Forum on New Energy

9th July 2016

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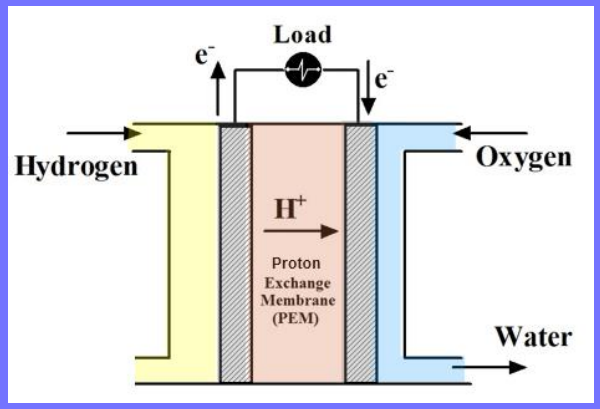
The Prospect of Fuel Cell



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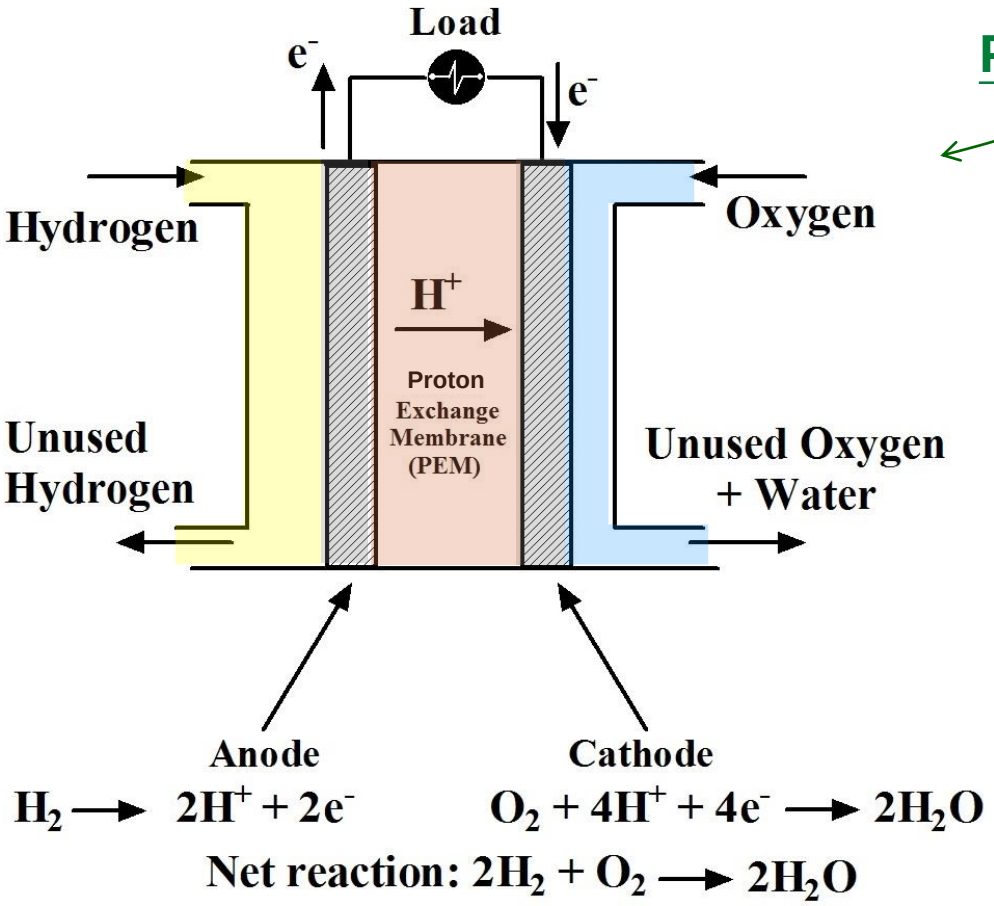
Outline

1. **Why Fuel Cell?**
2. **Fuel Cell Types**
   - **Proton exchange membrane fuel cell (PEMFC)**
   - **Solid oxide fuel cell (SOFC)**
3. **Applications**
4. **Future Challenges**

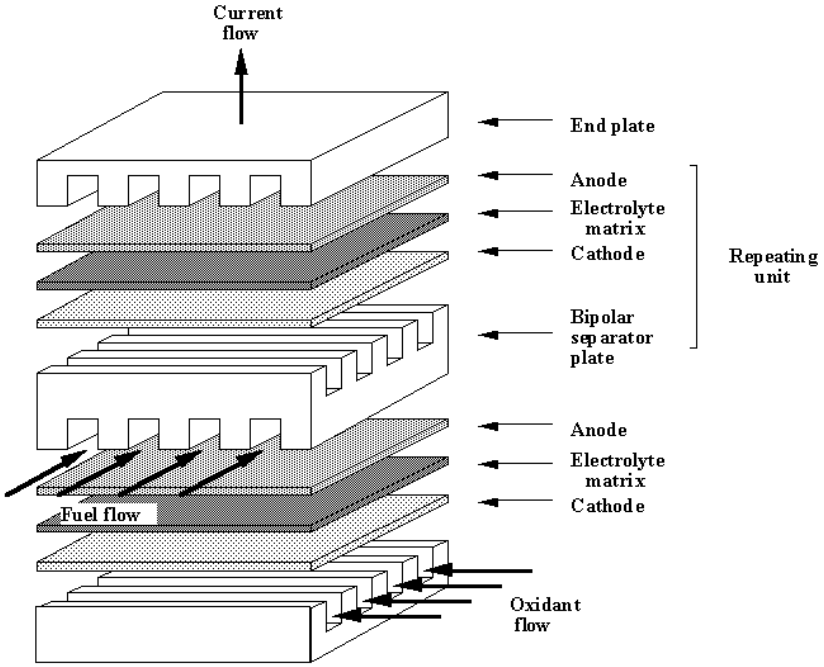
Fuel Cell

Fuel cell converts hydrogen into electricity by electrochemical reactions. Water and heat are byproducts.

