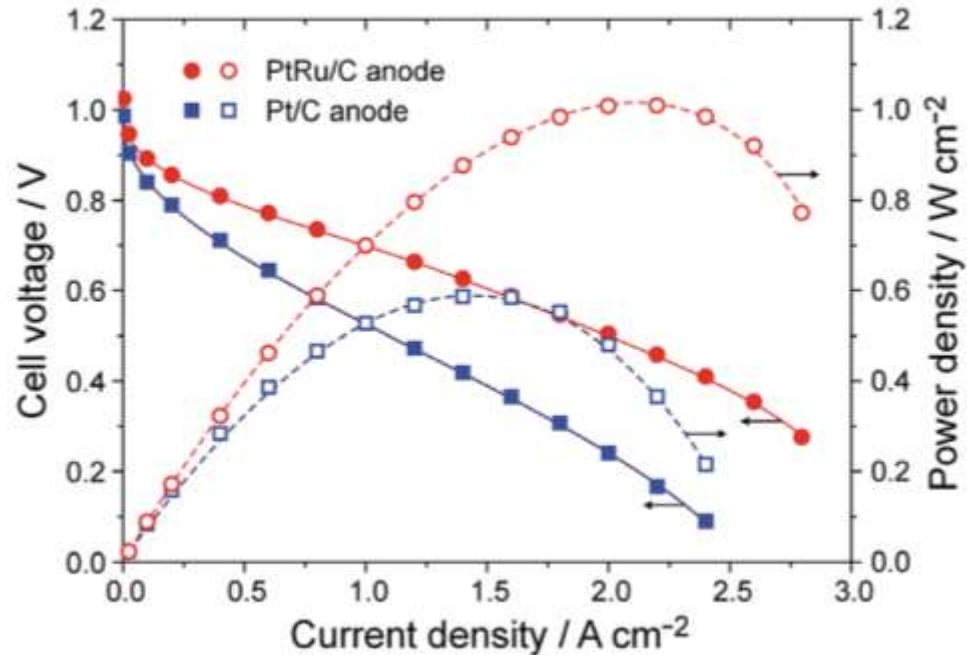
$0.4\text{mg}_{\text{Pt}}/\text{cm}^2$ **Pt/C**, $\text{RH}_{\text{cath}}=100\%$, $\text{H}_2 / \text{O}_2 \rightarrow 0.8\text{V @}350\text{mA}/\text{cm}^2$ (PPD=460mW/cm²)

$0.4\text{mg}_{\text{Pt}}/\text{cm}^2$ **Pt/C**, $\text{RH}=100\%$, $\text{H}_2 / \text{O}_2 \rightarrow 0.8\text{V @}420\text{mA}/\text{cm}^2$ (PPD=730mW/cm²)

Kaspar et al. (Yan); J. Electrochem. Soc. 162 (6) F483 (2015)

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Performance of AEM-FCs: hydrogen fuel



0.4mg/cm² **PtRu**, 0.4mg_{Pt}/cm² **Pt**, RH=100%, H₂ / O₂ → **0.8V @450mA/cm²** (PPD=1000mW/cm²)
 0.4mg/cm² **PtRu**, 0.4mg_{Pt}/cm² **PtRu**, RH=100%, H₂ / O₂ → **0.8V @550mA/cm²** (PPD=1200mW/cm²)

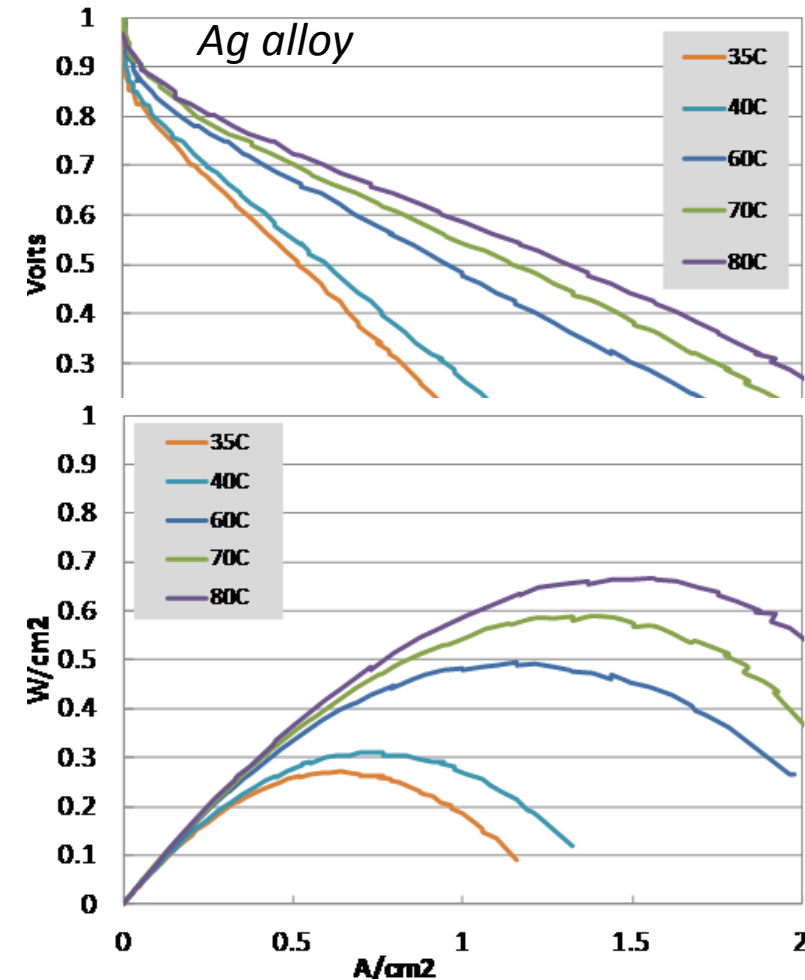
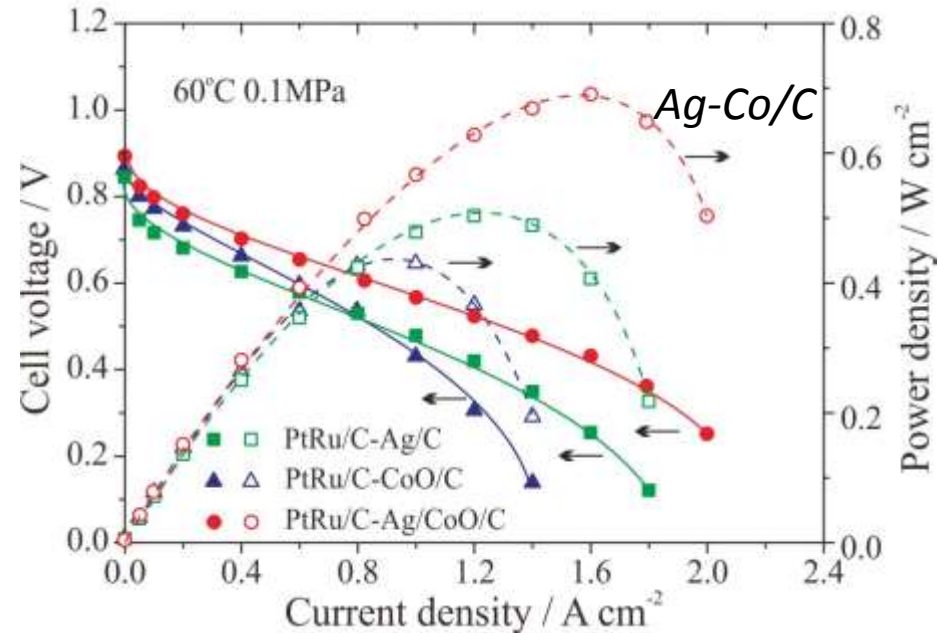
L. Zhuang, et al. *Energy Environ. Sci.* **2014**, 7, 354; **2015**, 8, 117

