Understanding Earth's Energy Sources

Grades: 9-12

Topics: Biomass, Wind Energy, Hydrogen and Fuel Cells, Solar, Vehicles, Geothermal

Owner: ACTS

This educational material is brought to you by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

Energy Sources

✓ Renewable Energy

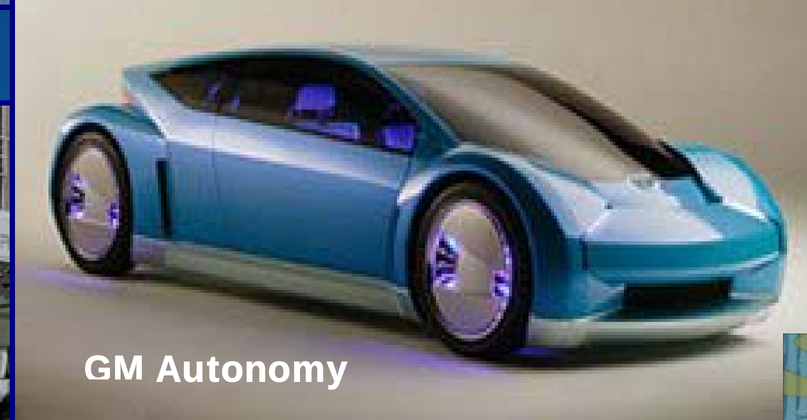
Hydrogen

Why Hydrogen?

- Fossil fuels release CO_2, SO_X, NO_X
- Declining reserves, national security

Hydrogen Energy

__Hydrogen__- the use of Hydrogen gas in fuel cells to make electricity. Production of hydrogen can be accomplished with other renewable energy sources.


GM Autonomy

Energy is as important to modern society as food and water.

What energy-producing technologies can be envisioned that will last for millennia, and just how many people can they sustain?

Sustainable Energy Systems

Energy systems that can last for millennia

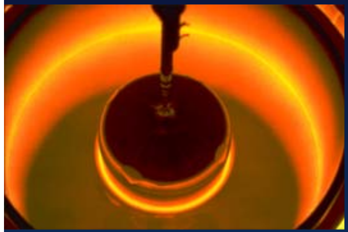
Questions:

- Sustainability
- Resource availability
- Energy Payback
- Environmental impacts
- Geopolitical factors
- Security
- The Developing World
- Energy Carrier

Answers:

- Biomass
- Solar-Derived
- Wind
- Geothermal
- Nuclear
- Hydro
- Wave
- Hydrogen

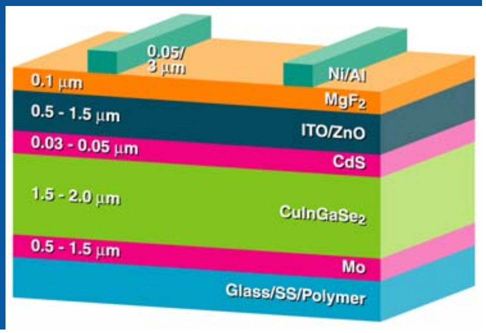
Energy Payback for Wind and PV



- Crystalline PV is about 3-4 years.
- Thin film is about 2-3 years.
  - Both include cells, frames, and supports.
- Wind is 3-4 months!
  - Includes scrapping the turbine at the end of its life.
- Nuclear is about 1 year, but does not include 10,000 years of waste storage.

Nuclear Engineering International magazine

http://www.neimagazine.com/



http://www.rmi.org/sitepages//pid171.php#E05-15

Sustainable Energy Systems

Energy systems that can last for millennia

Questions:

- Sustainability
- Resource availability
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- Environmental impacts
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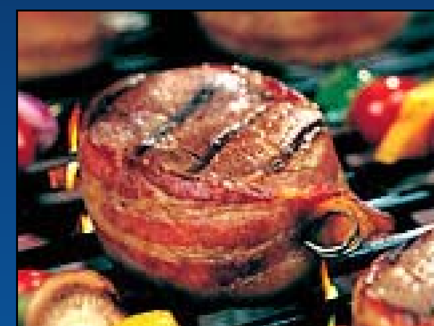
- Wave
- **Hydrogen**

Food

Stored Solar Energy

Food + O_2 ⇨ Life + CO_2 + H_2O



People take food + oxygen and "burn" the food to release energy (stored Sunlight) and carbon dioxide

The Sustainable Hydrogen Economy

The production of hydrogen, primarily from water but also from other feedstocks, its distribution and utilization as an energy carrier.

Energy Generation

- Biomass
- Nuclear
- Geothermal
- Renewable e^-
  - Solar
  - Wind
  - Hydro

Production

- Electrolysis
- Thermolysis
- Conversion

Feedstock

- Water
- Biomass

Distribution

- Used onsite
- Pipelines
- Compressed gas
- Liquid

Utilization

- Fuel cells
- Turbines
- IC Engines

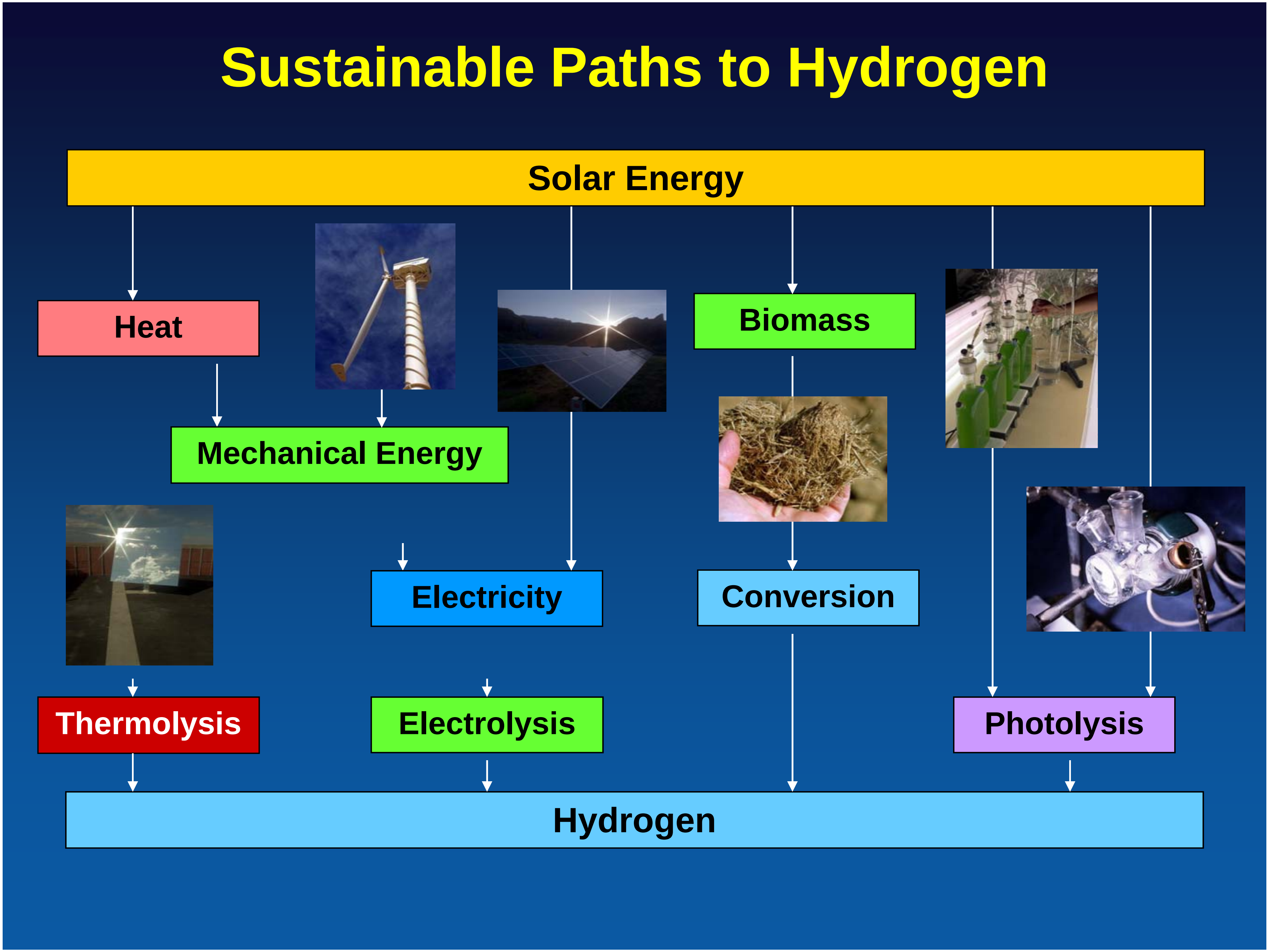
Transportation fuel and energy storage.

Vision

"Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable....Water will be the coal of the future" (J. Verne, The Mysterious Island, 1874)

www.literature-web.net/verne/mysteriousisland

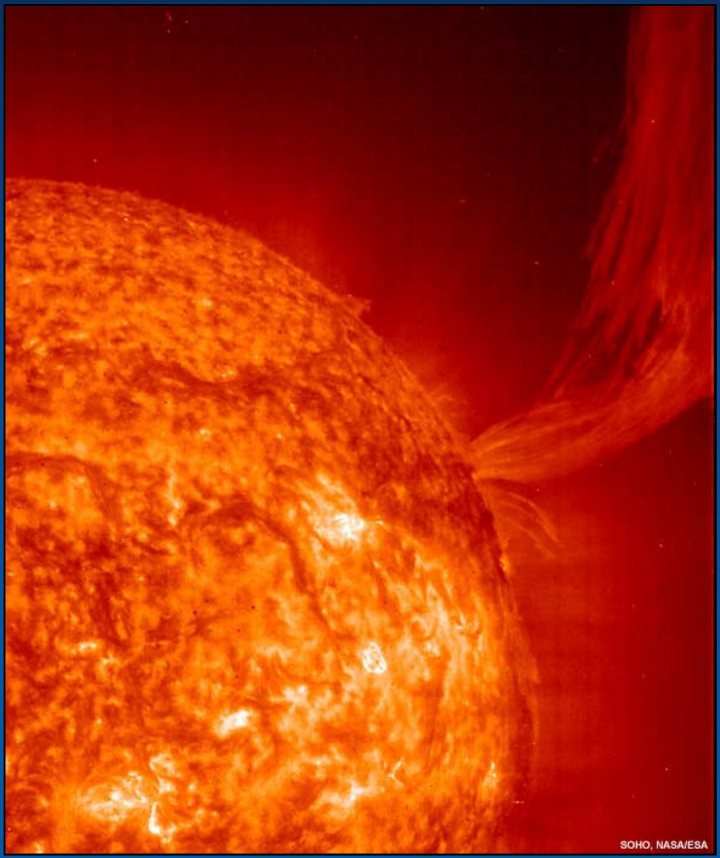
SOHO, NASA/ESA


Sustainable Paths to Hydrogen
Solar Energy
Heat
Biomass
Mechanical Energy
Electricity
Conversion
Thermolysis
Electrolysis
Photolysis
Hydrogen

Direct Conversion Systems

Visible light has sufficient energy to split water (H_2O) into **Hydrogen and Oxygen**