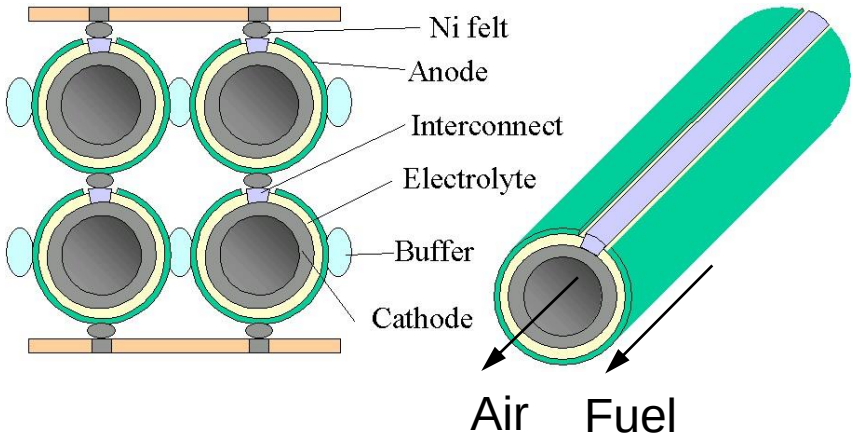


Fuel Cell Stack

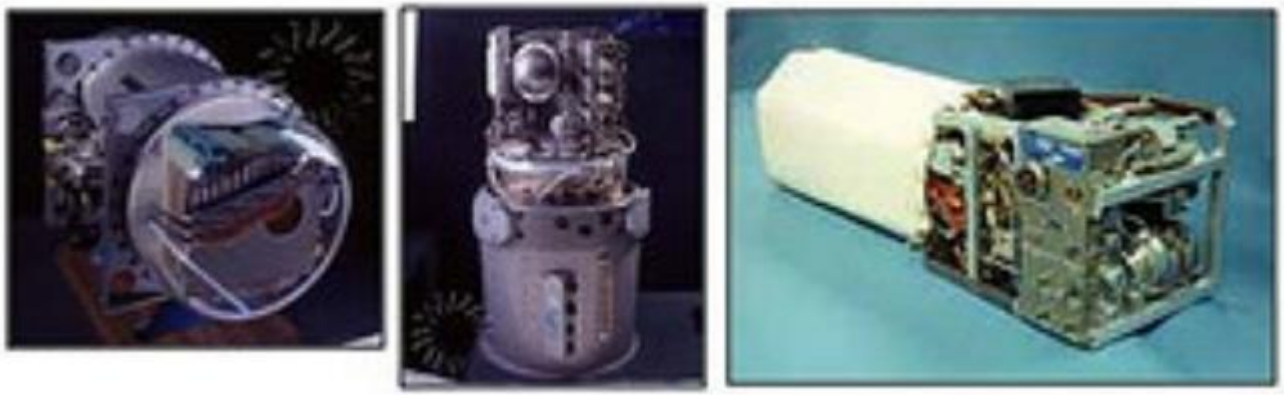
Planar Configuration:



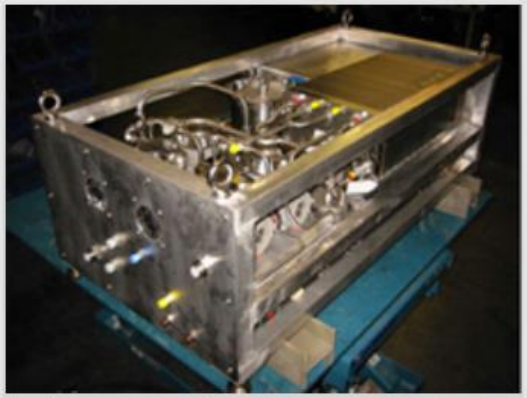
Tubular Configuration:



Originally Designed by NASA for Space Applications



Gemini, Apollo and Space Shuttle alkaline fuel cells (1965 to today)



A phase-one proton exchange membrane fuel cell design for space exploration developed by Teledyne. Credit: NASA

Ref.: www.nasa.gov

Features:

- **Use available hydrogen fuel**
- **Produce drinkable water**
- **Effective hydrogen recycling**

For Commercial Applications

- **Reduce greenhouse gas emissions**
- **Reduce depletion of finite fossil fuels**
- **Hydrogen is clean and, in practice, it can be produced from water, which is abundant.**
- **Promote diverse, domestic, and sustainable energy resources**
- **Increase reliability and efficiency of electricity generation**
- **Hydrogen technologies can be viable with a transition from conventional technologies**

Fuel Cell Products

Fuel Cell Cars

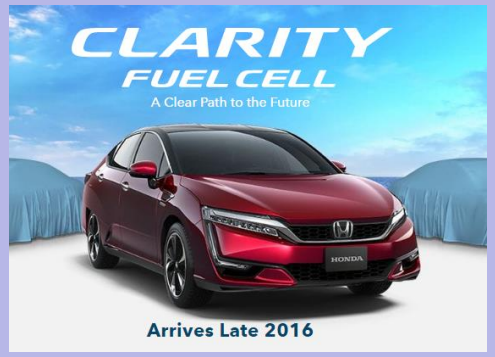
Mercedes-Benz plug-in hydrogen fuel-cell

