PEFC Technology Development

Göran Lindbergh, Björn Eriksson, Annika Carlson, Rakel Wreland Lindström, Carina Lagergren, KTH

Fuel Cell 2015

Arlanda, December 3, 2015

Layout of presentation

- Introduction
- Drivers for commercial introduction of fuel cells
- Research funding and roadmaps
- Cost for fuel cells
- Employments in fuel cell industry
- Reducing the amount of platinum catalyst
- Replacing platinum
- Ongoing research at KTH

Drivers for fuel cell adoption

- **Resilience**
  Blackouts
- **Futureproofing**
  Long term investments, insurances
- **Shifting Models of Adoption**
  New business models
- **Water**
  Fuel production
- **Emissions**
  Pollutants, green house gases

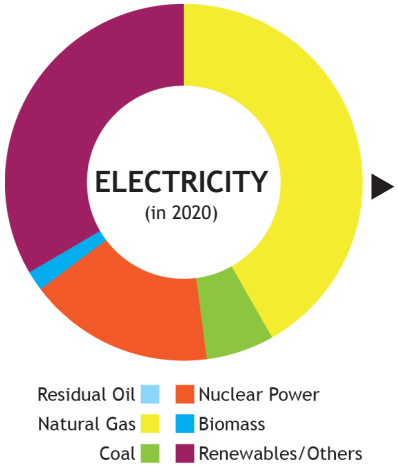
Source: 4th Energy Wave, Fuel Cell Annual Review, 2015

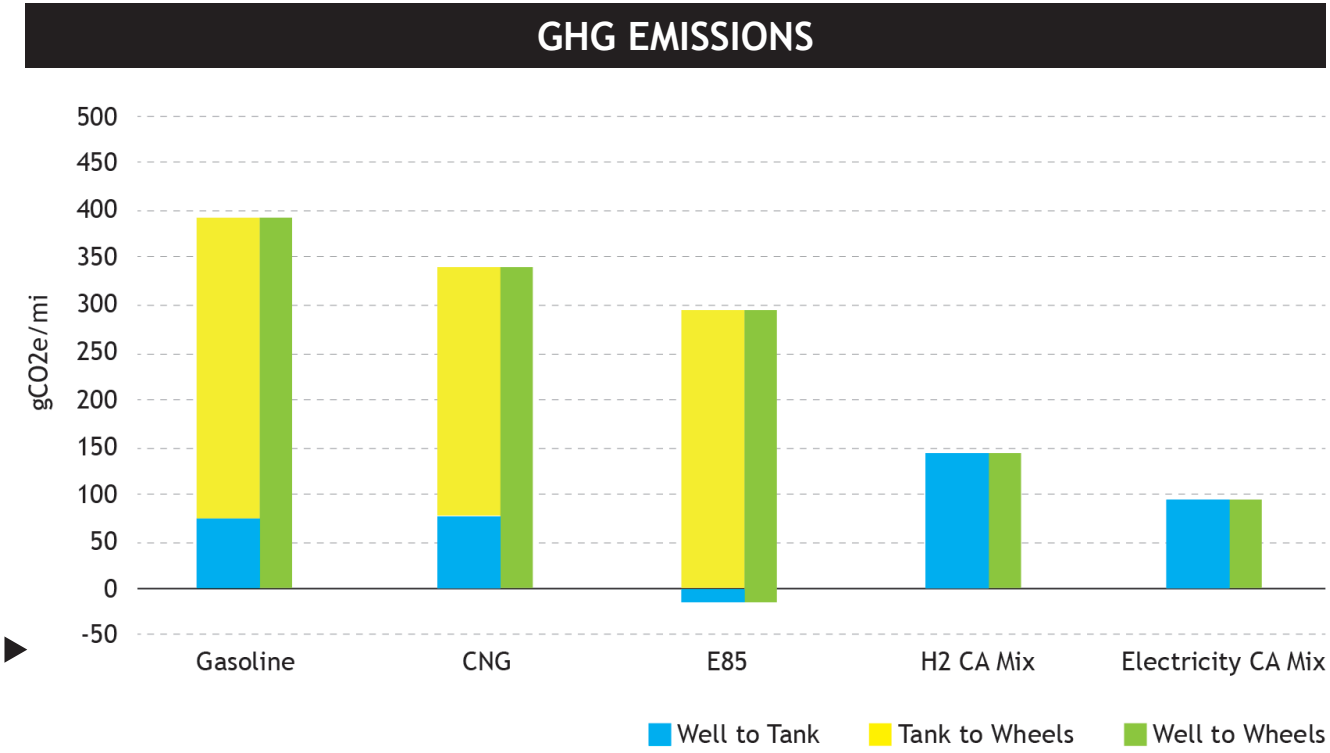
Drivers for Fuel Cell Cars in California

- **AIR:** California home to some of the most polluted air in the US. 89% of residents living in counties with unhealthy air during some parts of the year.
- **ENERGY**: About 38% of the energy use in California is associated with transportation.
  CLIMATE: Transportation is the largest source of emissions, accounting for 37 percent.
- **WATER**: Producing fuels requires substantial water input.
- **SECURITY**: California produces only 37% of the transport fuel used.

Source: California Fuel Cell Partnership

Greenhouse gas emissions

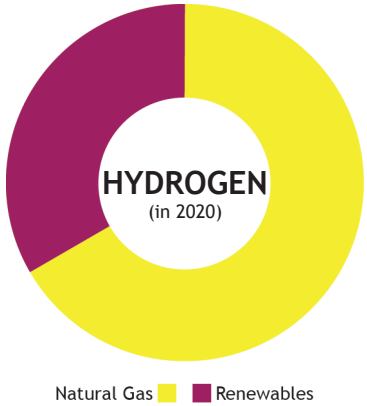




GREET V1_2013

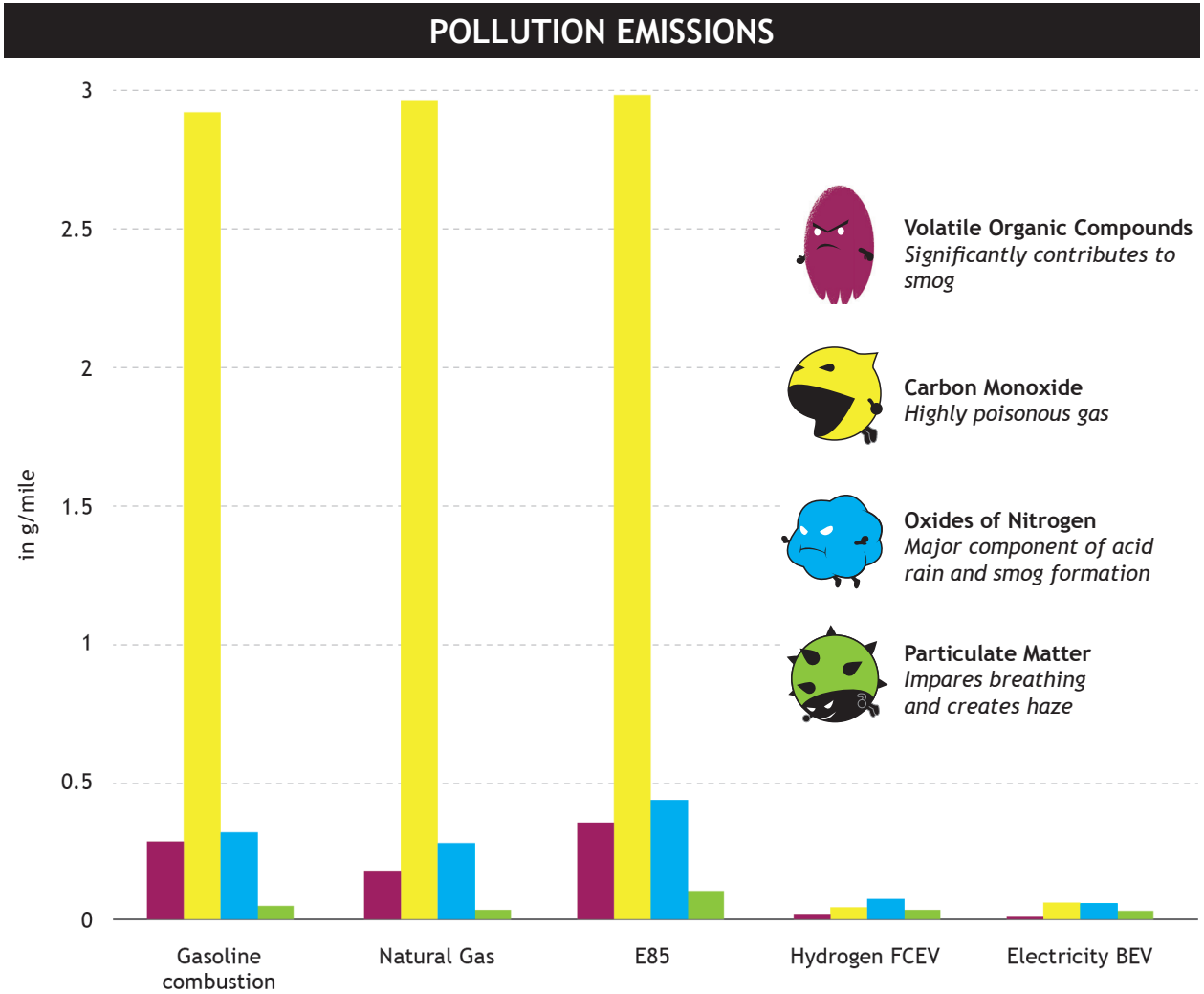
Assumes a 2020 model year mid-sized sedan, California mix of electricity in all pathways, and California blend of gasoline.

greet.es.anl.gov



Source: California Fuel Cell Partnership

Pollution emissions



GREET V1_2013

Assumes a 2020 model year mid-sized sedan, California mix of electricity in all pathways, and California blend of gasoline.

