Fuel Cells: Challenges and Opportunities

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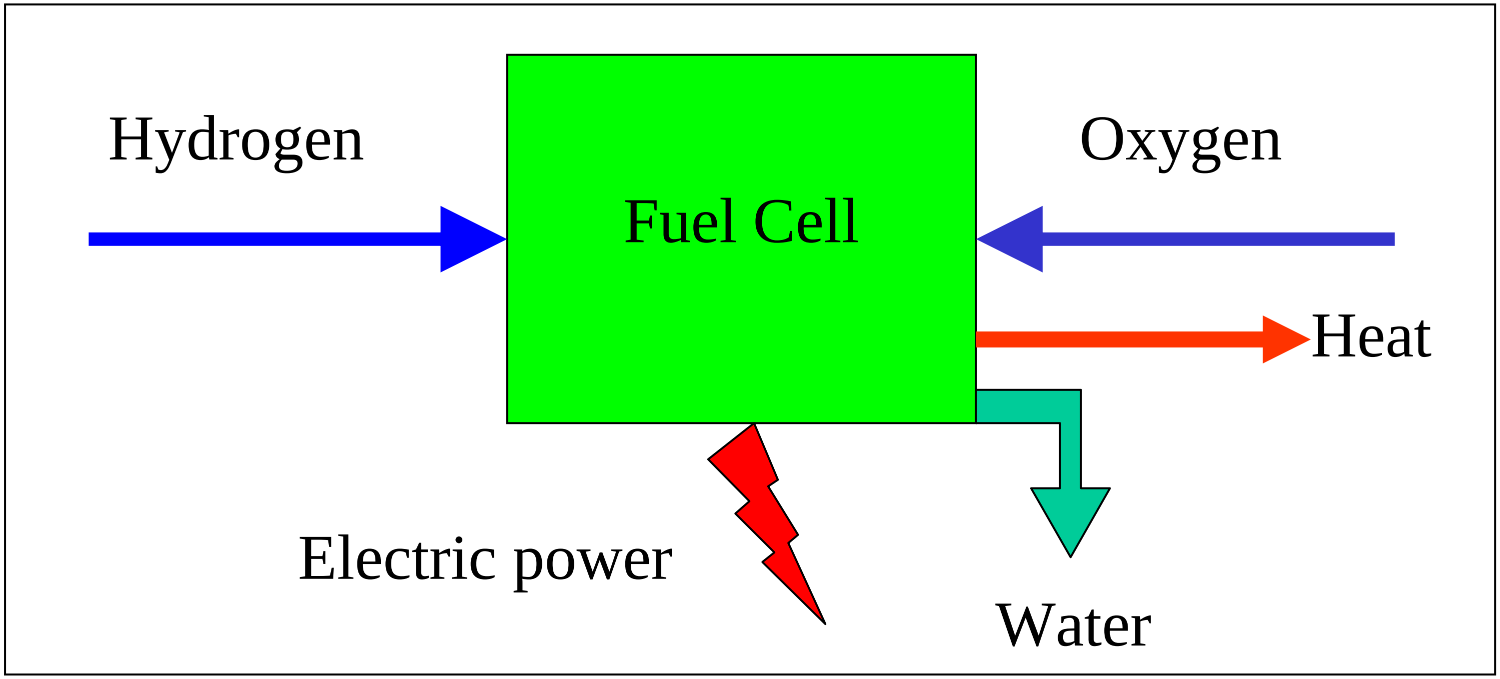
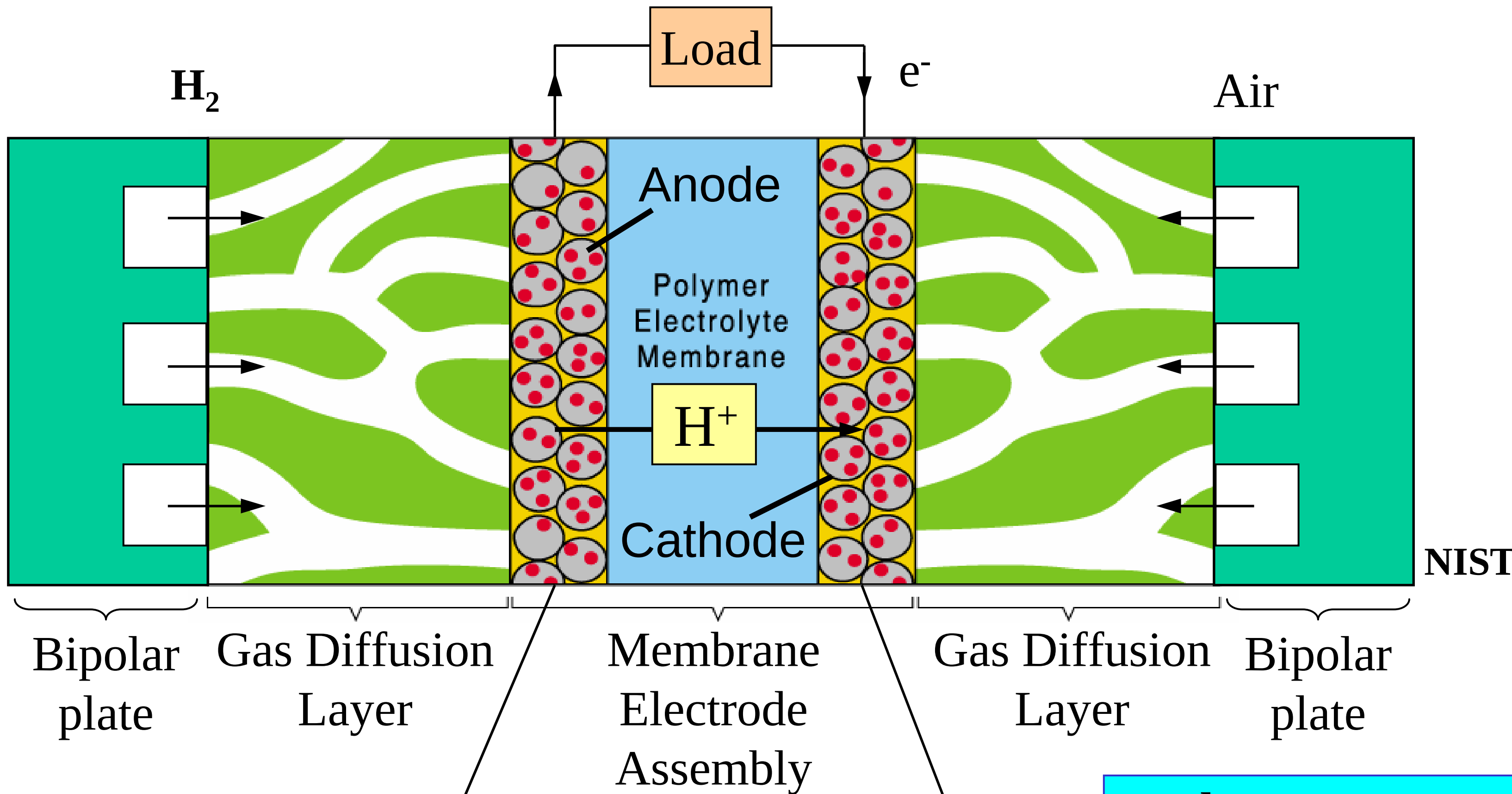
UD Energy Institute Symposium

March 17, 2008

What is a Fuel Cell?



- A fuel cell combines fuel and oxidant electrochemically to produce electricity
- Two to three times more efficient that an internal combustion engine
- Fuel cell stack is quiet, has no moving parts, produces *zero emissions*