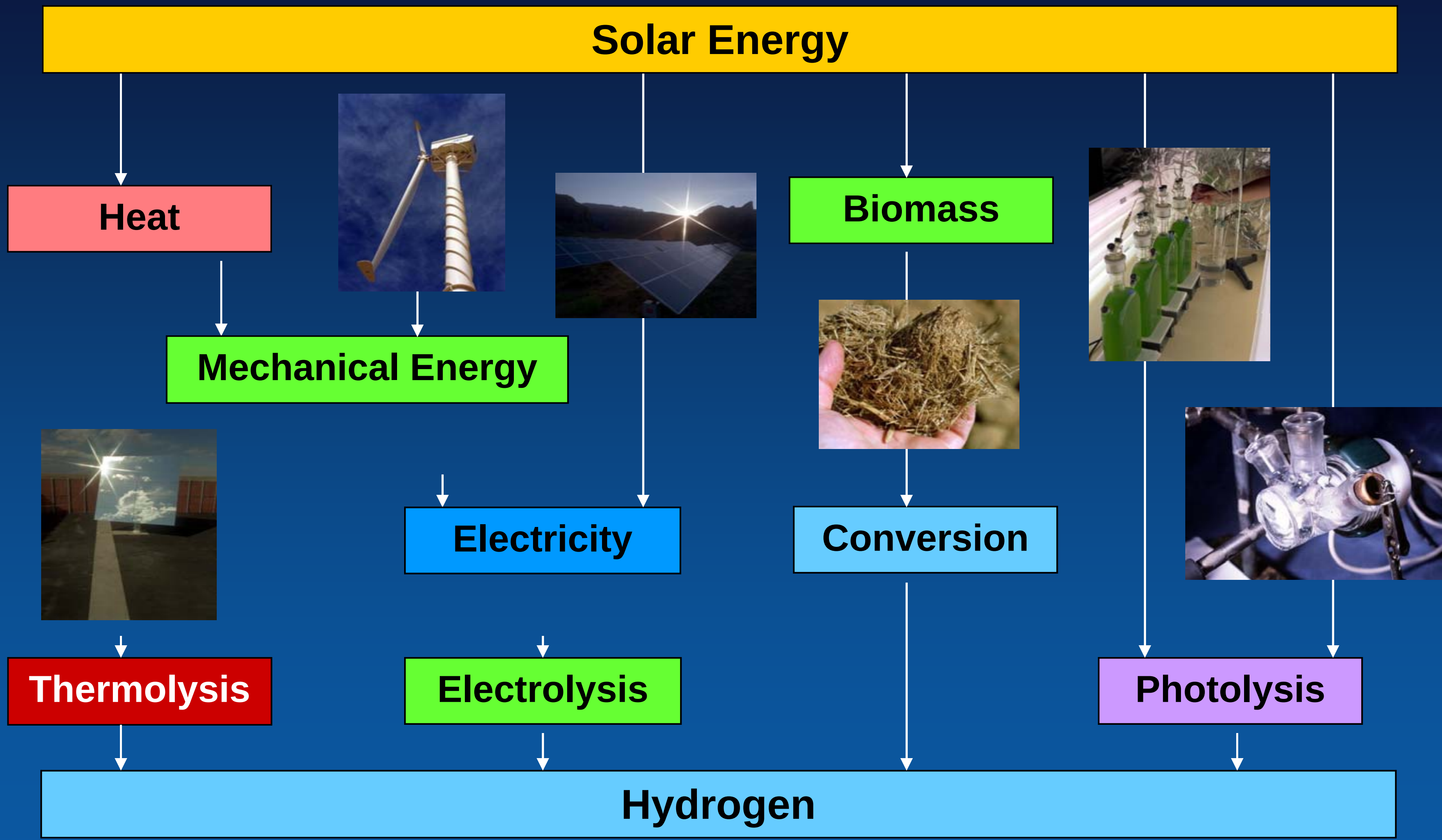
Combination of a Light Harvesting System and a Water Splitting System



- ✓ Semiconductor photoelectrolysis
- ✓ Photobiological Systems
- ✓ Homogeneous water splitting
- ✓ Heterogeneous water splitting
- ✓ Thermal cycles

(Sunlight and Water to Hydrogen with No External Electron Flow)

Sustainable Paths to Hydrogen



Biomass Feedstocks

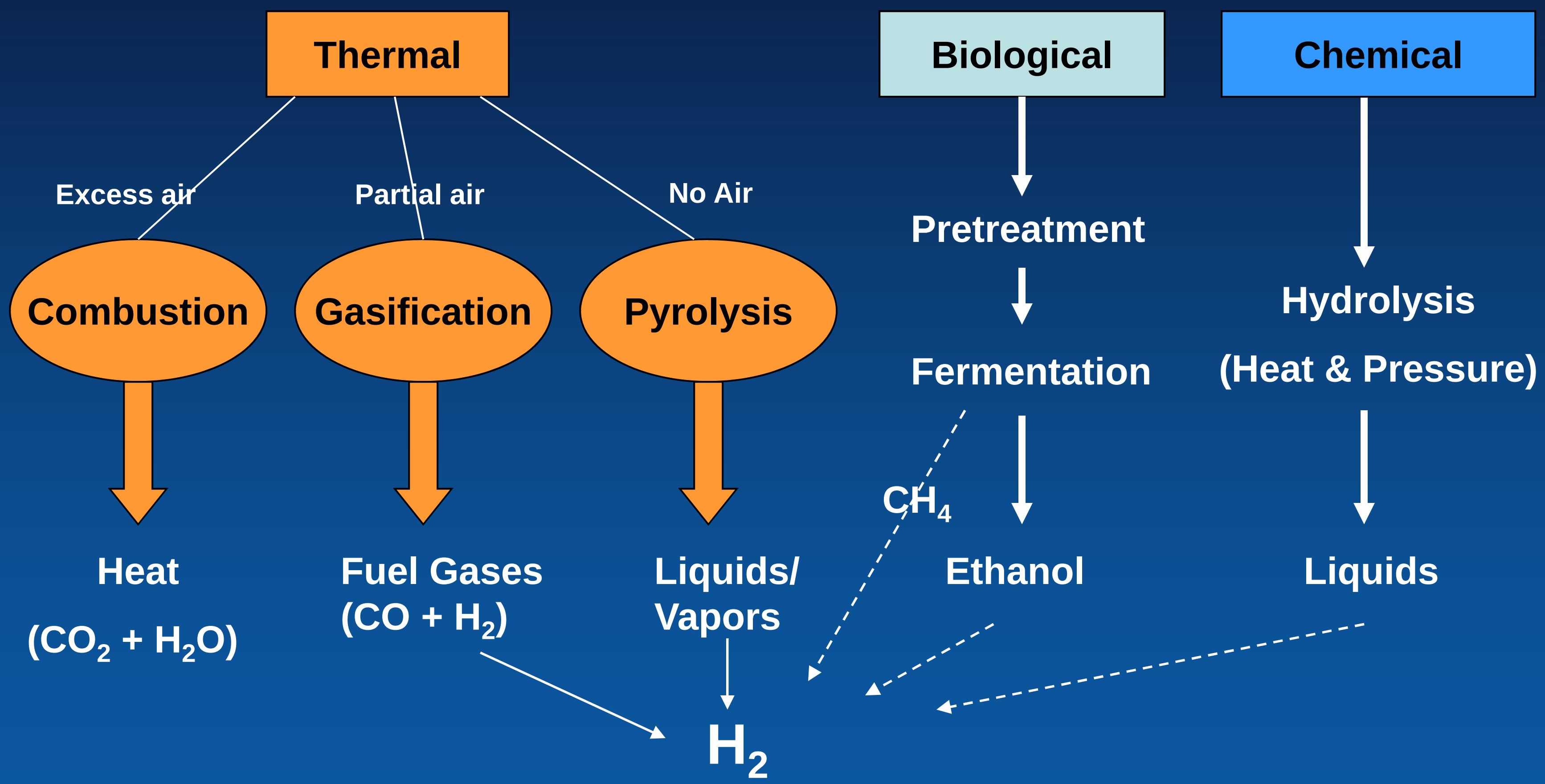
$$6\,CO_2 + 6\,H_2O \xrightarrow[\text{sunlight}]{} C_6H_{12}O_6 + 6\,O_2$$

Potential : 15% of the world's energy by 2050.
Fischer and Schrattenholzer, *Biomass and Bioenergy* 20 (2001) 151-159.

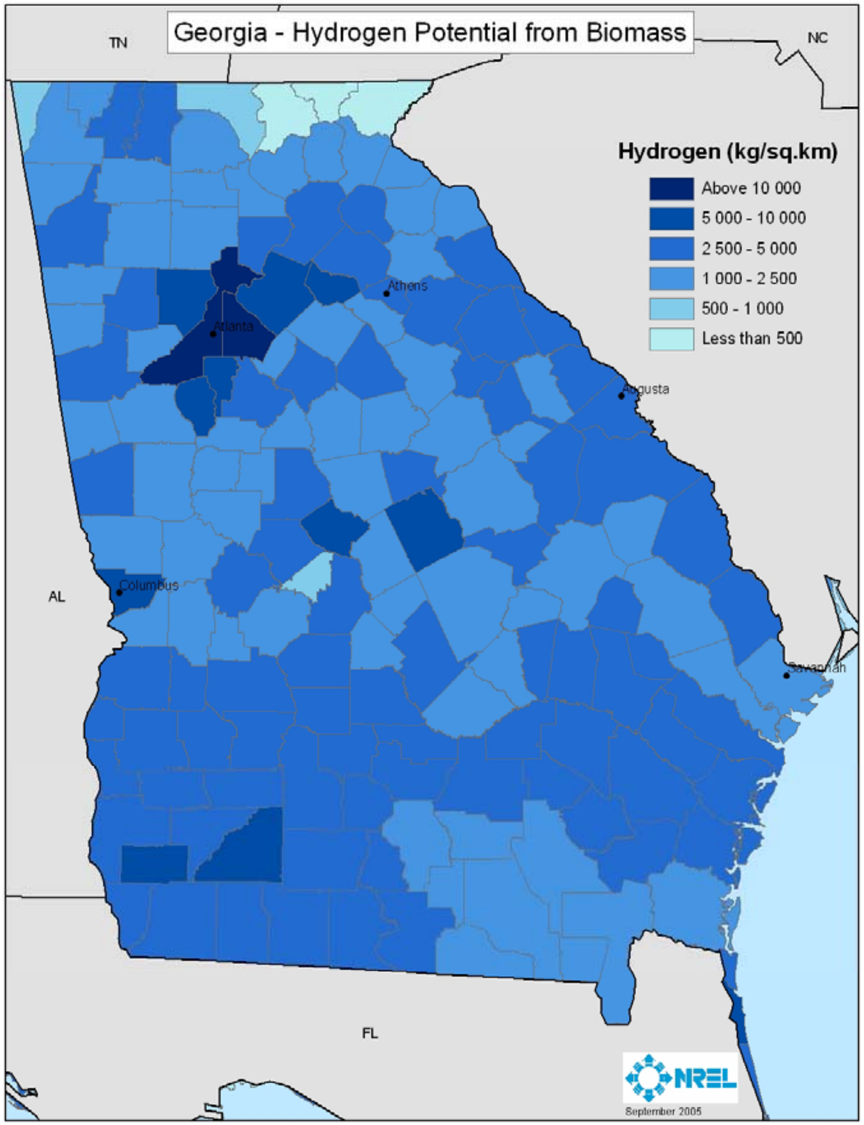
Crop residues
Forest residues
Energy crops
Animal waste
Municipal waste

Issues: Biomass Availability, Cost and Physical and Chemical Properties

Biomass and H_2 Energy Pathways



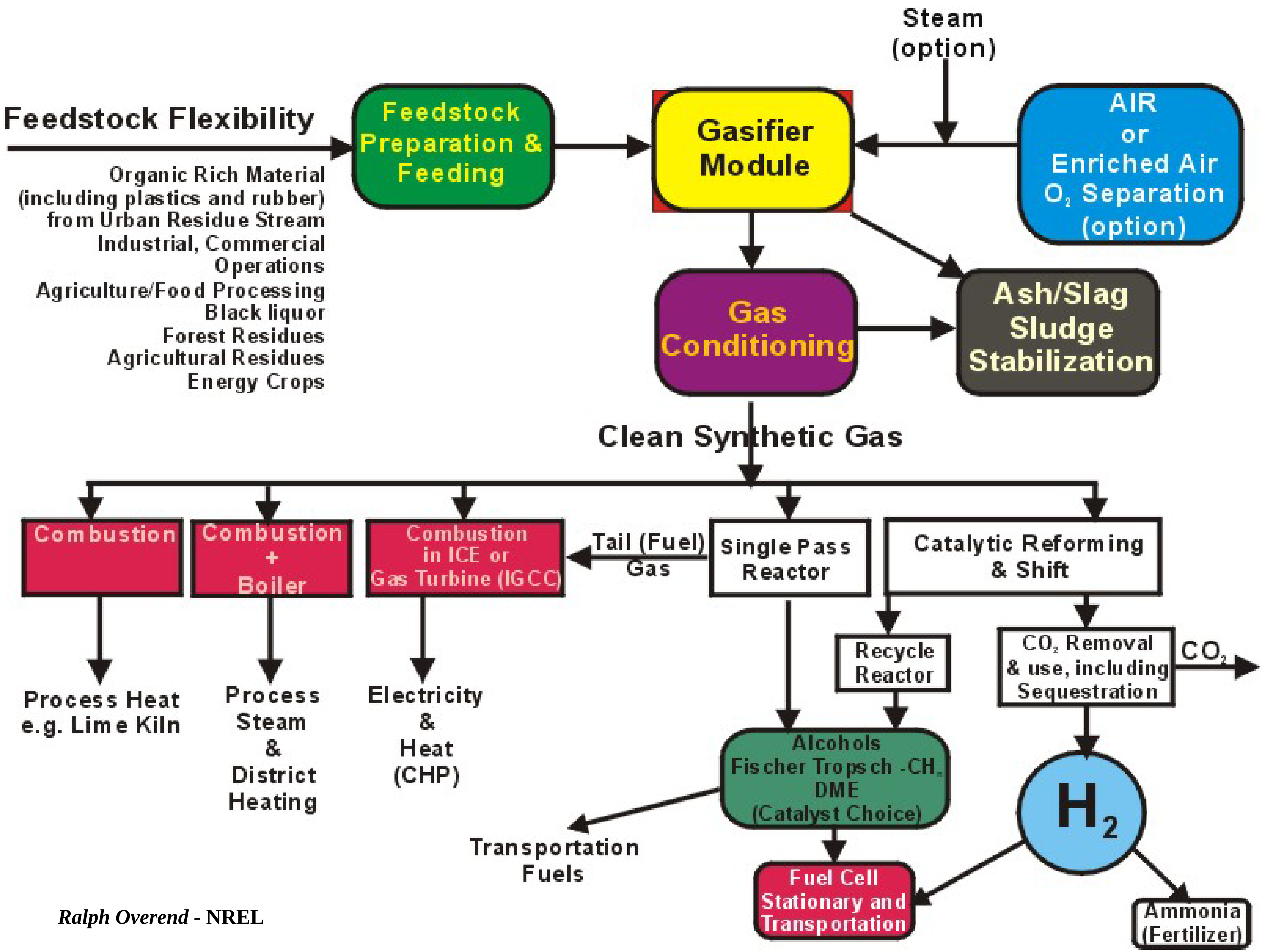
Biomass to Hydrogen Potential for Georgia ~450 million kg