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Performance of H₂ AEM-FCs: non-Pt catalysts

Non-Pt ORR catalysts:

Ag-Co/C* and Ag alloy-based catalysts



*received from L. Zhuang (Wuhan)

H₂ / O₂ → 0.8V @150mA/cm² (PPD=700mW/cm²)

H₂ / air → 0.8V @330mA/cm² (PPD=680mW/cm²)

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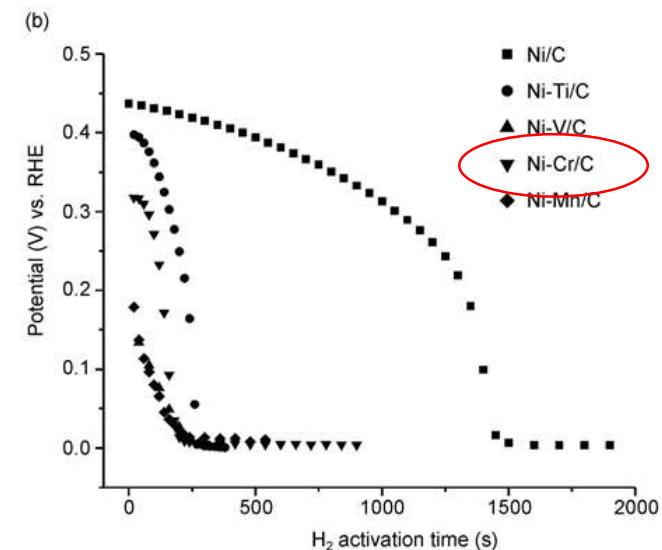
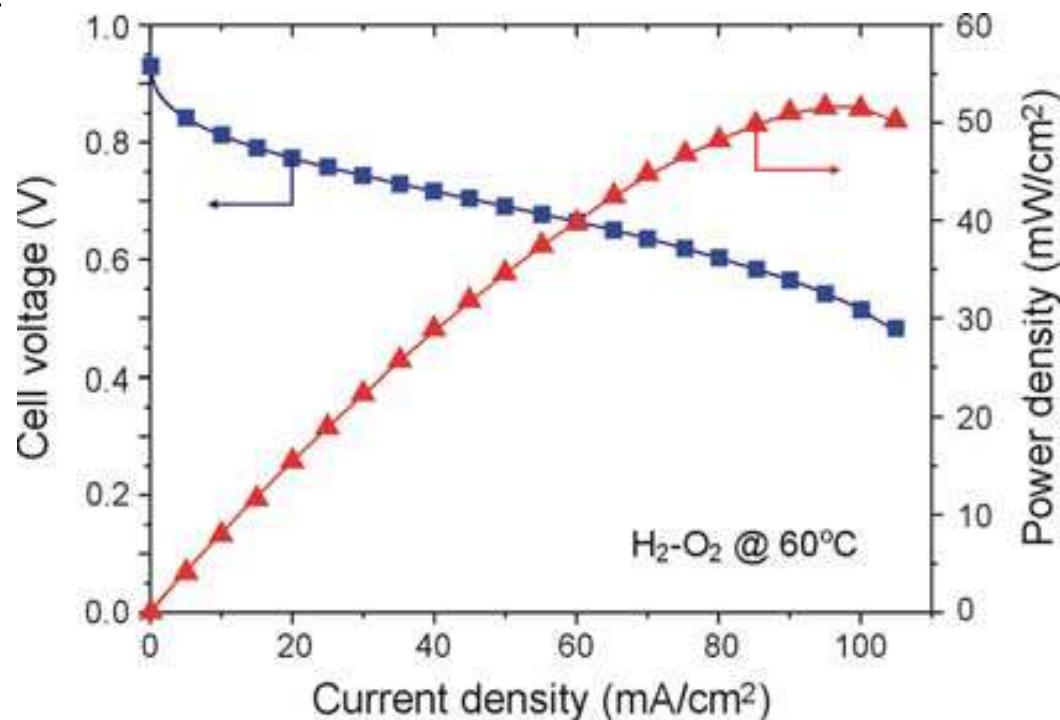
L. Zhuang, et al. to be submitted.