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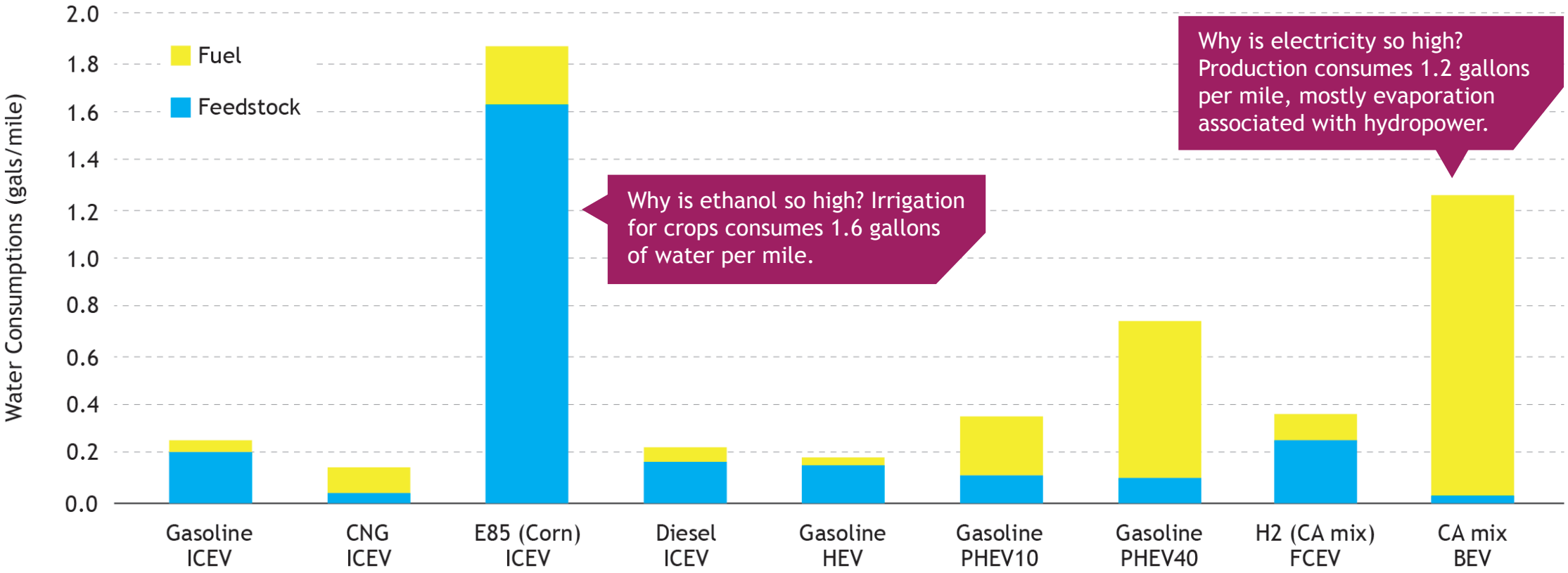
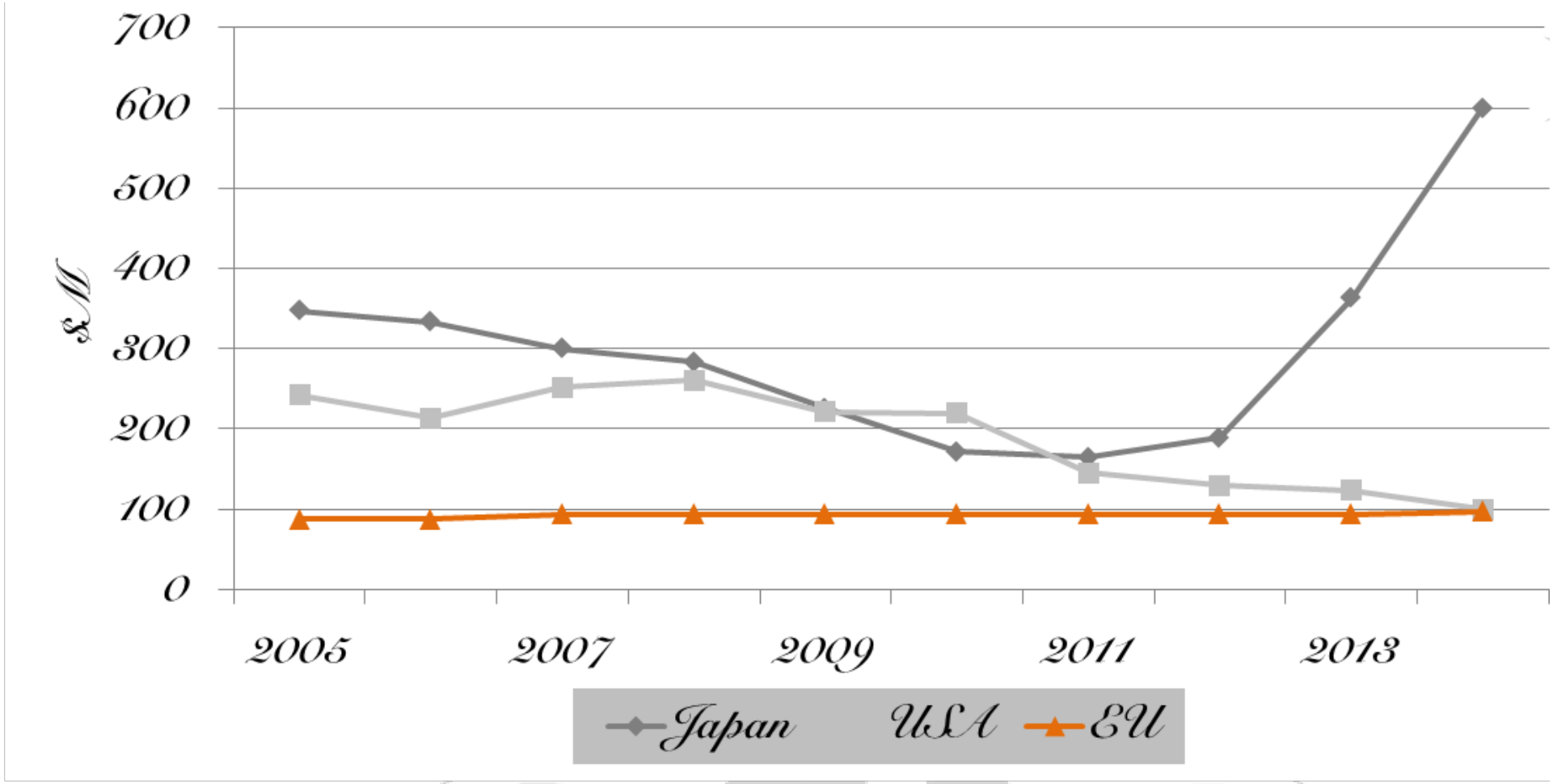
Source: California Fuel Cell Partnership