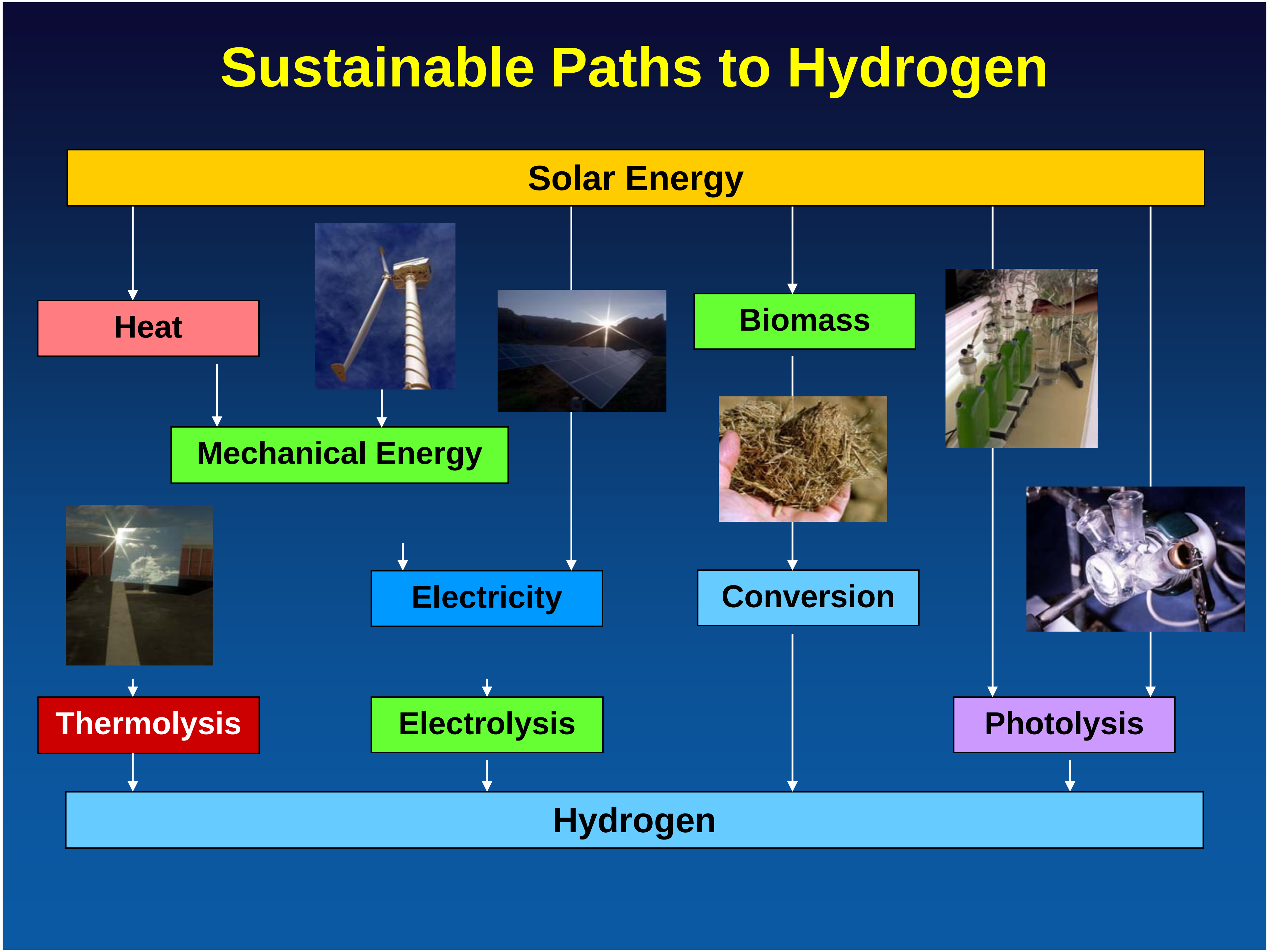
Feedstocks included in this analysis:

- ✓ crop residues
- ✓ forest residues
- ✓ primary mill residues (lumber industry)
- ✓ CH_4 emissions from landfills and animal manure
- ✓ urban wood residues.

Enough H_2 for about 2 million fuel cell vehicles (50 miles/kg).



Ralph Overend - NREL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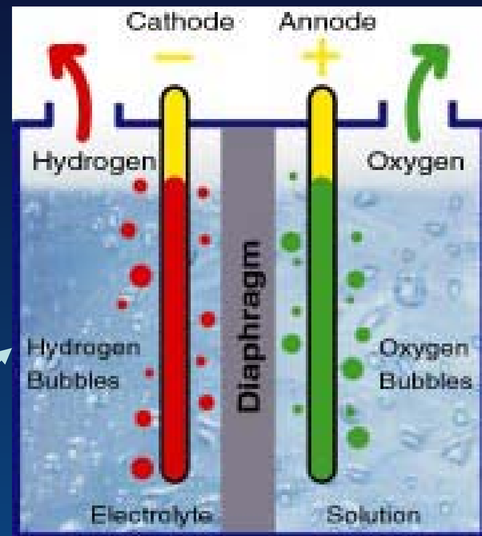
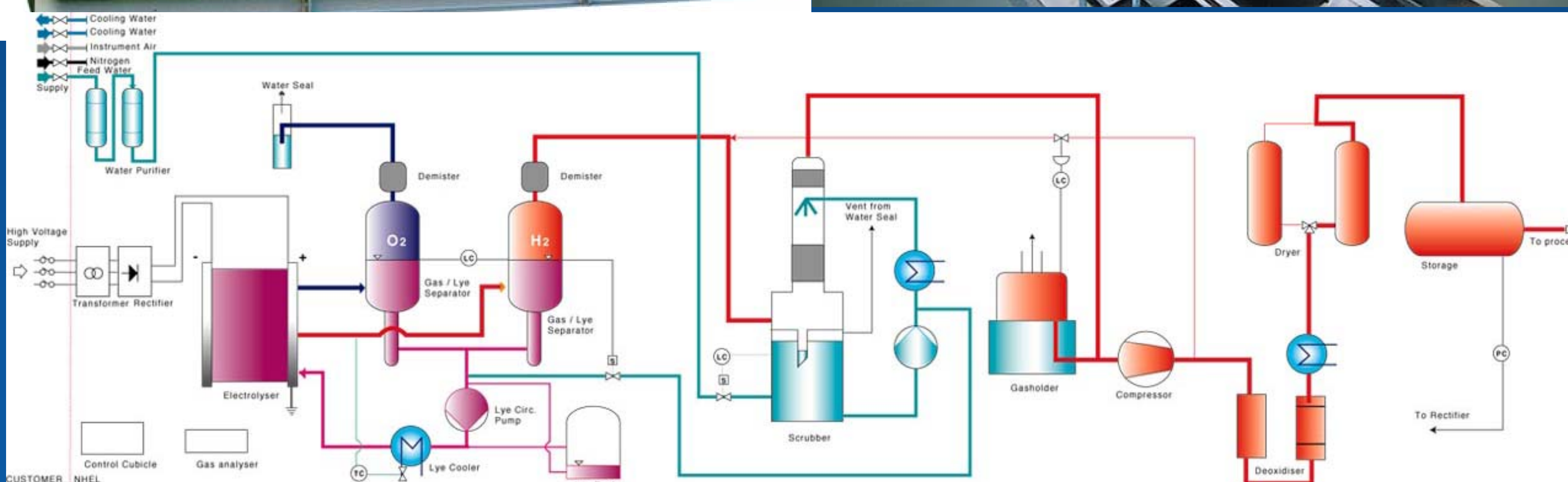
Renewable Hydrogen Production via Electrolysis



Norsk Hydro Large-Scale Electrolyzers

http://www.electrolysers.com/

5150 A at
400 V



Chlor-Alkali Industry

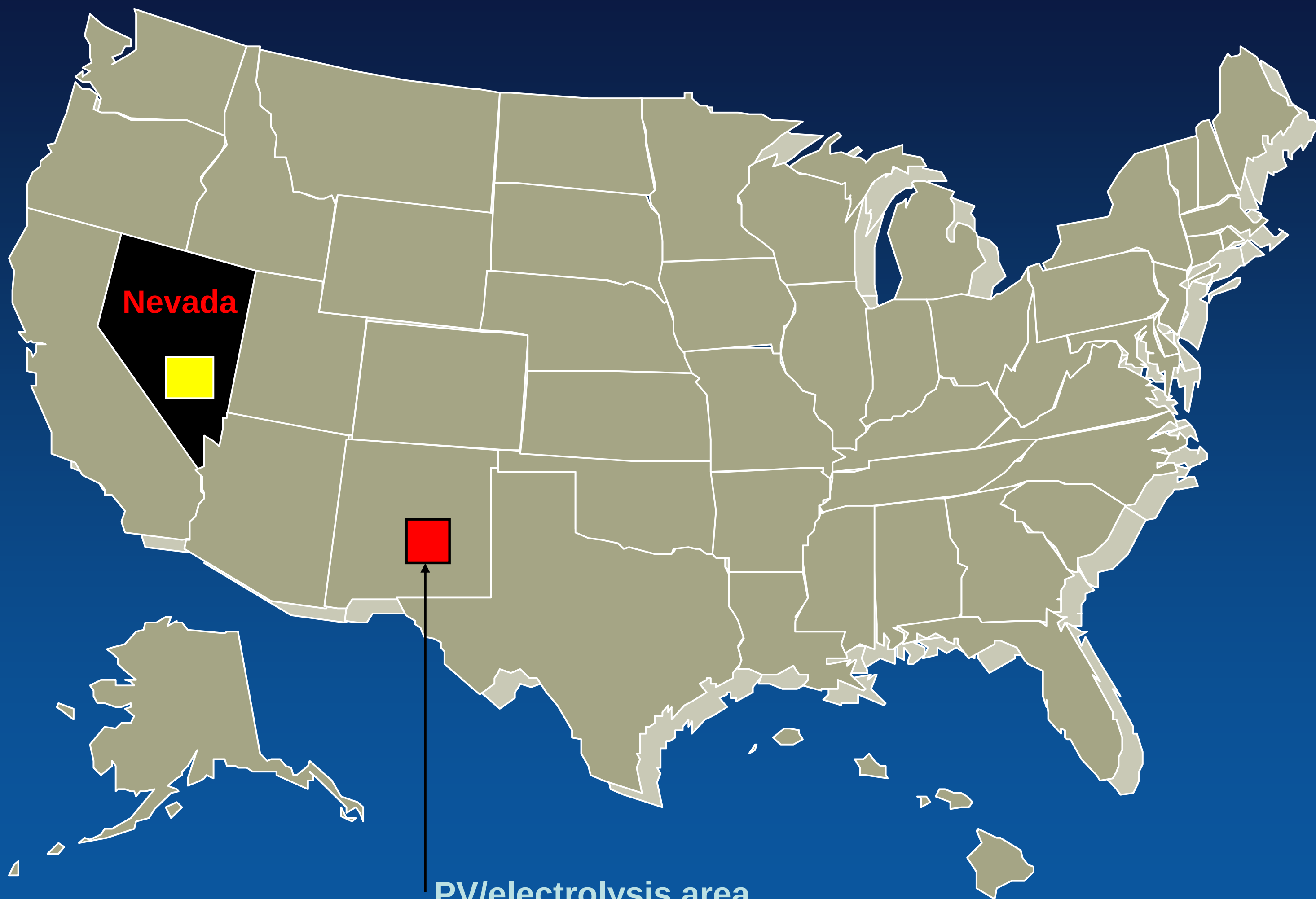
7-10 MW typical

Largest plants ~ 20MW

U.S. Chlorine Production =
13 million tons/year

400,000 tons/year byproduct hydrogen

Total Area Required for a Photovoltaic Power Plant to Produce the Total U.S. Annual Electrical Demand