Voltage = 0.6 V

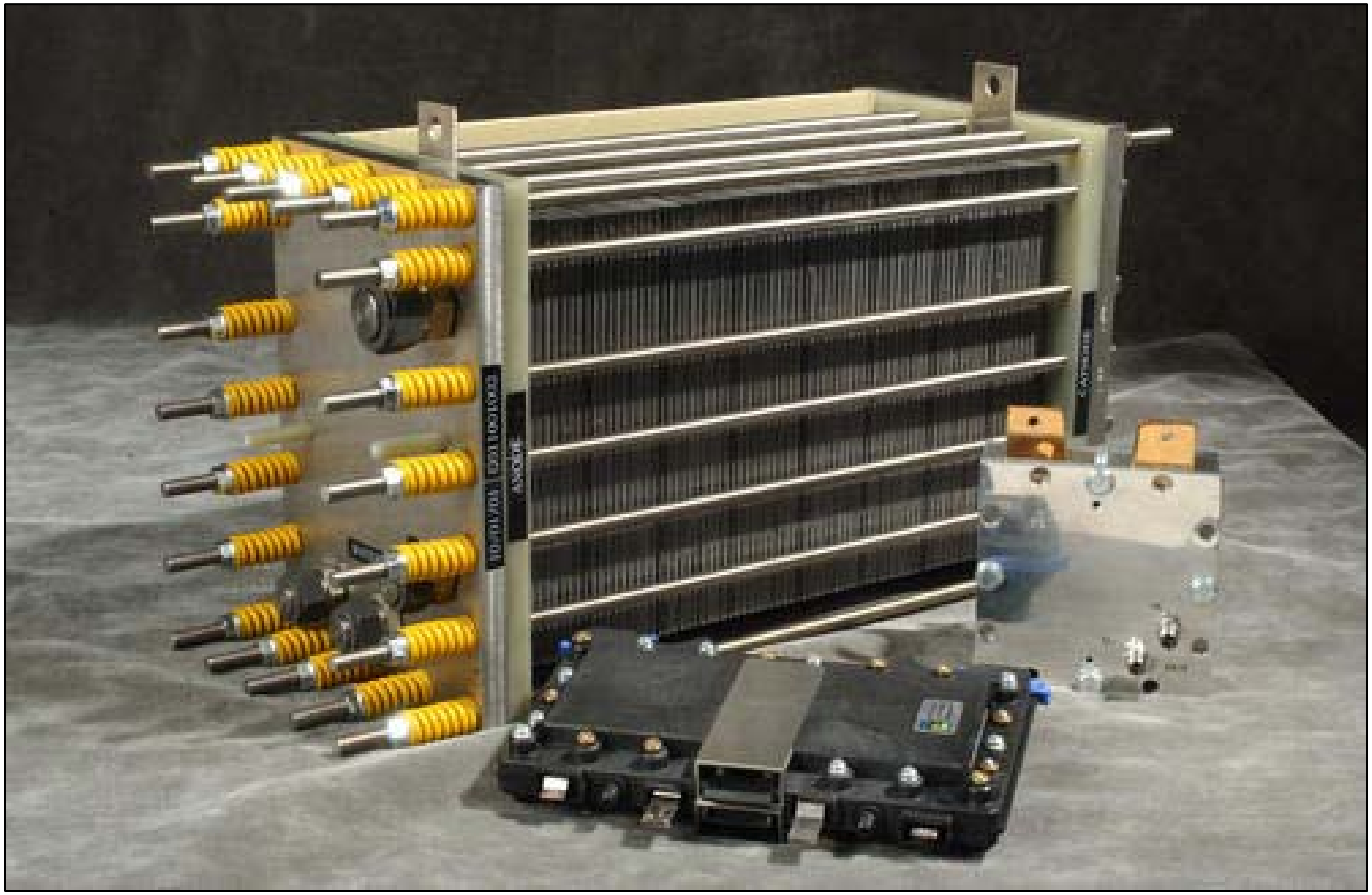
Anode Reaction

$$2H_2 \rightarrow 4H^+ + 4e^-$$

Cathode Reaction

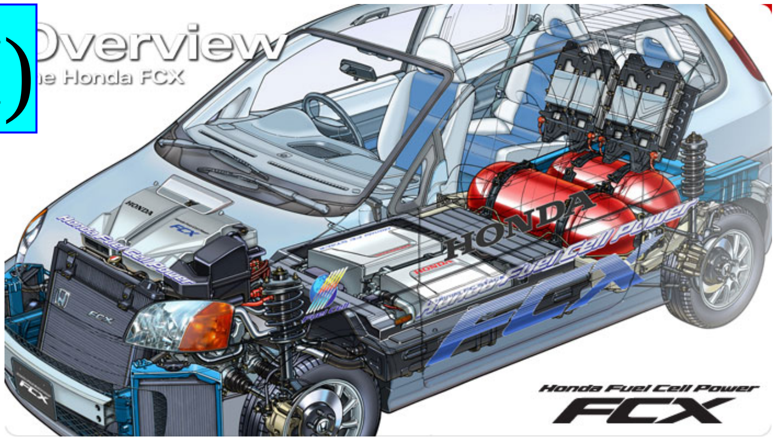
$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

Fuel cell "stack"



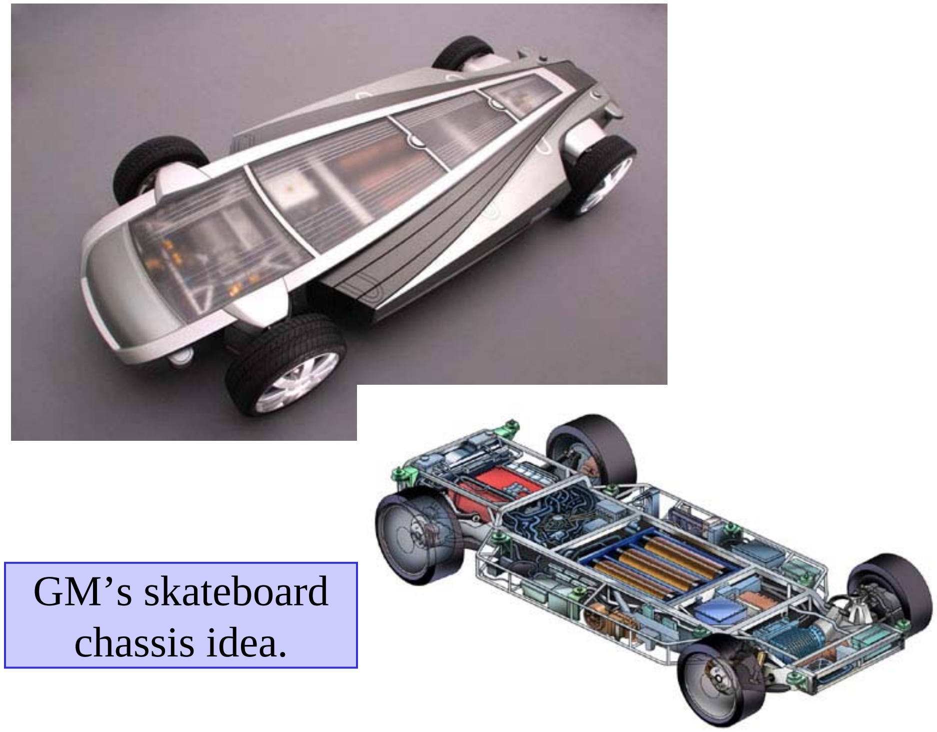
NREL

Automotive fuel cells (PEM)



Honda FCX Clarity

Clean Urban Transport in Europe (CUTE): 30 fuel cell buses operated in European capitals over the past two years.



GM's skateboard chassis idea.

Fuel cells for stationary power (SOFC)

UTC Fuel Cells: (PureCell™ 200) 200kW of electricity and 900,000 BTUs of usable heat. This system provides clean, reliable power at locations including a New York City police station, a major postal facility in Alaska, a credit-card processing system facility in Nebraska, and a science center in Japan.

UTC Fuel Cells: 5kW fuel cell power plants for backup power for telecommunications towers, power for small businesses, and residential use.

Fuel cells for portable power (DMFC)

Casio: World's smallest fuel cell for use in laptop PC, and aims to market it in 2007. The polymer electrolyte fuel can power a typical laptop computer for eight to 16 hours.

Samsung Electronics: 100Wh laptop PC fuel cell using 100cc of methanol solution, enabling continuous usage for more than 10 hours without recharging.

Fuel cells for soldier power, automotive and stationary power

<u>DARPA, Defense Science Office- Robust Portable Power:</u>

"Today's warfighter must often carry an extremely cumbersome number of heavy primary batteries in order to provide power to various radios, laptops, laser designators, and other mission critical electronic equipment. DARPA's investments in portable power have demonstrated that fuel cell and Stirling engine generators can achieve energy densities up to seven times that of today's military logistic batteries."

(Nicholas Sifer, Army Power Division)

Objective: Reduce the logistics burden of batteries by demonstrating novel, high density, energy conversion devices for soldier-portable or robotic applications

55 BA-5590 +2 BA-5800 = 125 lbs

... A typical requirement for ONE operational day for a radio reconnaissance team!!!

Portable, lightweight, devices that convert logistic fuels to electrical power

(Valerie Browning, DARPA)

Outline

- Fuel cell basics
- Application areas for fuel cells: Automotive, stationary power, potable power (soldier power)
- Challenges and Opportunities:
  - Cost: materials, labor, economies of scale
  - Durability: membrane, catalyst
  - Lack of H2 infrastructure: production, transport and storage of H2
- UD Fuel Cell Bus Program, other major initiatives
- Center for Fuel Cell Research

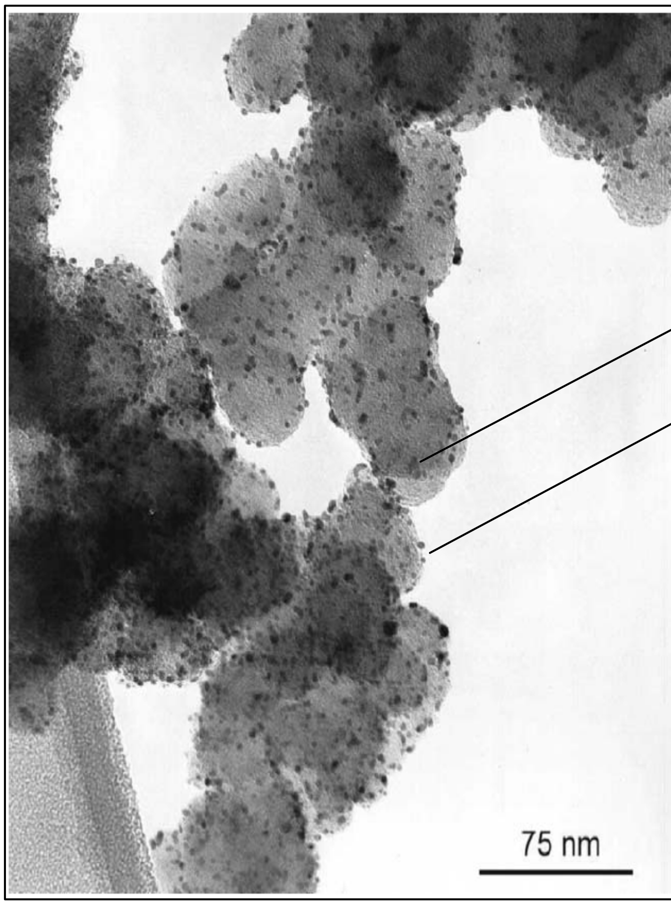
Research Opportunities

1. Components: electrolyte, electrodes (catalyst, catalyst support), gas diffusion layers, bipolar plates

→Polymers, ceramics, nanomaterials, metals, composites

→Electro-chemical, electrical, thermal, flow, and structural properties

TEM image of fuel cell catalyst layer

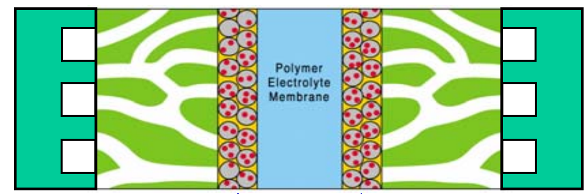


Johnson Matthey

- NY spot price of Pt: \$70/g
- Need 0.2 g/kW of Pt, so 20 g for a 100 kW vehicle (\$1400 Pt/vehicle)