Water consumption



Source: California Fuel Cell Partnership

Fuel Cell Funding in Japan, the USA and the EU: 2005 – 2014



Source: N Behling, 4th Energy Wave

Roadmap Japan

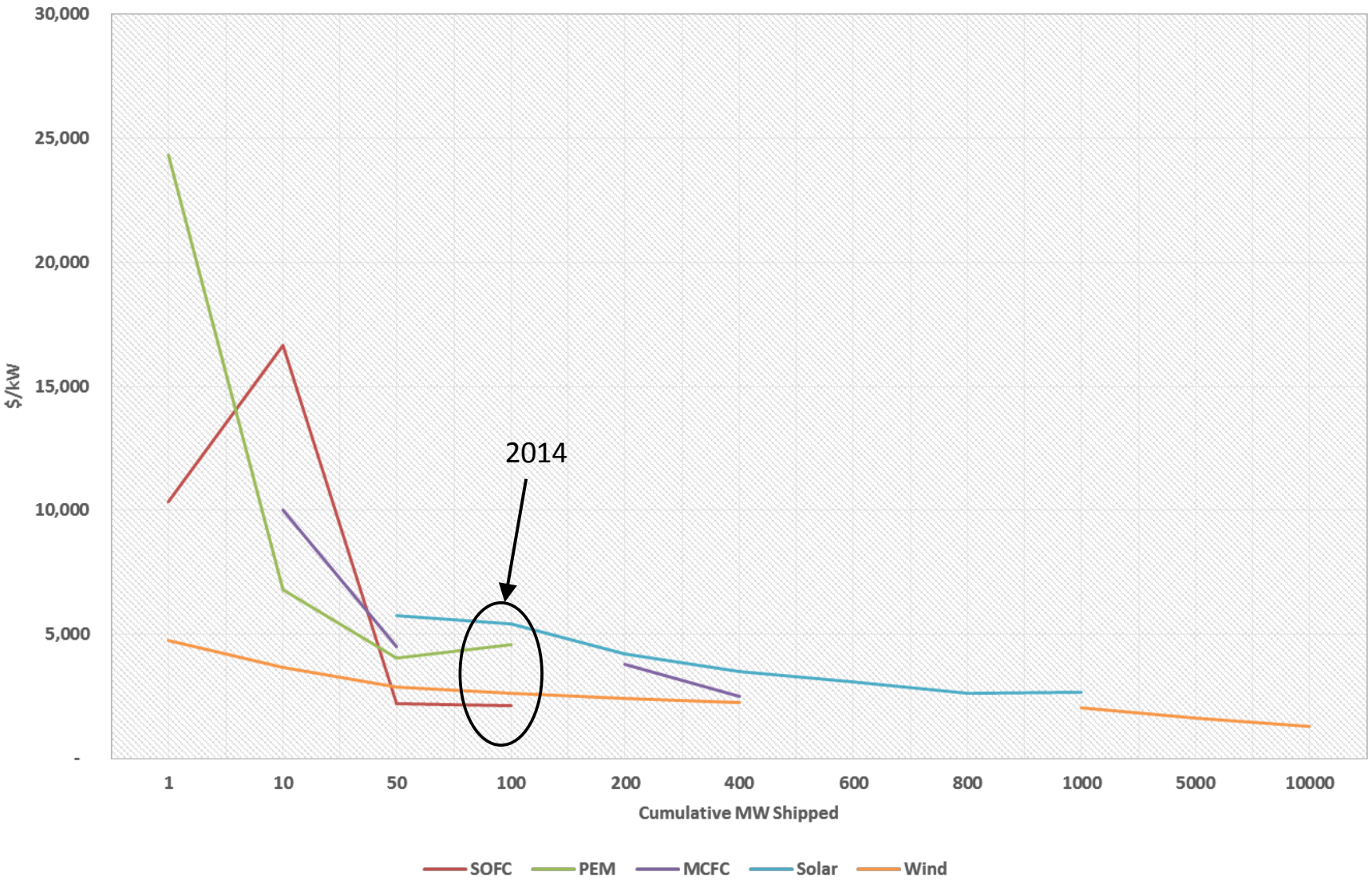
Policy favouring fuel cells and hydrogen:

- Increase the number of residential fuel cells to 1.4 million in 2020 and 5.3 million in 2030
- Increase the number of hydrogen refuelling stations to 100 by 2015
- Commercialise fuel cell vehicles by 2015 and fuel cell buses by 2016
- Support the introduction of fuel cell vehicles with a 2 million Yen subsidy

Long term targets:

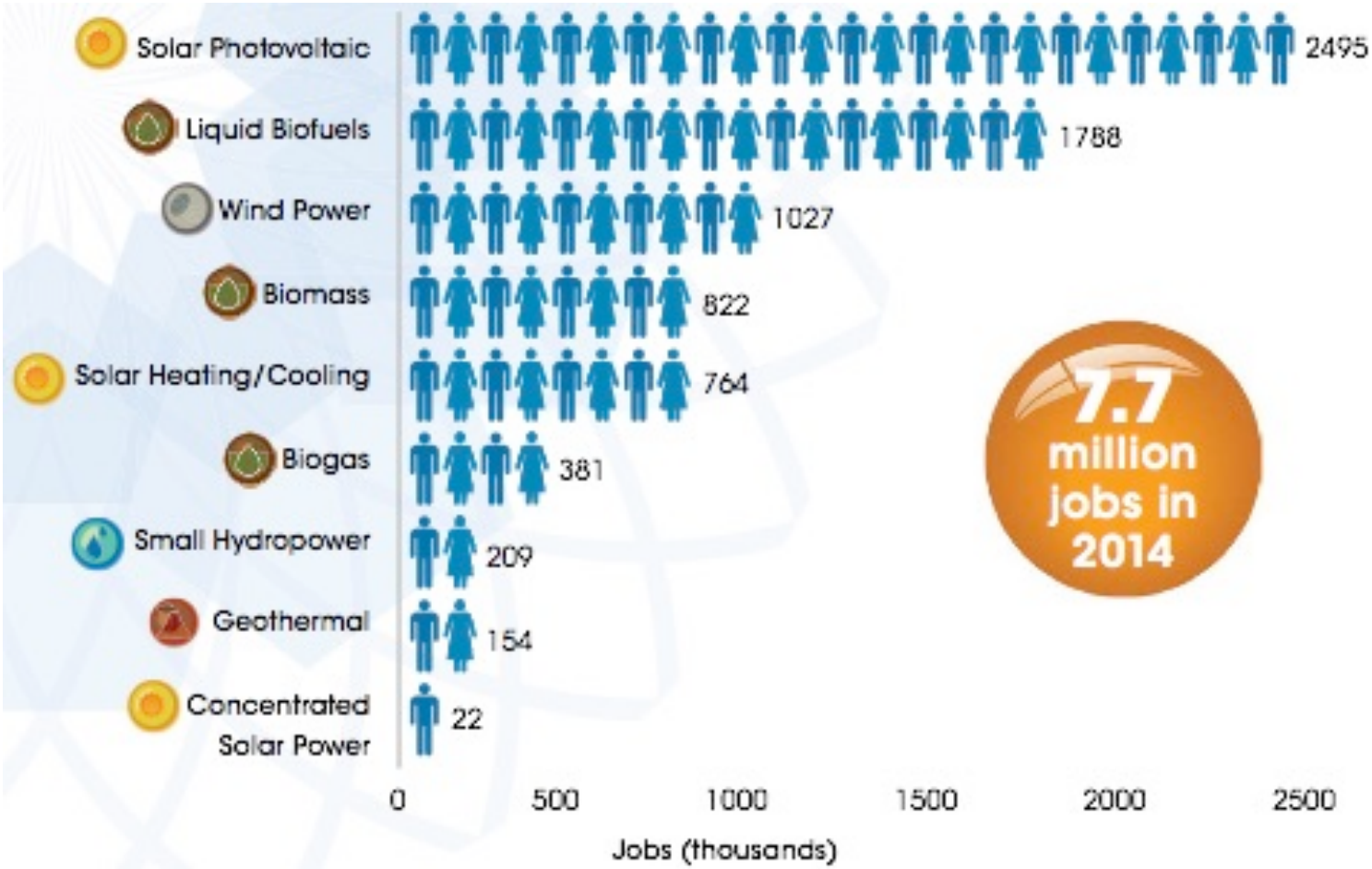
- Be able to purchase commodity hydrogen from abroad, at 30 Yen/m^3 (about 3 US$/kg)

Fuel cell cost for fuel cells, solar and wind



Source: IRENA, 2012 and 4th Energy Wave, 2015

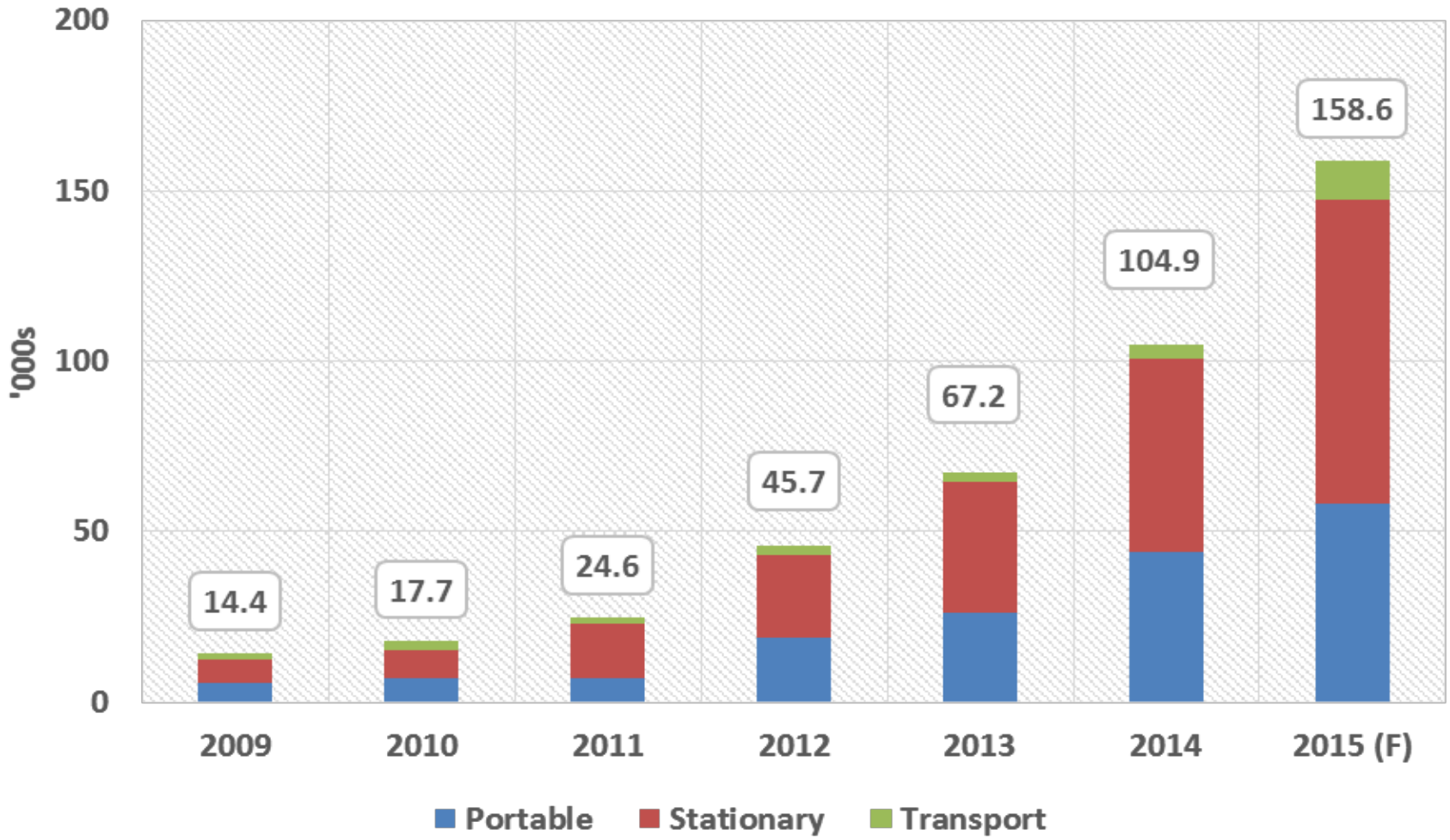
Renewable energy employment by technology