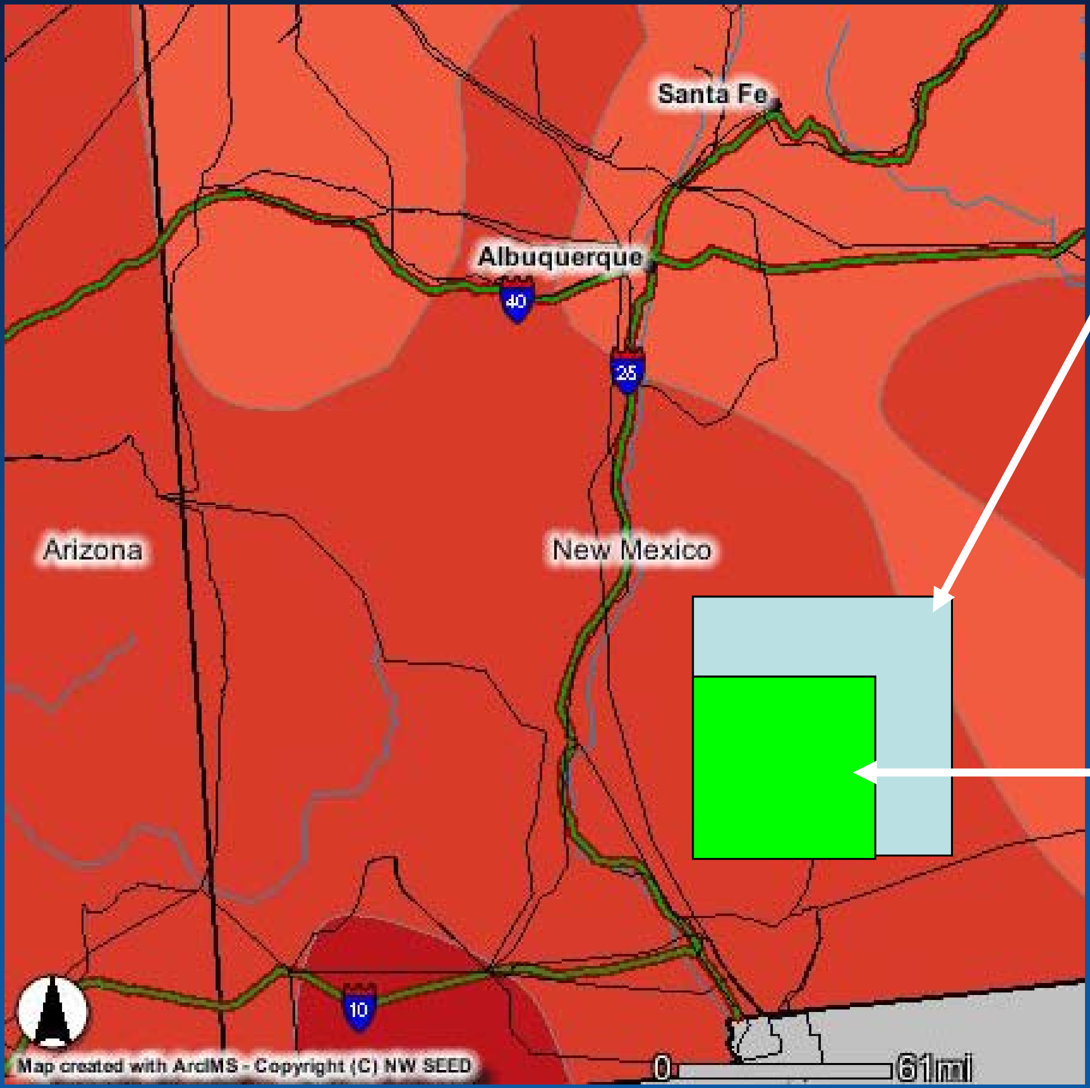


PV/electrolysis area
for 120M tons H_2.

P109 G1055201

J. A. Turner, “A Realizable Renewable Energy Future”, Science, 285, p 5428, (1999).

Hydrogen From Solar Energy and Water:
PV/Electrolysis vs. PEC Direct Conversion



PV panel area to produce hydrogen for current US fleet (10% system, 70% electrolysis efficiency)

PEC direct conversion system for same amount of hydrogen

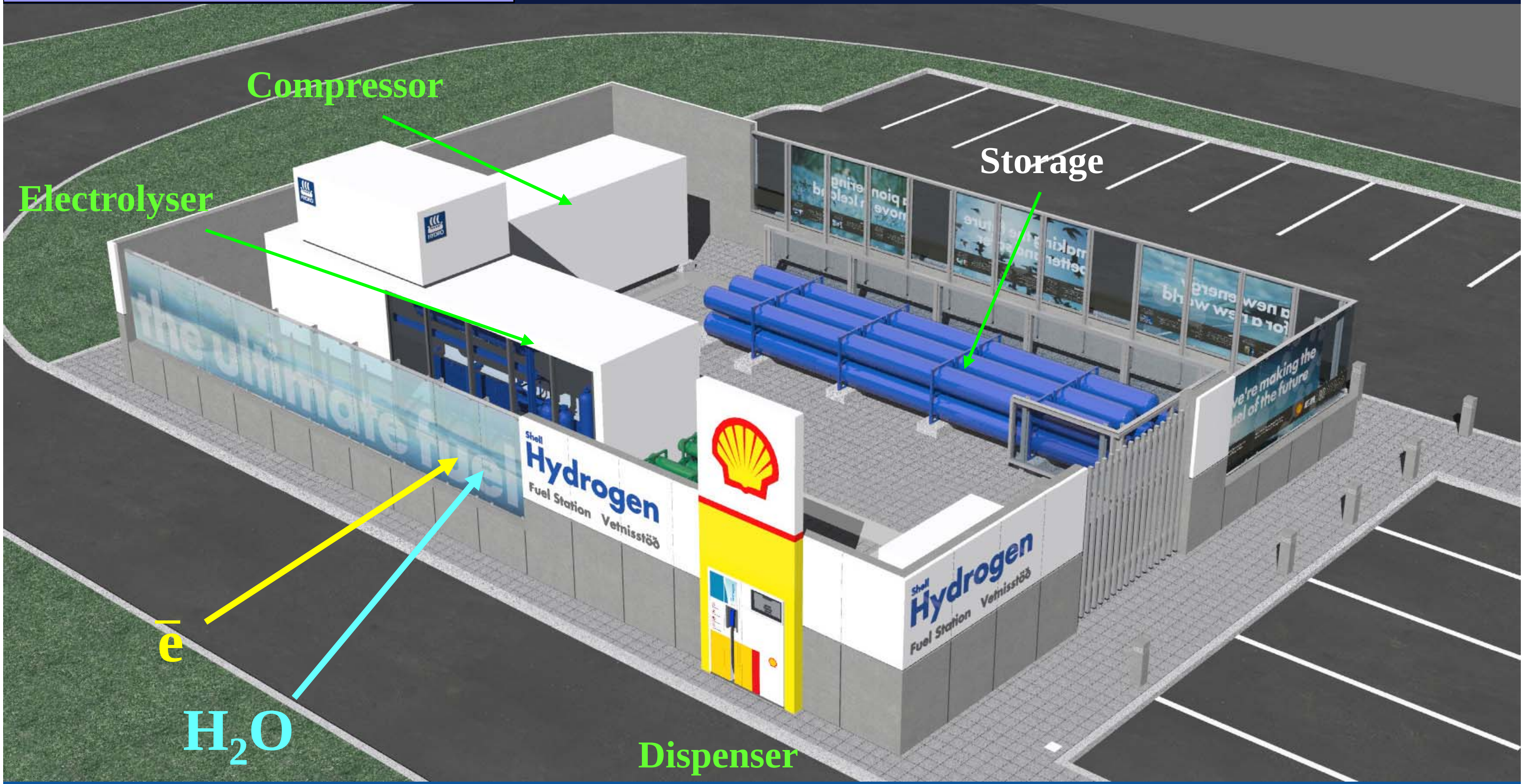
Water Issues

Water Required to Produce Hydrogen for a U.S. Fuel Cell Vehicle Fleet ~*100 billion gallons water/year*.

- ✓ We use about 300 billion gallons of water/year in the gasoline refinery industry alone.
- ✓ Domestic water use in the U.S. is about 4,800 billion gallons per year.
- ✓ U.S. uses about 70 trillion gallons of water per year for thermoelectric power generation.
- ✓ Fossil production of electricity consumes about 0.5 gal water per kWh produced.
- ✓ Wind and PV consume no water during their electricity production. This means that every kWh of wind that replaces a kWh of coal saves 0.5 gallons of water. If we aggressively install wind, then our overall water usage would drop.

The ECTOS-hydrogen station,

An example of pre-commercial filling station



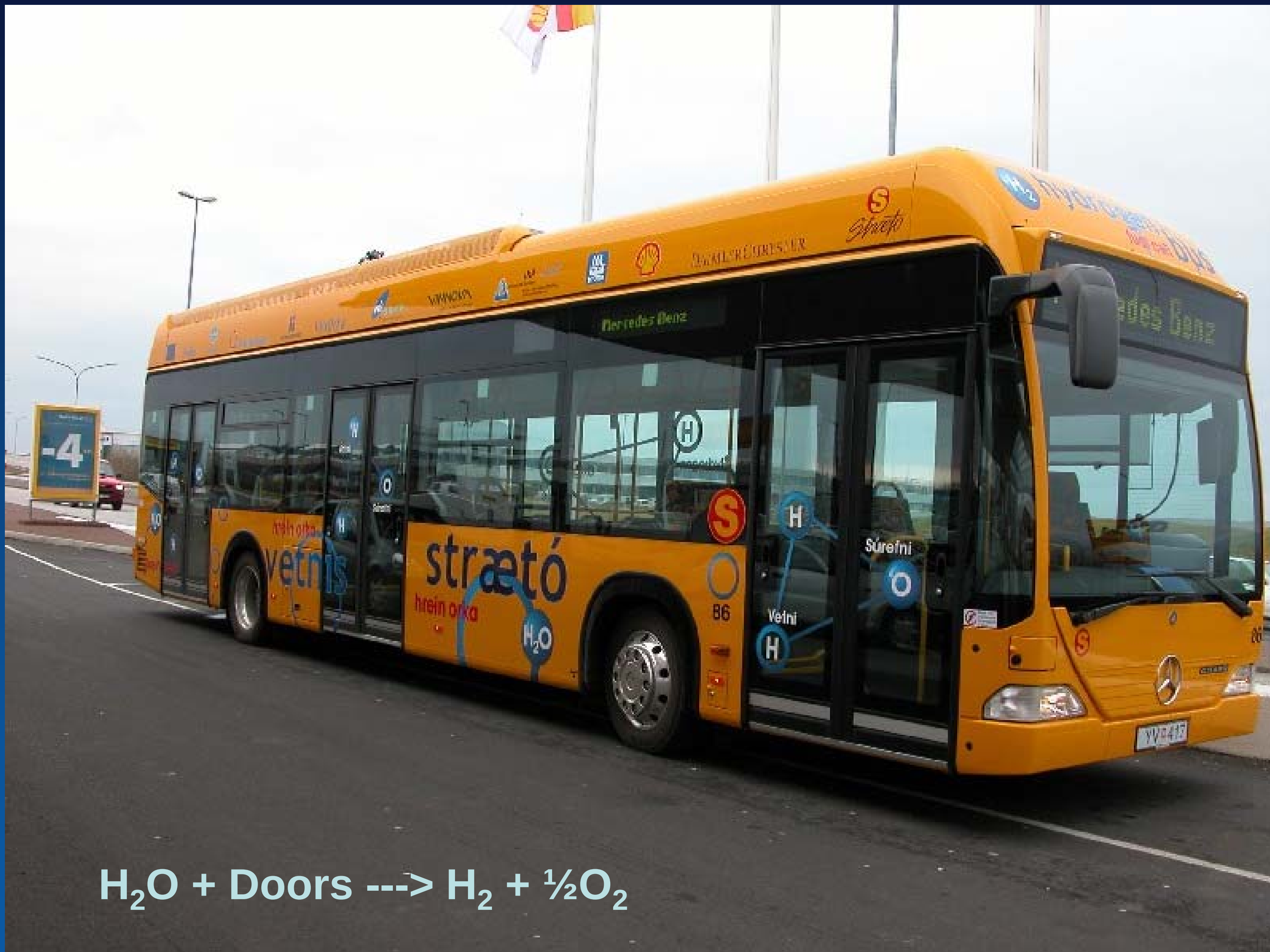
Icel. New Business Venture Fund, Reykjavik Energy, The National Power Company, Hitaveita Sudurnesja, University of Iceland, The Technological Institute of Iceland, Fertilizer Plant, Reykjavik Resources, Government of Iceland

Hydrogen Station

Opened April 24, 2003

Only station in the world operating at a conventional gasoline station (has full commercial license)

Water-splitting Reaction

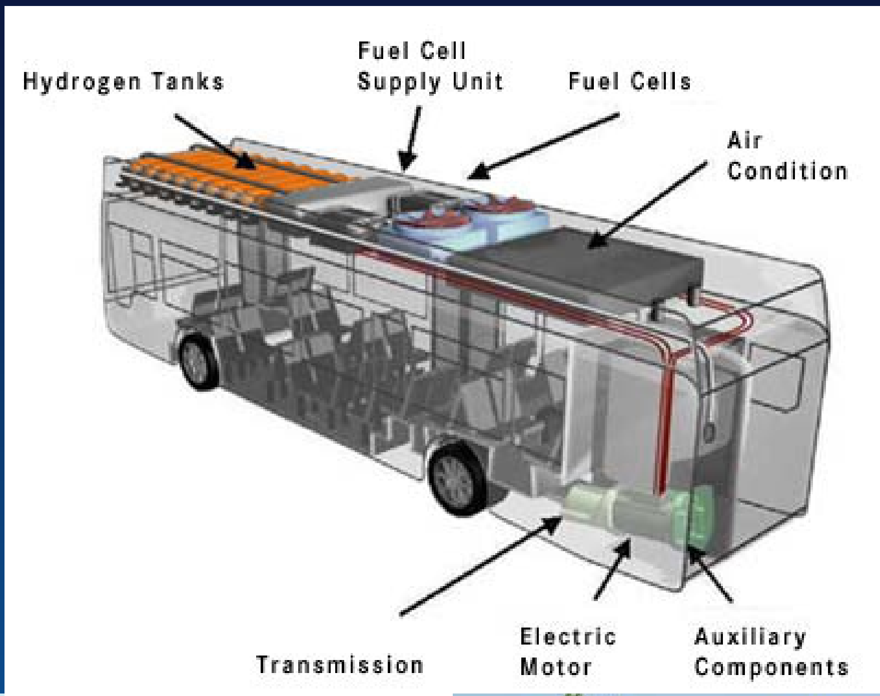


H_2O + Doors ---> $H_2 + \frac{1}{2}O_2$

Fuel Cell Powered Zero Emission Busses

(www.sunline.org)

www.fuel-cell-bus-club.com



California Fuel Cell Partnership Vehicles

Hydrogen-fueled zero-emission vehicles

Clockwise from top left:
Hyundai, Daimler-Chrysler, Ford, Nissan, Volkswagen, Honda, GM(center)

www.fuelcellpartnership.org/

PEM Fuel Cells

An electrochemical device that converts the chemical energy in a fuel directly to electricity without the intervening combustion used in a conventional power system

Fuel cells are like batteries except that the chemicals are continuously fed from an external source.