Carbon black (50 nm)

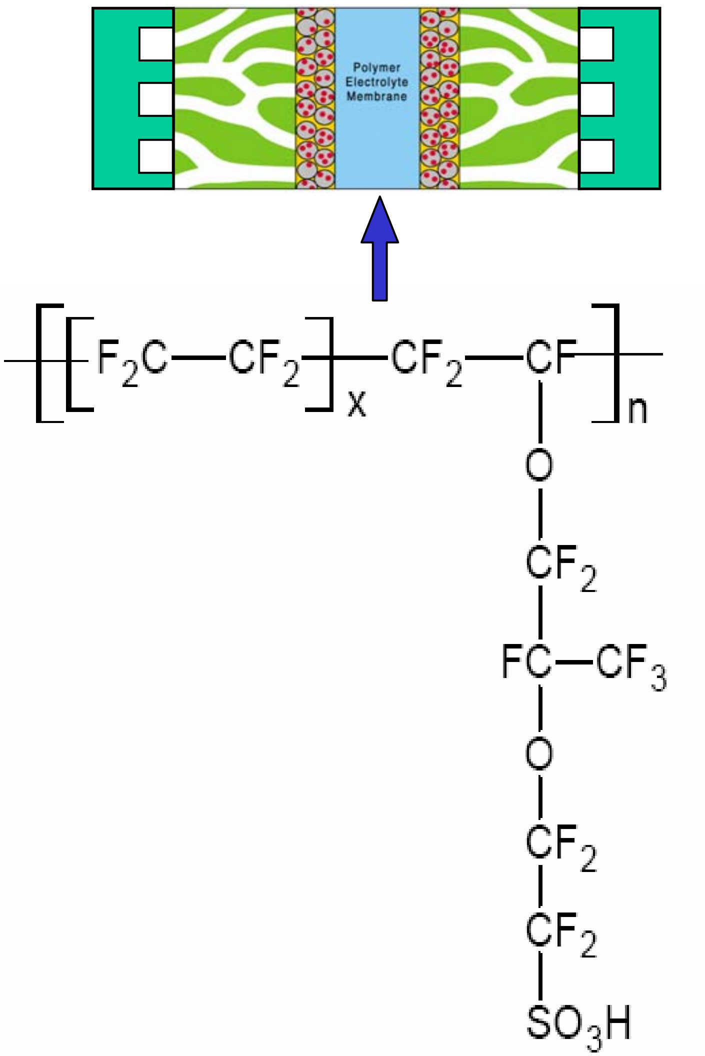
Platinum (5 nm)



Issues:

- Pt dissolves at OCV in acid environment
- Pt agglomeration
- Carbon corrosion
- Effect of contaminants: CO, S, etc.

Polymer Electrolyte Membrane (PEM)



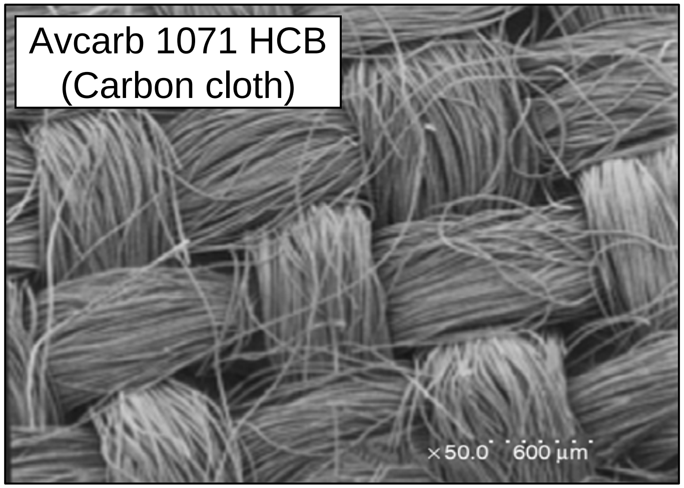
PFSA (Nafion®)

- Nafion cost is ~ \$2000/kg.
  Need ~ 1kg for 100 kW vehicle.
- GM projects that cost will drop to \$50/kg at high production volume (million cars/year).

<u>Issues:</u>

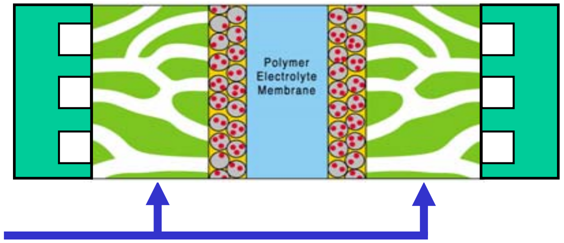
- Low temperature membrane, high Pt loading, CO poisoning
- Requires careful control of hydration
- Suffers from fuel crossover
- Undergoes hygrothermal loading
- Freeze-tolerance?

Gas Diffusion Layers (GDL)



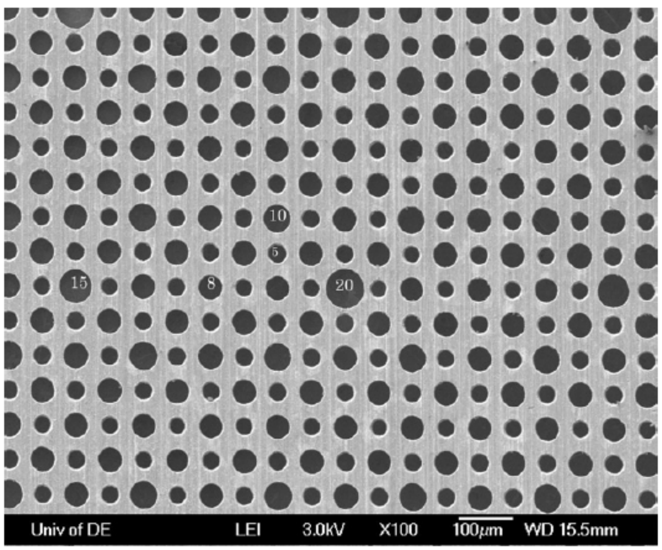
Avcarb 1071 HCB (Carbon cloth)

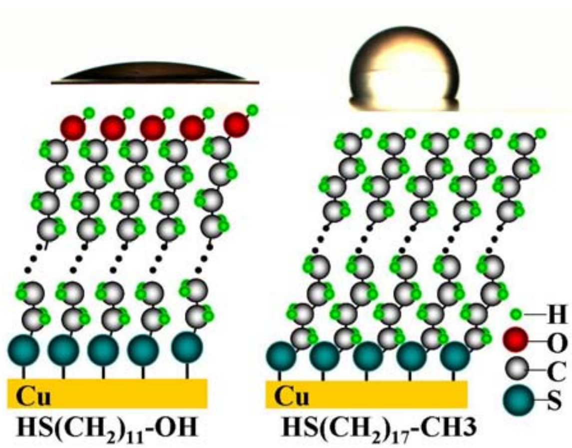
SGL31BA (Carbon paper)

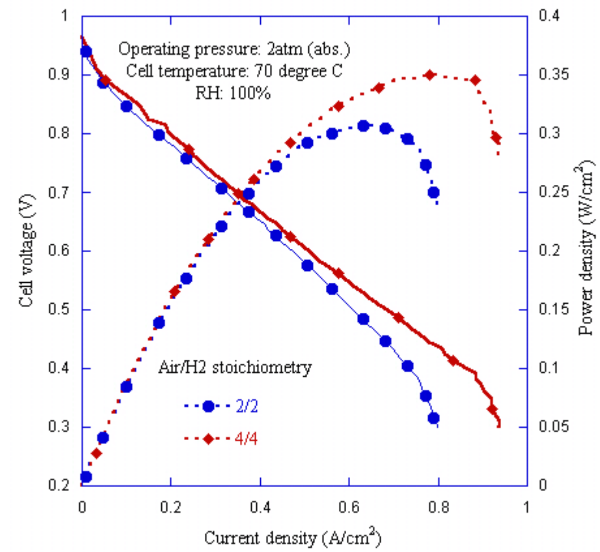


Highly porous, good electrical and thermal conductivity, water management

Novel metallic gas diffusion layer (Zhang, Prasad and Advani)