BMW hydrogen fuel-cell vehicle

Toyota Mirai

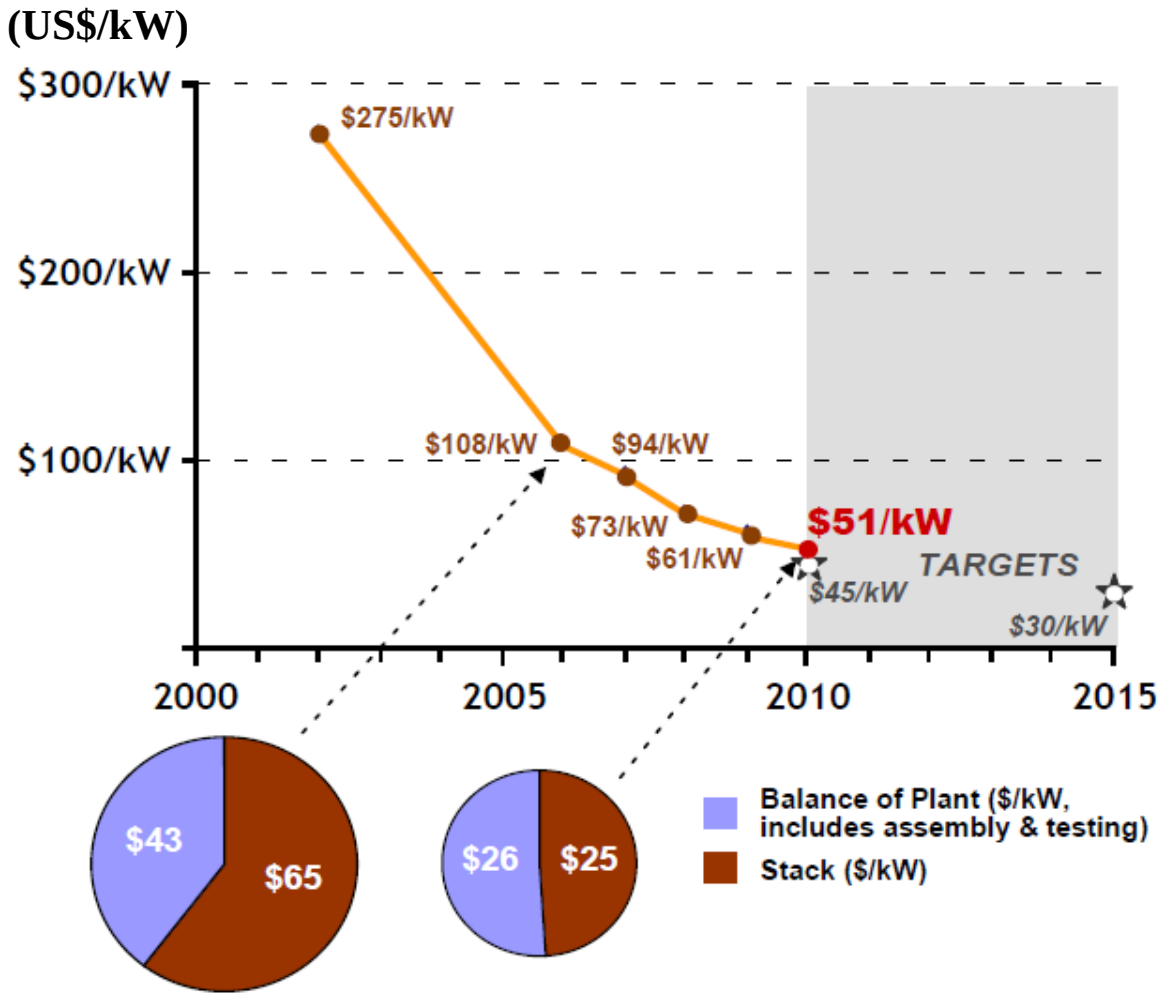
GM Opel HydroGen4

Honda Clarity fuel cell



Hyundai Tucson Fuel Cell

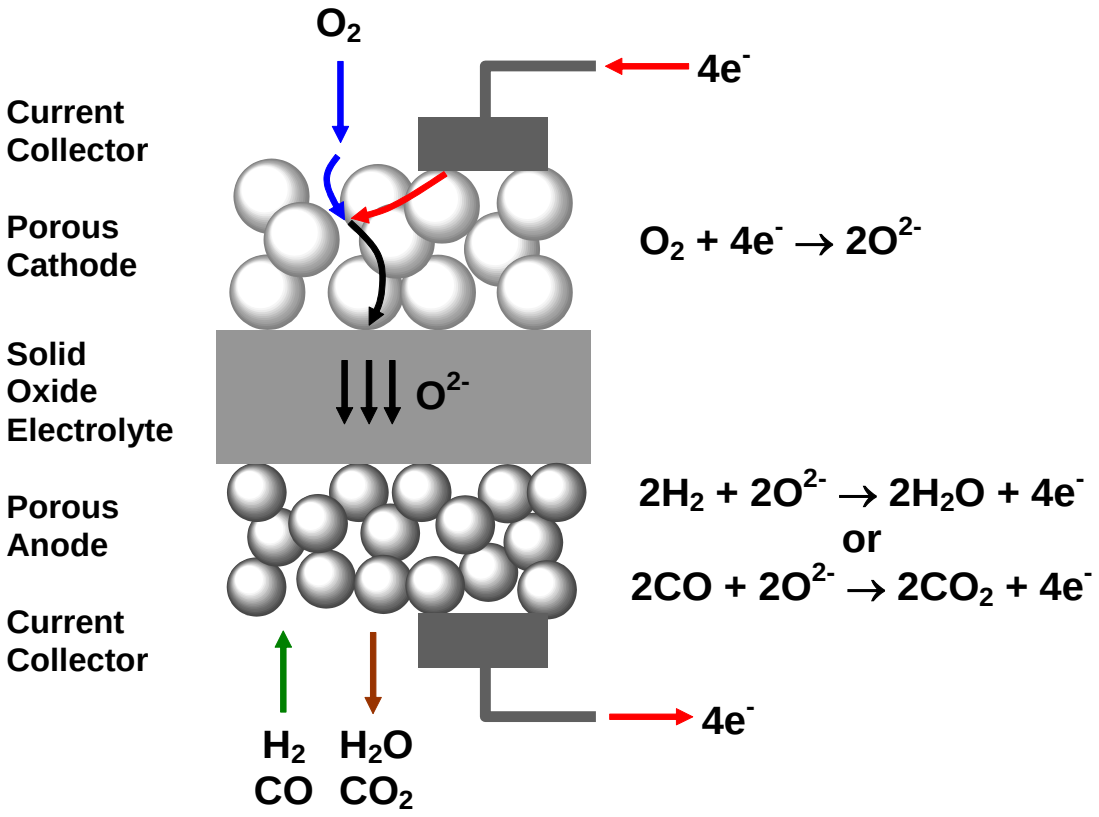
Capital Cost of Fuel Cell



Ref.: U.S. DOE, 2010

Solid Oxide Fuel Cell (SOFC)

- Oxygen ions pass through oxygen ion conducting electrolyte
- SOFC has higher efficiency than PEMFC
- High operating temperature at 600-1000^{o}C.



Electrolyte	Stabilized Zirconia	Dense