Composed of 3 basic elements:

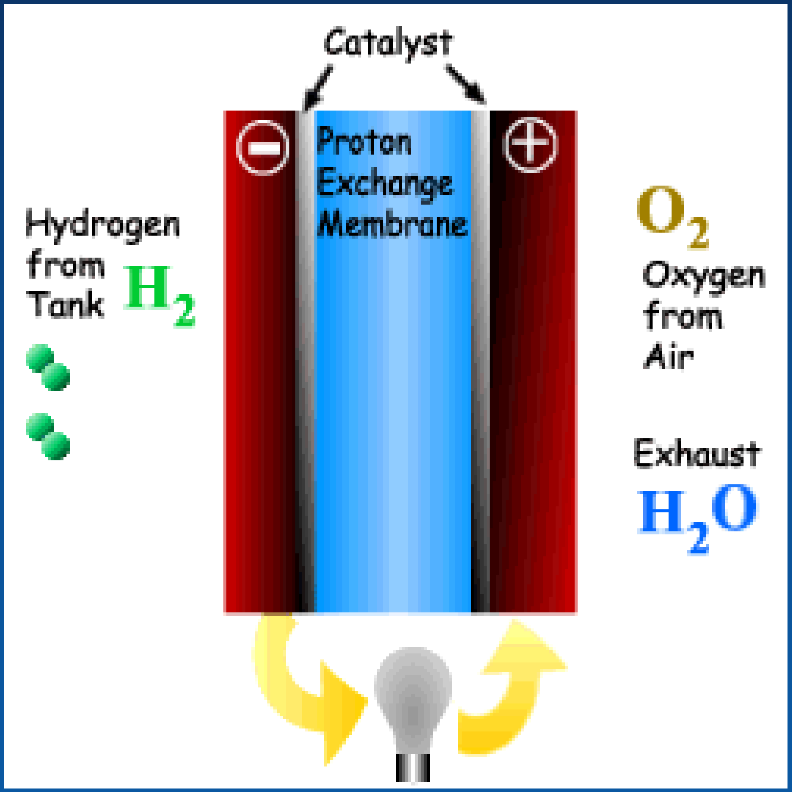
- Anode (negative electrode)

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

- Electrolyte
- Cathode (positive electrode)

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

In a typical fuel cell, hydrogen and oxygen react electrochemically at separate electrodes, producing electricity, heat, and water.



Ford Focus Fuel Cell Vehicle Undergoing High Altitude Testing on Pike's Peak (11/03)

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Energy Generation

- Biomass
- Renewable e^-
  - Solar
  - Wind
  - Hydro
- Geothermal
- *Nuclear*

Production

- Electrolysis
- Thermolysis
- Conversion

Feedstock

- Water
- Biomass

Distribution

- Used onsite
- Pipelines
- Compressed gas
- Liquid

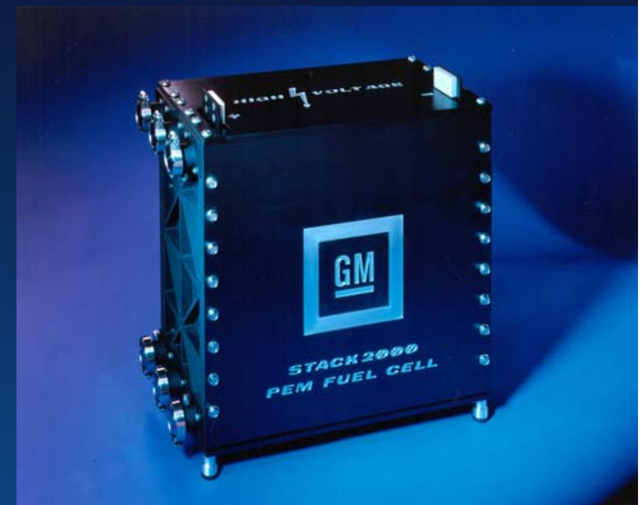
Utilization

- Fuel cells
- Turbines
- IC Engines

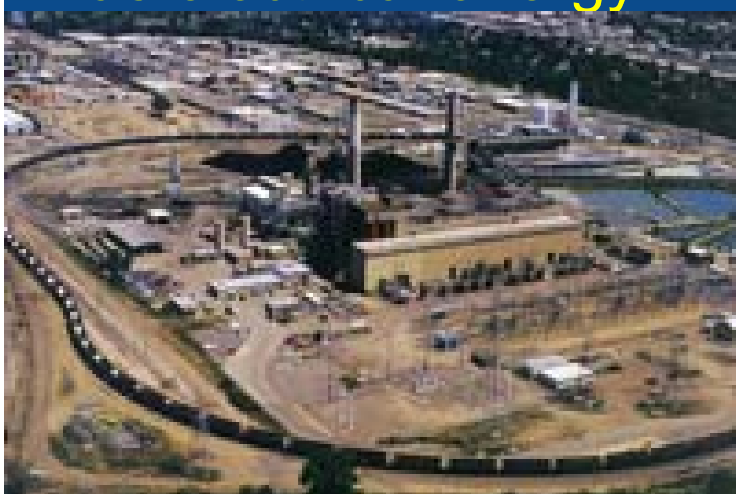
Transportation fuel and energy storage.

Efficiency and the Hydrogen Economy

The efficiency of electrolysis is about 70%, and the efficiency of fuel cells is around 50%. The efficiency then of electricity-to-hydrogen and back to electricity is about 35% (.7 x .5).



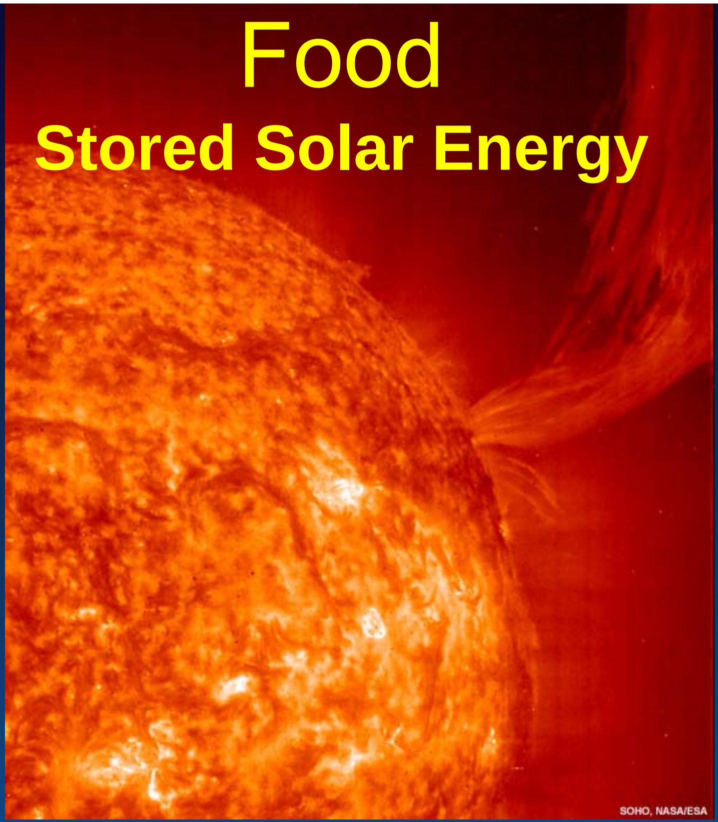
"Hydrogen energy will be at least twice as expensive as electrical energy." -Dr. Ulf Bossel



Electricity is always going to be at least twice as expensive as the natural gas used to generate it. Electricity is always going to be at least 4 times as expensive as the coal used to generate it.

