Fuel Cells for Renewable Energy and for Transportation

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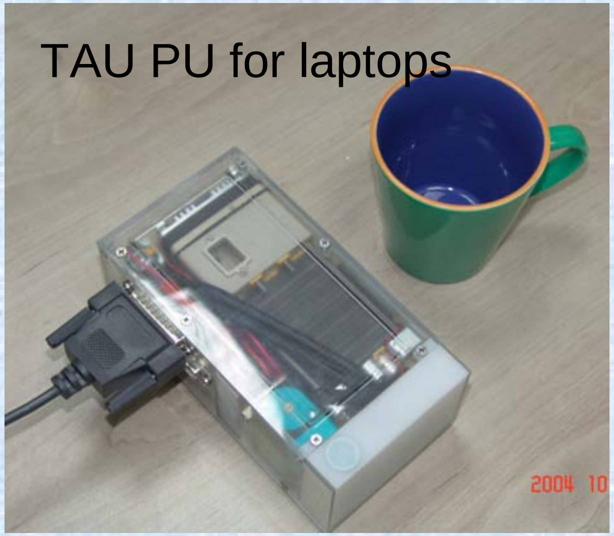
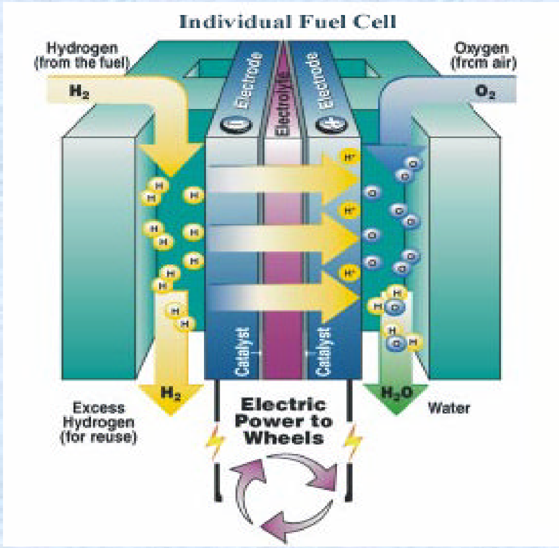




Outline

- The problem: dependence on oil import and ecology damages.
- The solution: renewable energy and alternative fuels (hydrogen (the Hydrogen Economy), alcohols).

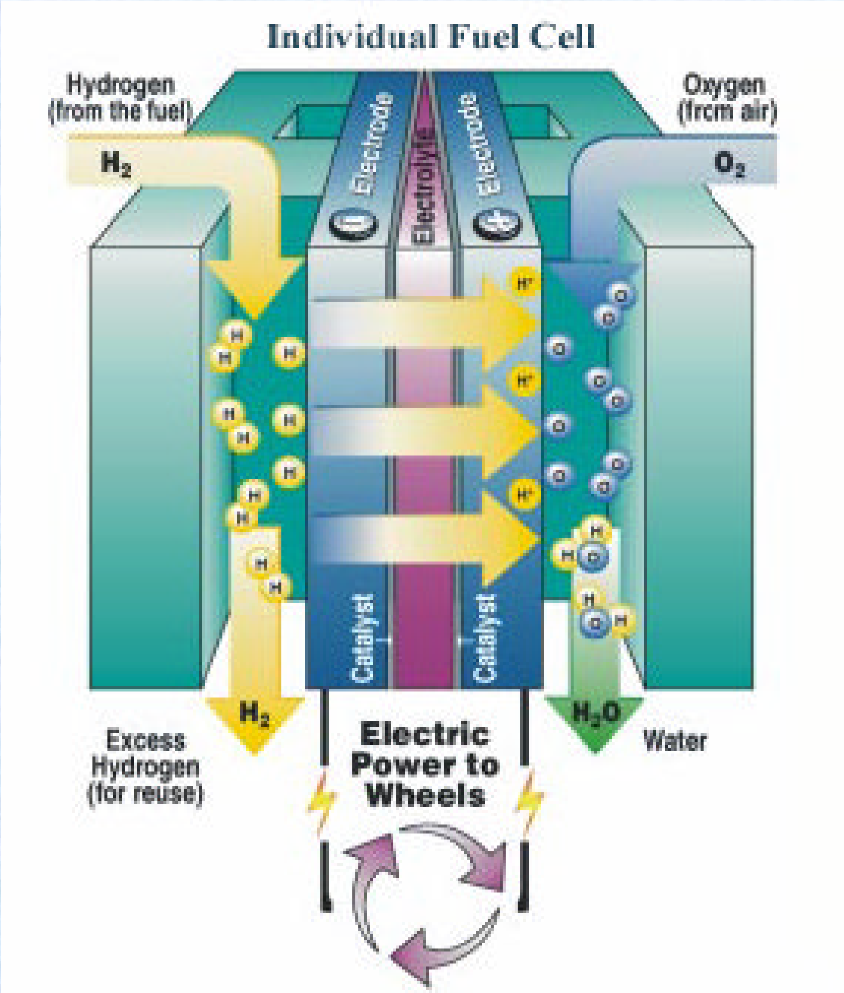
  a) FC systems for cars and small electric vehicles (scooters)

  b) RFC and redox battery (VRB) for renewable-energy storage and load leveling.
- World activity and markets .
- Factors that inhibit PEM FC commercialization – the cost of membranes and platinum catalysts.

The goal: reducing oil import and producing "green" energy

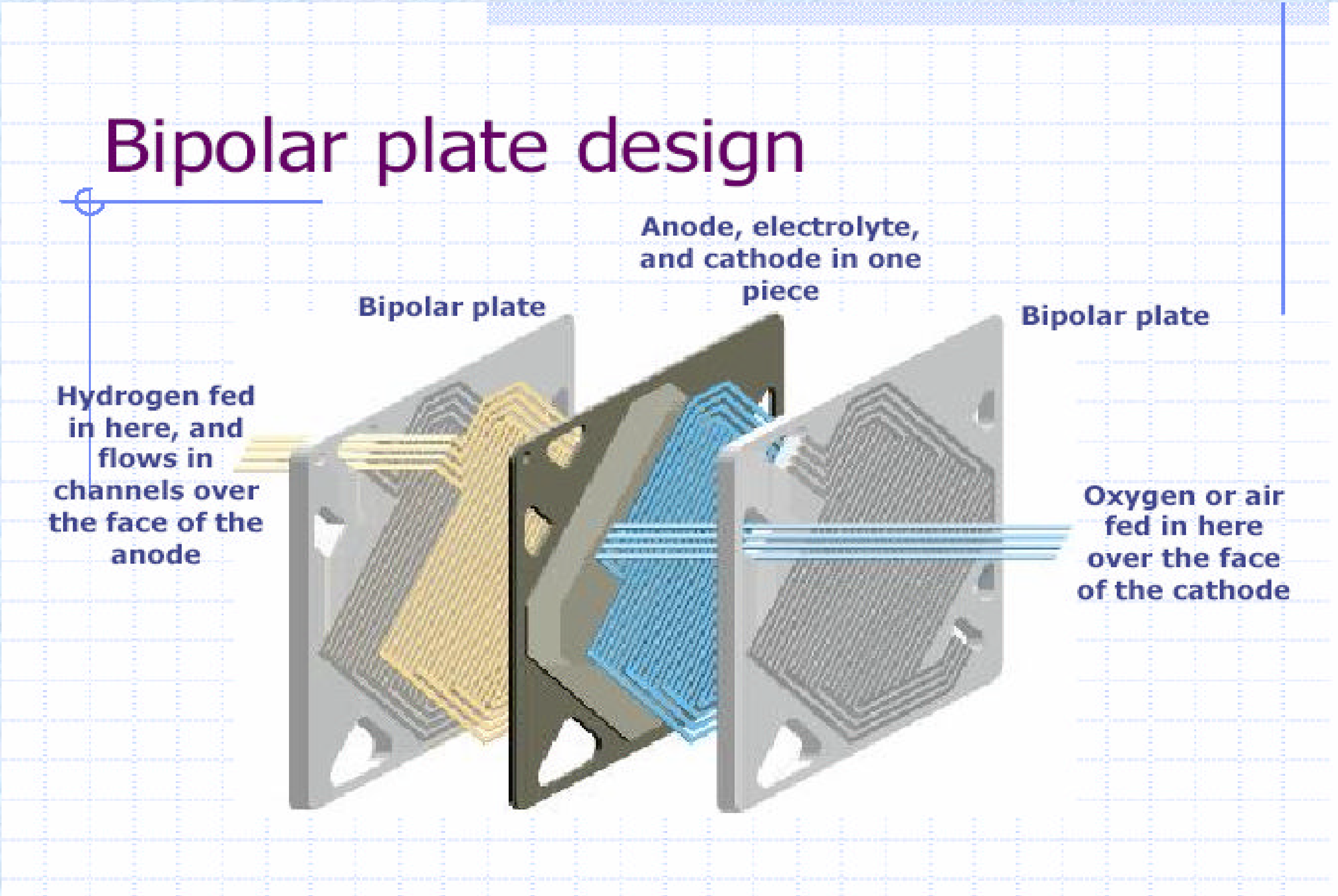
- Israel imports over 95% of its oil.
- Most oil reserves are located in politically unstable states.
- The solution: to shift power production to renewable energy and to develop vehicles powered by renewable energy and by new fuels.
- An efficient and "green" way to convert fuels into energy is by the use of fuel cells.
- Most leading car manufacturers are developing FC or FC-hybrid cars.
- Alternative fuels being considered are hydrogen and alcohols, with most of the effort going into the development of hydrogen FCs.
- Alcohol-fed FCs have some advantages over hydrogen FCs.
- Alcohols can be produced from natural gas, which has a supply reserve of over 50 years and is produced by biological processes.