Anode	Nickel / Stabilized Zirconia Cermets	Porous
Cathode	Lanthanide Perovskite	Porous
Interconnect	Chromites / Alloys	Dense
Seals	Glass or Braze	Dense
Manifolds	Heat resistant alloys	Dense

Table 2-2

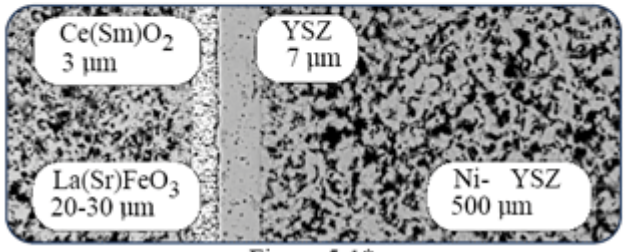


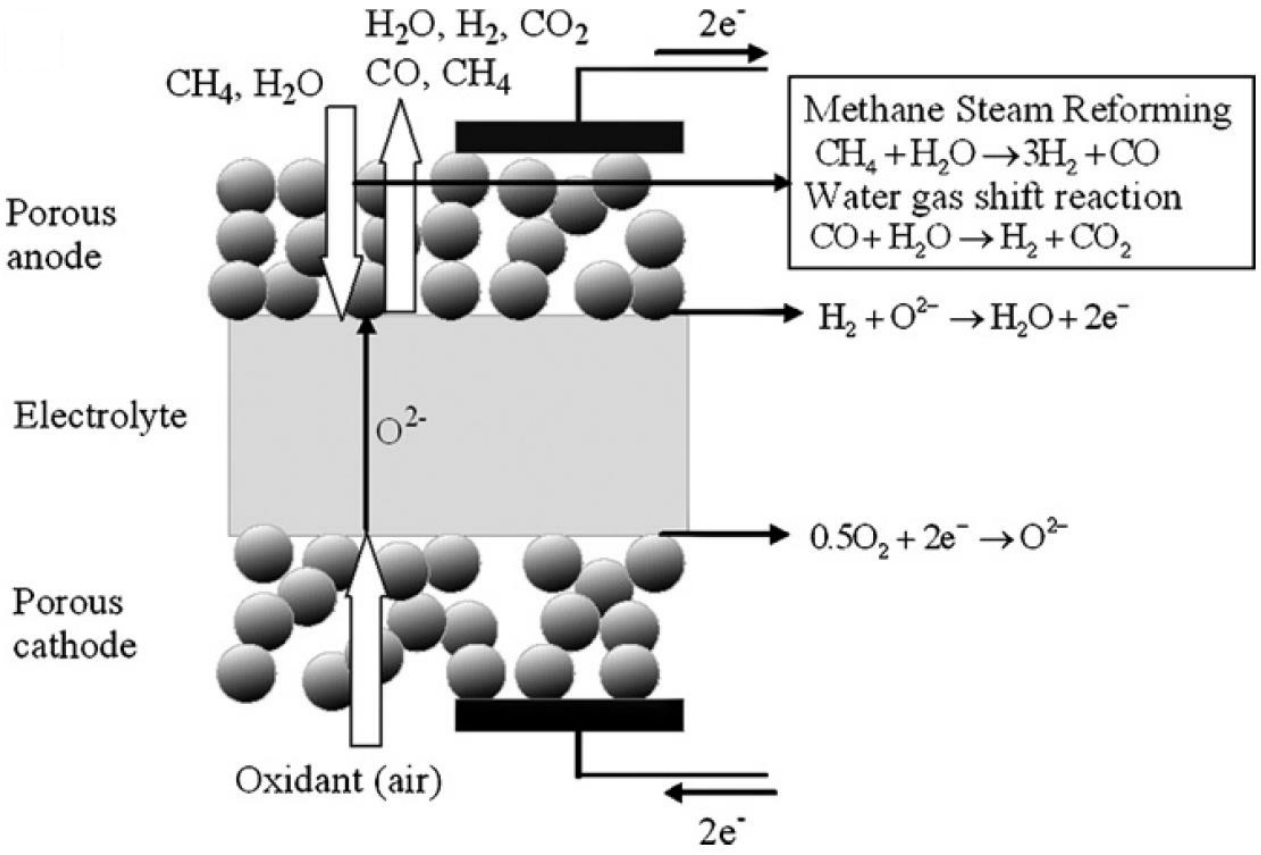
Figure 5-1*

Ref.: Meng Ni**, Michael K.H. Leung**, Dennis Y.C. Leung, Parametric study of solid oxide fuel cell performance, *Energy Conversion & Management*, 2007, vol. 48, pp1525-1535.