Food

Stored Solar Energy

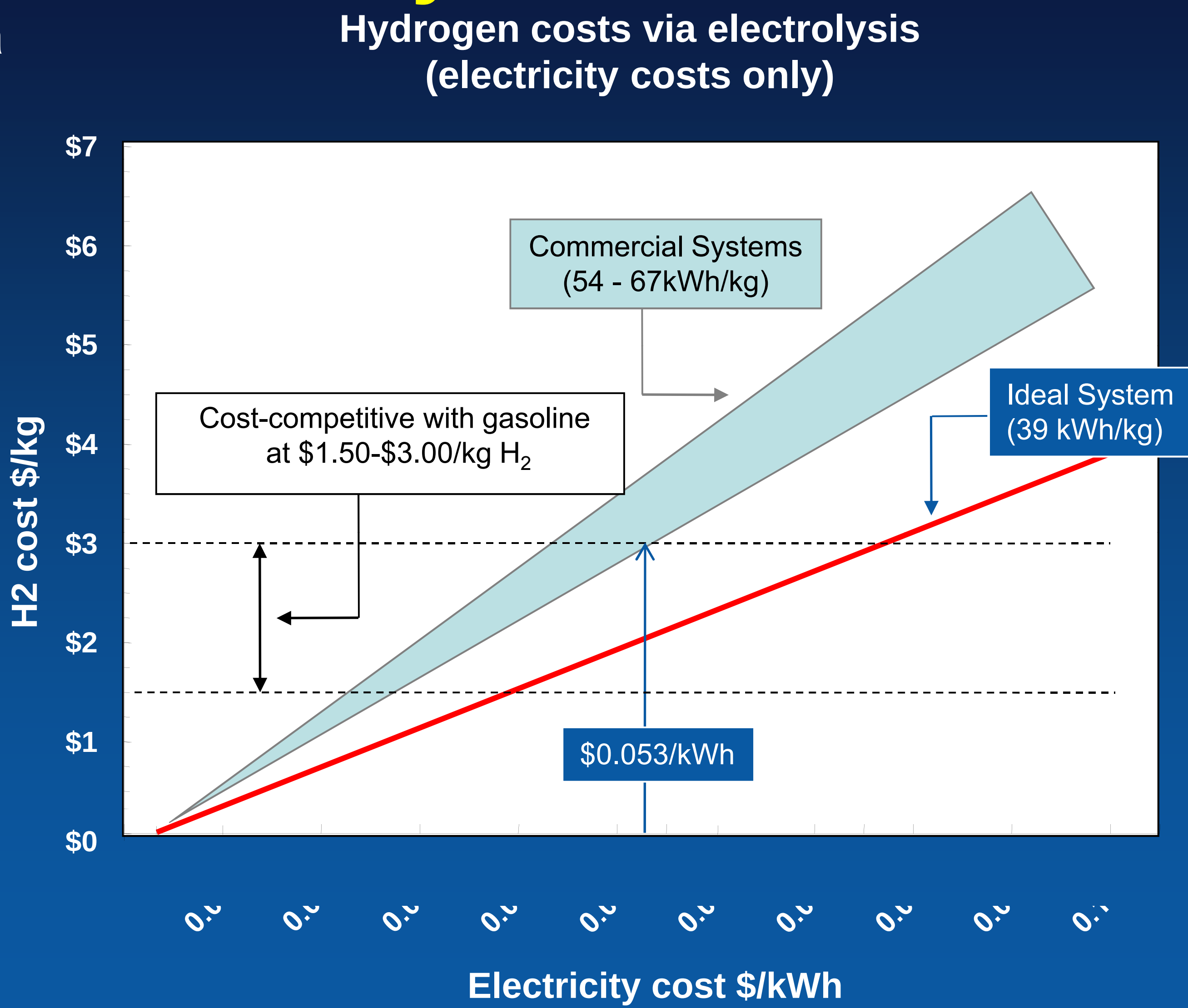


$Food + O_2 \Rightarrow Life + CO_2 + H_2O$

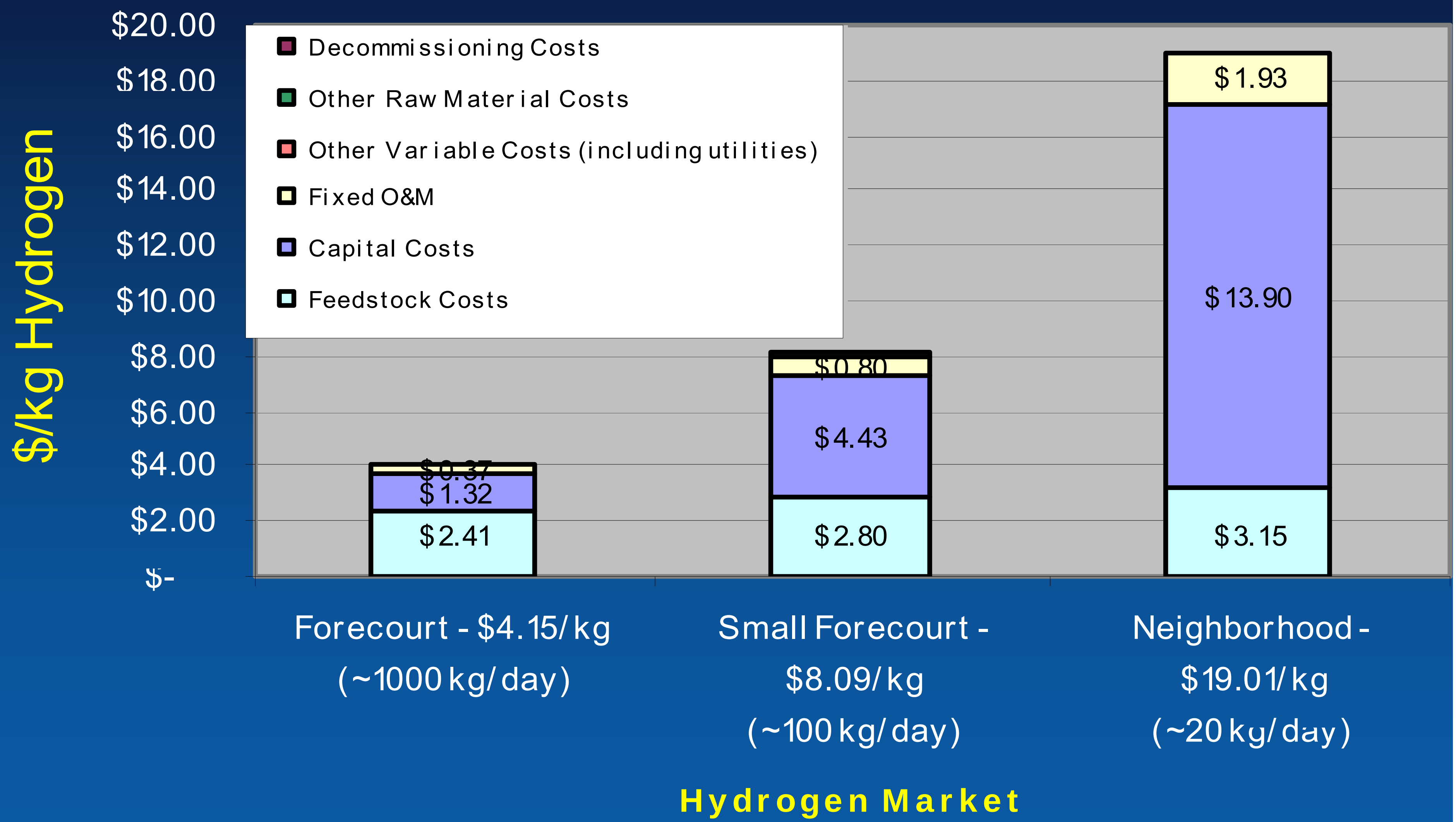
While important, energy losses do not necessarily dictate the viability of any technology. Photosynthesis has an efficiency of less than 1%, and yet it powers almost all life on this planet - over 6 billion people.

Current Energy Efficiency of Electrolysis

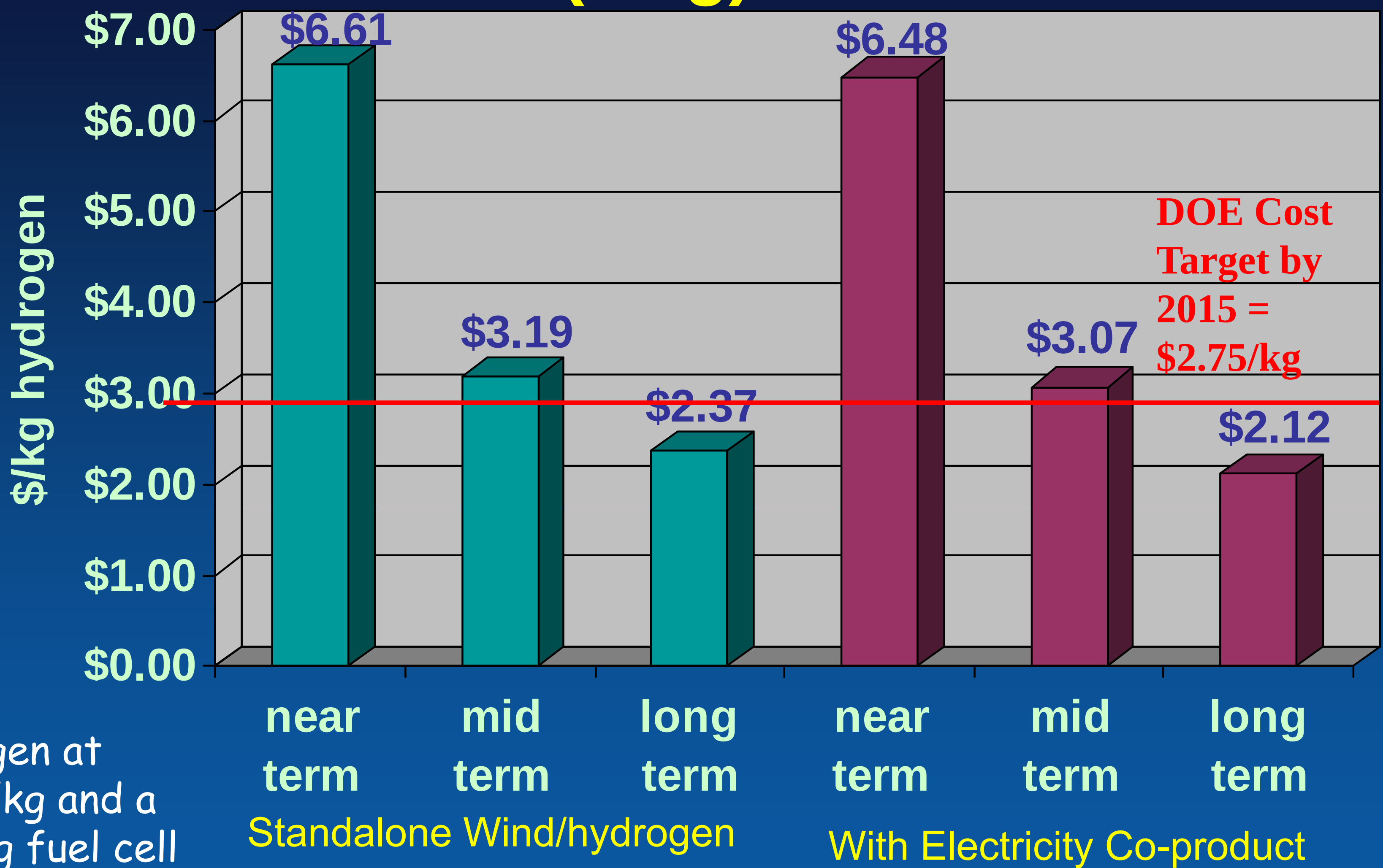
- Electricity costs are a major contributor to the cost of electrolysis.
- Capital costs, especially for smaller systems, are also significant
- Larger electrolyzers arrays are needed to take advantage of potential low cost, high volume electricity production methods like wind.



Hydrogen Selling Price (Year 2000 dollars)
Industrial Electricity - 4.8¢/kWr



Central Wind Results – Hydrogen Costs ($/kg)

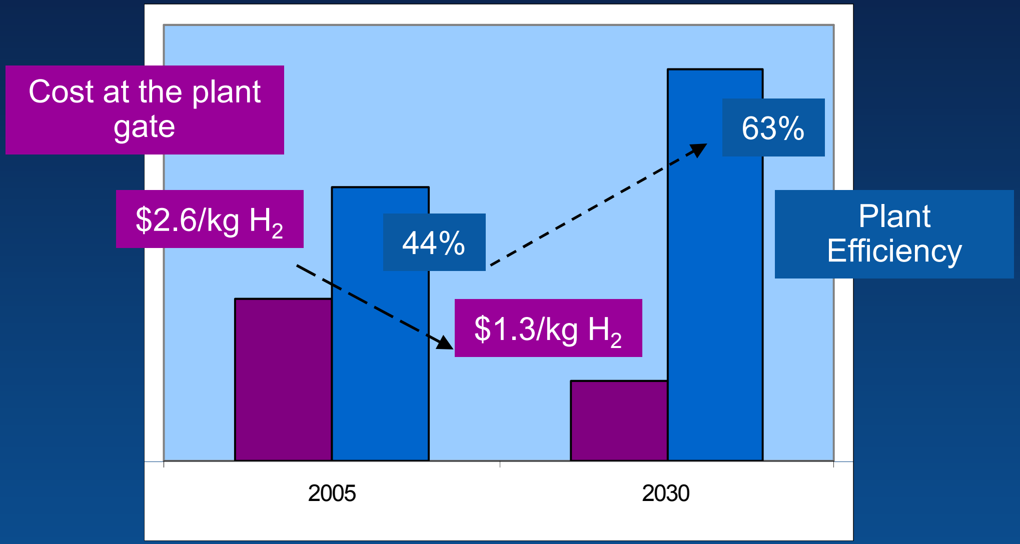


Hydrogen at $6.00/kg and a 50m/kg fuel cell vehicle = 12¢/mile

Economics of Thermochemical Biomass to Hydrogen Processes

- Biomass Gasification
  - Central production
  - 74,000 kg H_2/day
  - H2A analysis methodology (10% IRR, equity financing, 40-year plant life, 1.9% inflation)

Biomass Gasification to Hydrogen Cost Targets



- Potential Cost Reduction Strategies
  - Pyrolysis for lower cost feedstock and chemical co-products
  - Co-reforming with natural gas at existing facilities
  - Combined gasification and reforming operations
  - Feedstock yield improvements

Transportation costs: Hydrogen vs. Gasoline

- Gasoline at \$3.00/gal and a 25mpg vehicle = 12¢/mile
- Hydrogen at \$4.00/kg and a 50m/kg fuel cell vehicle = 8¢/mile
  - Honda FCV is 70 miles/kg hydrogen
  - GM HydroGen3 is 54 miles/kg
  - GM Sequel (Cadillac SRX) is 39 miles/kg and 300 mile range.