> 12,000 working direct in the fuel cell industry across the supply chain

Source: IRENA Renewable Energy and Jobs – Annual Review 2015

Global fuel cell shipments by application



Source: 4th Energy Wave, 2015

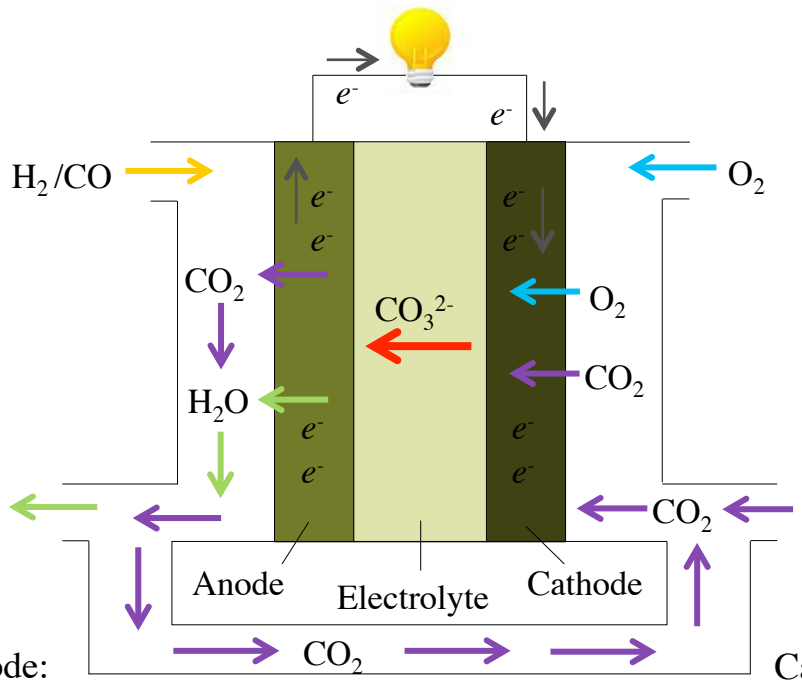
Molten Carbonate Fuel Cell (MCFC) for combined heat and power generation

59 MW_{el} fuel cell plant in Hwasung City, South Korea

What is Molten Carbonate Electrolysis Cell (MCEC)?

- Fuel Cell (MCFC)

Chemical energy → Electricity



Anode:

$H_2+CO_3^{2-} \rightarrow H_2O+CO_2+2e^-$

$CO+CO_3^{2-} \rightarrow 2CO_2+2e^-$

Cathode:

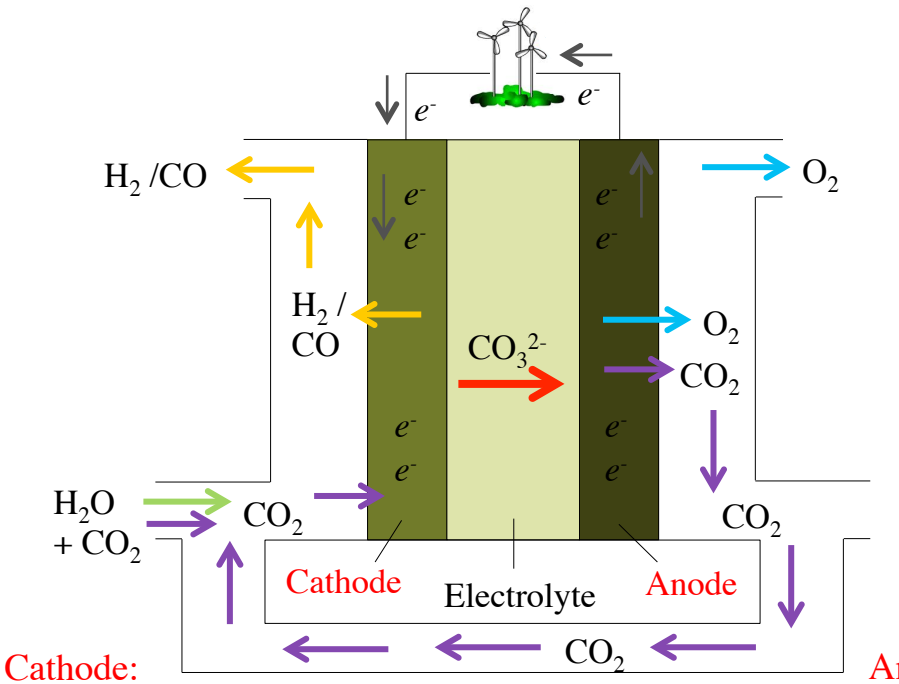
$\frac{1}{2}O_2+CO_2+2e^- \rightarrow CO_3^{2-}$

Overall: $H_2+\frac{1}{2}O_2+CO_{2,Cat} \rightarrow H_2O+CO_{2,An}$

$CO+\frac{1}{2}O_2+CO_{2,Cat} \rightarrow 2CO_{2,An}$

- Electrolysis Cell (MCEC)

Electricity → Chemical energy



Cathode:

$H_2O+CO_2+2e^- \rightarrow H_2+CO_3^{2-}$

$2CO_2+2e^- \rightarrow CO+CO_3^{2-}$

Anode:

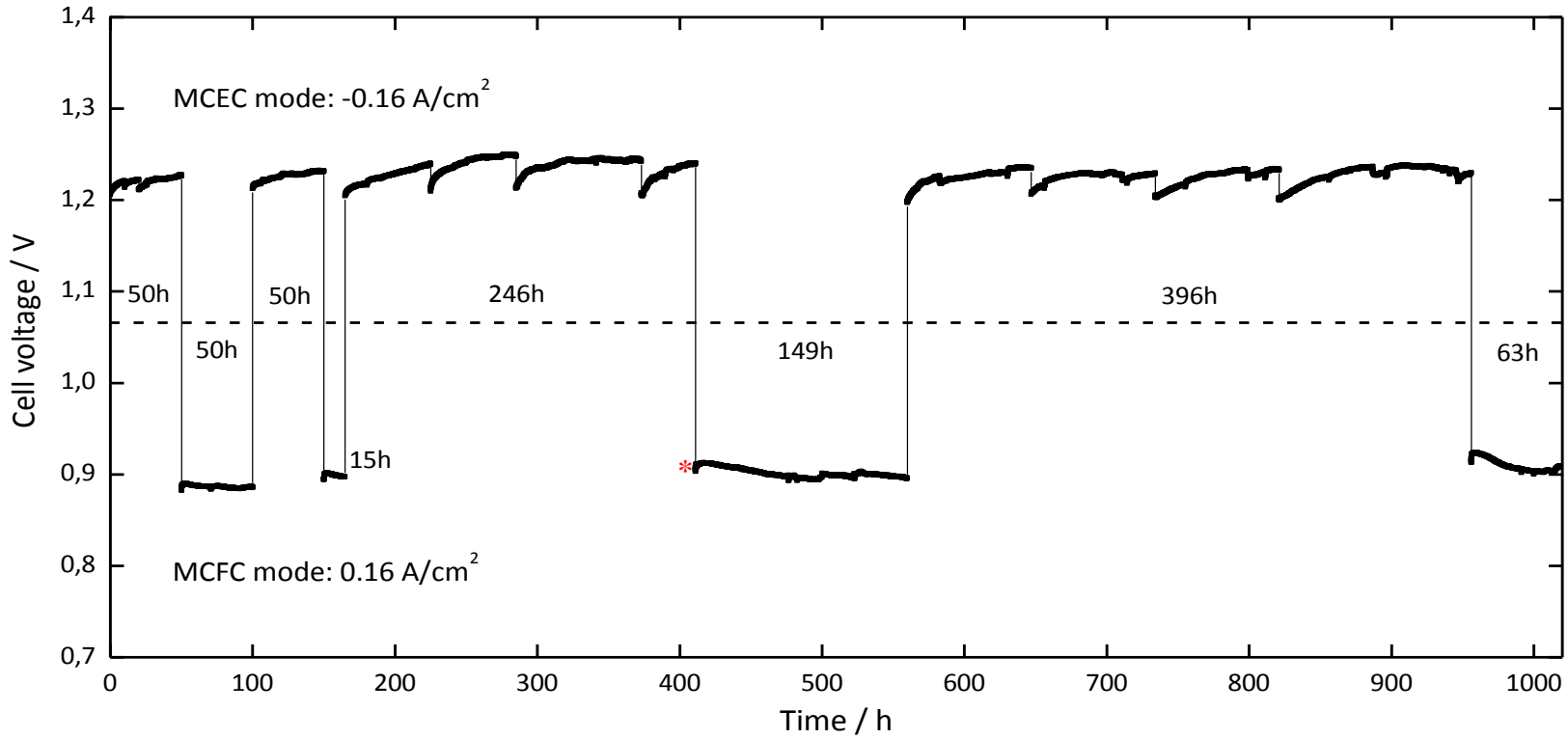
$CO_3^{2-} \rightarrow \frac{1}{2}O_2+CO_2+2e^-$