Basic Operation of a PCM Fuel Cell

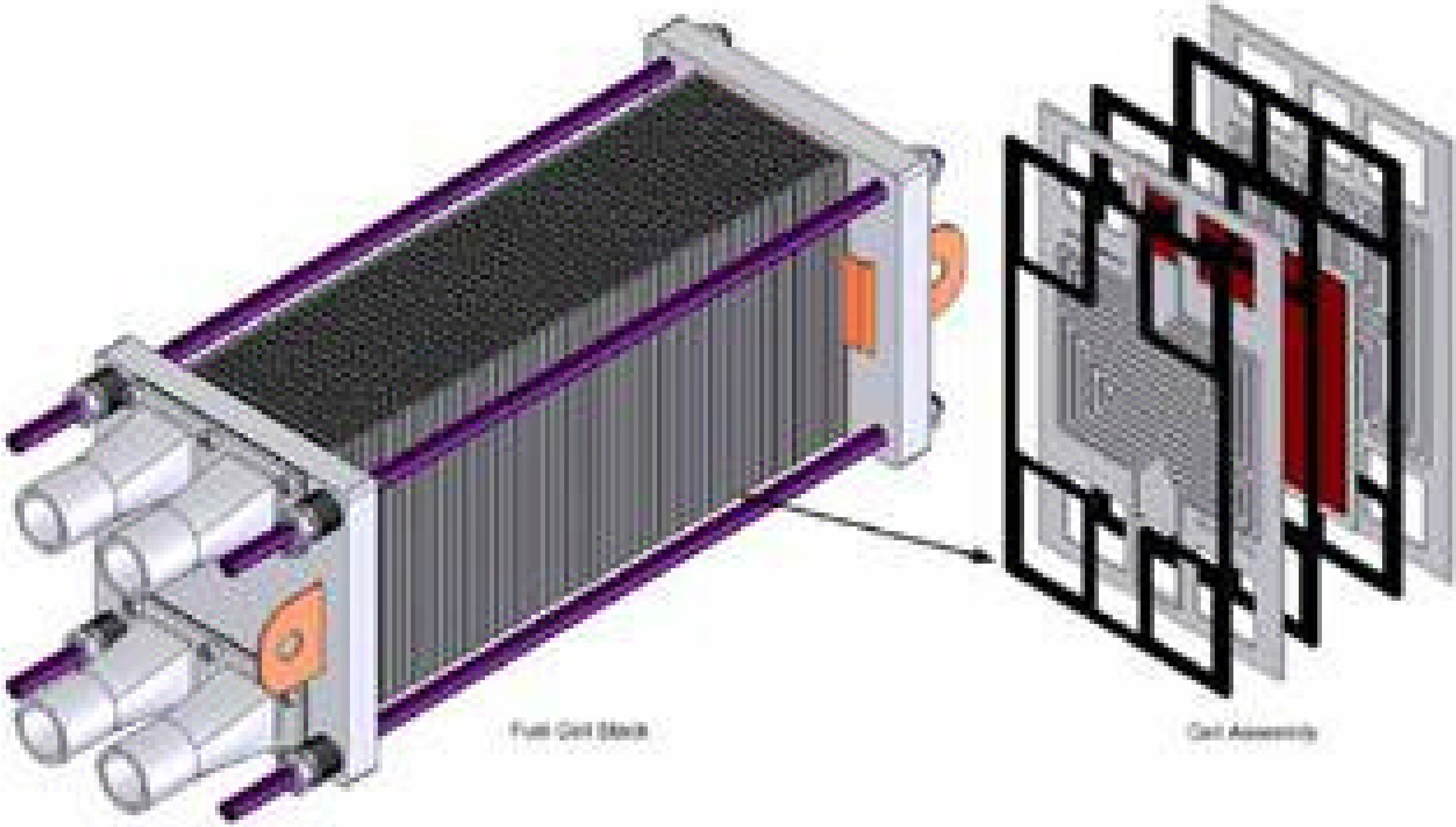


- Chemical Reaction Produces Electricity
- Fuel - H_2, O_2
- By-Product - H_2O
- Electrons Released at Anode
- Electrons Collected at Cathode