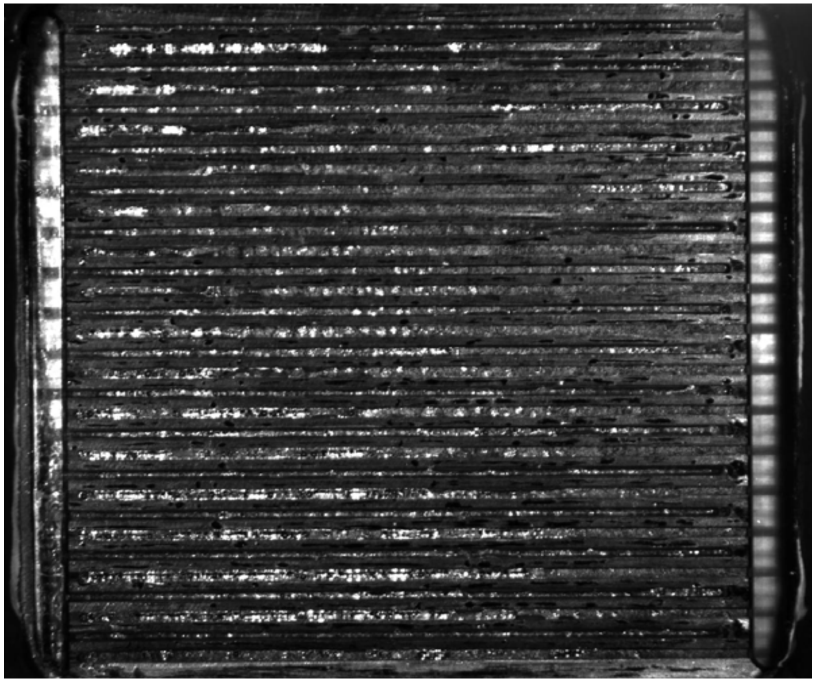


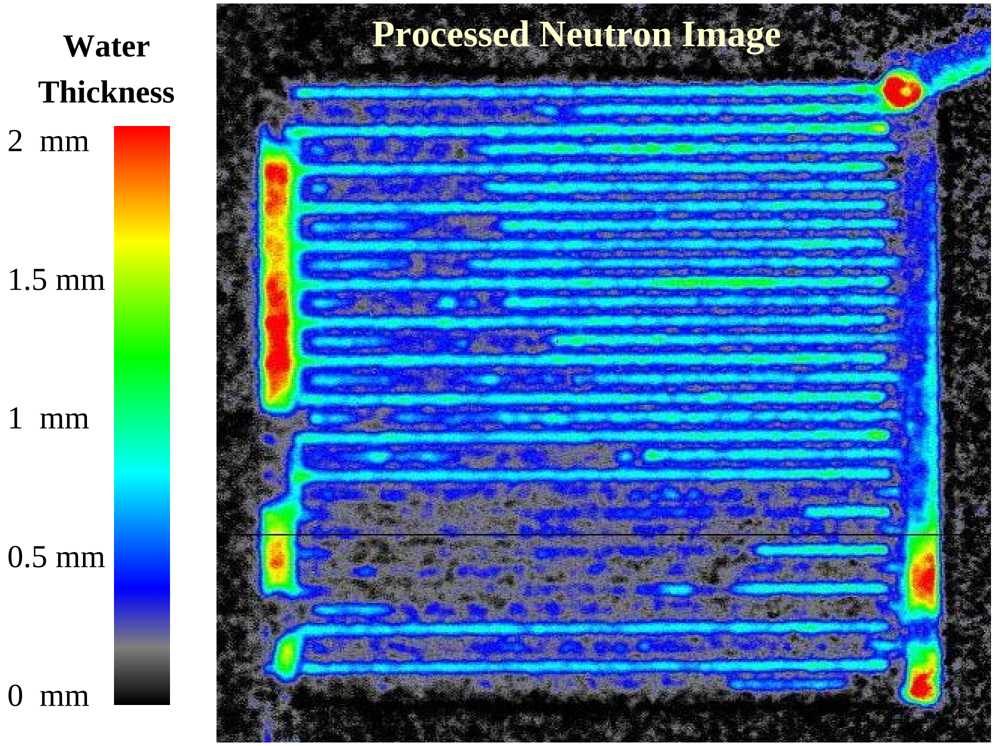
2. Experiments and modeling: flow of gases, water (vapor and/or liquid), reaction kinetics, temperature field, ionic charge, electronic charge, and species→ wide range of length scales

Water management: optical and thermal neutron imaging (NIST)

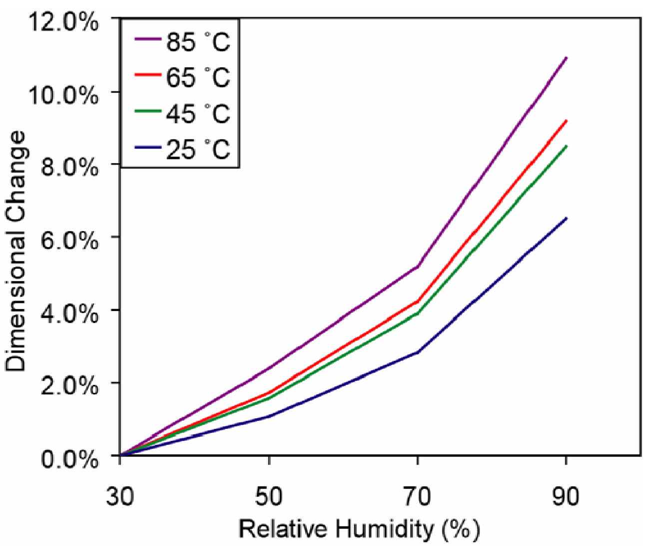
(Spernjak, Advani and Prasad)

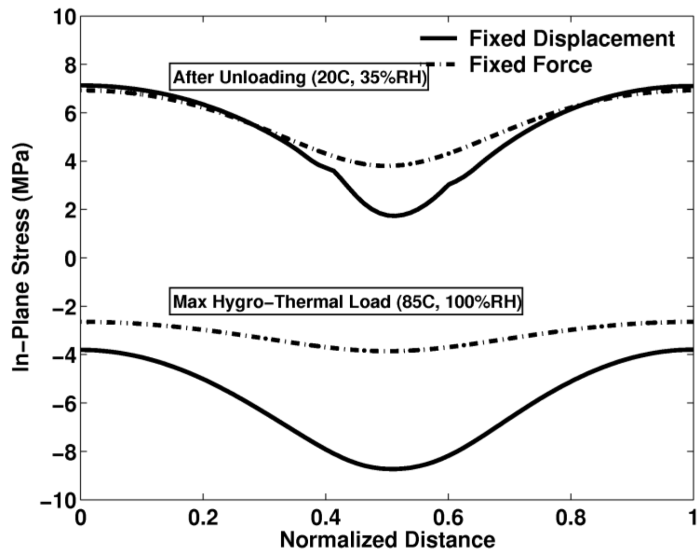
Optical Image: Cathode Flow Field



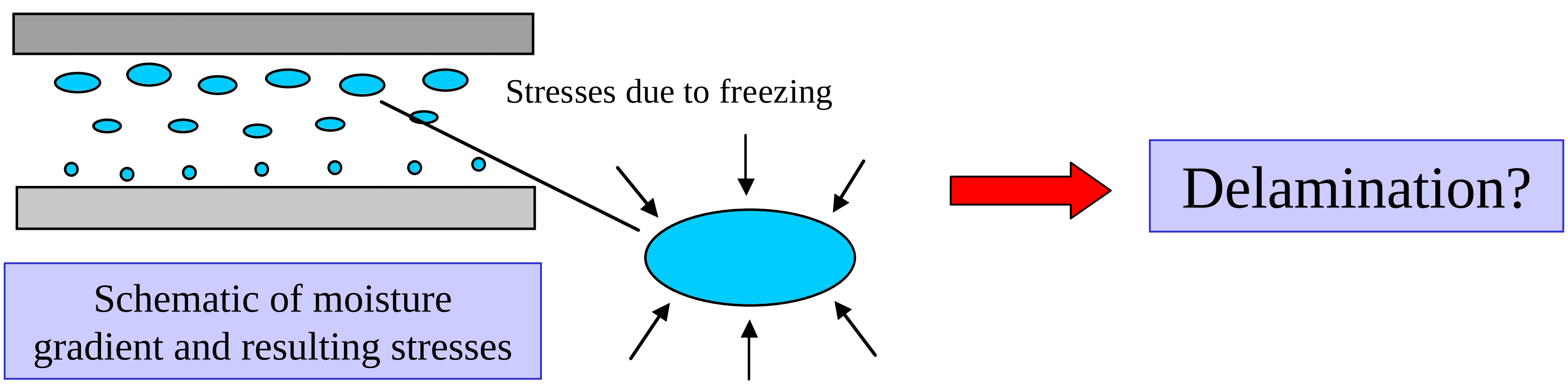


Mechanical degradation of PEM membranes under hygrothermal loading
(Santare and Karlsson)





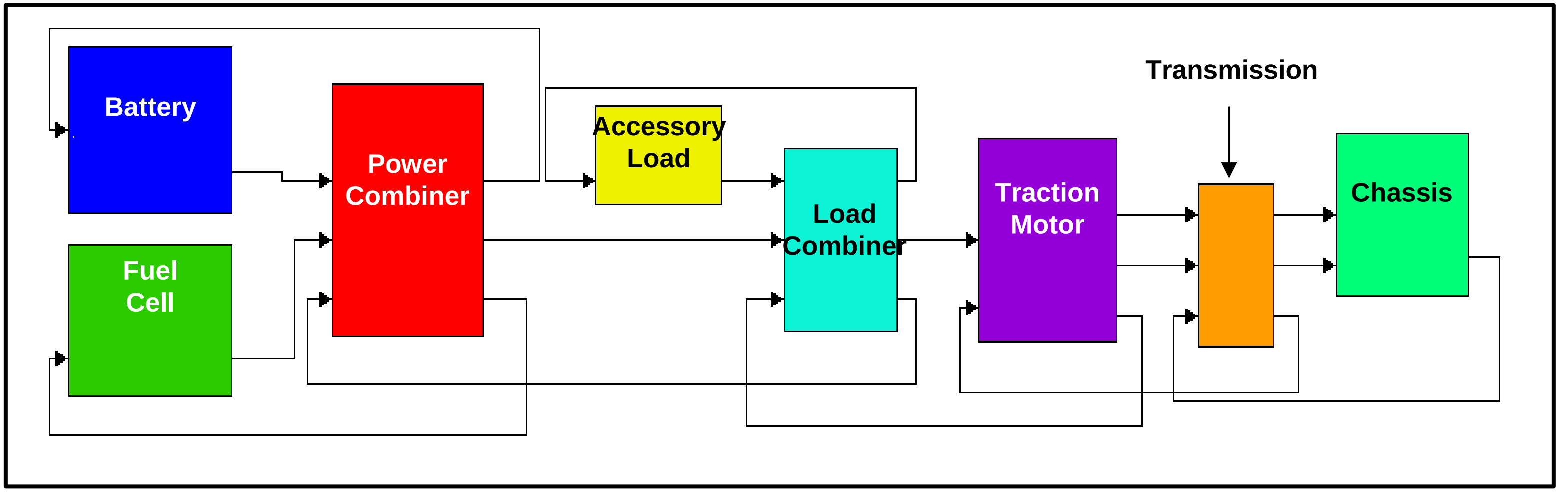
Mechanics of freeze-thaw in PEM membranes (Santare and Karlsson)