Overall: $H_2O+CO_{2,Cat} \rightarrow H_2+\frac{1}{2}O_2+CO_{2,An}$

$2CO_{2,Cat} \rightarrow CO+\frac{1}{2}O_2+CO_{2,An}$

Stability of the reversible molten carbonate fuel cell

Fuel gas: 64/16/20% $H_2/CO_2/H_2O$
Oxidant gas: 15/30/55% $O_2/CO_2/N_2$
Temperature: 650 °C



The long-term test shows stable cell performance in both MCEC and MCFC mode.

2015 Toyota Mirai Fuel Cell Sedan

Range:
About 650 km

FC Stack:
Power: 114 kW
Power density:
3.1 kW/L

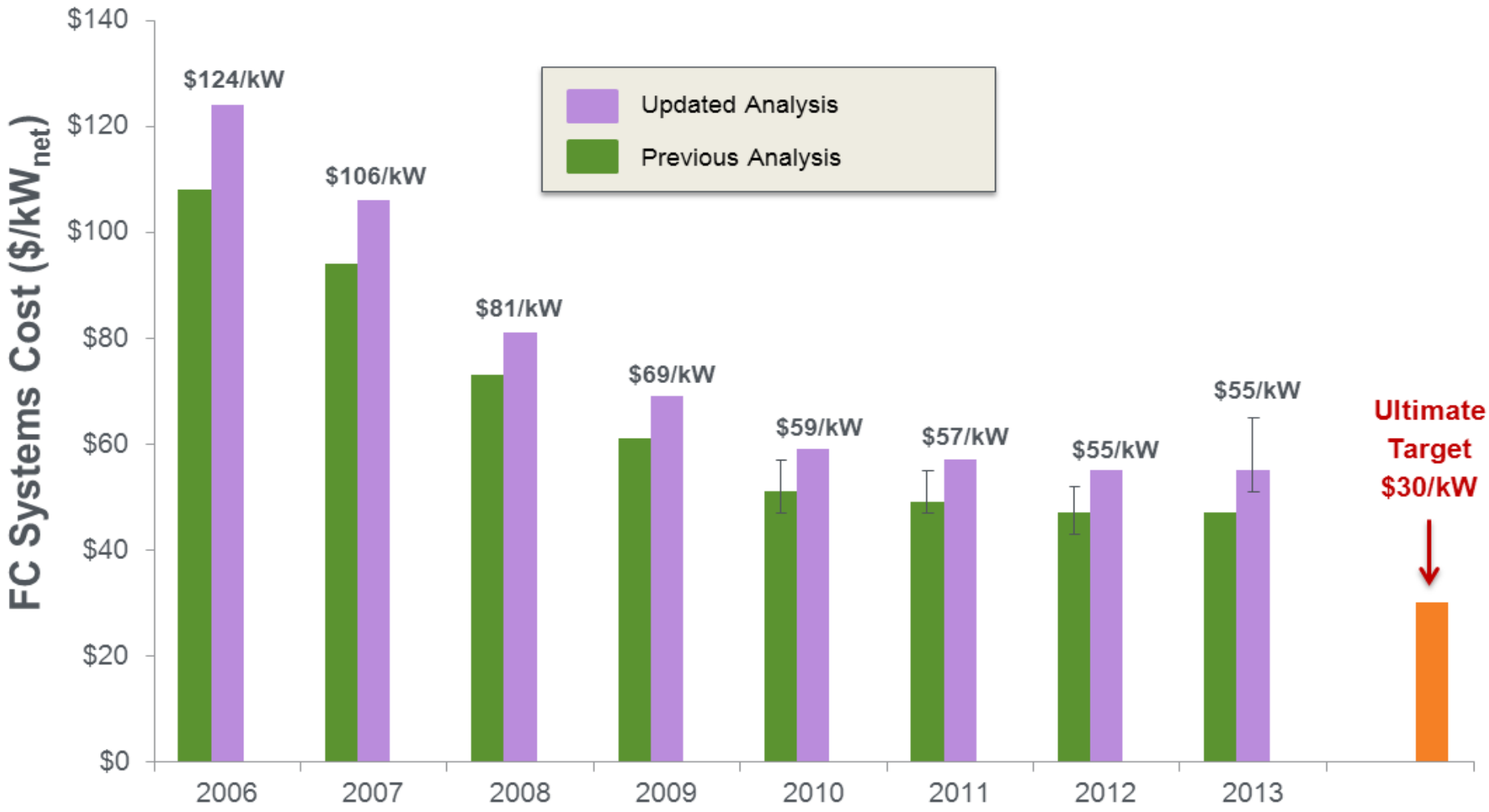
Battery:
1.6 kWh Nickel-metal hydride

Hydrogen tank:
Energy density:
5.7 wt%

http://commons.wikimedia.org/wiki/File:Toyota_mirai_trimmed.jpg

Modelled cost of PEM fuel cell system

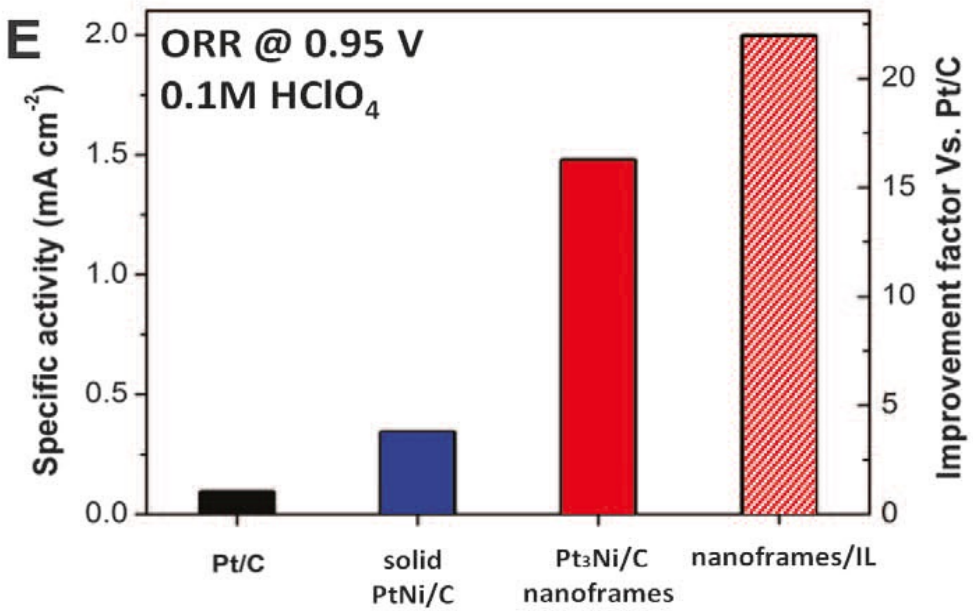
80 kW system projected to high-volume manufacturing (500,000 units/year)