Various Types of Fuel Cells

Fuel cell types	Alkaline Electrolyte Fuel Cell (AFC)	Phosphoric Acid Fuel Cell (PAFC)	Molten Carbonate Fuel Cell (MCFC)	Proton Exchange Membrane Fuel Cell (PEMFC)	Solid Oxide Fuel Cell (SOFC)
Electrolyte	Potassium Hydroxide	Phosphoric Acid	Molten carbonate salt	PEM	Yttria-Stablized Zirconia (YSZ)
Operating Temp (^oC)	50-200	160-210	630-700	50-90	600-1000
Charge carrier	OH^-	H^+	CO_3^{2-}	H^+	O^{2-}
Fuel	H_2	H_2	H_2, CO, CH_4, C_3H_8	H_2	H_2, CH_4
Oxidant	O_2/air	O_2/air	O_2/air/CO_2	O_2/air	O_2/air
Efficiency	50-55%	40-50%	50-60%	40-50%	45-60%
Power density(W/cm^2)	0.05-0.2	0.1-0.3	0.1-0.2	0.3-0.8	0.1-0.3

Methane Fed SOFC



Ref.: Meng Ni, Dennis Y.C. Leung, **Michael K.H. Leung**, Electrochemical modeling of methane fed solid oxide fuel cells: comparison between proton conducting electrolyte and oxygen ion conducting electrolyte, Journal of Power Sources, 2008, 183, 133-142.

Stationary Electricity Supply

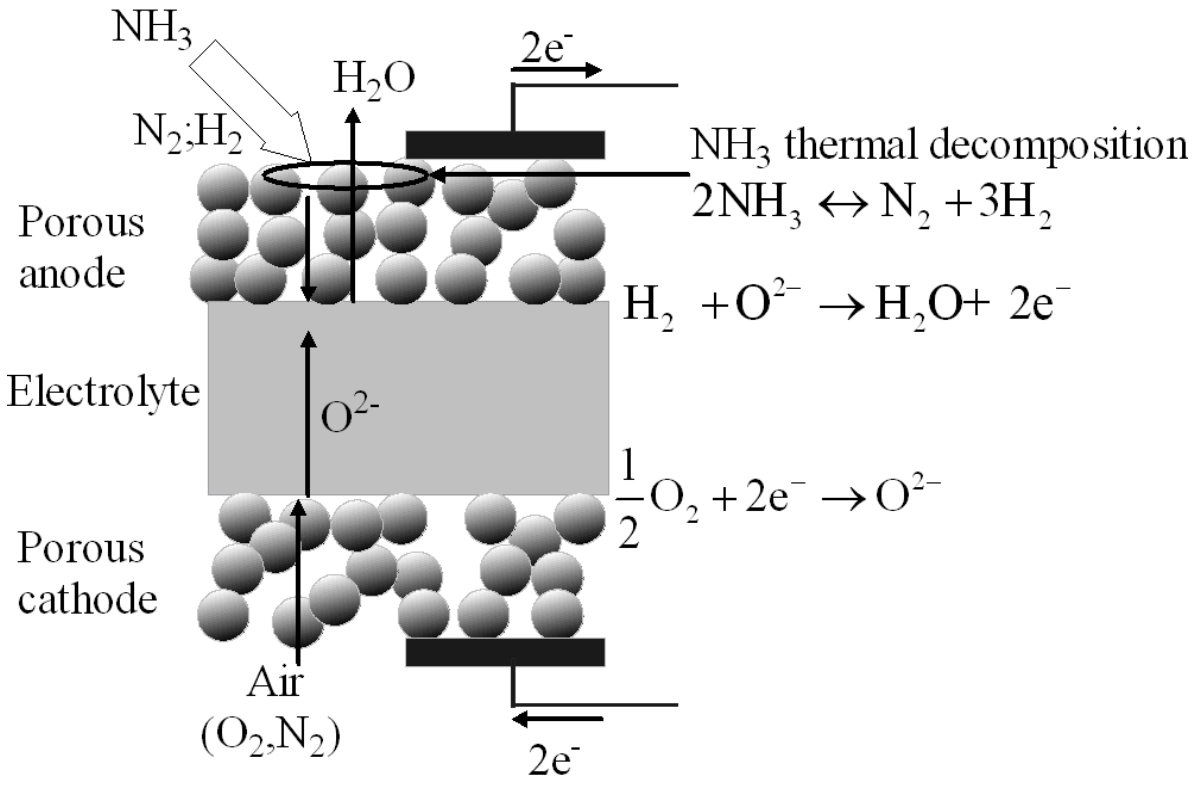
400-kW hydrogen fuel cell plant in Connecticut