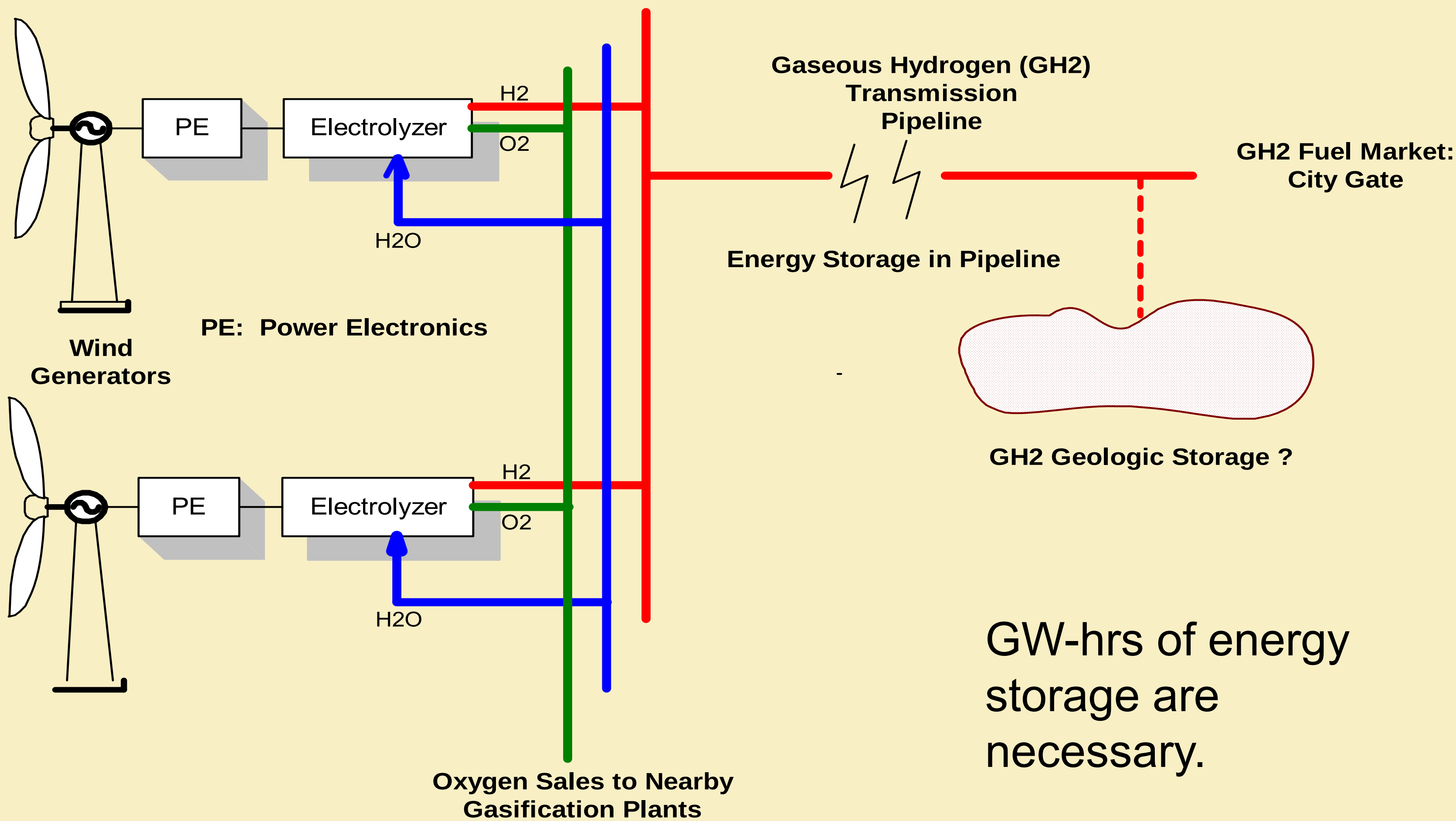
Cost of wind-source GH2 fuel delivered at end-of-pipe at distant city gate

PIPELINE LENGTH	320 km / 200 miles	480 km / 300 miles	800 km / 500 miles	1600km /1000 miles
	Cost / kg	Cost / kg	Cost / kg	Cost / kg
@CRF = 12%	$2.19	$2.34	$2.64	$3.38
@CRF = 15%	$2.72	$2.91	$3.28	$4.21
@CRF = 18%	$3.26	$3.48	$3.93	$5.04
@CRF = 21%	$3.75	$4.01	$4.53	$5.82

Assumes: Unsubsidized (no federal PTC, or other); No oxygen sales
Windplant @ $US 830 / kW Total Installed Capital Cost (TICC)
Electrolyzers @ $ 330 / kW Total Installed Capital Cost (TICC)
Pipeline 20" OD @ $US 29 / inch diam / m length

William C. Leighty, Director, The Leighty foundation; Jeff Holloway, Pipeline Technologies, Inc.; Rupert Merer, Stuart Energy; Dr. Brian Somerday, Dr. Chris San Marchi, Sandia National Laboratory; Geoff Keith, Synapse Energy Economics Presented at Windpower05, Denver, 15-18 May; 2005 World Solar Congress, Orlando, 6-12 Aug.

Hydrogen as Energy Storage for Firm Power Generation and Seasonal Storage in Geological Reservoirs



GW-hrs of energy storage are necessary.

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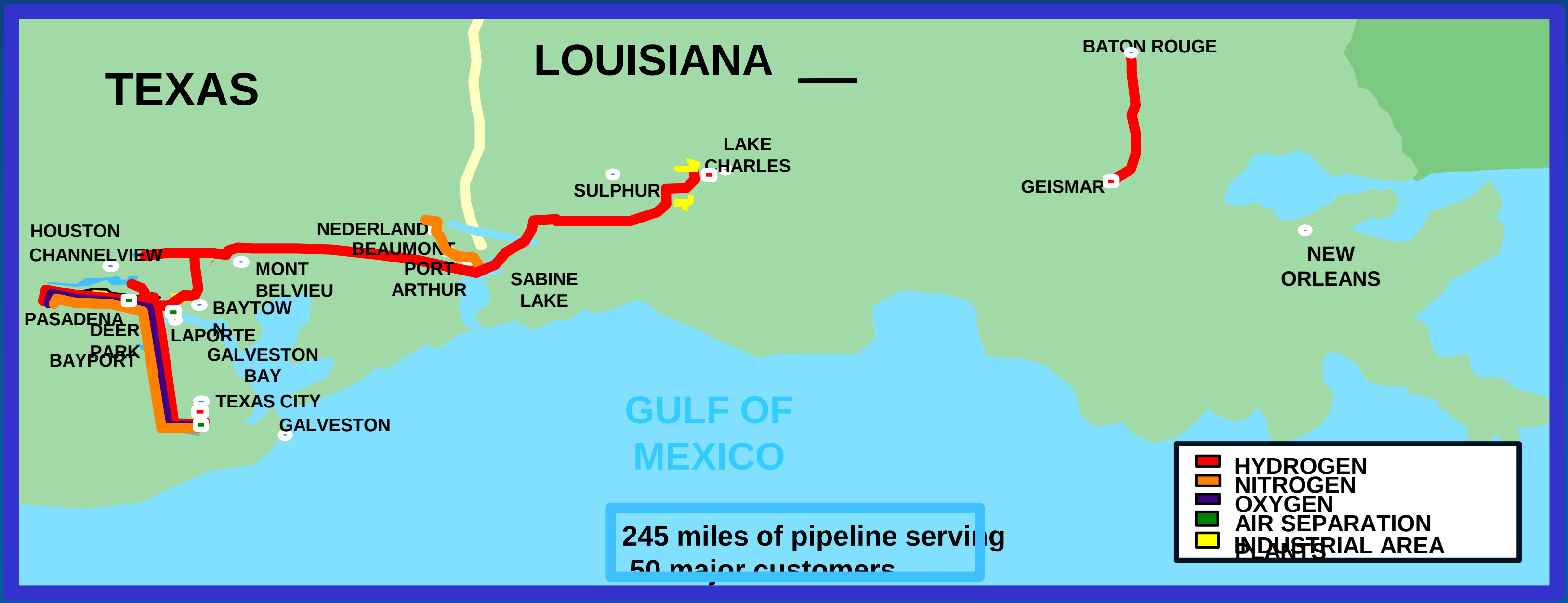
Transportation fuel and energy storage.

Hydrogen Distribution Systems

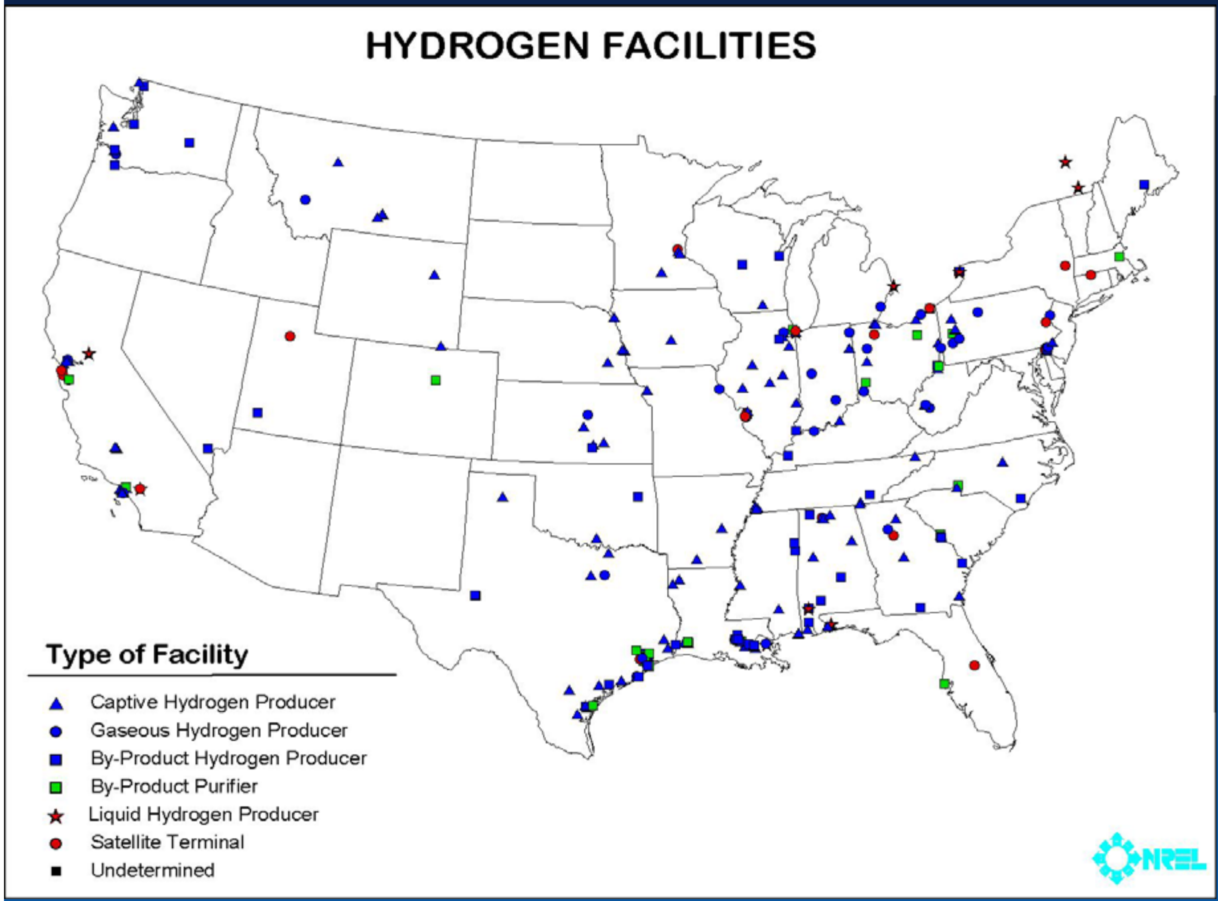
Liquid Hydrogen

Compressed Hydrogen

70 million gallons of liquid hydrogen per year

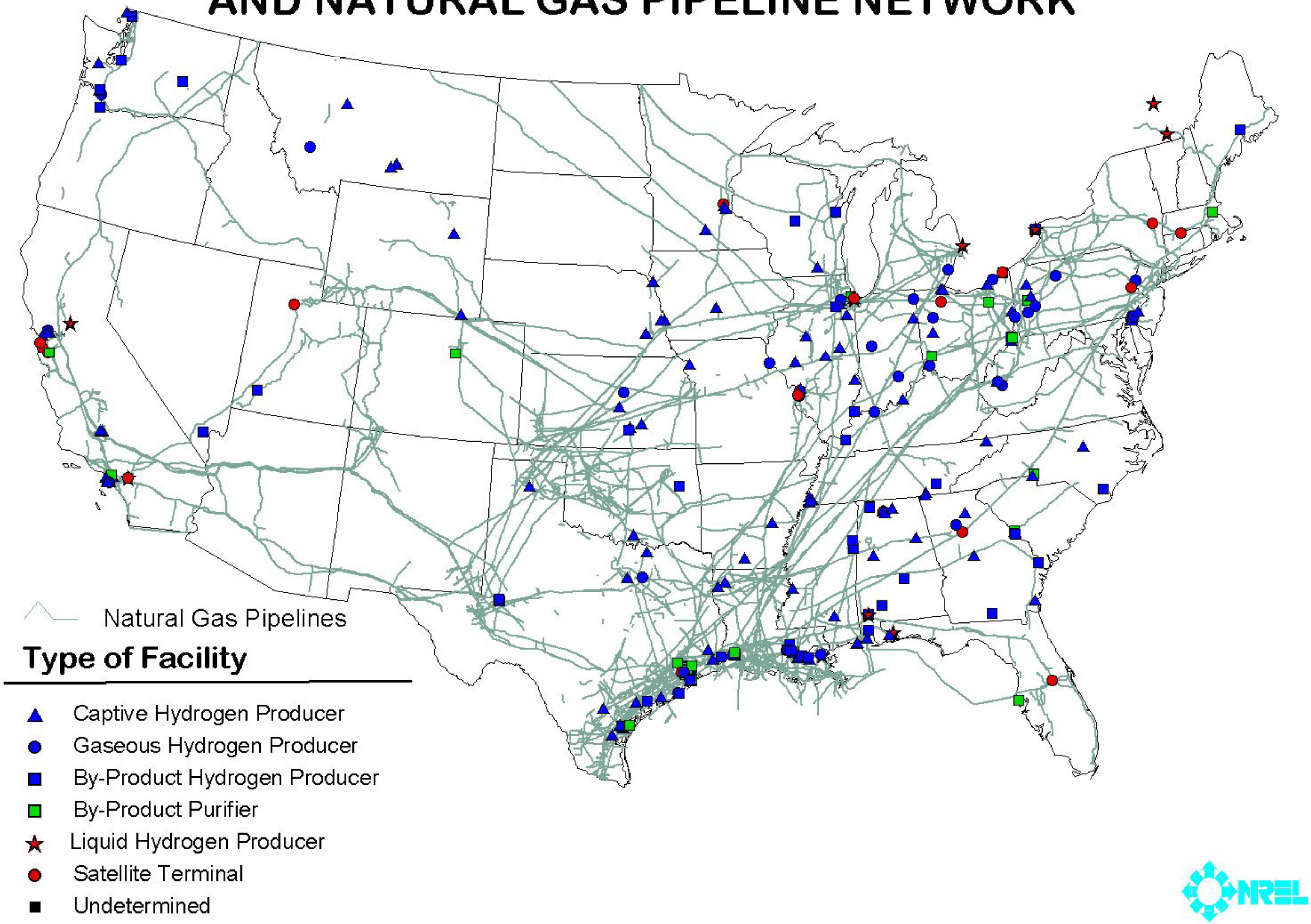


Pathway to Hydrogen-based Transportation System



- Hydrogen from current natural gas based technologies
  - 25% less CO_2 than gasoline hybrids
  - 50% less than standard ICEs
- Biomass-based production
- Electrolysis when coupled to sustainable energy systems (PV & wind)

HYDROGEN FACILITIES AND NATURAL GAS PIPELINE NETWORK



Hydrogen Fueling Scenarios

Gasoline Marketers Association

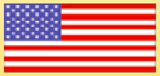
$2 billion to convert 10% of current retail stations to hydrogen.

