
*HYDROGEN GENERATION
AND
FUEL CELLS*

*CSE ENGINEERING CONFERENCE
ENERGY DEMAND AND SUSTAINABLE DEVELOPMENT
April 17, 2004*

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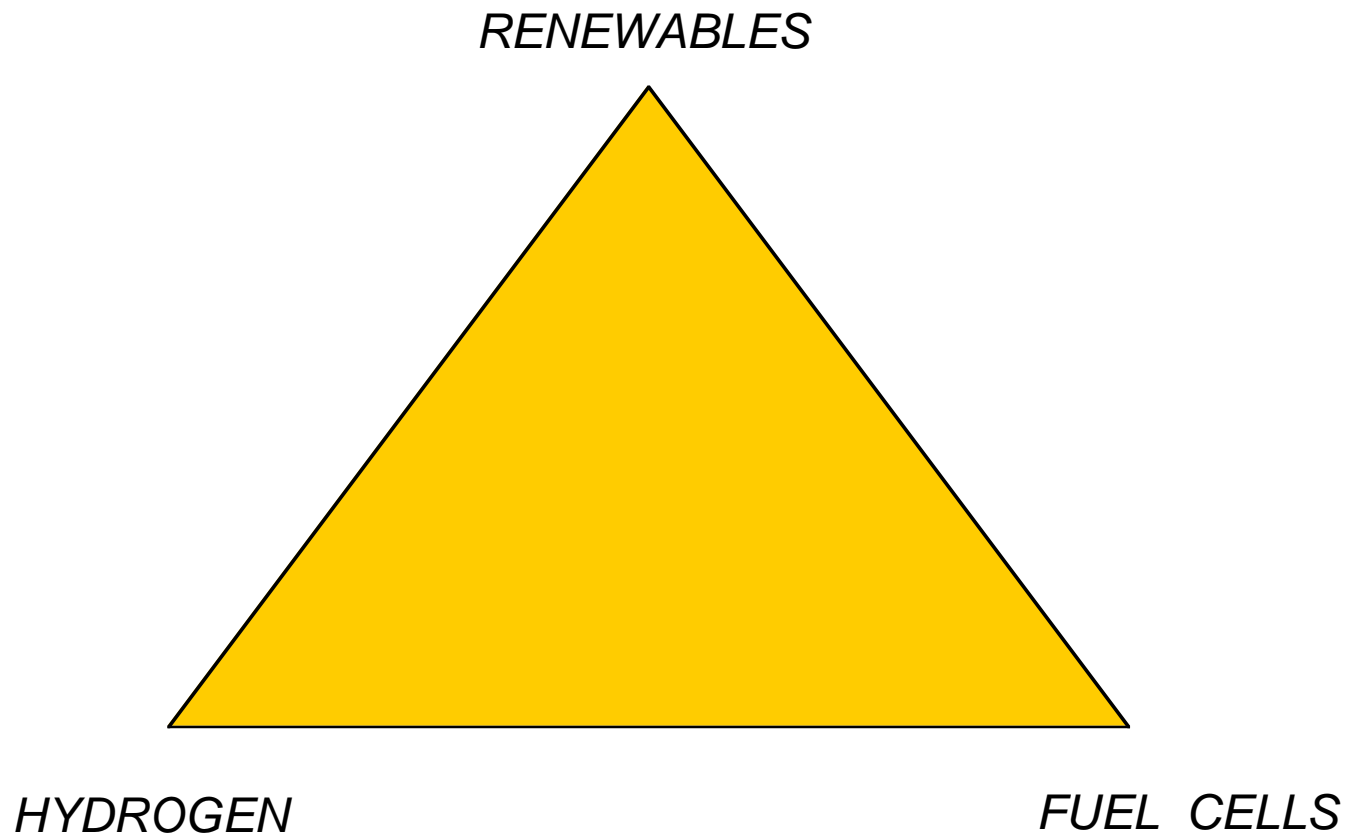
ARETÊ:

Many Years of Investing in Sustainable Energy Technologies

- | | |
|---|---|
| 1. <u>Ballard Power Systems, Inc.*</u> | <i>P.E.M. Fuel Cells</i> |
| 2. <i>Astropower, Inc.*</i> | <i>Photovoltaics</i> |
| 3. <i>American Superconductor, Inc.*</i> | <i>HTSC wire</i> |
| 4. <i>Superconductivity, Inc.</i> | <i>Micro-SMES (now ASC)</i> |
| 5. <i>Evergreen Solar, Inc.*</i> | <i>Photovoltaics</i> |
| 6. <i>World Power Technologies, Inc.</i> | <i>Power Quality monitoring</i> |
| 7. <i>Statpower Technologies Corp</i> | <i>Inverters (now Xantrex)</i> |
| 8. <i>Northern Power Systems, Inc.</i> | <i>System Integrator (now part of DESC)</i> |
| 9. <u>Proton Energy Systems, Inc.*</u> | <i>P.E.M. Electrolyzers / URFC (now part of DESC)</i> |
| 10. <i>Capstone Turbine Corp*</i> | <i>Microturbines</i> |
| 11. <u>Metallic Power, Inc.</u> | <i>Zn - Air fuel cell</i> |
| 12. <i>Encorp, Inc.</i> | <i>Controls and Integration</i> |
| 13. <i>BurstPower Technologies</i> | <i>Ultracapacitors (now CellTech)</i> |
| 14. <i>Beacon Power Corp*</i> | <i>Flywheel UPS / PQ systems</i> |
| 15. <u>Hydrogenics Corporation*</u> | <i>P.E.M. Test Stations</i> |
| 16. <i>Bowman Power Systems, Ltd.</i> | <i>Microturbine CHP</i> |
| 17. <i>Powerzyme</i> | <i>Organic Battery / Fuel Cell</i> |
| 18. <u>CellTech Power, Inc.</u> | <i>Solid Oxide Fuel Cell</i> |
| 19. <u>H2 Gen Innovations, Inc.</u> | <i>Steam Methane Reformer</i> |
| 20. <i>STM Power, Inc.</i> | <i>Stirling Engine Gensets</i> |
| 21. <u>Angstrom Power, Inc.</u> | <i>Micro P.E.M. Fuel Cell</i> |

* Public Company

HYDROGEN: Pathway to a Sustainable Energy System?

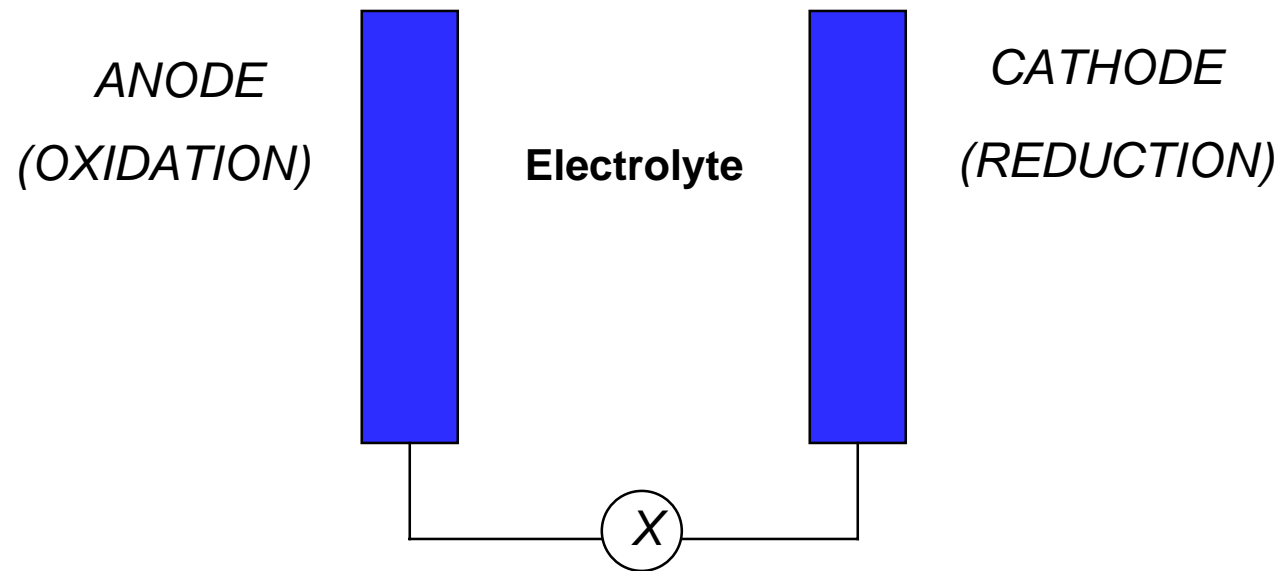


FUEL CELLS HAVE RECEIVED A LOT OF PRESS

- *Several different types*
 - » *Alkaline (AFC)*
 - » *Phosphoric Acid (PAFC)*
 - » *Molton Carbonate (MCFC)*
 - » *Proton Exchange Membrane (PEMFC)*
 - » *Solid Oxide (SOFC)*
 - » *Metallic (Zn-Air)*

FUEL CELLS...

- *Basically similar*

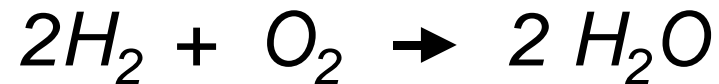


FUEL CELLS ...

- *But with significant differences*
 - » *Operating temperature*
 - » *Electrolytes*
 - » *Ion crossing the electrolyte*
 - » *Electrodes*
 - » *Technical challenges*

HYDROGEN

- *The Perfect “Fuel”: Zero Pollution*



- *Except for one problem -- Hydrogen does not exist in the free state, at least in any quantity, on earth*

HYDROGEN ...