200-kW natural gas fuel cell plant in Sydney

Natural gas fuel cell plant in New Jersey

2.4-MW biogas fuel cell plant in San Diego

Ammonia Fed SOFC



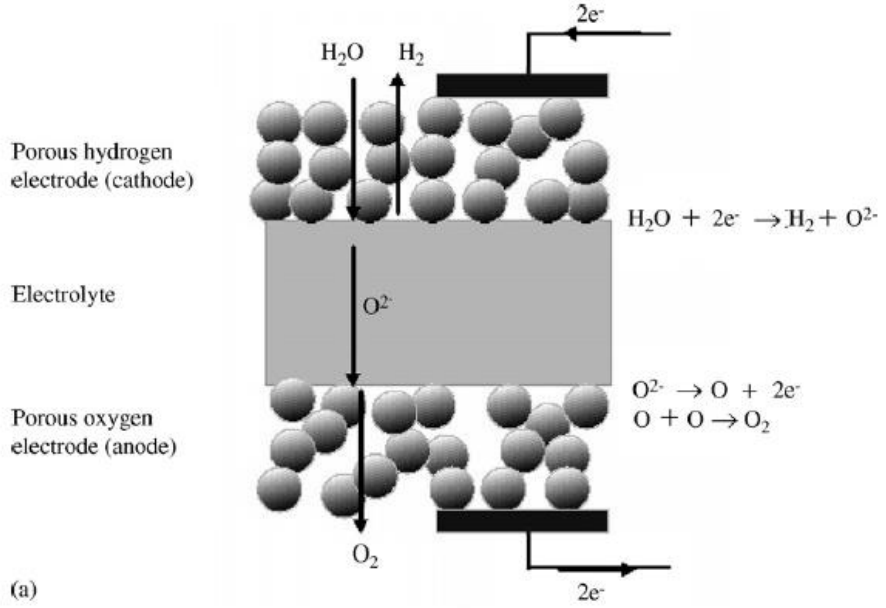
Ref.:

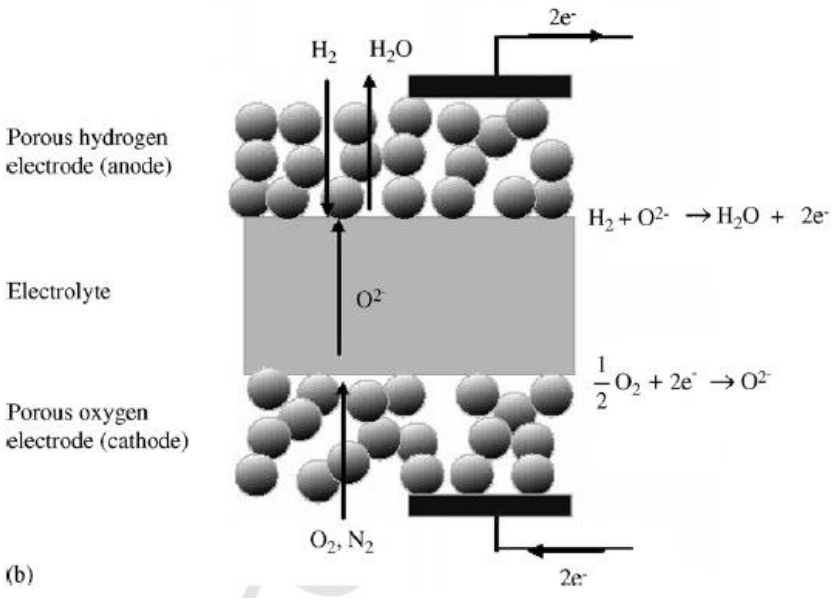
Meng Ni, Dennis Y.C. Leung, **Michael Kwok-Hi Leung**, Thermodynamic analysis of ammonia fed solid oxide fuel cells: comparison between proton conducting electrolyte and oxygen ion conducting electrolyte, Journal of Power Sources 183(2008) 682-686.

Ni M., Leung Y.C. and **Leung M.K.H.** Mathematical modeling of ammonia-fed solid oxide fuel cells with different electrolytes, International Journal of Hydrogen Energy, 2008, 33, 5765-5772

Reversible Solid Oxide Fuel Cell

A single reversible solid oxide fuel cell (RSOFC) can perform dual functions:
(1) as a solid oxide steam electrolyzer (SOSE) for hydrogen production
(2) as a solid oxide fuel cell (SOFC) for power generation.

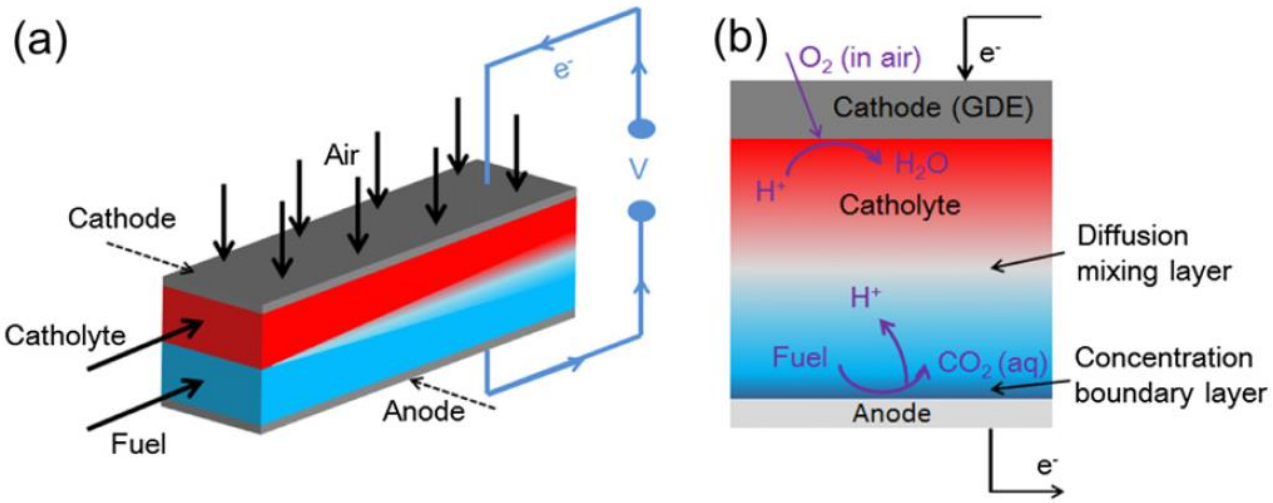




RSOFC can potentially offer a low-cost approach to support hydrogen economy.