Dekel D.; Carisma 2012, Copenhagen, Denmark 2012

Dekel D.; PRiME 2012, 222nd ECS Meeting, Honolulu, Hawaii 2012

Performance of H₂ AEM-FCs: non-Pt catalysts

Non-Pt HOR/ORR catalysts:
Ni-based/Ag-based catalysts



$5\text{mg}_{\text{Ni}}/\text{cm}^2$ **Ni-Cr**, $1\text{mg}_{\text{Ag}}/\text{cm}^2$ **Ag**, RH=100%, H₂ / O₂ → **0.8V @13mA/cm²** (PPD=50mW/cm²)

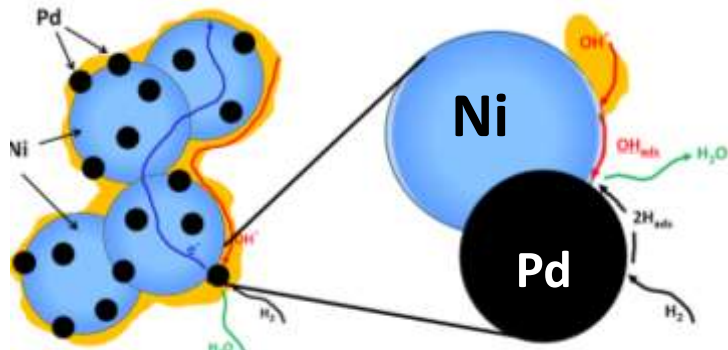
Lu et al.; Proc. Natl. Acad. Sci. USA, 105 (2008) 20611

Tang et al.; Sci China Chem (2010) 53 (2) 357

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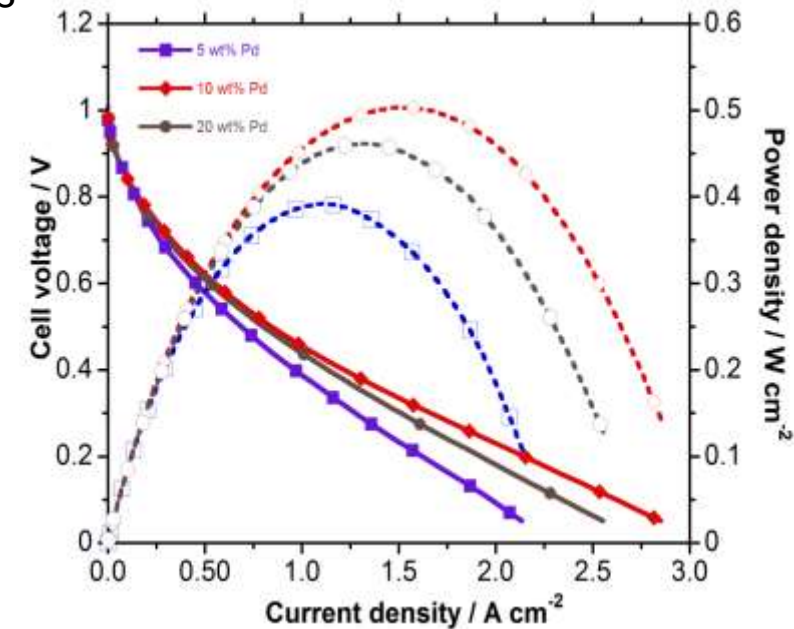
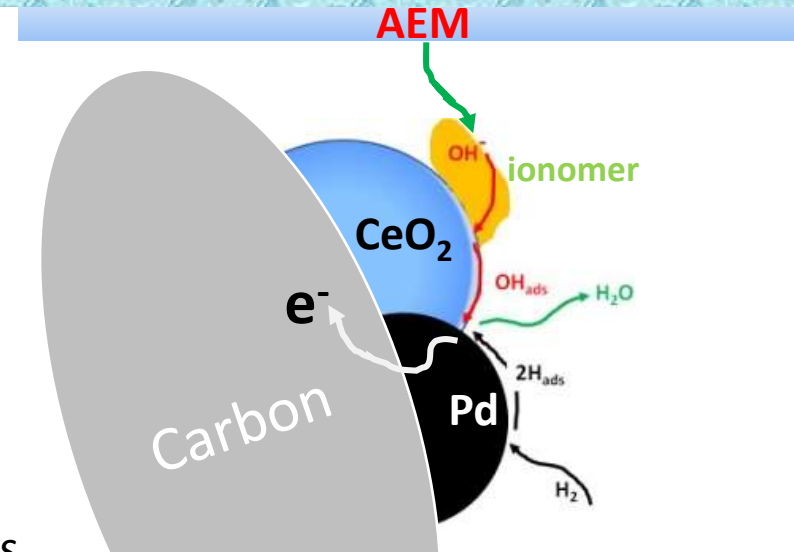
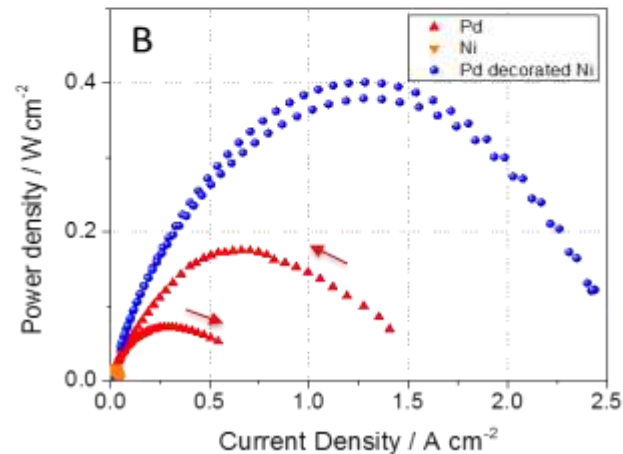
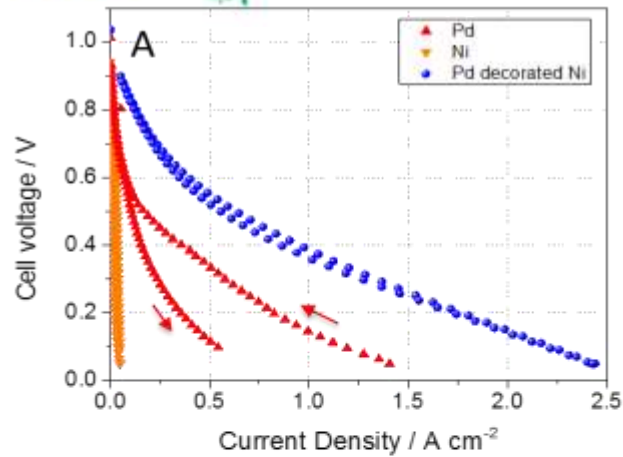
Performance of H₂ AEM-FCs: non-Pt catalysts