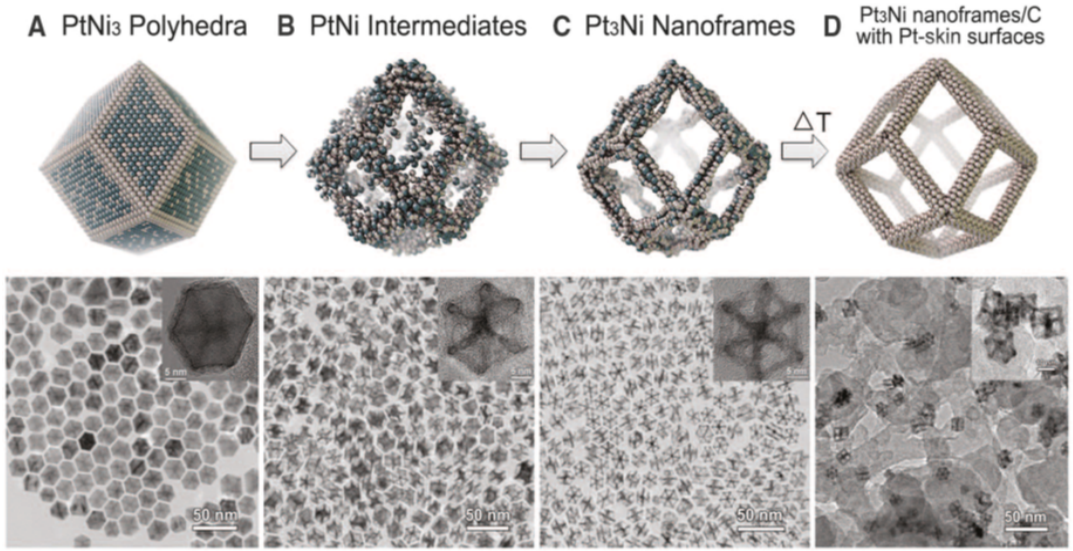


Source: DOE Fuel Cell Technologies Office Record, Fuel Cell System Cost – 2013

Approach 1: Reduce the amount of platinum

- Hollow Frame
- Very high specific activity

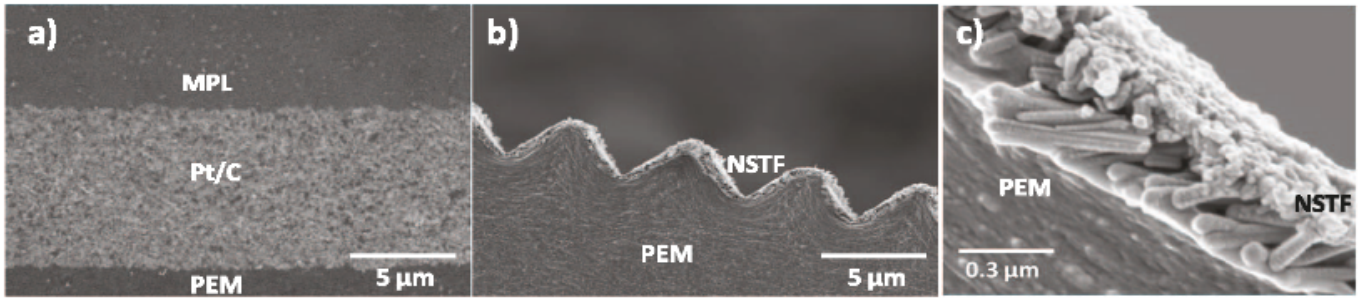


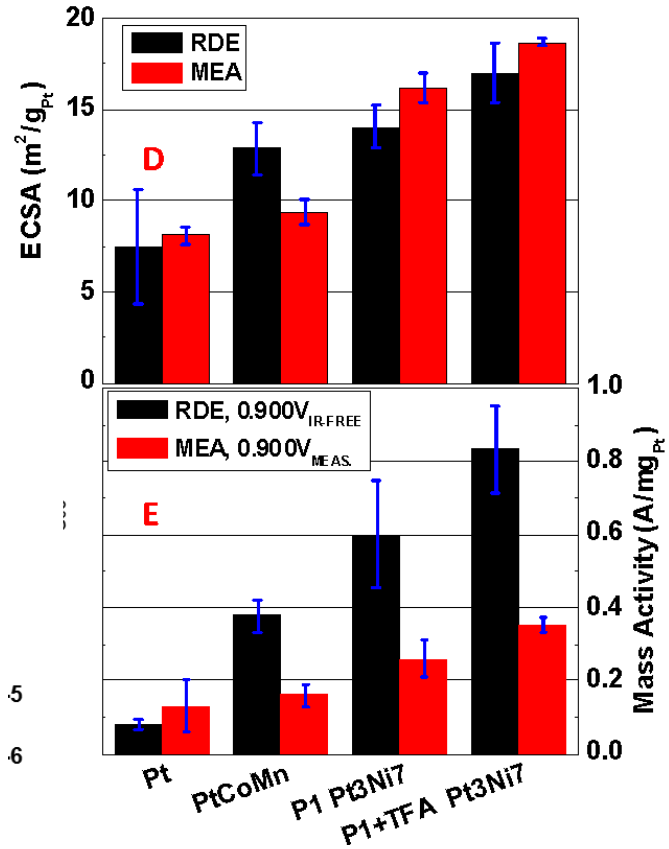


Chen C. et al. , 2014, 'Highly Crystalline Multimetallic Nanoframes with Three-Dimensional Electrocatalytic Surfaces', Science , vol. 343, pp. 1339-1343

Approach 1: Reduce the amount of platinum

- Nanostructured thin film (NSTF)
- High electrochemical surface area



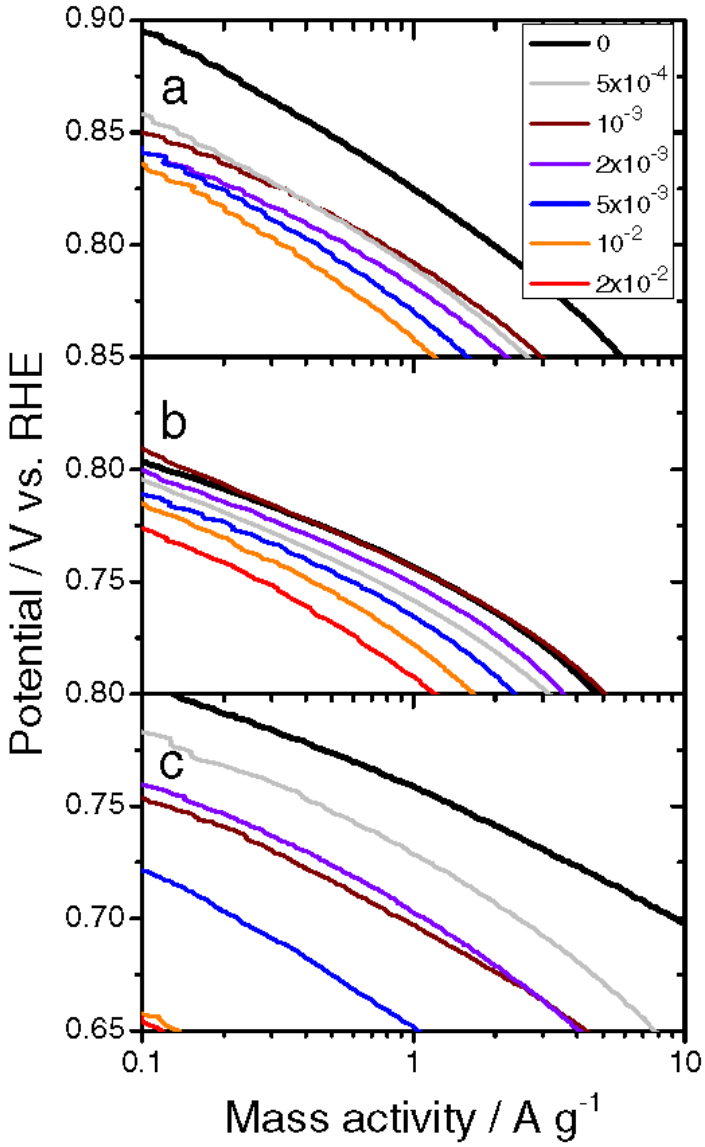


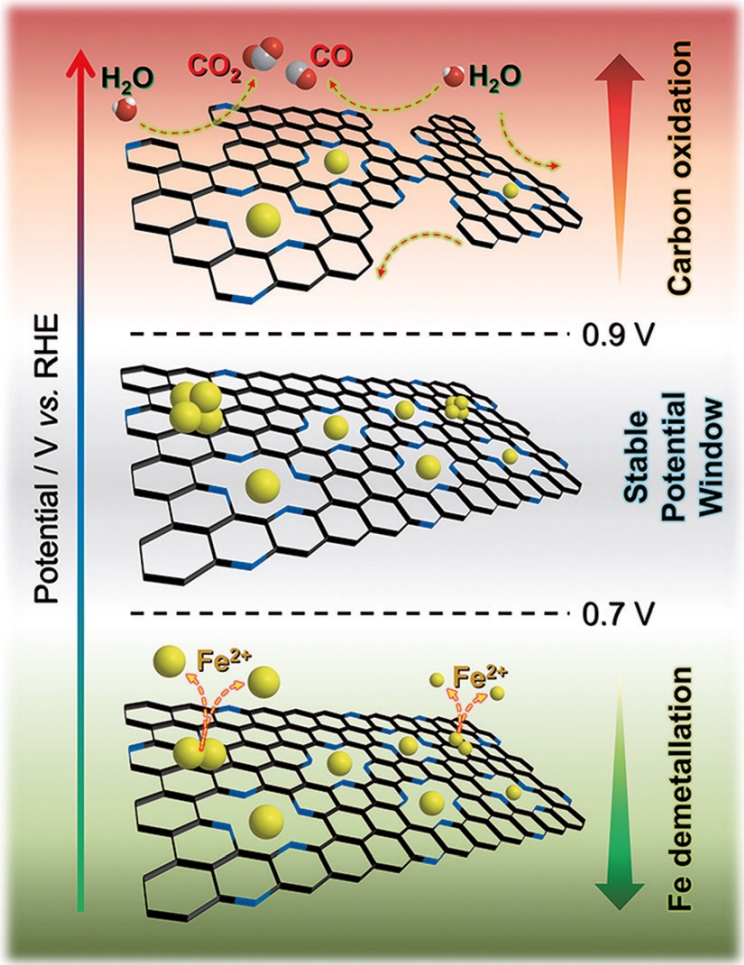
Kongkanand A.. et al. , 2014, "Degradation of PEMFC Observed on NSTF Electrodes" Journal of The Electrochemical Society,, vol. 161 , pp. F744-F753