Ref.: Meng Ni, **Michael K.H. Leung**, Dennis Y.C. Leung, Theoretical analysis of reversible solid oxide fuel cell based on proton-conducting electrolyte, Journal of Power Sources 177 (2008) 369–375.

Membraneless Microfluidic Fuel Cell (MFC)



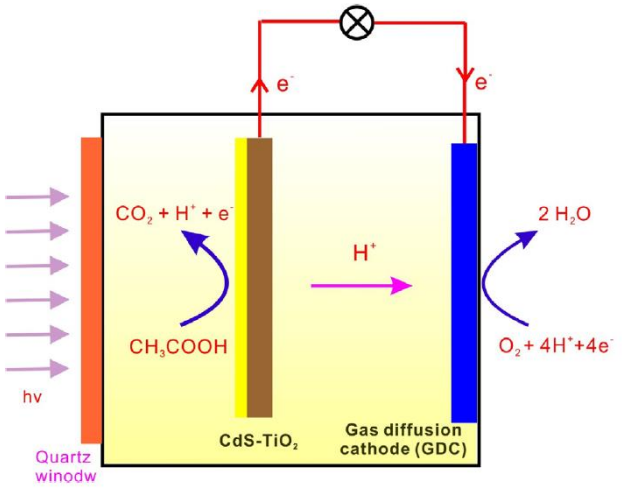
- Laminar flow naturally separates two streams
- No membrane is needed
- Low cost

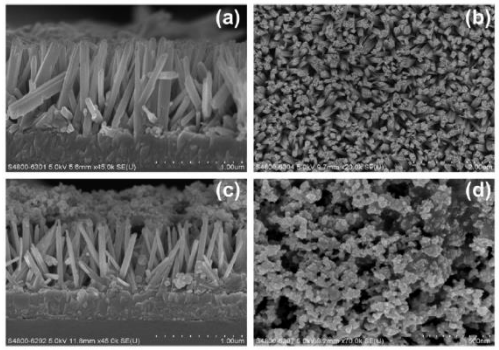
Ref.:

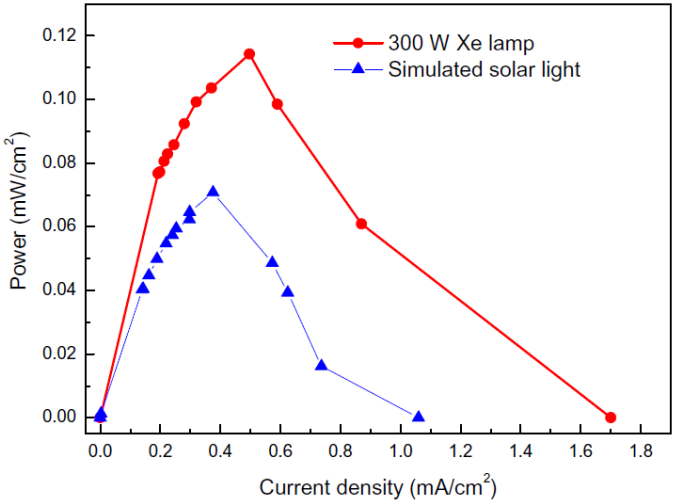
Jin Xuan, Huizhi Wang, Dennis Y.C. Leung, **Michael K.H. Leung**, Hong Xu, Li Zhang, Yang Shen, Theoretical Graetze-Damköhler modeling of an air-breathing microfluidic fuel cell, Short Communication, Journal of Power Sources 231 (2013) Pages 1-5.

Jin Xuan, **Michael K.H. Leung**, Dennis Y.C. Leung, Huizhi Wang, Laminar flow-based fuel cell working under critical conditions: The effect of parasitic current, Applied Energy, Volume 90, Issue 1, 2012, Pages 87-93.

Photocatalytic Fuel Cell (PFC)