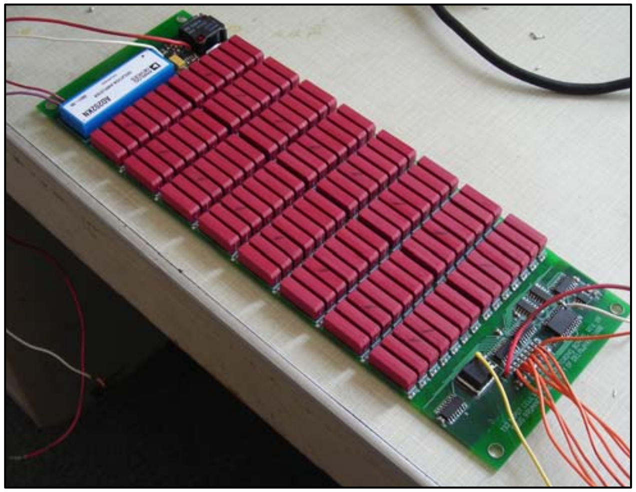
Schematic of moisture gradient and resulting stresses

3. System level: Balance of plant, degree of hybridization, control algorithms

Matlab/Simulink drive-train simulator for fuel cell hybrid transit vehicles
(Brown, Advani and Prasad)

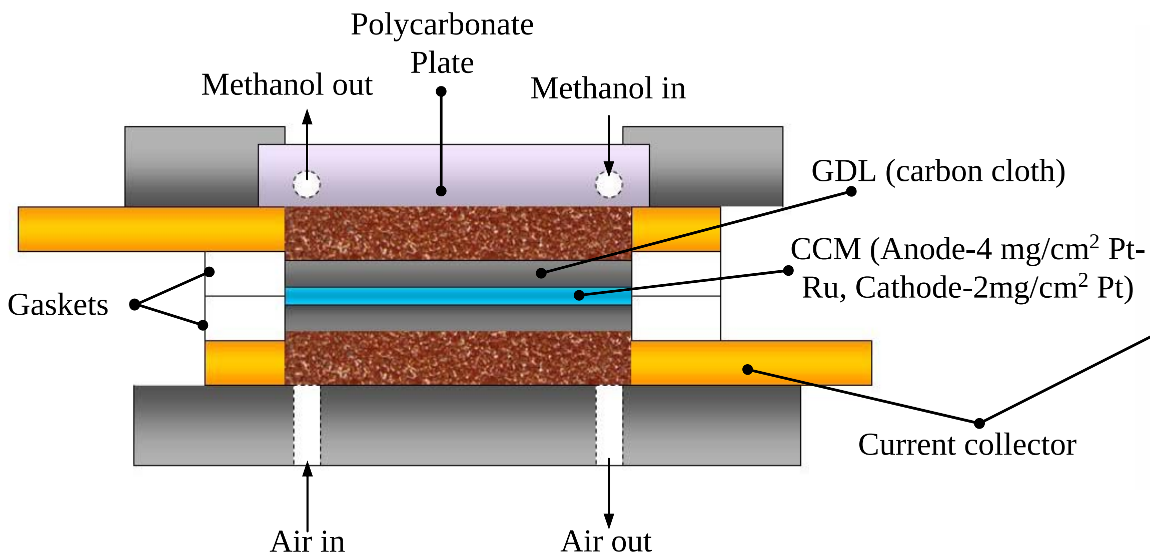


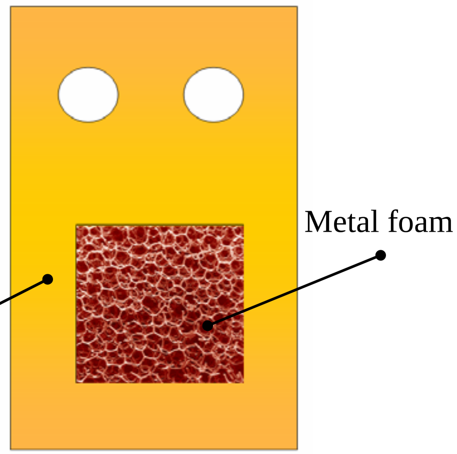
Cell voltage monitoring system for real time fuel cell stack diagnostics (Brunner, Advani, and Prasad)

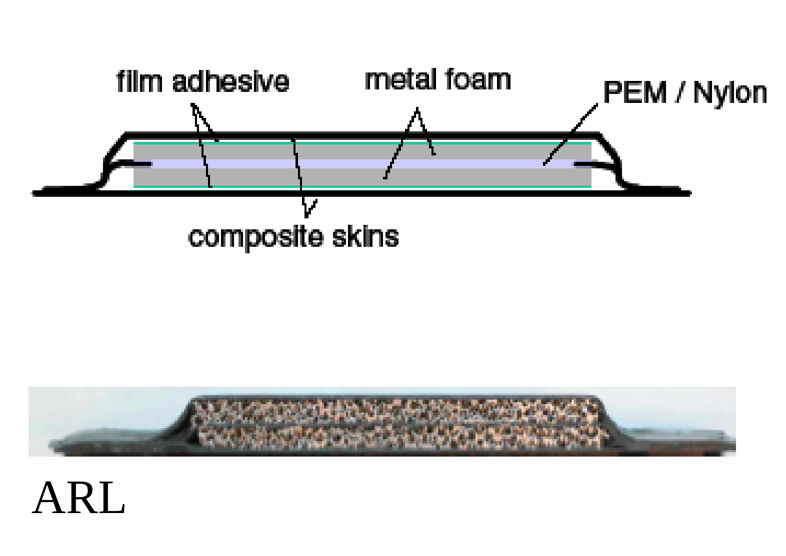


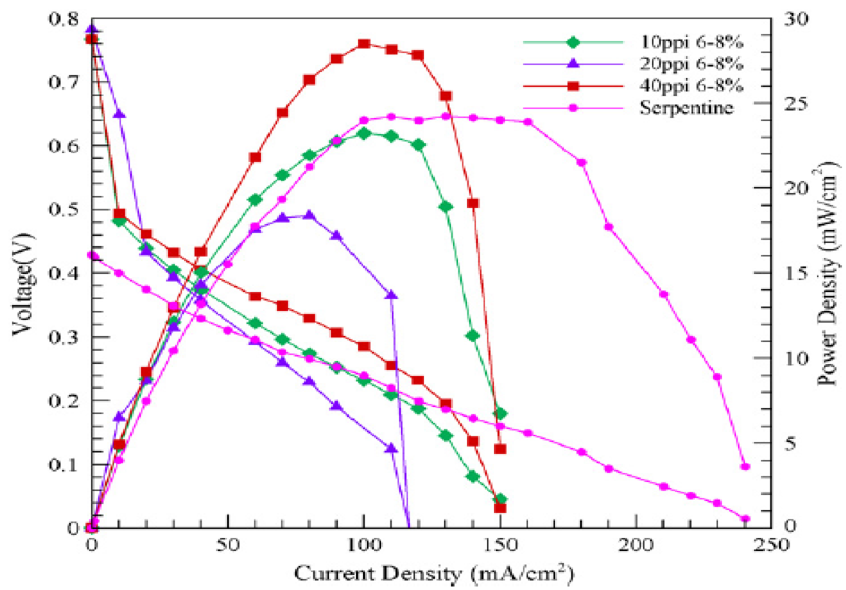
Multifunctional composites: Use of metal foams in DMFC

(Arisetty, Advani and Prasad)