Steinbach A.J. et al. , 2015, 'Recent Progress in Nanostructured Thin Film (NSTF) ORR Electrocatalyst Development for PEM Fuel Cells', ECS Transactions, vol. 69, pp. 291-301

Approach 2: Replace platinum

- Me-C-N
- High activity
- Stability issues



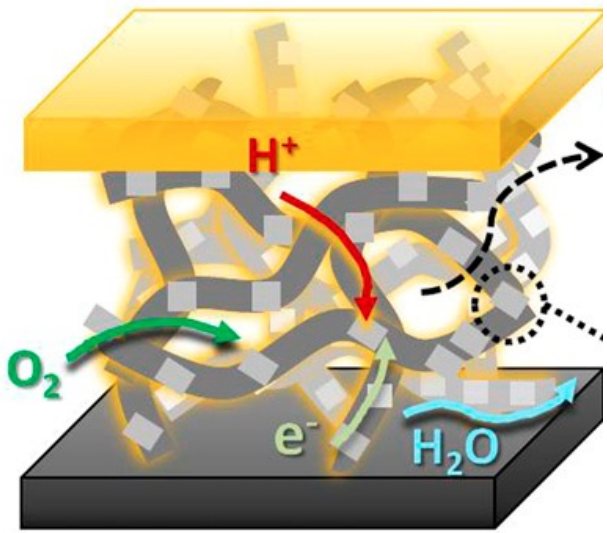


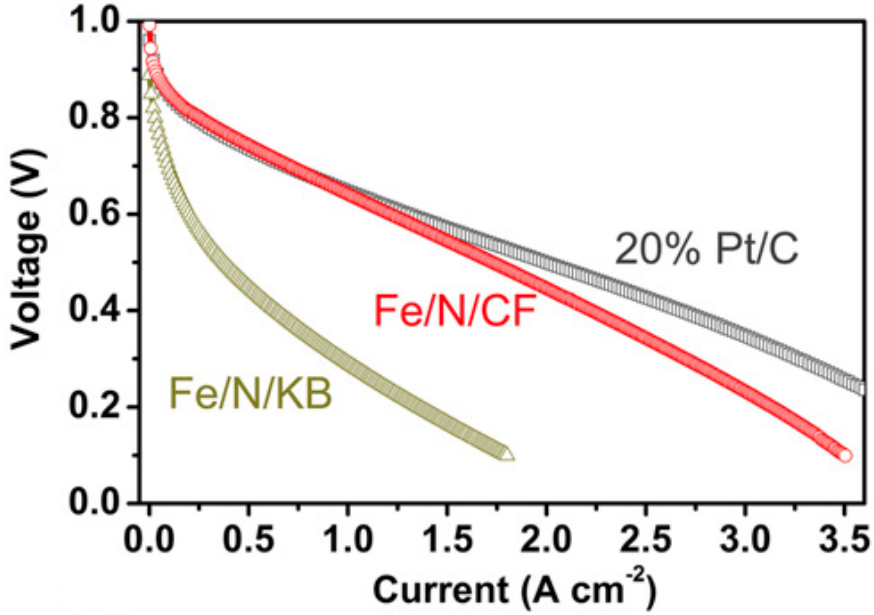
Goellner V. et al. , 2015, 'Degradation by Hydrogen Peroxide of Metal-Nitrogen-Carbon Catalysts for Oxygen Reduction', Journal of The Electrochemical Society, vol. 162, pp. H403-H414

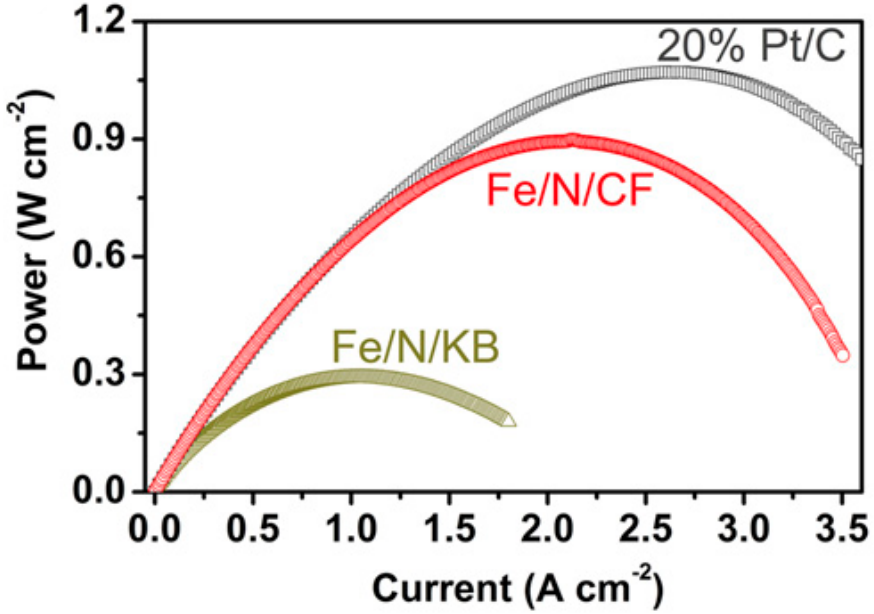
Zhao D. et al. , 2014, 'Highly Efficient Non-Precious Metal Electrocatalysts Prepared from One-Pot Synthesized Zeolitic Imidazolate Frameworks', Advanced materials, vol. 26, pp. 1093–1097

Approach 2: Replace platinum

- Nanofiber network
- High volumetric activity



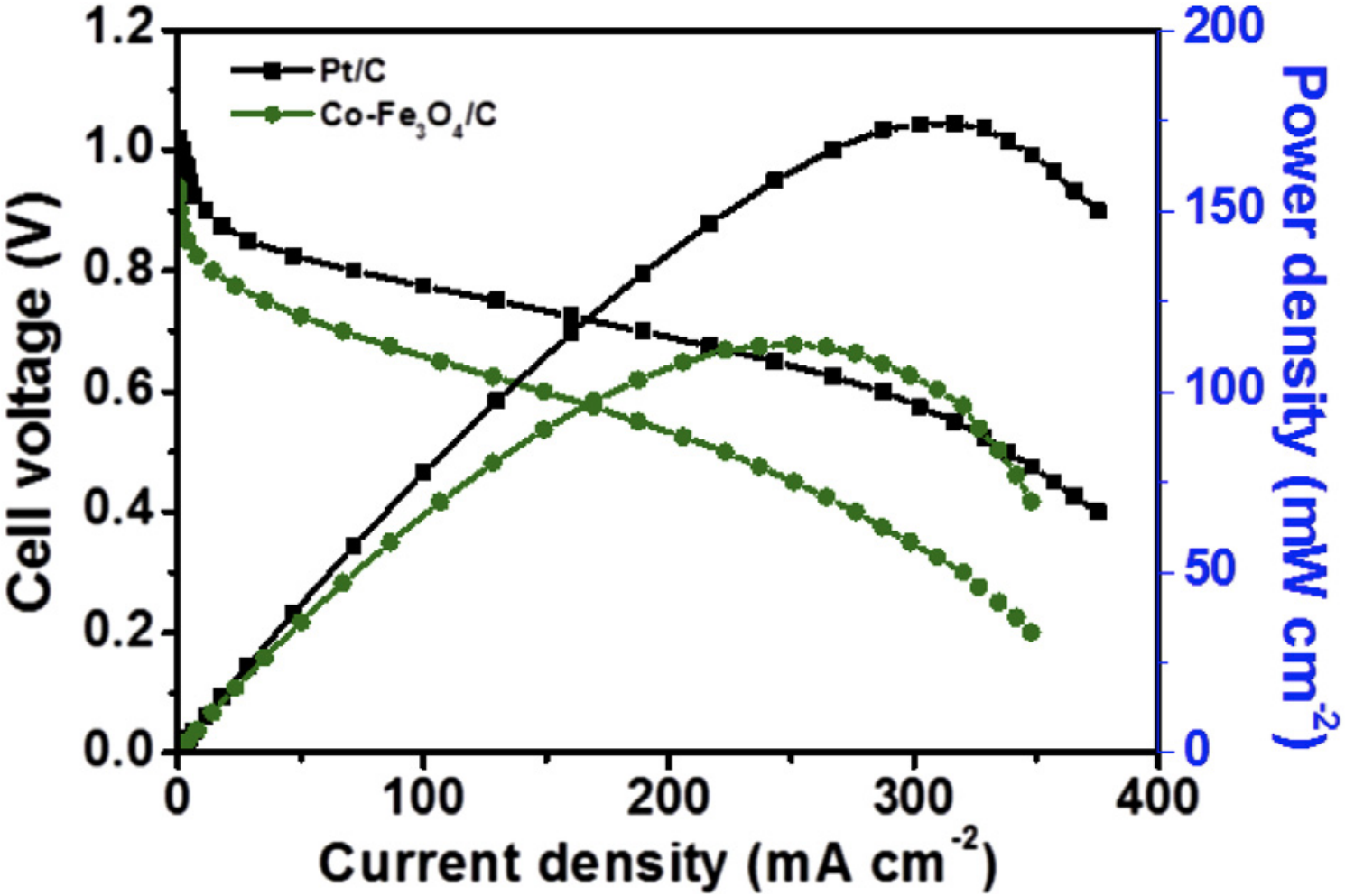




Jianglan S.. et al. , 2015, 'Highly efficient nonprecious metal catalyst prepared with metal–organic framework in a continuous carbon nanofibrous network', Proceedings of the National Academy of Sciences of the United States of America, vol. 112, pp. 10629-10634