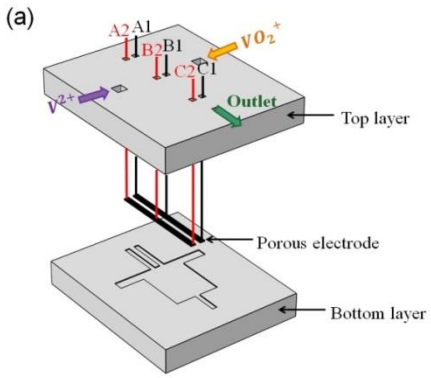


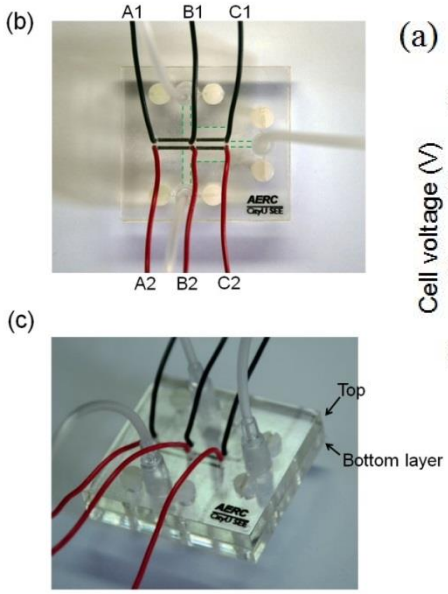


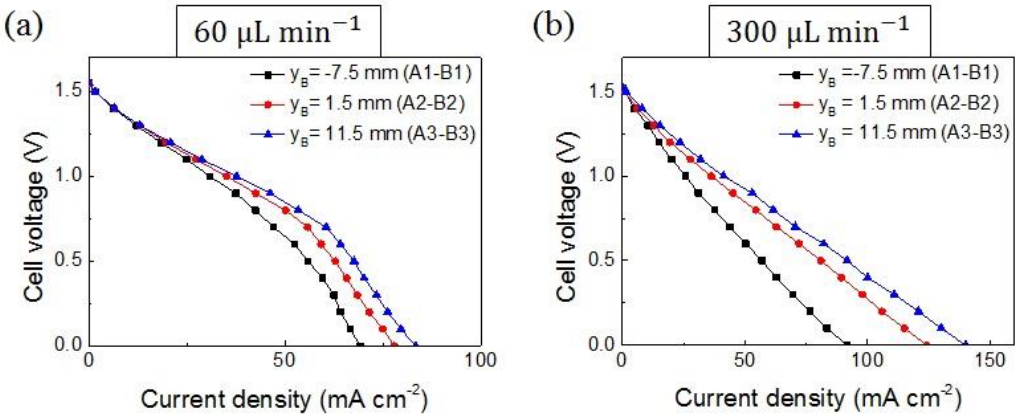
- **Effective wastewater treatment and simultaneous production of electricity**
- **Low-cost fabrication**
- **Environmental-friendly operation**

Ref.: Bin Wang, Hao Zhang, Xiao-Ying Lu, Jin Xuan, **Michael K.H. Leung**, Solar photocatalytic fuel cell using $CdS–TiO_2$ photoanode and air-breathing cathode for wastewater treatment and simultaneous electricity production, Chemical Engineering Journal, Volume 253, 2014, Pages 174-182.

Flow-through Porous Electrodes



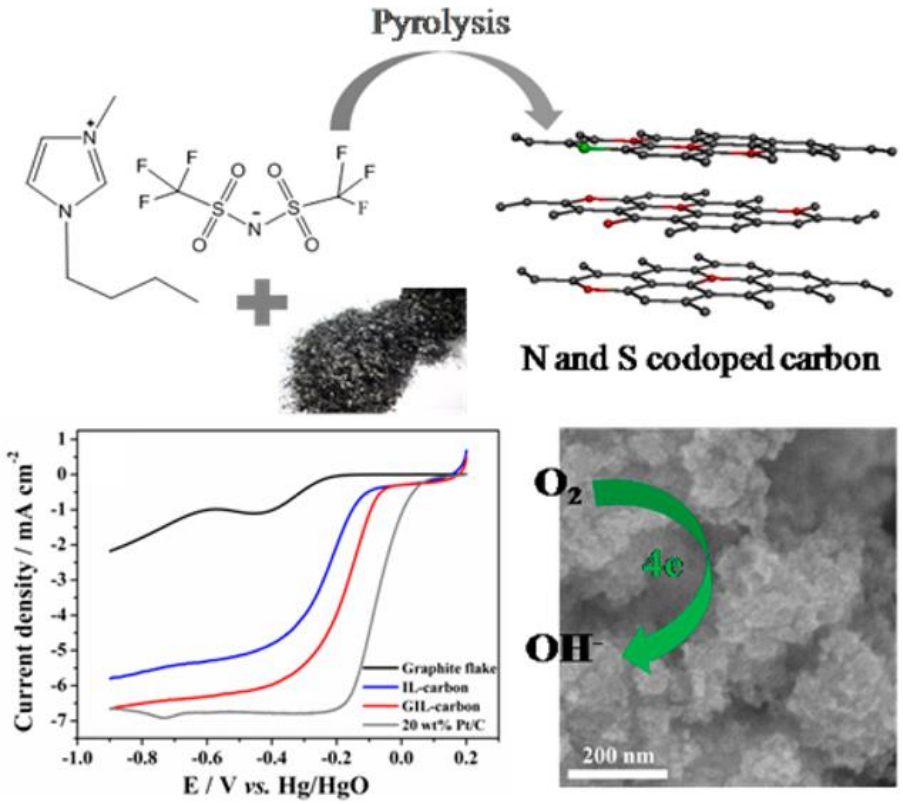




Performance of difference cell design

Ref.: Li Li, Wenguang Fan, Jin Xuan, **Michael K.H. Leung**, Dimensionless parametric sensitivity analysis of microfluidic fuel cell with flow-through porous electrodes, Electrochimica Acta 2016, 187: 636–645.

Advanced Functional Nanomaterials for Fuel Cell Electrodes



Ref.: She, Yiyi; Lu, Zhouguang; Ni, Meng; Li, Li; **Leung, Michael K.H.**, Facile Synthesis of Nitrogen and Sulfur Co-doped Carbon from Ionic Liquid as Metal-free Catalyst for Oxygen Reduction Reaction, ACS Applied Materials & Interfaces 2015, 7(13):7214-21.

Sustainable Hydrogen Economy

Acknowledgements

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- Ability R&D

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Thank You

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