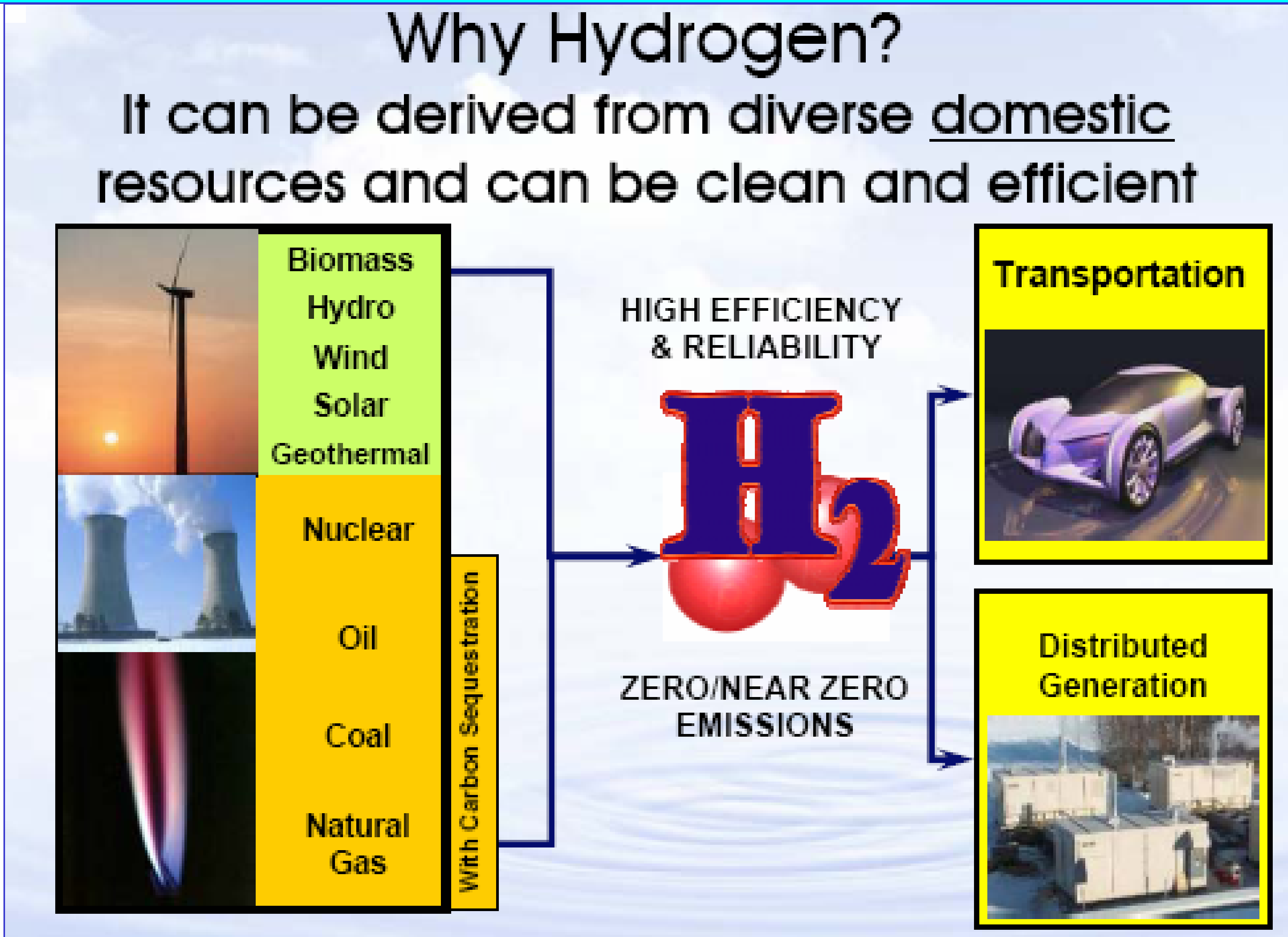








4. Hydrogen production: Reforming fossil fuels → GHG's!
renewable sources → thermochemical, photo-electro-chemical, biological

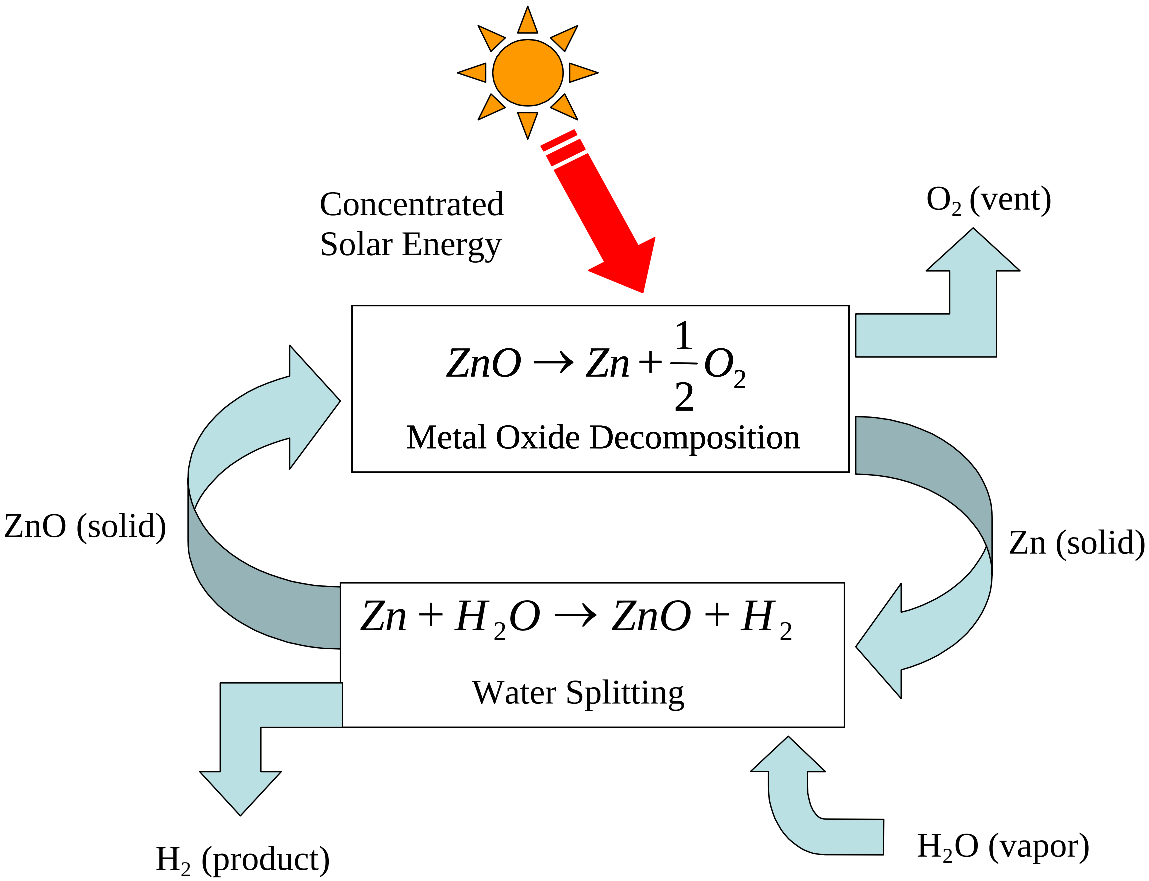


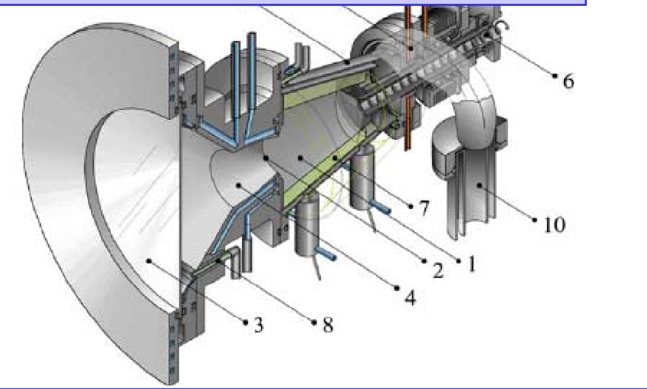
DOE

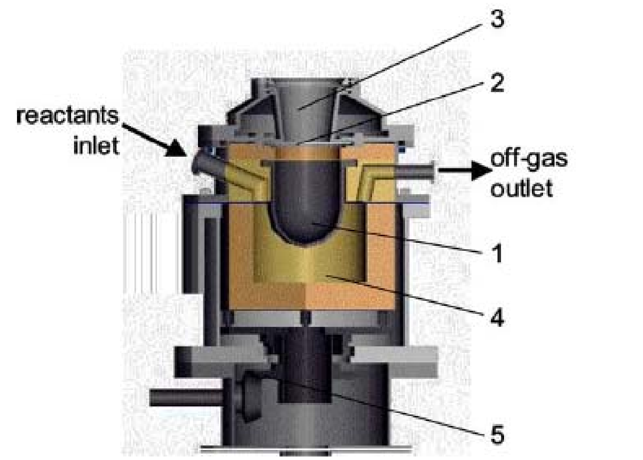
H2 production from solar energy: Thermochemical cycles

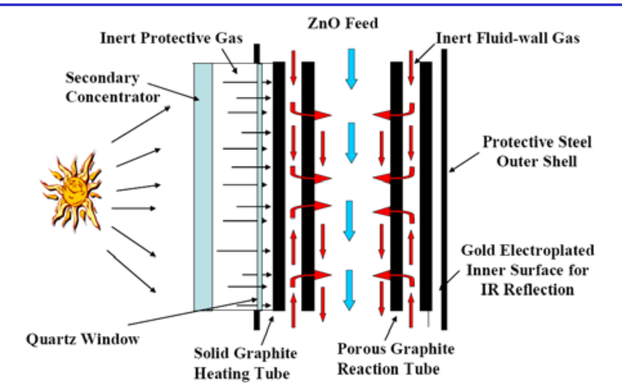
(Koepf, Advani and Prasad)