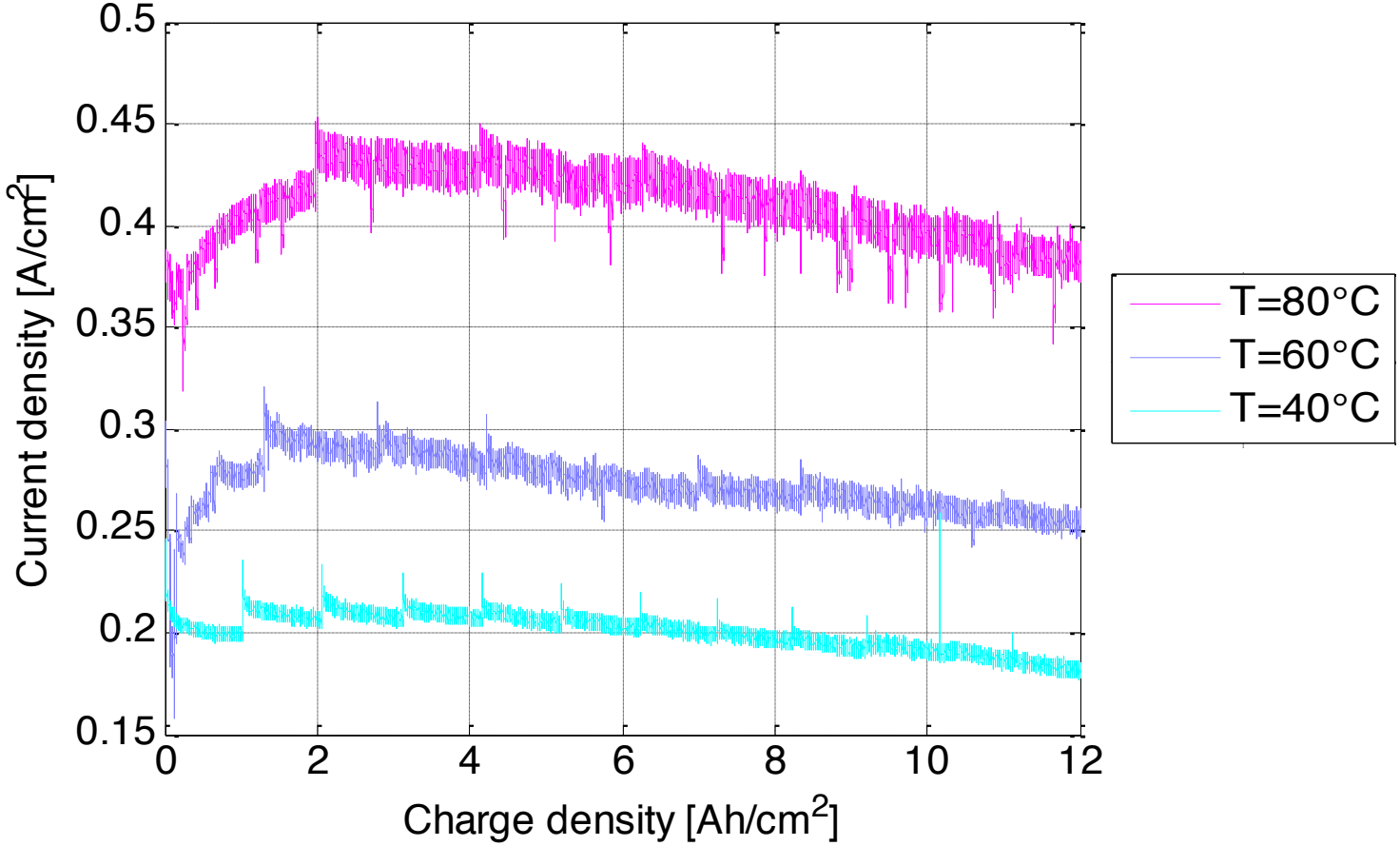
Approach 3: Alkaline Exchange Membrane Fuel Cell (AEMFC)

- Anion conducting polymer
- Allows for new catalysts



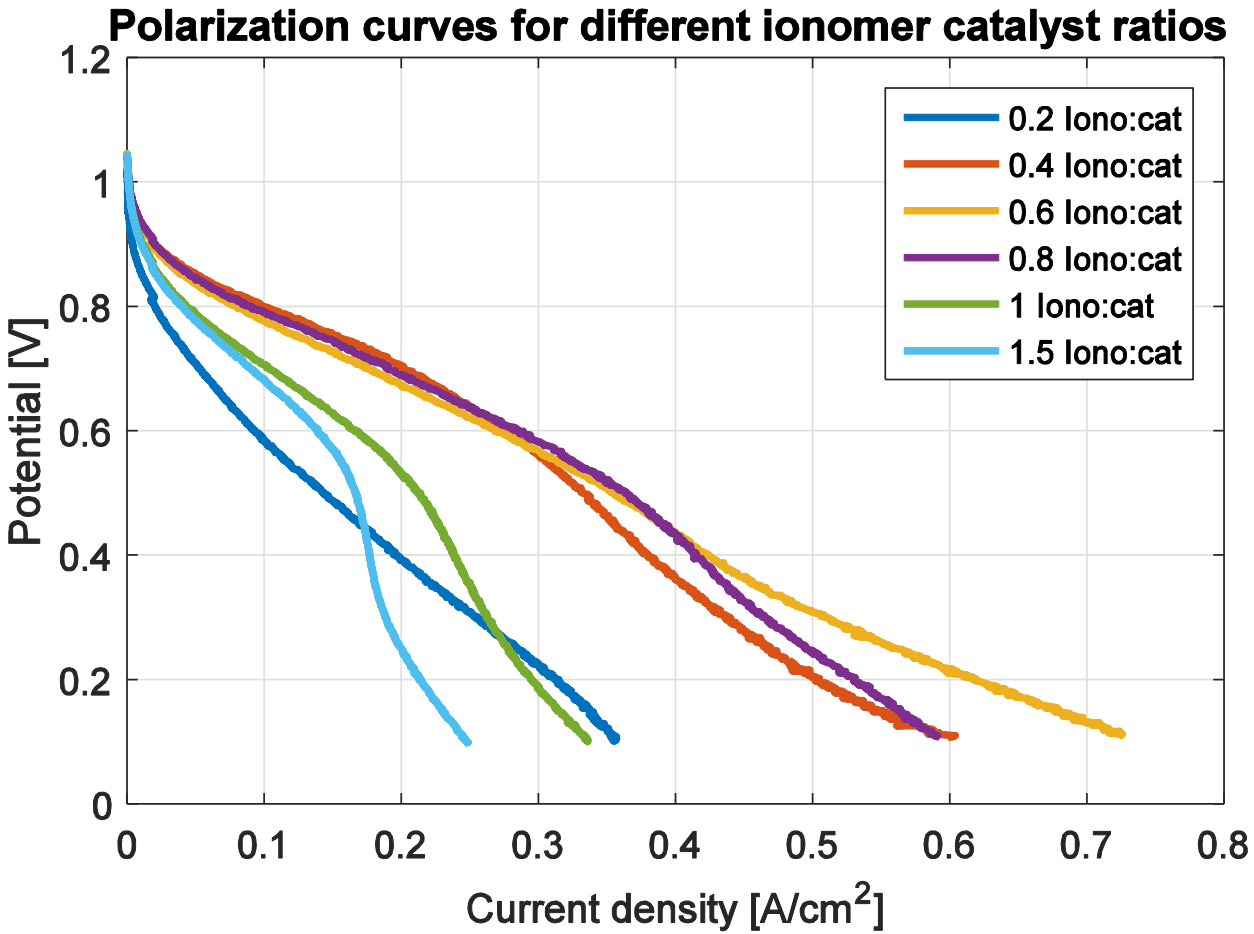
Chen-Hao W. et al. , 2015, 'Cobalteiron(II,III) oxide hybrid catalysis with enhanced catalytic activities for oxygen reduction in anion exchange membrane fuel cell', Journal of Power Sources, vol. 277, pp. 147-154

Our research in ongoing FFI-project: Non-Precious Metal Catalyst (NPMC)



Potentiostatic 0.5V (IR-corrected)
4mg Fe-C-N/cm^2 ,T=80°C, H_2/O_2 1.5bar pressure, 100 %RH

Our research in ongoing FFI-project: AEMFC



0.4mg Pt/cm^2 ,T=50°C, H_2/O_2, 1 bar gauge pressure, 95 %RH

Thank you for listening!

gnli@kth.se