- *Hydrogen is everywhere -- but it is bound up in various molecules*
 - » *Water: H_2O*
 - » *Hydrocarbons: CH_4*
 - » *Ammonia: NH_3*
 - » *Hydrogen sulfide: H_2S*
 - » *Hydrides and hydrates: NaH*
- *To create hydrogen as an energy carrier, one has to*
 - » *Break it free*
 - » *Clean it up (PSA, membrane)*

MAKING HYDROGEN

- *Electrolysis*
 - » *Alkaline (KOH)*
 - » *PEM*
 - » *Solid oxide*
- *Steam Reforming of Light HC's*
 - » *Methane (SMR)*
 - » *Naptha*
- *Partial Oxidation (POX) of Heavy HC's*
 - » *Heavy oils*
 - » *Coal*
- *Autothermal Reactions (ATR)*
- *Thermal Water Splitting (Nuclear)*
- *Chemical Water Splitting (Steam iron)*

SMALL-SCALE COMMERCIAL H_2 PRODUCTION

- *Electrolysis*
 - » *KOH:* *Stuart Energy*
Van den Borre
Norsk Hydro
Teledyne
 - » *PEM:* **Proton Energy**
Hydrogenics
 - » *SOFC:* *Ion America*
Onsite

SMALL-SCALE COMMERCIAL H_2 PRODUCTION...

- *Steam Methane Reformer*
 - » **H₂Gen Innovations**
 - » *Hydrogen Source*
 - » *Harvest Energy*
- *ATR*
 - » *Hyradix*
 - » *Nuvera*
 - » *MesoFuel*
- *Membrane*
 - » *Idatech*
 - » *HY 9*

Proton Energy Systems PEM Electrolyzers



Hogen 40

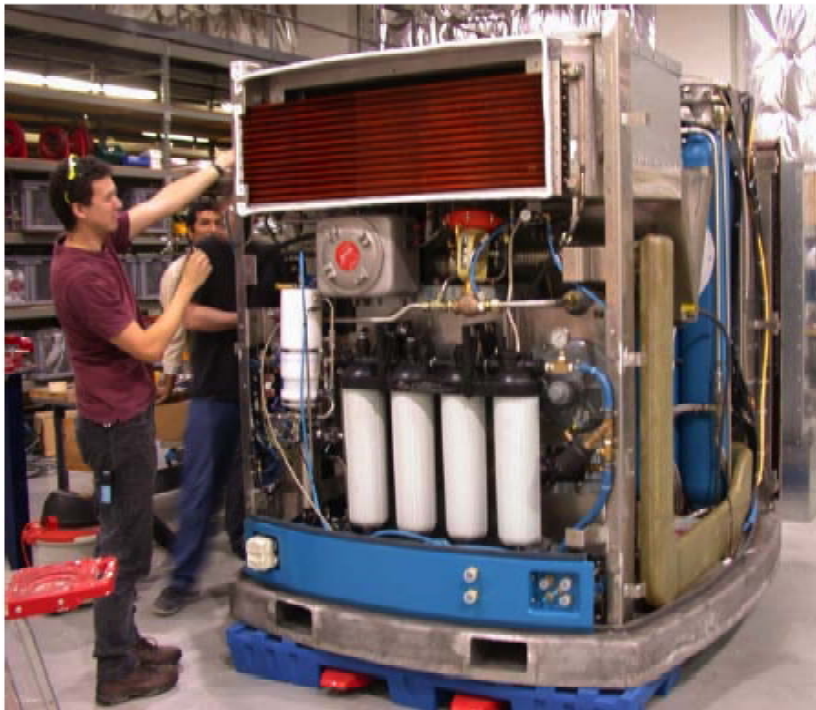
Proton Energy Systems PEM Electrolyzers



Hogen 240 Series

H₂Gen™

H₂Gen Innovations SMR



HYDROGEN AS AN ENERGY CARRIER

- *Very light gas*
 - » *Diffuses rapidly: minimum safety risk*
 - » *One (1) gallon of gasoline =*
 - *~ 1 kg*
 - *~ 380 SCF**of hydrogen*

HYDROGEN AS AN ENERGY CARRIER ...

- *Storage is a major issue*
 - » *High pressure tanks (5000 - 10,000 PSI)*
 - » *Liquid (LH₂)*
 - *-253 °C*
 - *Cryogenic tanks: boil off*
 - » *Hydrides / hydrates*
 - *Metal hydrides*
 - *Alkaline hydrides*
 - *Sodium borohydrate*
 - » *Carbon*
 - *Nanotubes*
 - *Powders*
 - *Buckyballs*
 - » *New ideas??*

HYDROGEN INFRASTRUCTURE

- *The components are all available*
 - » *Distributed H₂ Production Systems*
 - *Work: SMR, Electrolysis*
 - *Are available commercially*
 - *Are reasonably cost effective, even at low production volumes*
 - » *Storage: High Pressure Tanks*
 - *Are available commercially*
 - *Not a perfect solution*
 - *But they meet most of the tests*
 - » *Propulsion Systems*
 - *Fuel cells are not there yet on lifetime, or cost*
 - *ICE's can be tuned to burn H₂*

HYDROGEN INFRASTRUCTURE ...

- *The critical issue is which comes first*
 - » *The Fueling Infrastructure, or*
 - » *The Hydrogen Vehicles*
 - *Hydrogen hybrids with ICE's*
 - *Fuel cell vehicles*

HYDROGEN INFRASTRUCTURE ...



Grid



wind turbine



hydrogen generator



fueling station