Key concept for successfully catalytic effect in alkaline: bi-functionality

Ni based catalysts

C-CeO₂ based catalysts



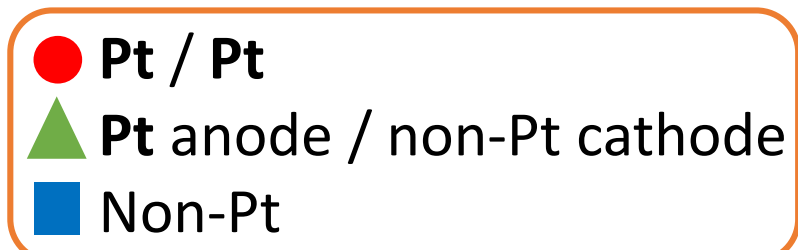
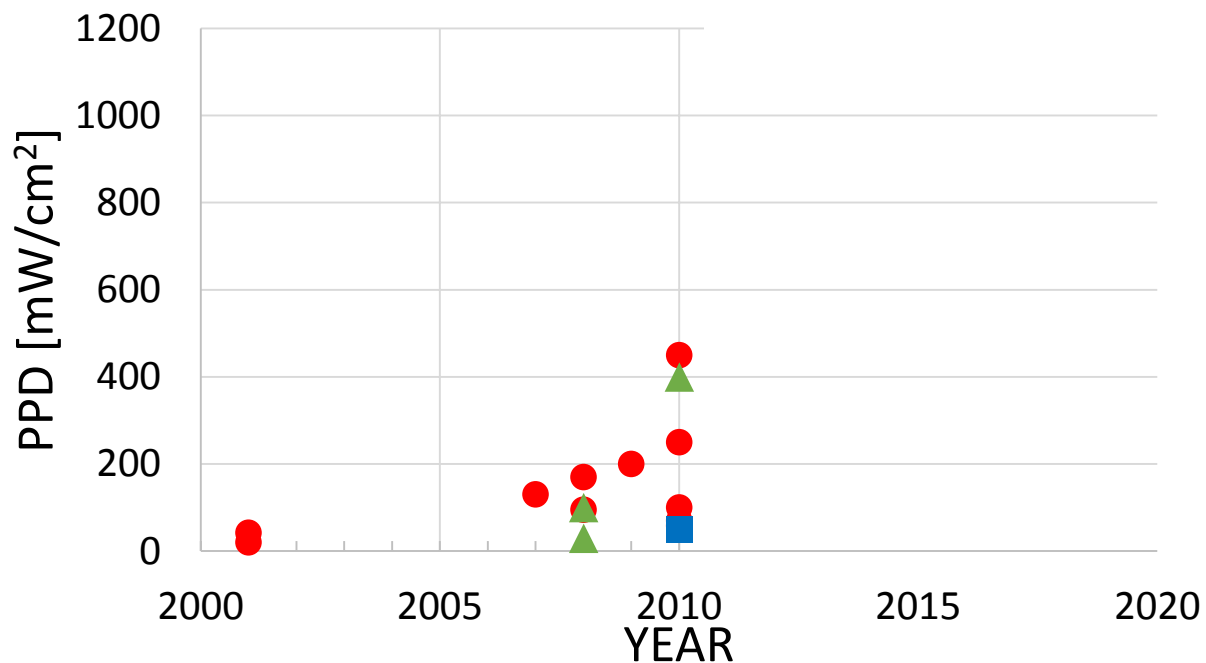
Dekel et al.; EP Patent 2,847,814, **2015**