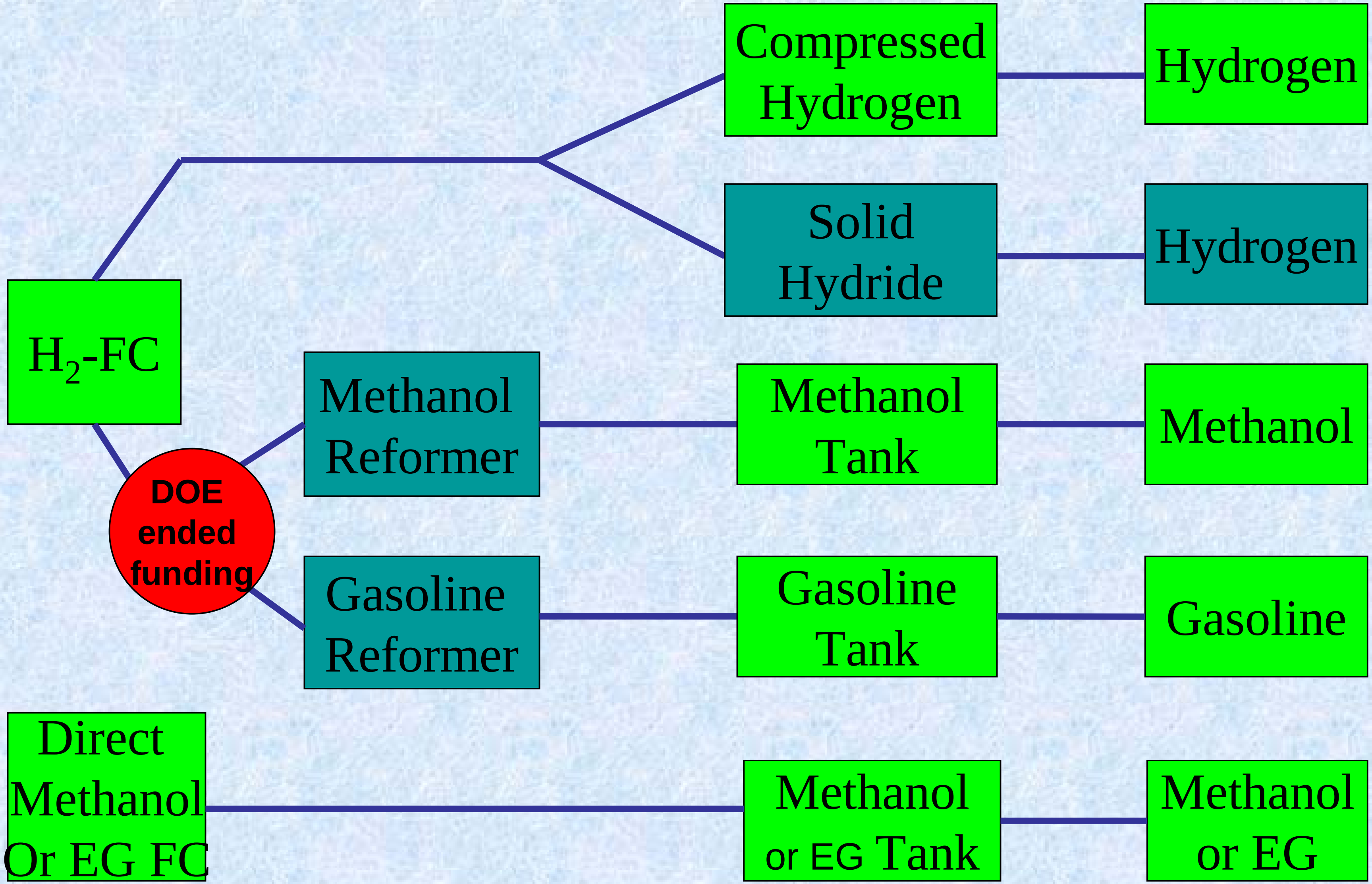
PEM fuel cells



PEM FC stack



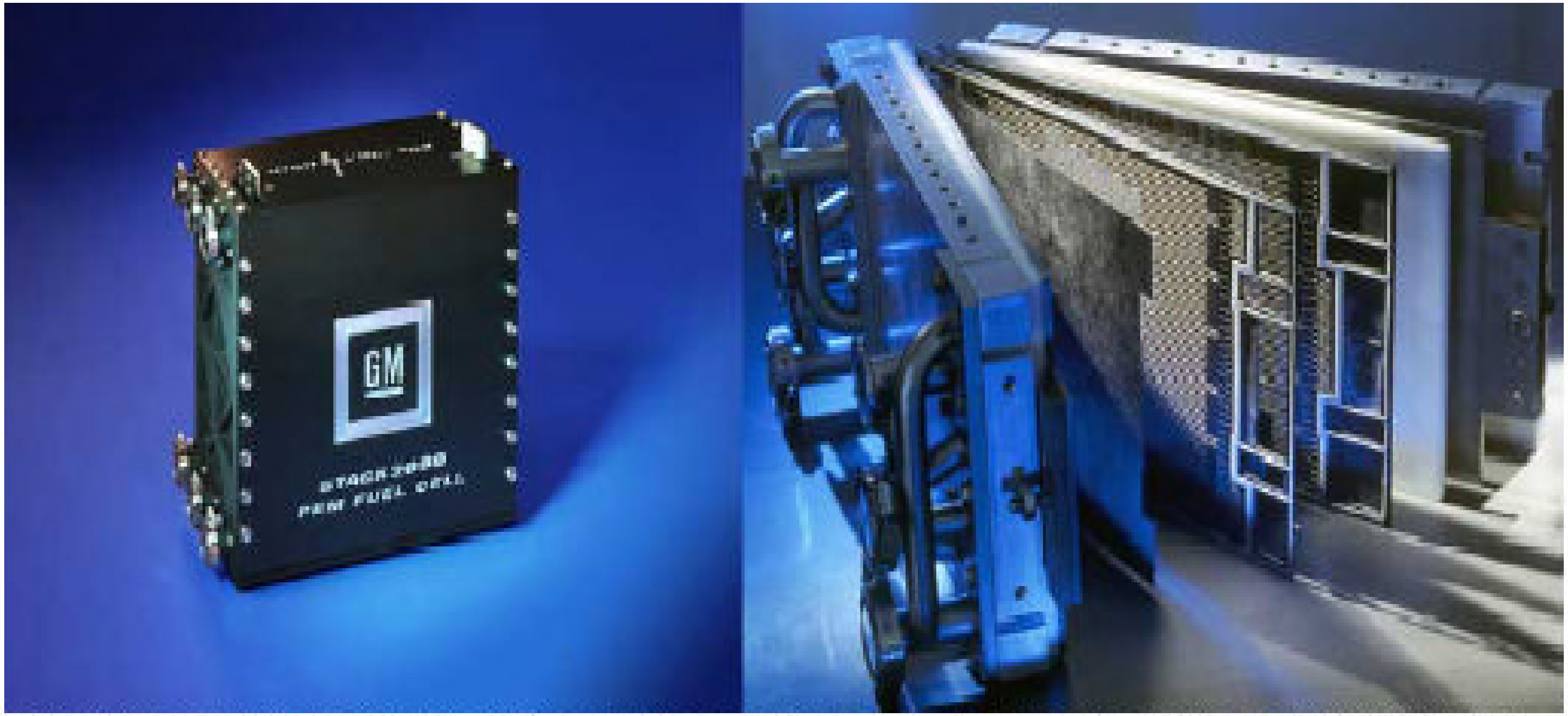
Possible System Configurations: which is the best?



World Activity, Investments and Markets

- Over a billion dollars per year investments.
- Estimated production rate of more than a million FC cars per year by about 2015.
- Very large national and private-sector FC projects in most industrial countries, including India and China.
- Most car manufacturers are involved; some have already demonstrated FC EVs and FC–battery hybrid EVs.
- Several FC-powered scooter projects.

FCEVs
Recent GM PEM FC Stack For EVs (9.2004)



The General Motors HydroGen3 incorporates a proton exchange membrane fuel cell (PEMFC) stack (pictured left) developed by its own team in the USA. Right, detail of the stack showing the various layers such as bi-polar plates and electrodes. (Source: General Motors)

DMFC (up) and hydrogen FC (down) Scooters

Yamaha's methanol fuel cell scooter, unveiled in 2003 (Source: Yamaha)

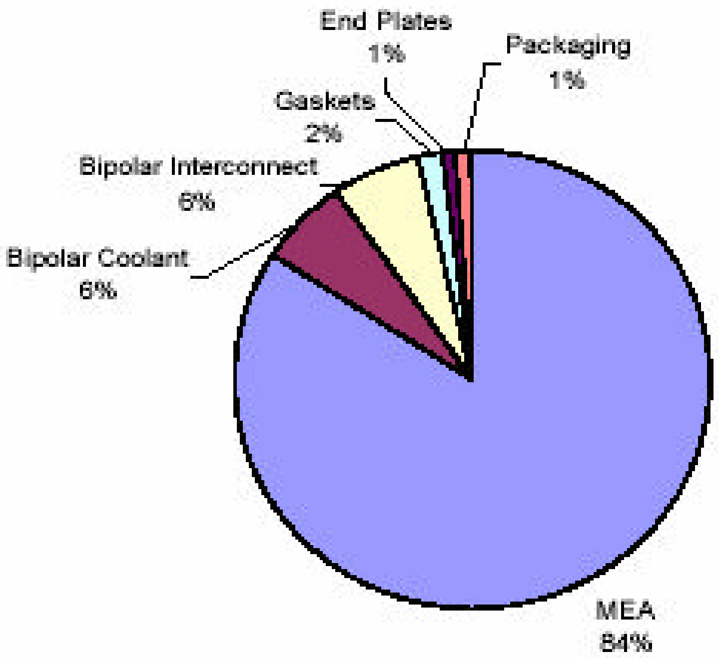
Honda's fuel cell scooter which have been seen on the streets of Vietnam **2006**

The cost problem of PEM FC for EVs

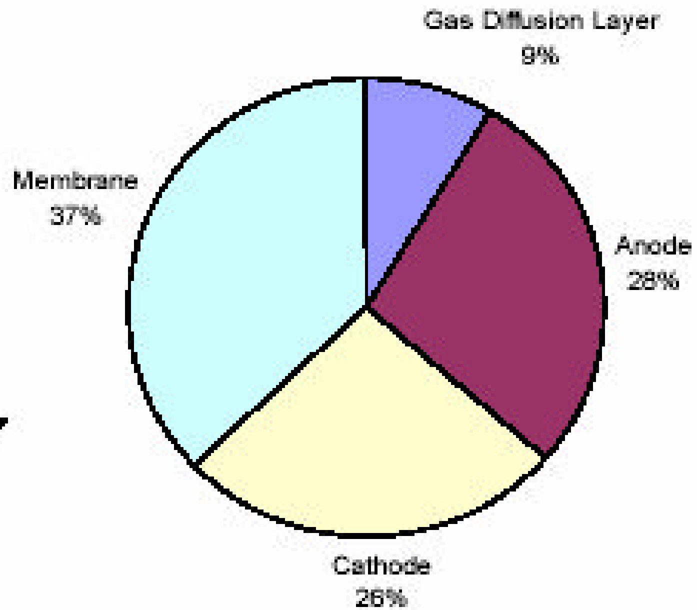
Results Baseline System *Fuel Cell Stack Cost Breakdown*

Platinum and the electrolyte membrane are the major contributors to the stack cost.