Zinc Oxide cycle for the thermochemical splitting of water

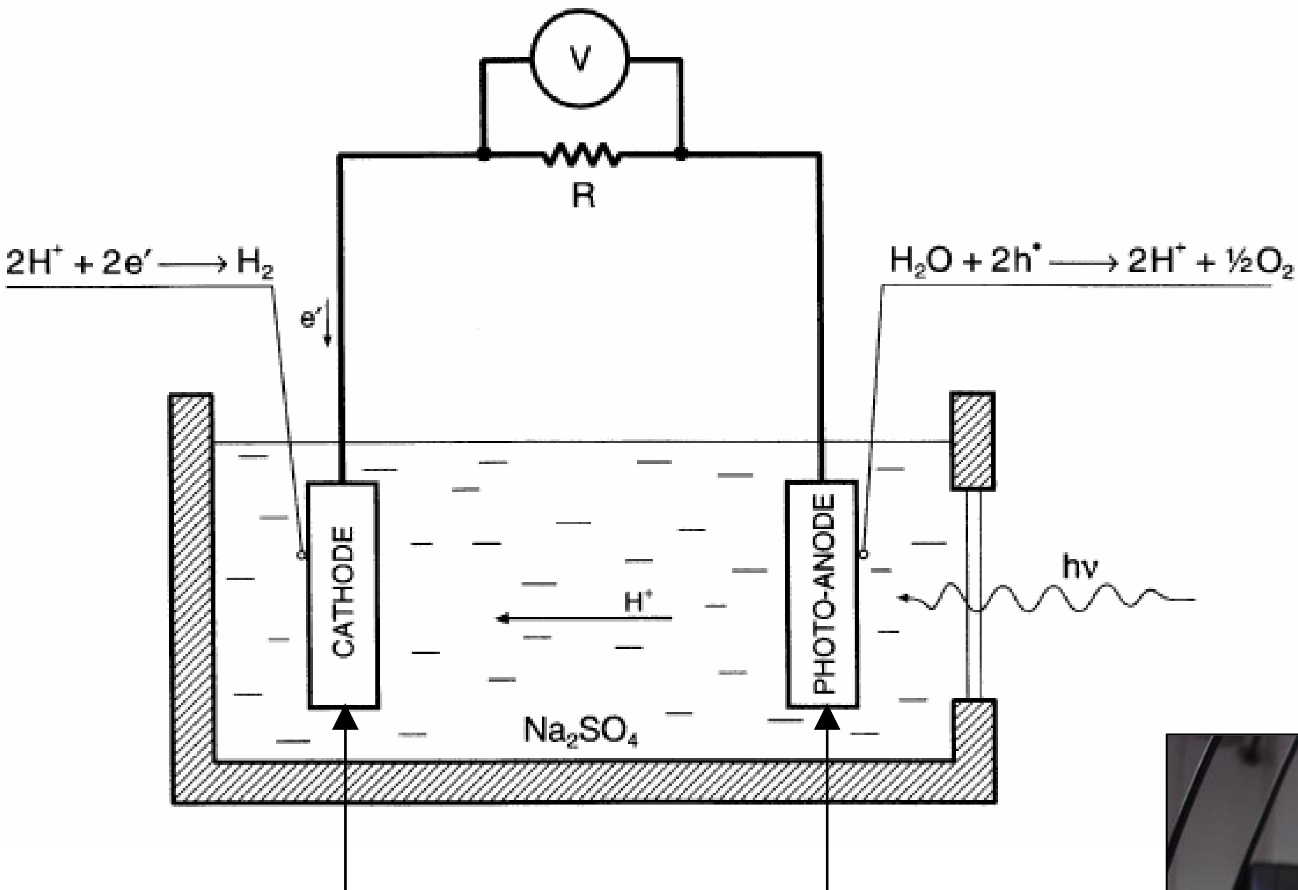






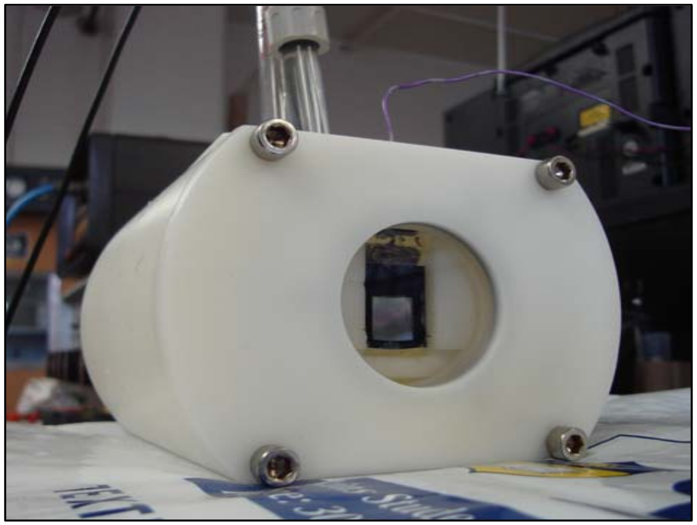


H2 production from solar energy: Photo-electro-chemical (PEC)

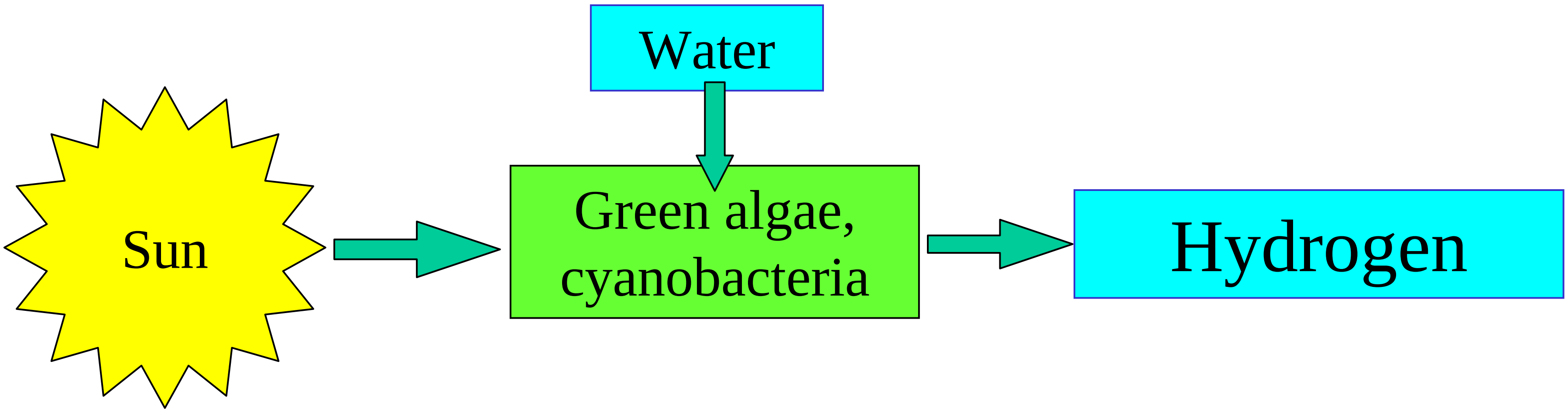


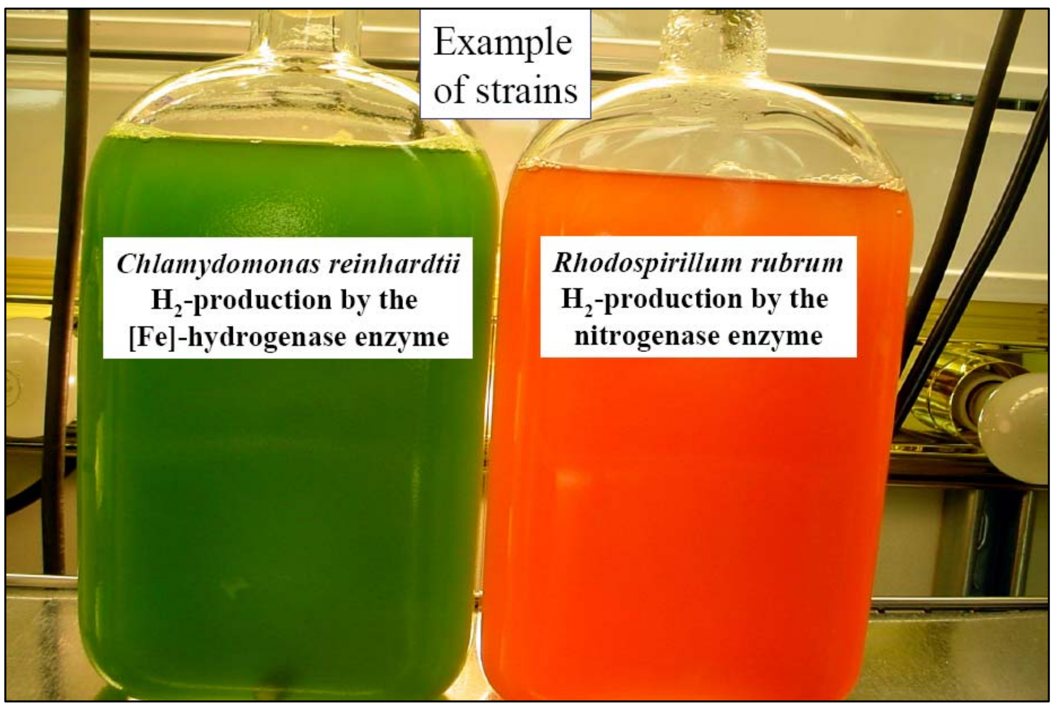
Tungsten Monocarbide as a novel low-cost counter electrode for PEC (Esposito, Chen and Birkmire)

N-doped TiO_2 Photoelectrodes for Solar Hydrogen Generation (Schulz and Shah)