Alesker, ... Dekel and Zitoun; J. Power Sources 304 (**2016**) 332

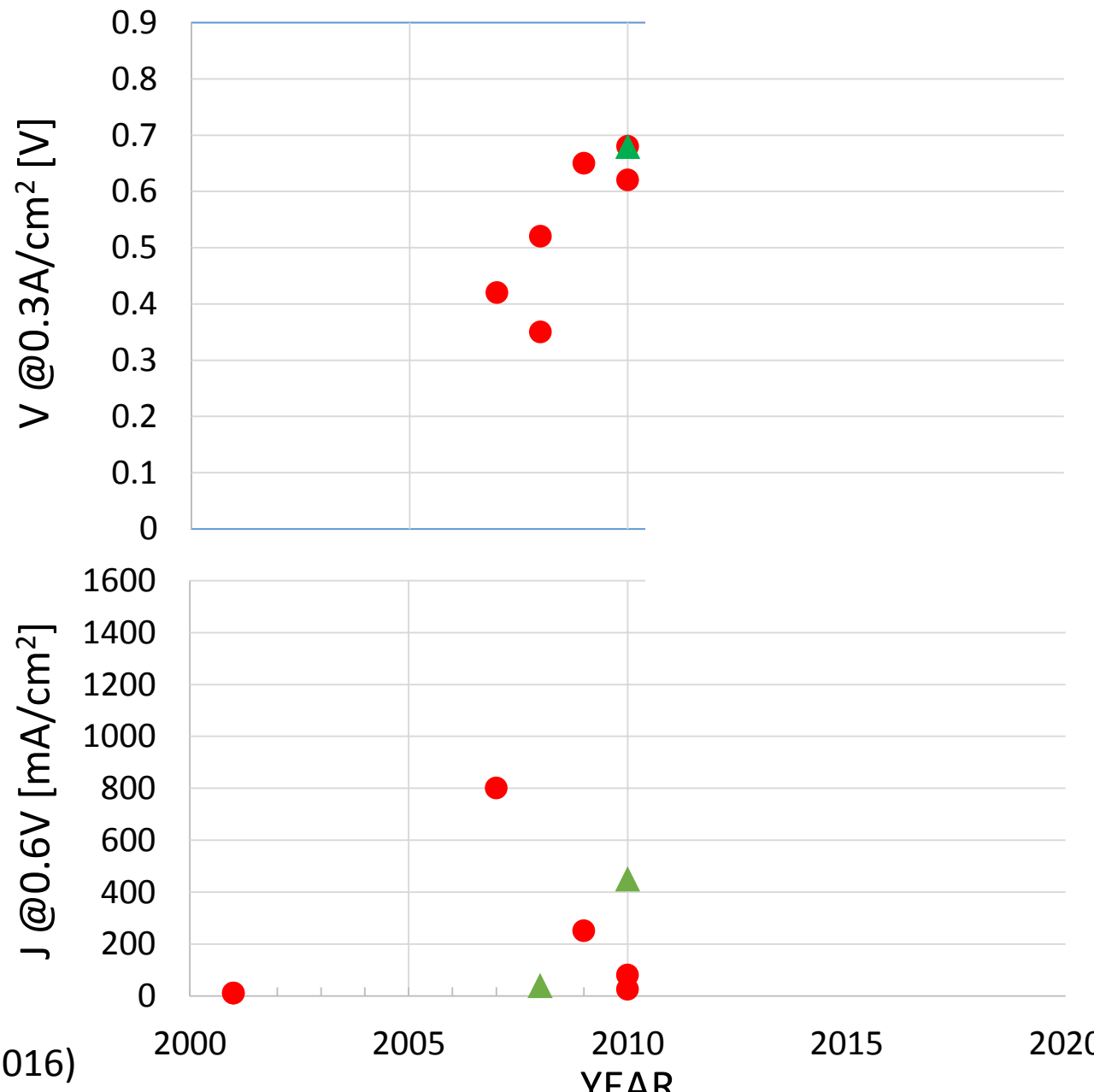
Miller, ... Page and Dekel; Angewandte Chemie (accepted), **2016**

Performance of H₂ AEM-FCs: summary

Initial performance of H₂-O₂ (air) AEM-FC:



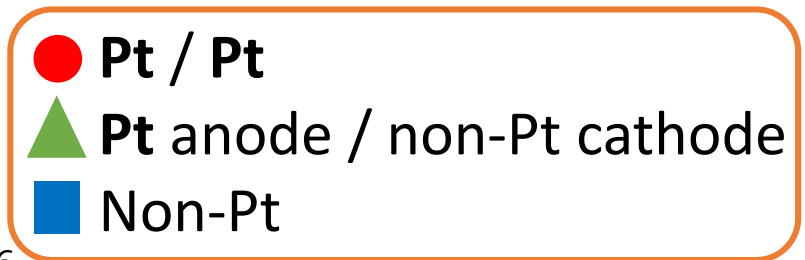
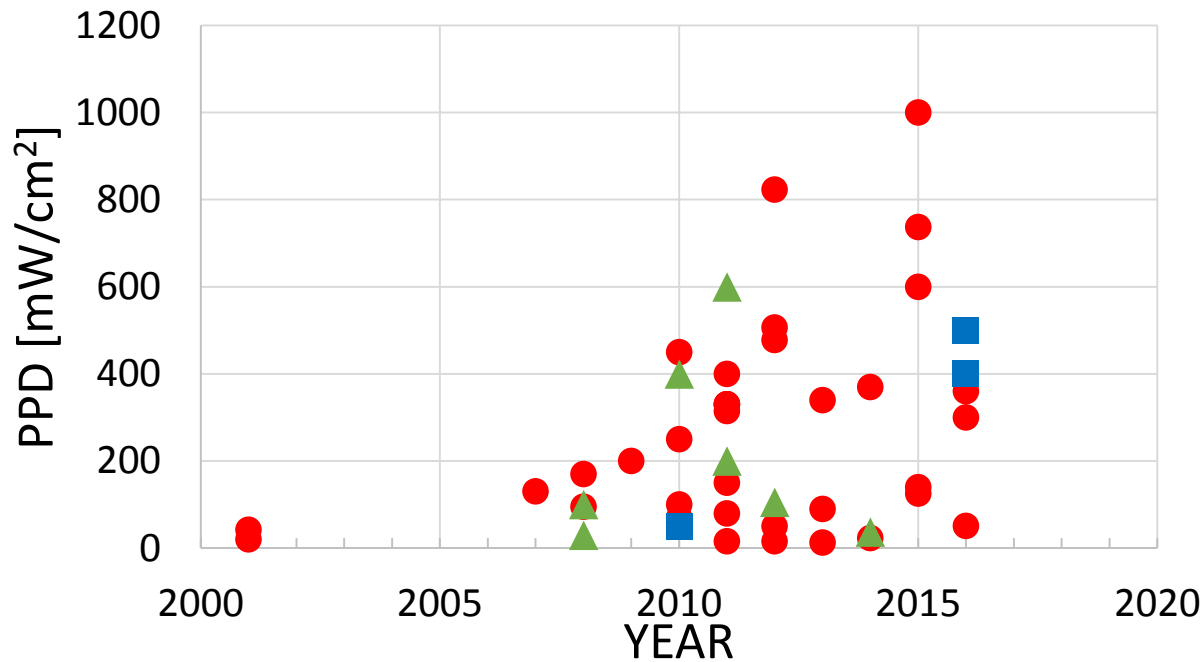
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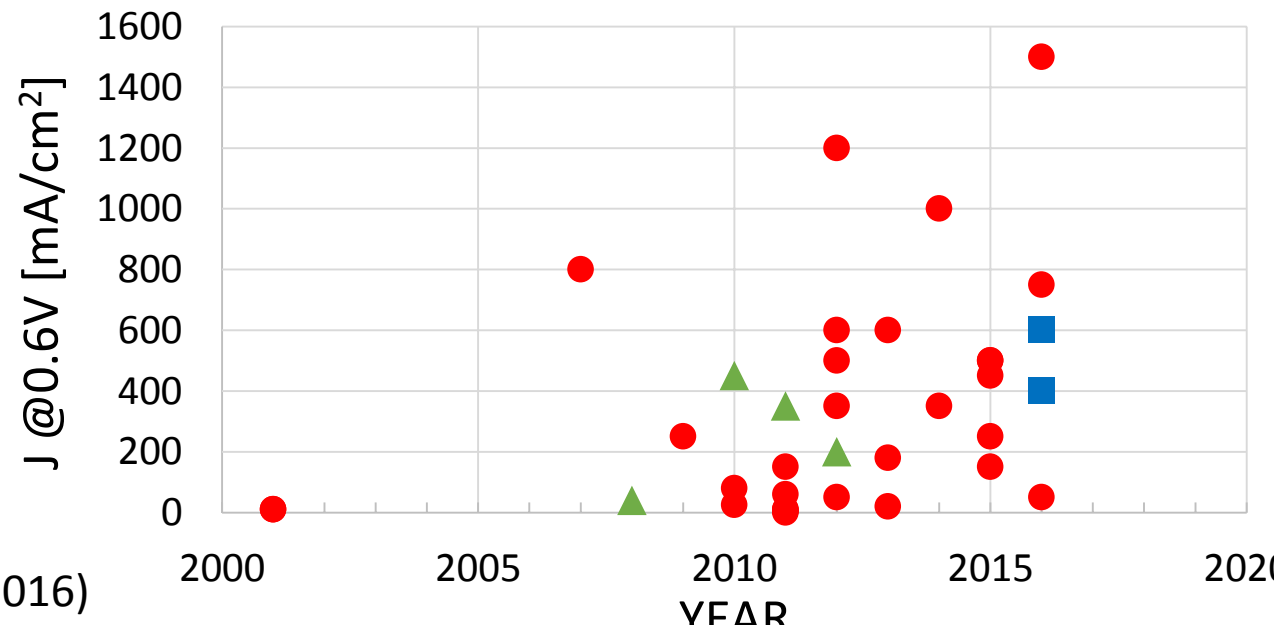
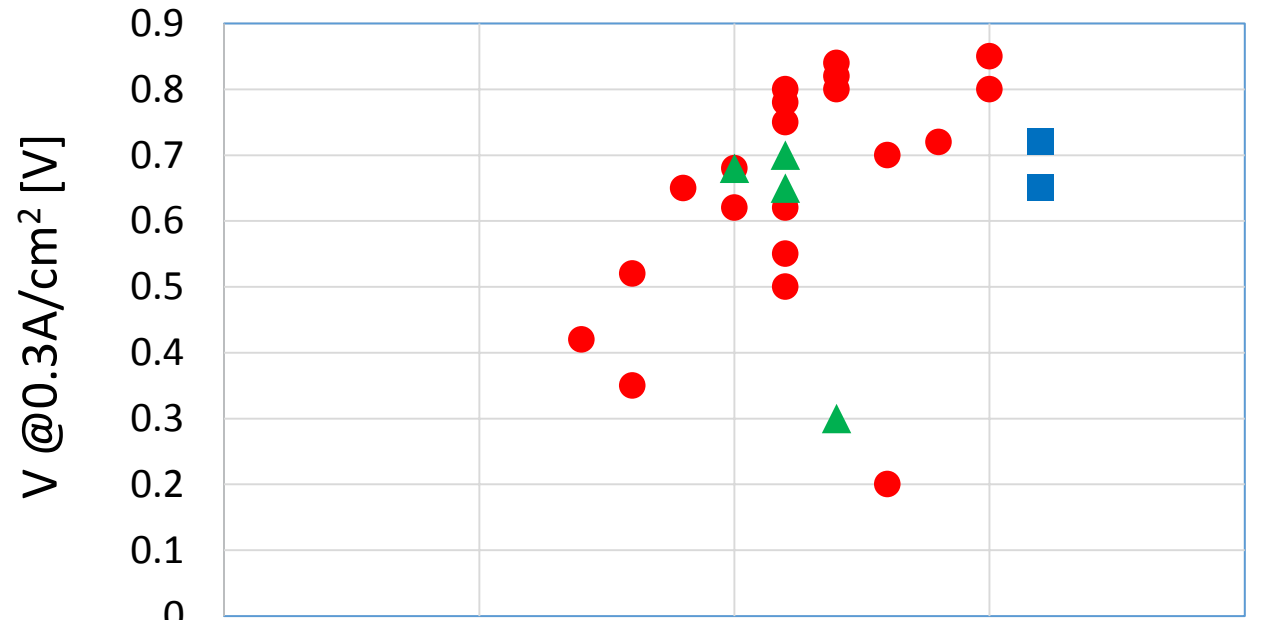
D. Dekel et al., to be submitted (2016)