Yr 2001 Fuel Cell Stack Cost Breakdown (Stack Cost: $181/kW)



Yr 2001 MEA Cost Breakdown (MEA Cost: $152/kW)

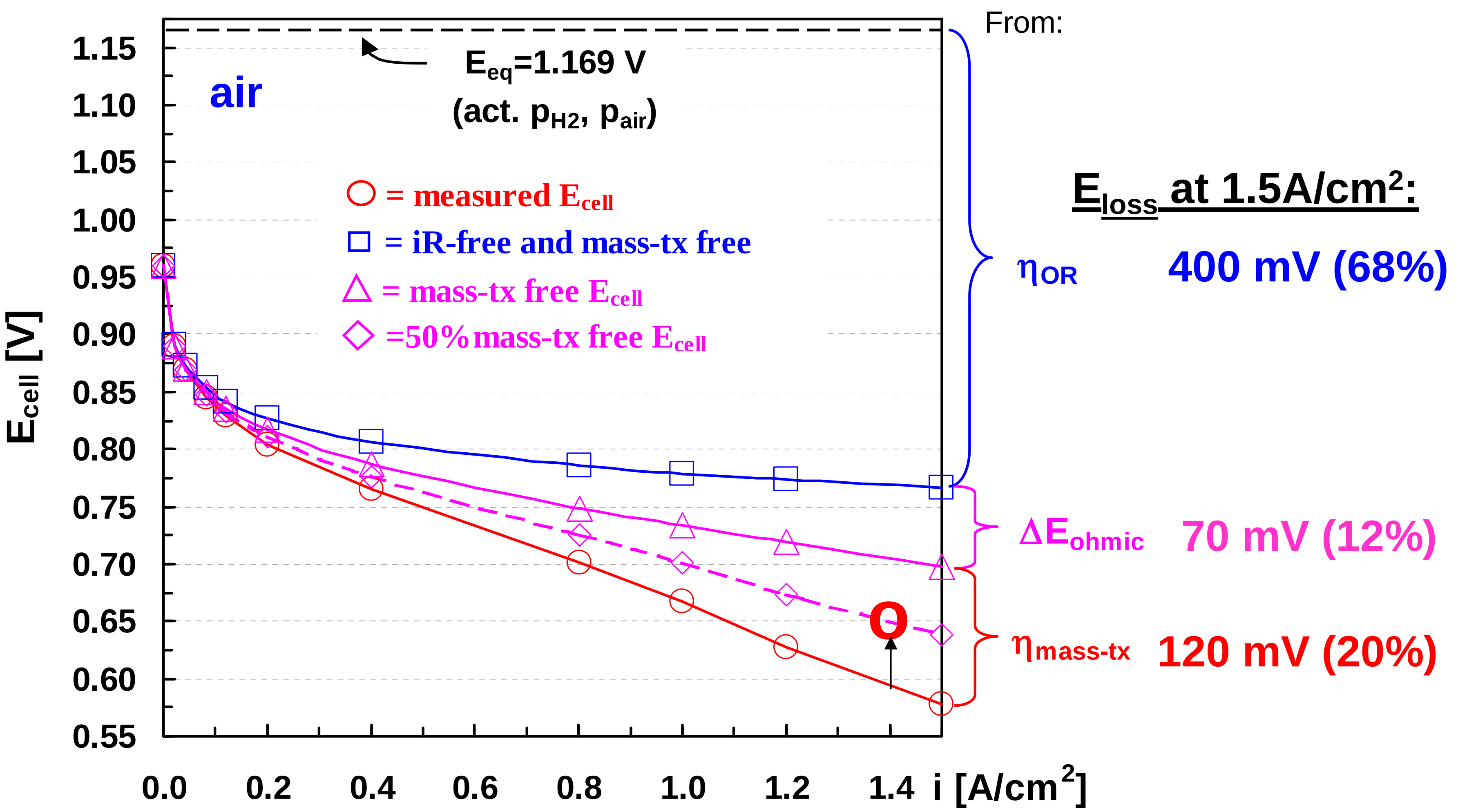


180 grams Pt (0.8 mg/cm^2) for 0.8V @ 250 mW/cm^2

*Basis: 50 kWe net, 500,000 units/yr. Not complete without assumptions.

While power density determines the actual amount of material in the system. Parasitic power losses further increase size and cost.

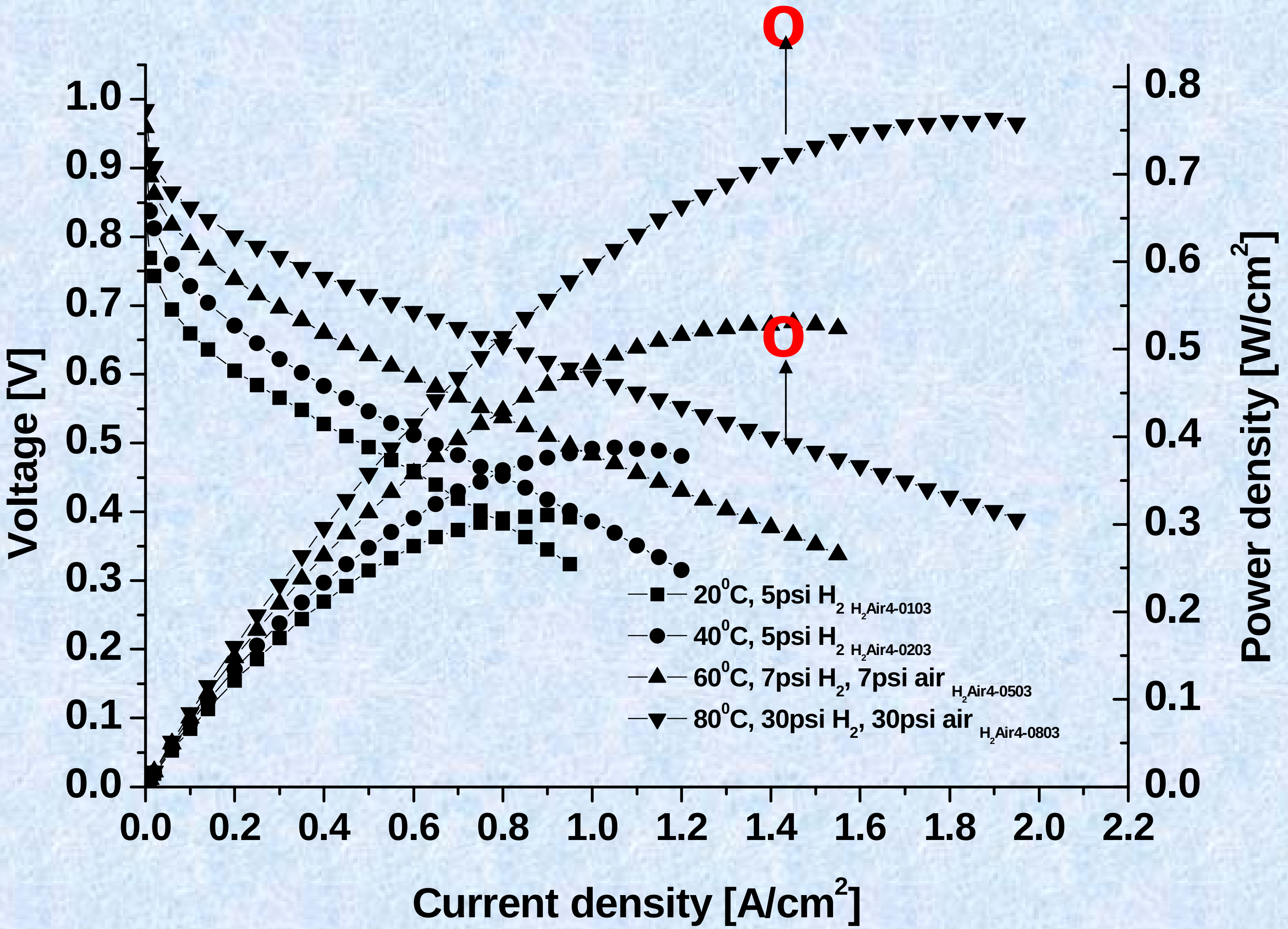
Performance Issue - Voltage Losses in State-of-the-Art H_2/air Fuel Cells (0.4 mgPt/cm^2)



- major losses due to poor cathode kinetics (ORR)
- minor losses by ohmic resistance
- gains through improved flowfields/diffusion media (mass-tx)

TAU NP-PCM-Based H_2/Air Fuel Cell Performance

no air humidification, 2 mg Pt/cm^2 on each electrode, 2M triflic acid, PVDF based NP-PCM (EV goal: 0.9W/cm^2 at 0.65V and 0.1 mgPt/cm^2).