H2 production from solar energy: Photobiological water splitting





DOE

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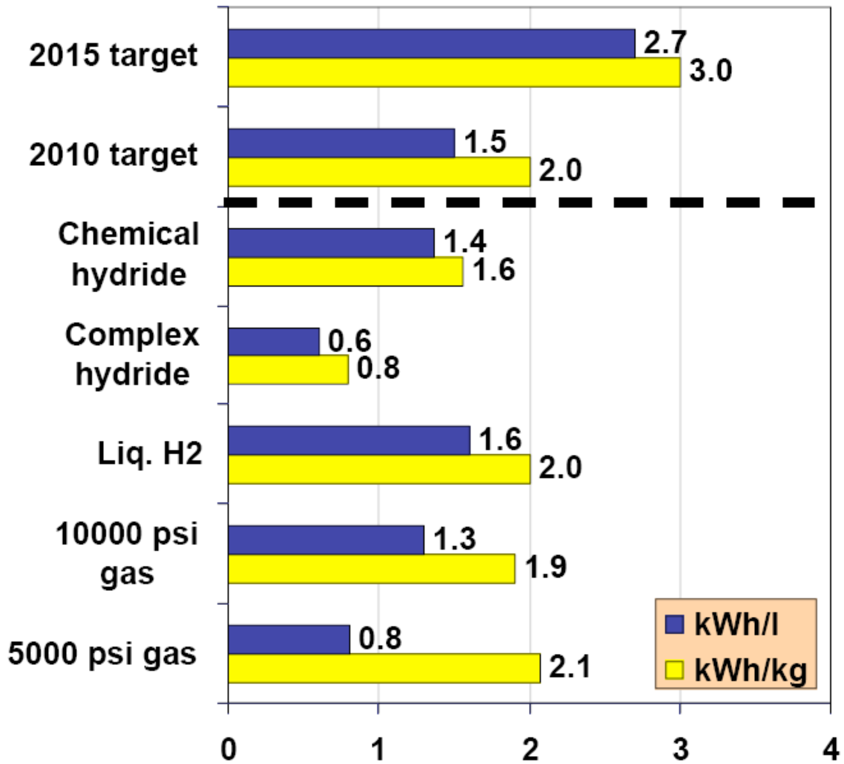
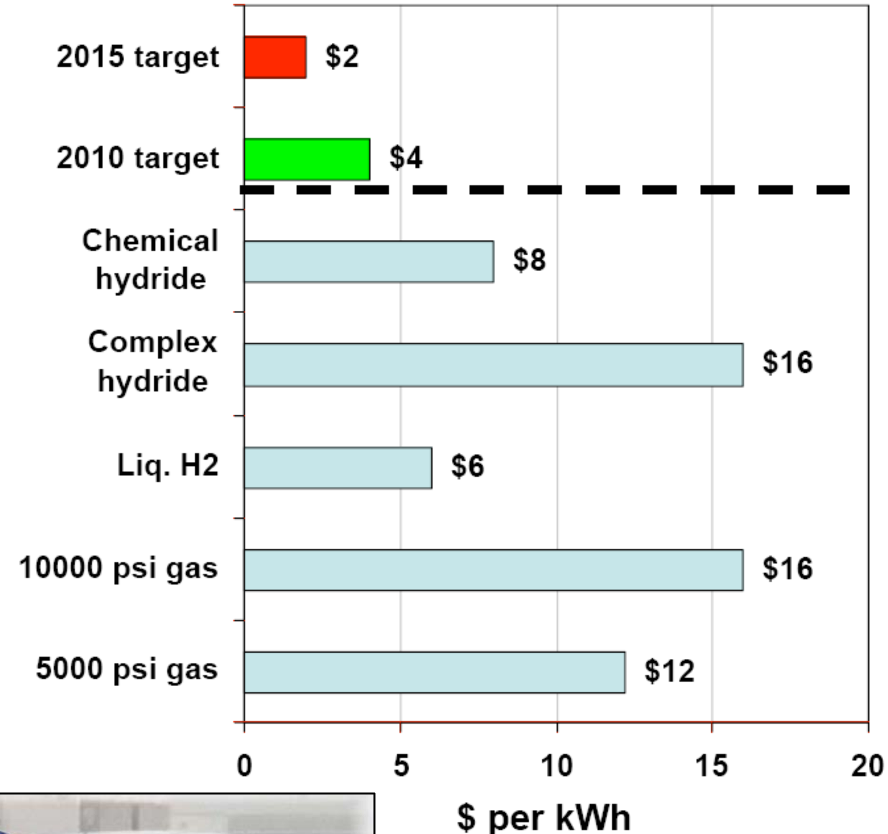
5. H2 storage: H2 is light (2 g/mole, LH2 is 70 g/L)

Volumetric & Gravimetric Energy Density



Cost per kWh, $/kWh



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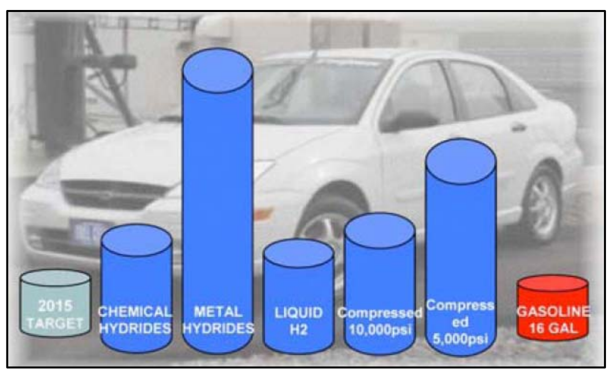

UD Fuel Cell Hybrid Bus Program

UD Fuel Cell Bus Program: 05-09

- Phase 1: 22-ft bus, 20 kW stack, Ni-Cad batteries (in operation, 100 students/day)
- Phase 2: 22-ft bus, 40 kW stack, Li-Ti batteries (Spring ’08)
- Phase 3: 30-ft bus (Spring ’09)

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Department of Mechanical Engineering

Fuel Cell Research Laboratory

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Delaware's First Fuel Cell Powered Bus

Recent News:

WHYY News Report (Real Media)
UDaily news report
Fox 29 News at 10 video
The News Journal (UD Bus Aids Fuel Cell Research)
The News Journal (Fuel Cells Power Bus at UD)
ABC 6 Action News video

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HIGHLIGHTS

Blue Hens defeat SIU in NCAA semifinals

Antarctic blog: Glad to go, but sorry to leave

Prof receives early career award in literacy field

Delaware playoff tickets sell out quickly

LIFE Fest fosters public speaking, presentation skills

Murray receives Crystal Apple Award in education

UD drinking-water technology named one of year's top advances

Drive gathers bushels of food for charity

Nominations sought for awards, alumni

Delaware researchers part of fuel cell team

10:50 a.m., March 27, 2007--University of Delaware scientists are part of a team headed by Nuvera Fuel Cells Inc. of Cambridge, Mass., that has won a $5 million U.S. Department of Energy grant for research and development of fuel cells.

Professors Michael Santare and Anette Karlsson are collaborating with Nuvera Fuel Cells Inc. of Cambridge, Mass., to make polymer electrolyte membrane fuel cells commercially viable for transportation applications.

Michael H. Santare, professor of mechanical engineering, and Anette M. Karlsson, assistant professor of mechanical engineering, are leading efforts at the University.

The funding will support UD research on polymer electrolyte membrane fuel cells (PEMFCs), which Santare said have many potential benefits for transportation applications. Among those benefits are increased fuel efficiency, lowered harmful emissions and a reduction of the world's dependence on petroleum, he said.

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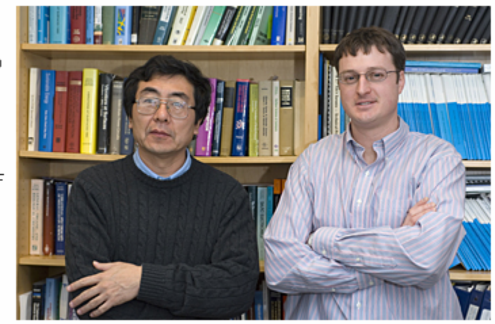
Nominations sought for awards, alumni board

UD, Del Tech leaders

Fuel cell research duo wins $4.6 million DOE grant

2:33 p.m., March 6, 2007--Two University of Delaware professors are part of a research team that has been awarded a $4.6 million research grant by the U.S. Department of Energy to find ways in which hydrogen fuel cells can be made less costly and more stable by using materials such as tungsten carbide modified with low concentrations of platinum instead of pure platinum.



Jingguang Chen (left), professor of chemical engineering and director of UD's Center for Catalytic Science and Technology, and Brian Willis, assistant professor of chemical engineering, are working in conjunction with major research labs across the country to improve hydrogen fuel cell technology.

Jingguang Chen, professor of chemical engineering and director of the Center for Catalytic Science and Technology, and Brian Willis, assistant professor of chemical engineering, will be working in conjunction with Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL) and Ballard Power Systems, a fuel cell manufacturer.

COE Faculty involved in FC research

CEE

Chu
Faghri
Huang

ChE

Barteau
Buttrey
Chen
Epps
Lauterbach
Vlachos
Wagner
Willis

ECE

Honsberg
Prather

MSE

Birkmire
Shah

ME

Advani
Karlsson
Prasad
Roy
Santare
Sarkar
Wang, LP
Wei

Center for Fuel Cell Research

- Thriving research in COE in fuel cells with funding from FTA, NSF, DOE, ARO, ONR, AFOSR, ARL, DNREC, DEDO, WL Gore, Air Liquide, Fuceltech, Amsen, DuPont, BP, ACS-PRF, ConocoPhillips, Rohm-Haas, Engelhard/BASF, and Praxair.
- Proximity to Dupont, WL Gore, Air Liquide, Air Products, Arkema, Johnson-Matthey, Ion Power.
- Strong buy-in and support for fuel cell research from Delaware congressional delegations and government.
- GM possibly establishing a fuel cell manufacturing plant in Delaware in 2011.

Fuel Cell Short Course: Basics and Applications

- Thursday, April 3, 2008
- 8 am to 4 pm
- Taught by Ajay Prasad
- am: lectures; pm: lab tour, bus tour
- Contact:
  - Kathy Werrell in UD Outreach Office, or
  - prasad@udel.edu