Performance of H₂ AEM-FCs: summary

Initial performance of H₂-O₂ (air) AEM-FC:



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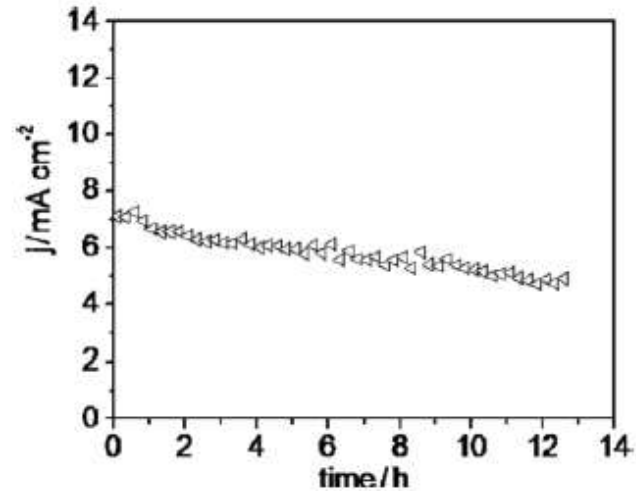


D. Dekel et al., to be submitted (2016)

Performance stability of AEM-FCs: longevity tests

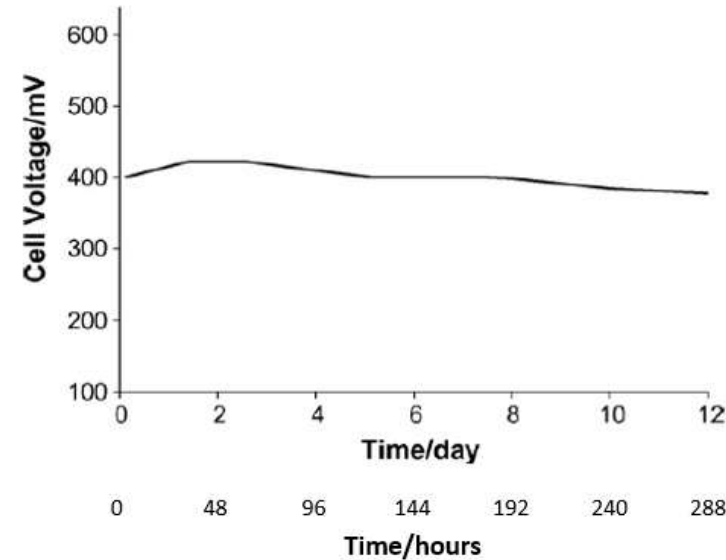
Liquid fuels (with KOH electrolyte):