Recent progress in MEA development for EVs

- Improved performance and lower Pt loading (currently about 0.4 mgPt/cm^2).
- Improved membrane durability.
- Better and more stable catalysts for ORR (Nina).
- Better corrosion-resistant carbon support for the Pt nanoparticles.
- More stop-and-start (load-change) cycles and better cold-start.

Interface, vol 14, #3,

Mathias et. al (2005).

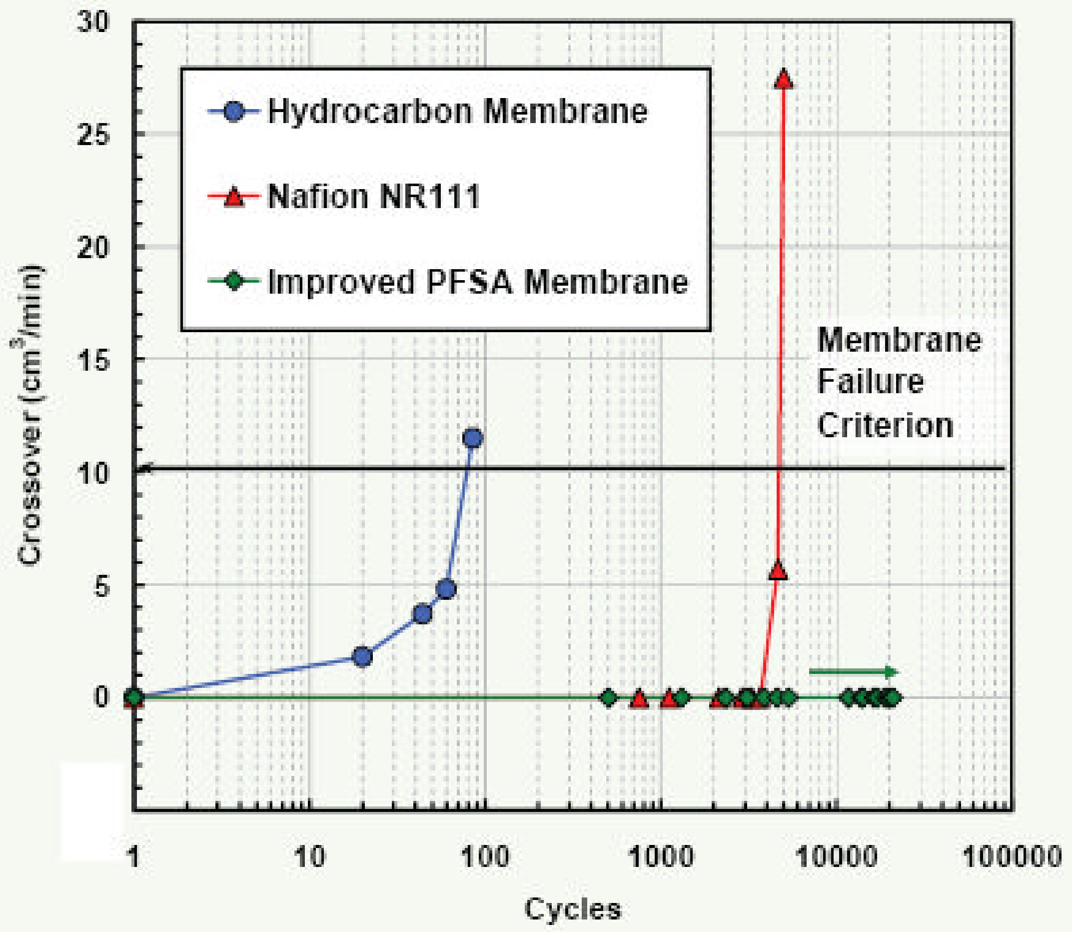


FIG. 4. MEA crossover leak vs. number of RH cycles for catalyst coated membranes based on different 25 μm thick membranes: two PFSA membranes and one hydrocarbon membrane. RH cycle conditions: 150% RH, 2 min ↔ 0% RH, 2 min cycles (air/air) at 80°C using 50 cm² catalyst coated membranes and carbon paper diffusion media. Membrane gas crossover leak rates (in sccm) were determined with air at a pressure differential of 20 kPa across the membrane.

Why use Pt-alloys? Lower area loss

Interface, vol 14, #3, Mathias et. al (2005).

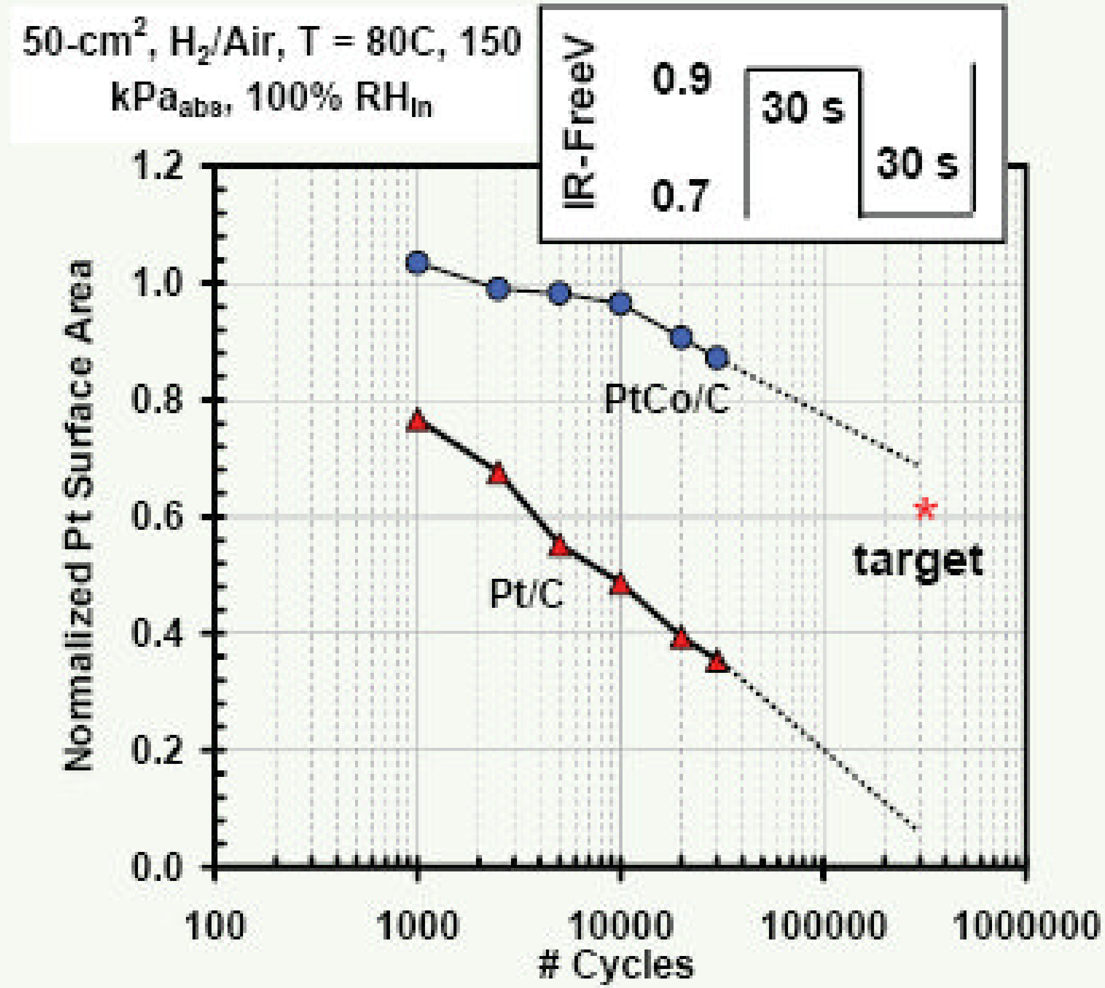


FIG. 8. Pt surface area loss of (▲) ≈50 wt % Pt/C, and (•) ≈30 wt % PtCo/C as a function of the number of potential cycles between 0.7 and 0.9 V (iR-free potentials) in H_2/air at 80°C and 100% RH.

Development goals for EV FCs

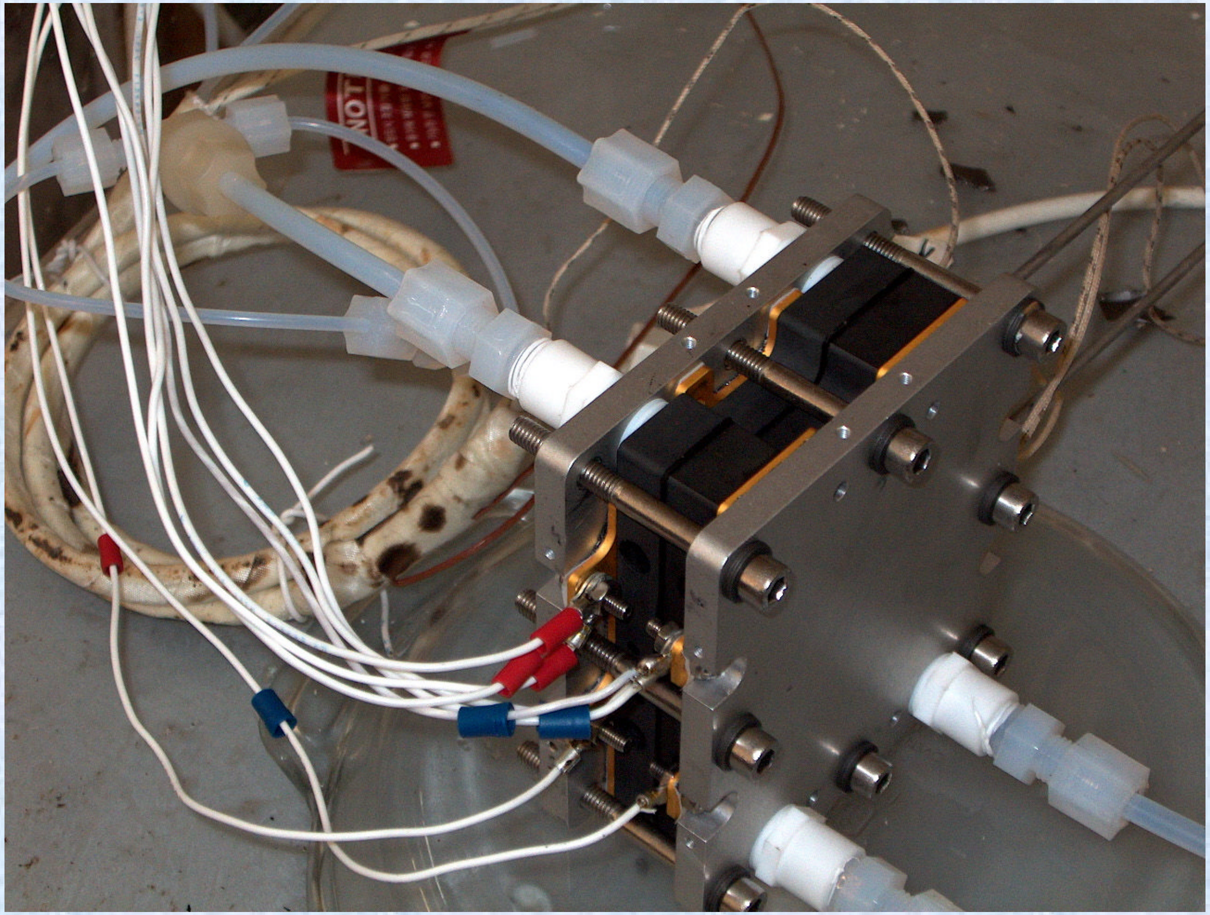
- Low-cost and low-RH (25-50%) high-temperature membrane (above 120ºC) in order to reduce Pt loading and to reduce the size and power loss of the cooling system (twenty research groups in the USA).
- Target cost for catalysts: less than $10/kW
- (or 0.2 gPt/cm^2 (total) at $35/g Pt)
- More active (by factor of only 3-4) and more stable ORR catalysts.
- Better understanding of the MEA-degradation mechanism and of the proton-conduction mechanism at low RH.
- Hydrogen cost will be at least twice that of gasoline. Thus FC efficiency must be twice that of ICE.
- ICE delivers about 1kW/l, FCs must meet this value.
- The best solution for EVs is a FC-battery hybrid system.

Development Goals for Small FC-powered EVs (e.g. scooters)

- The preferred fuels for this application are methanol or ethylene glycol (using a direct-oxidation FC).
- TAU novel NP-PCM based DOFC demonstrated 0.5W/cm^2 and 0.3 W/cm^2 for DMFC and DEGFC respectively.
- Much more active fuel-oxidation catalysts and also ORR catalysts are needed.
- Pt loading must be reduced, preferably to less than 1mg/cm^2 (today it is 3-8).
- The corrosion (degradation) rate of the Pt-Ru fuel-oxidation catalyst must be reduced.
- A low-cost and low-RH (25-50%) high-temperature membrane is needed.

TAU 50cm^2 single-cell DMFC (or H_2/air).

This cell size can be used to build a 1kW 70-cell stack which will have a volume of about 2-4 liters (enough to power a scooter).



Storage of solar and wind power and load leveling

- Hydrogen bromine RFC for remote sites
- Vanadium Redox Battery (VRB)

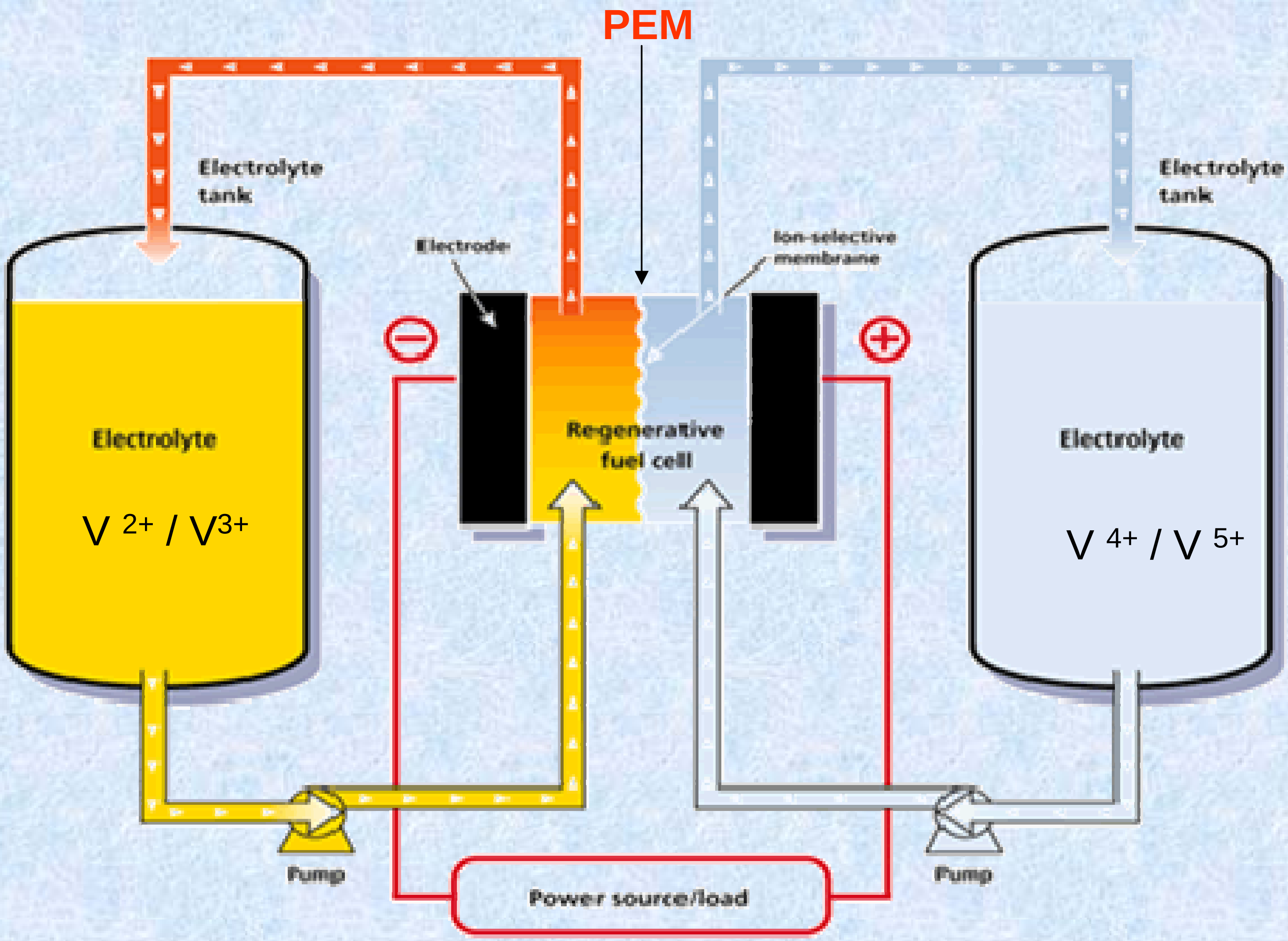
Commercialization of large solar and wind electric-power storage systems