DM carbonate FC



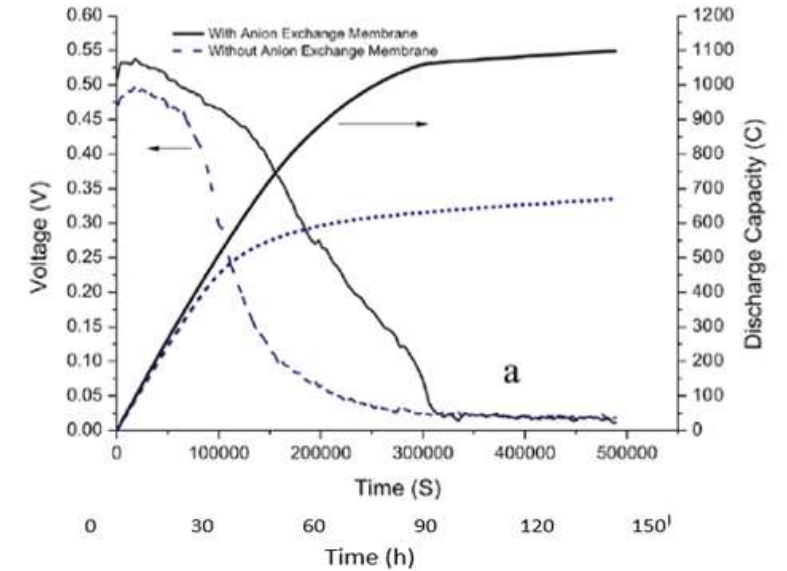
Wang et al., *Fuel Cells* 13 (2013) 817

DMFC



Scott et al., *J. Power Sources* 175 (2008) 452

DGFC

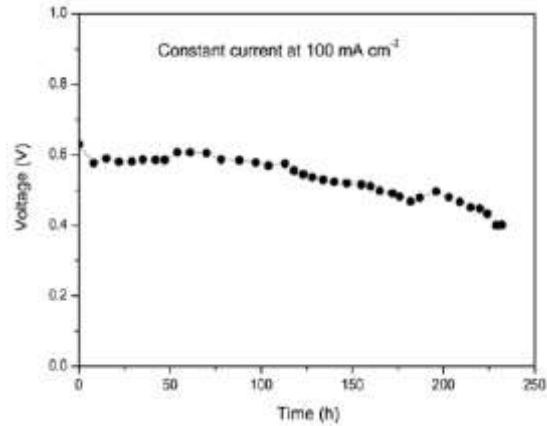


Yang et al., *Int. J. Hydrogen Energy* 40 (2015) 10979

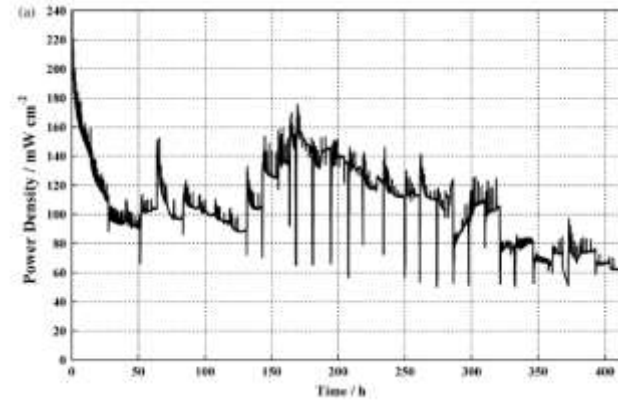
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Performance stability of AEM-FCs: longevity tests

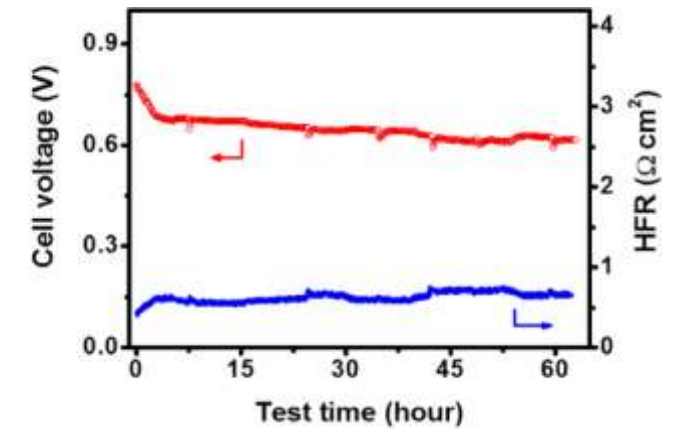
Hydrogen fuel:



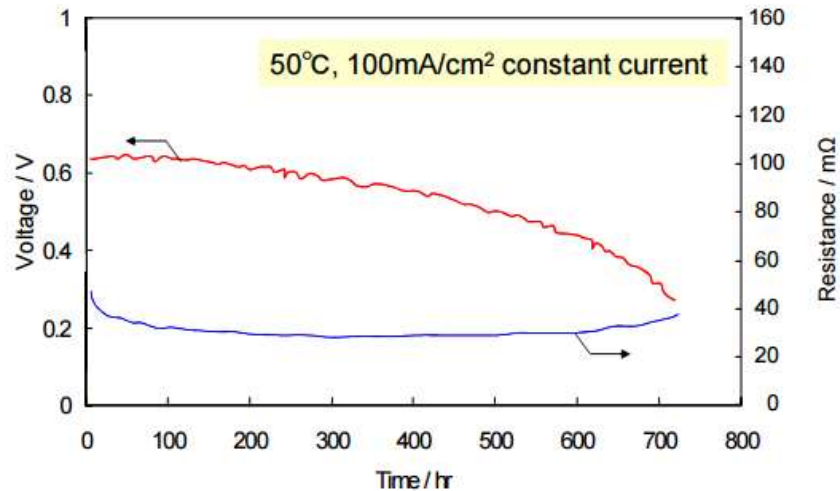
Zhao et al.; *J. Power Sources* 221 (2013) 247



Piana et al.; *J. Power Sources* 195 (2010) 5875

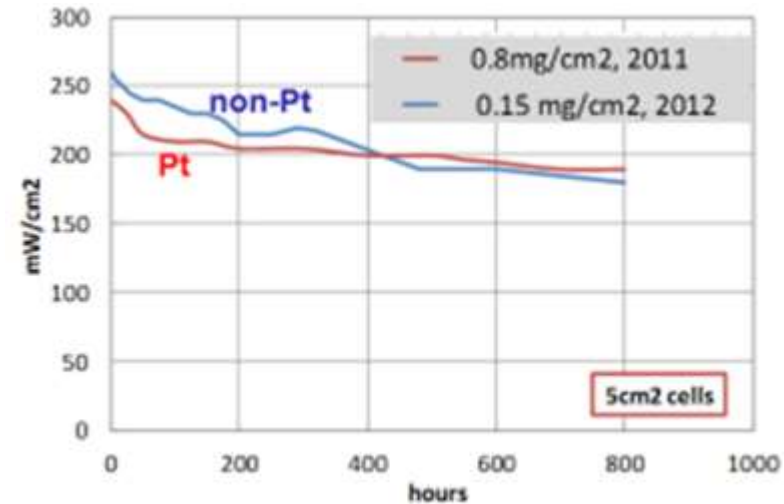


Li et al., *JACS* 135 (2013) 10124



Fukuta (2011)

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/amfc_050811_fukuta.pdf



Dekel D.; Carisma 2012, Copenhagen, Denmark 2012

Dekel D.; 222nd ECS Meeting, Hawaii 2012

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In summary – AEM-FC status:

So far, about 100 papers on performance of AEM-FCs were published. Half of them focused on hydrogen-fueled AEM-FC. From those papers we can summarize the following:

- Highest initial peak power densities achieved are around ~ 1 W/cm². ✓
- Pt-based catalysts (mainly for HOR) are still used in most of the studies. ✗
- First AEM-FCs with zero-platinum loading showing good performance were recently published (2016). ✓
- There are no significant AEM-FC tests based on PGM-free catalysts for HOR. ✗
- Most of the AEM-FC tests are limited to $T_{\text{cell}} < 60^{\circ}\text{C}$ (due to polymer degradation issues). ✗
- There are only very few AEM-FC tests showing (limited) longevity. ✗
- So far AEM-FC tests are limited to CO₂-free gases (mainly O₂). ✗

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