- **The market is huge, many billions of dollars.**
- **The problem:**
- **Today, all electric power-storage systems are too expensive for large solar and wind generators and for load leveling.**
- **The major problem is the cost of the chemicals used for electrical-energy storage.**

The solution:

- **The TAU hydrogen-bromine (RFC) energy-storage system is based on low-cost materials. Thus, when fully developed, it will be an enable technology for large solar- and wind-energy storage systems and for load leveling.**

VRB system scheme

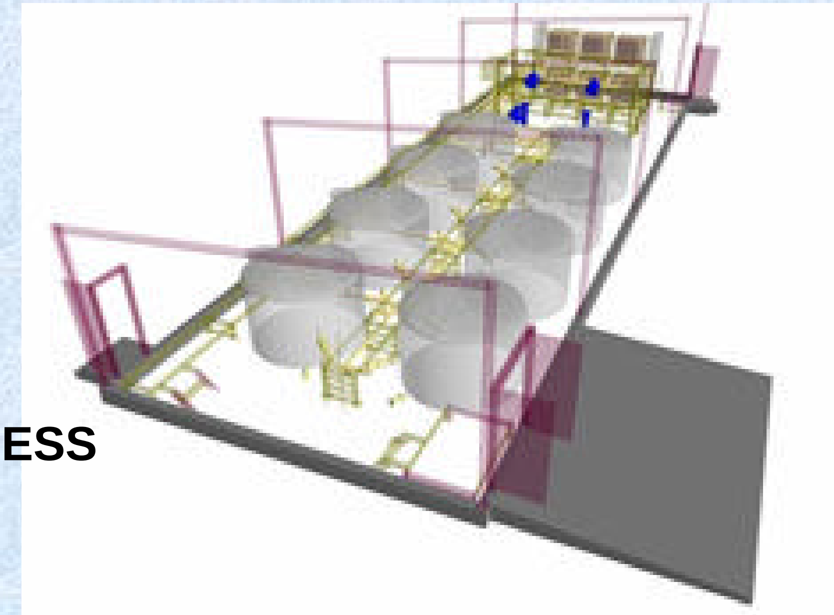


VRB-ESS

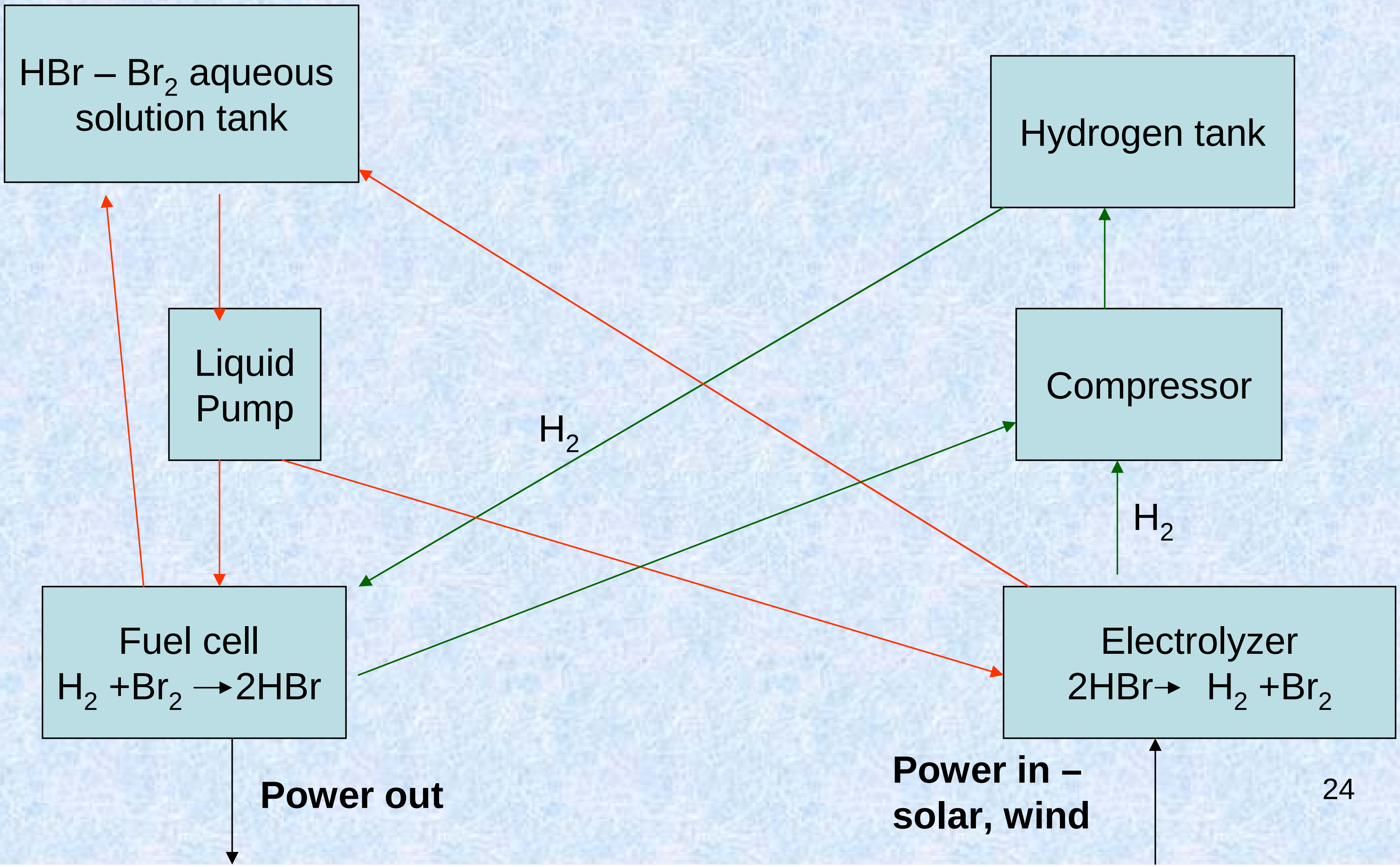
10 KWh ESS

Stacks

2 MWh ESS

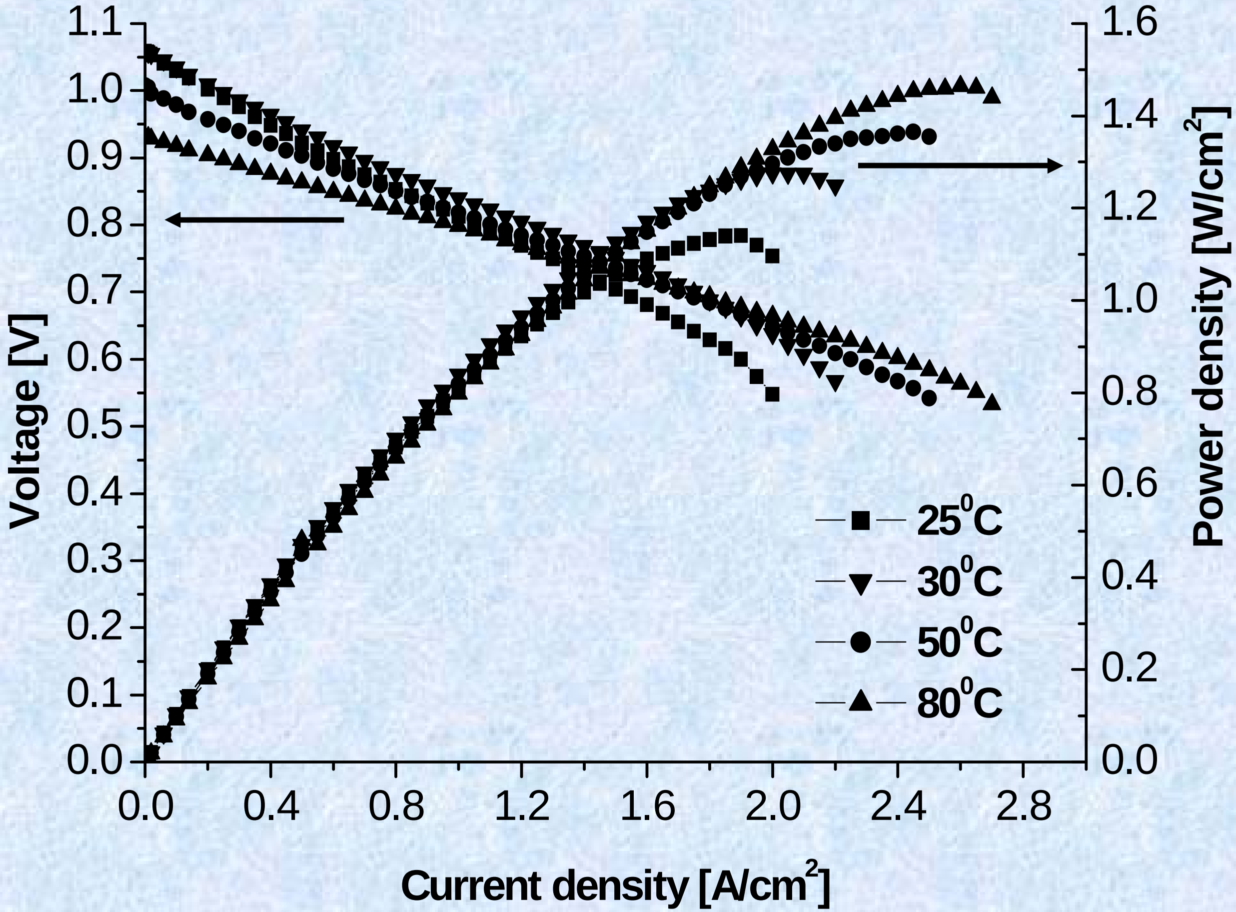


Schematic diagram for solar / wind energy storage system using regenerative H_2 – Br_2 fuel cell

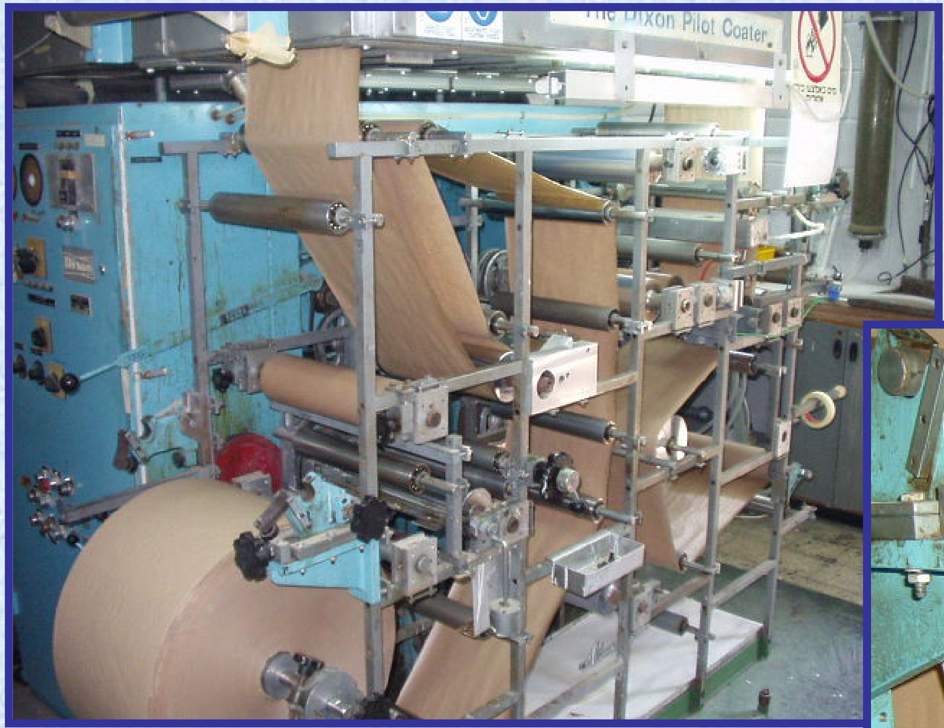


TAU NP-PCM based H_2/Br_2 FC - Effect of temperature on the performance .

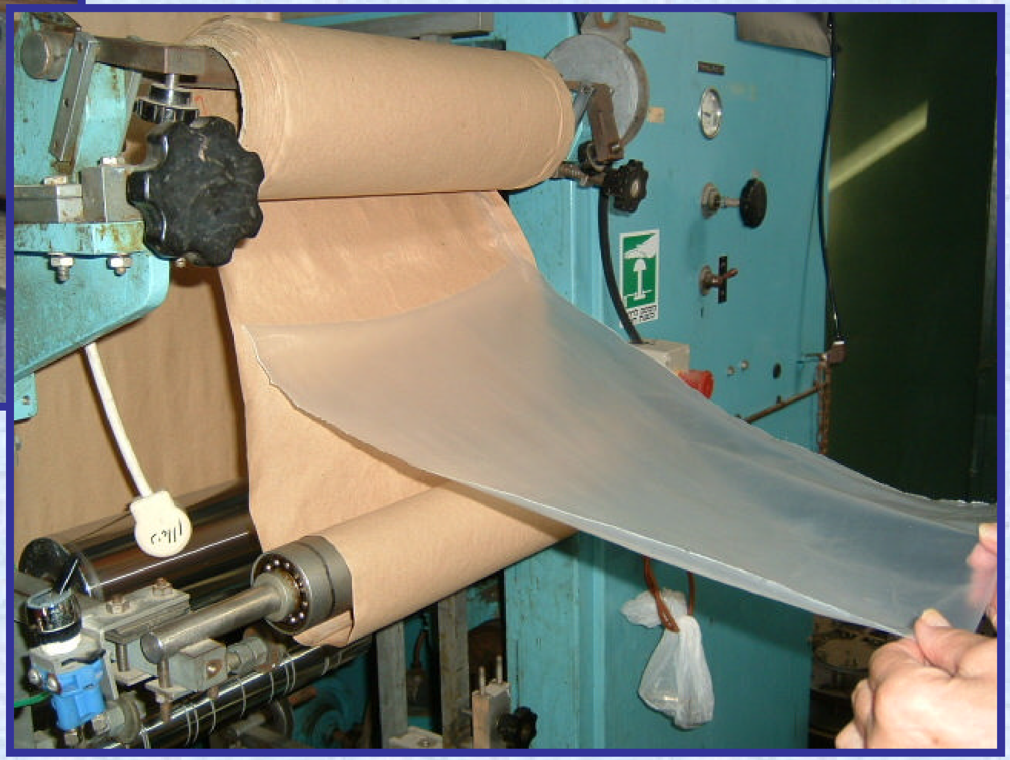
Ambient H_2 pressure, no H_2 humidification, stoich H_2 = 2; 0.6M Br_2, 1M HBr; 100µ PVDF based NP-PCM. Anode: 1 mgPt/cm^2 , cathode: 1.5 mgPt/cm^2



Scaling Up Production of NP-PCM - Continuous Coater ($15 m^2/h$)



33cm wide 2G NP-PCM



Comparison of Hydrogen-Bromine RFC with VRB

- VRB Power Systems produces and sells a vanadium-redox-battery (VRB) system for electrical-energy storage. These systems cost between **$350-$600 per kWh**, with sizes ranging from a few hundred kWhs to MWh-size systems
- They have just sold $6M systems to Ireland for wind-energy storage.
- The cost of bromine is much lower than that of vanadium oxides - **$3-6 per kWh** compared to over **$40/kWh*** (up to $120/kWh) in the case of VRB.
- **Conclusion: The TAU hydrogen bromine RFC system, based on a low cost NP-PCM, will be an enable technology (when fully developed) for solar, wind energy storage and load leveling.**

*** 5kg(V_2O_5)/kWh at $8/kg($V_2O_5$); 3.3kg($Br_2$)/kWh at $0.9/kg ($Br_2$) or 100% excess as bromide**

Summary

- **In order to meet the FC cost targets for EVs we need ORR catalysts that are four times more active and stable and/or high-temperature membranes.**
- **Methanol and ethylene glycol are promising fuels at least for small EVs. They have some advantages over hydrogen; however better fuel oxidation and ORR catalysts are required.**
- **TAU demonstrated the world most powerful direct methanol and ethylene glycol fuel cells.**
- **Israel and Western countries need alternative energy sources.**
- **Broad use of solar and wind electric generators (as well as load leveling) need large and low-cost storage systems.**
- **The low-cost TAU NP-PCM-based high power hydrogen-bromine RFC appears to be an enable technology for these applications.**