Shell Hydrogen: $19B for 25% conversion

Cost of initial nation-wide H_2 Infrastructure

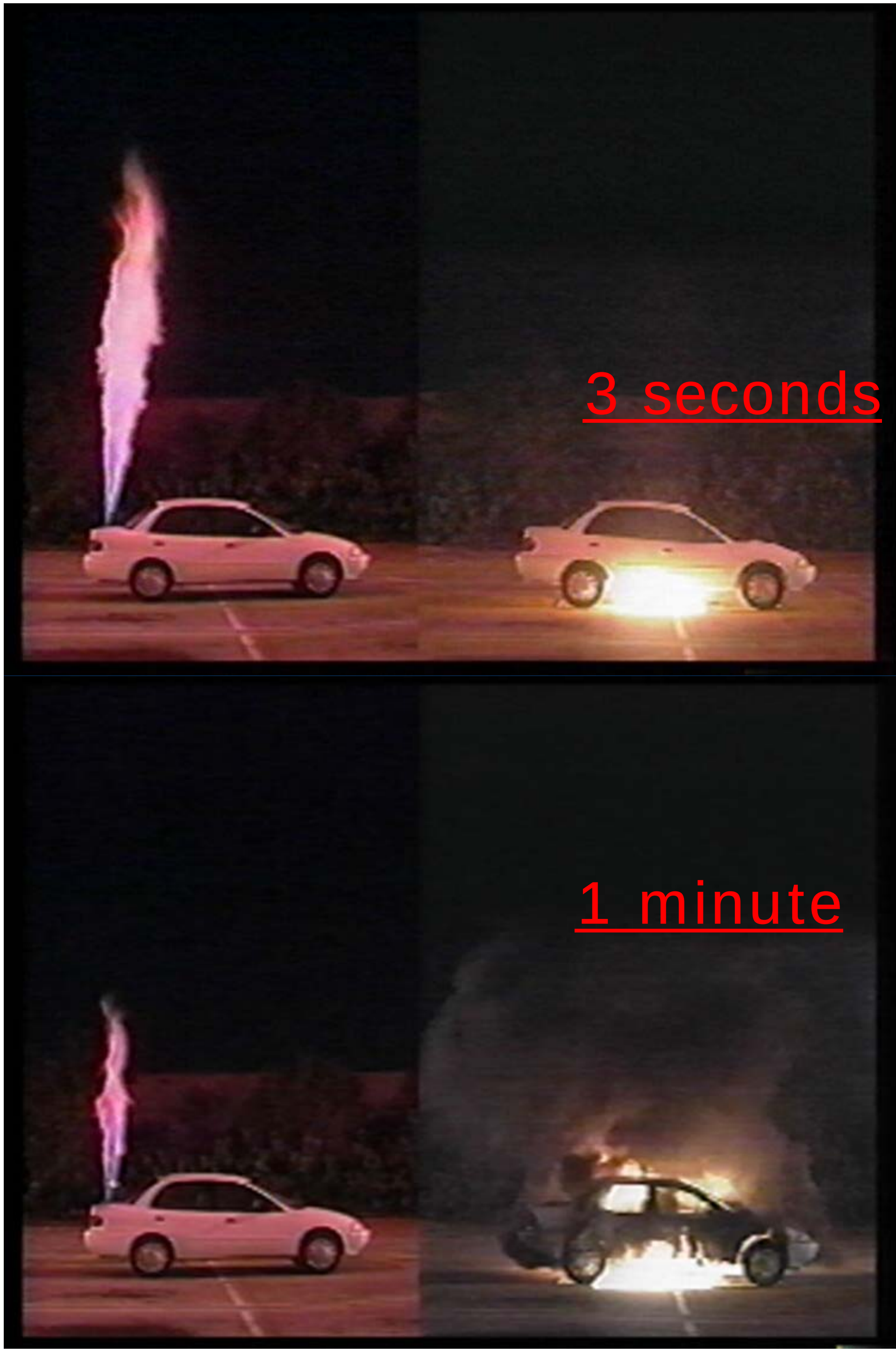
ASSUMPTIONS
- 2% of cars run on H_2
- H_2 sold at 25% of retail sites

- ¼ Onsite electrolysis
- ¼ Onsite POx reformer
- ¼ Trucked in gas
- ¼ Trucked in liquid

	Retail sites selling H_2	Cost of extra central production/ liquefaction	TOTAL COST
	43 980	$ 450m	$ 19bn
	3 425	$ 90m	$ 1.5bn
	13 831	$ 140m	$ 6bn

Shell Hydrogen

Home Refueler



Hydrogen Safety

- Fuel leak simulation
  - hydrogen on left
  - gasoline on right
  - equivalent energy release
- Hydrogen has safety advantages as well as energy security and environmental advantages.

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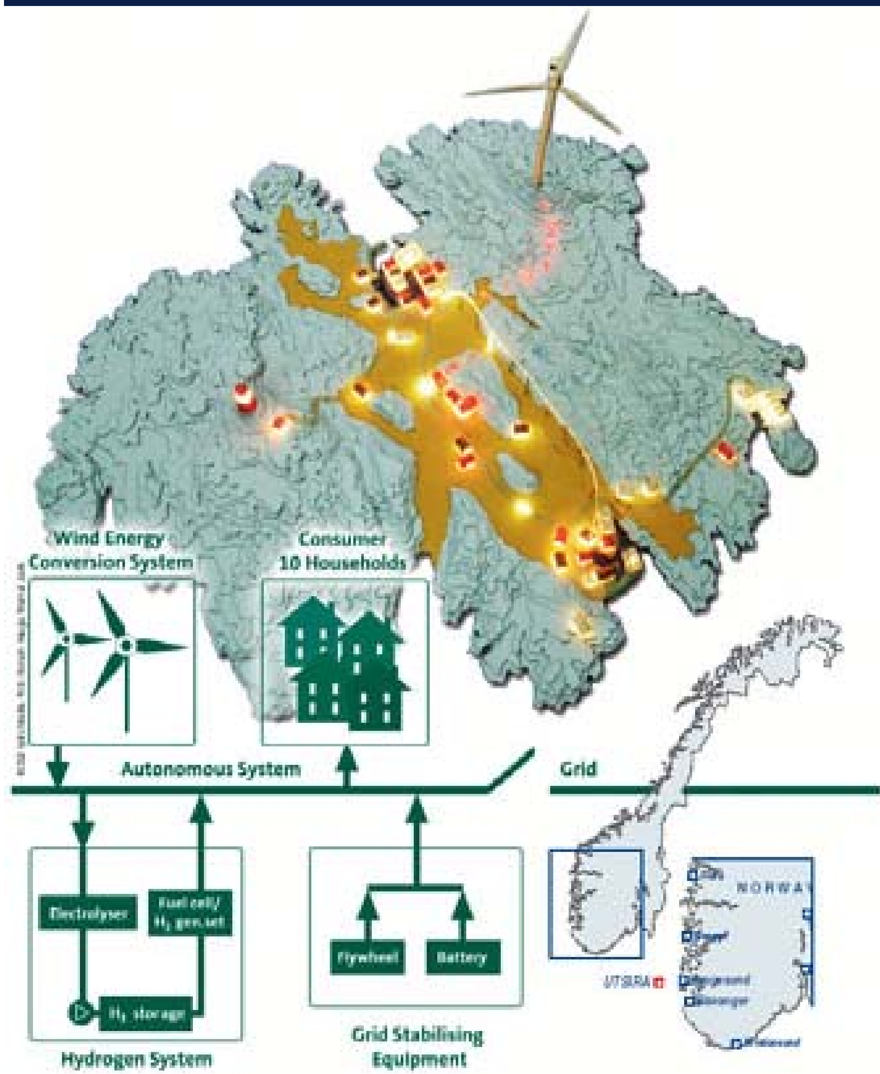
Transportation fuel and energy storage.

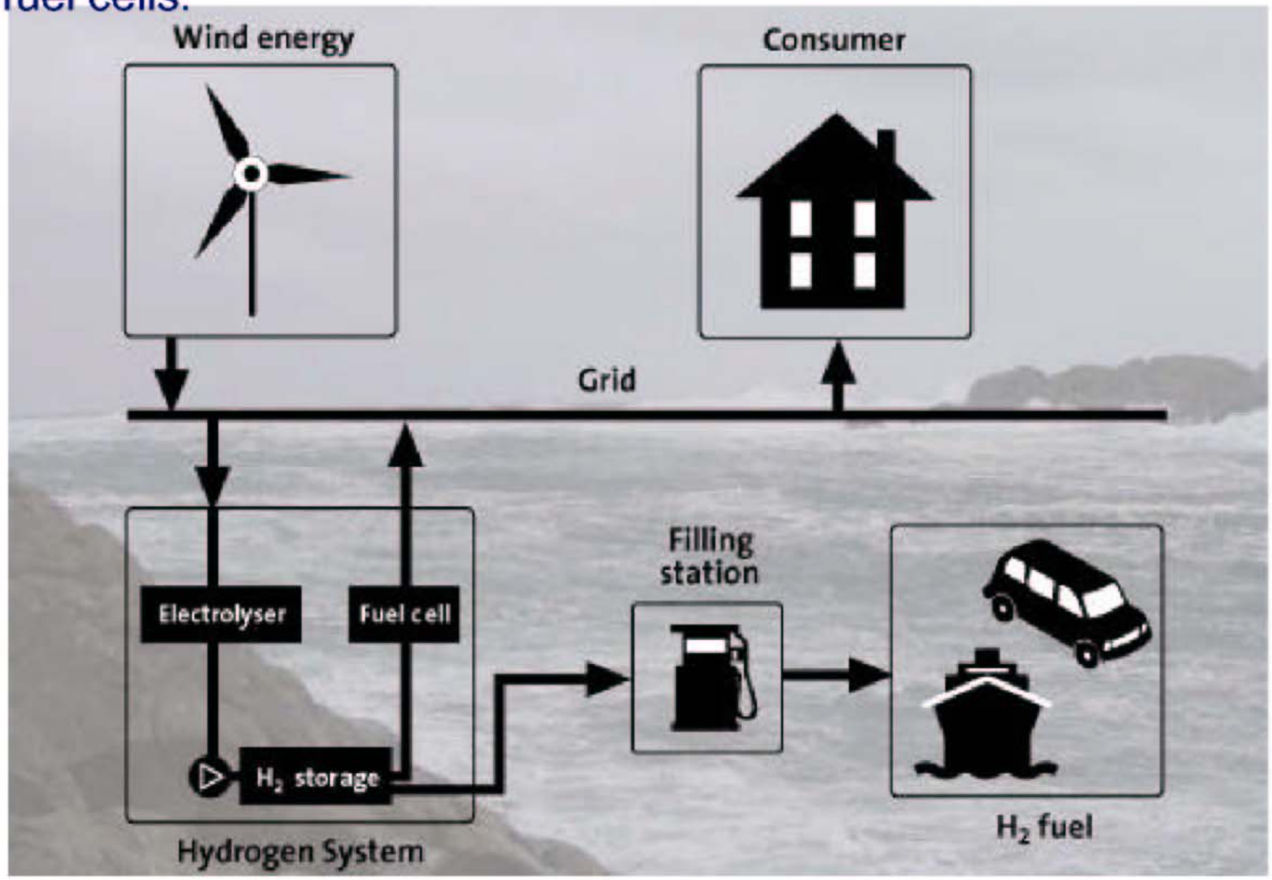
Utsera Project
Opened July 1, 2004

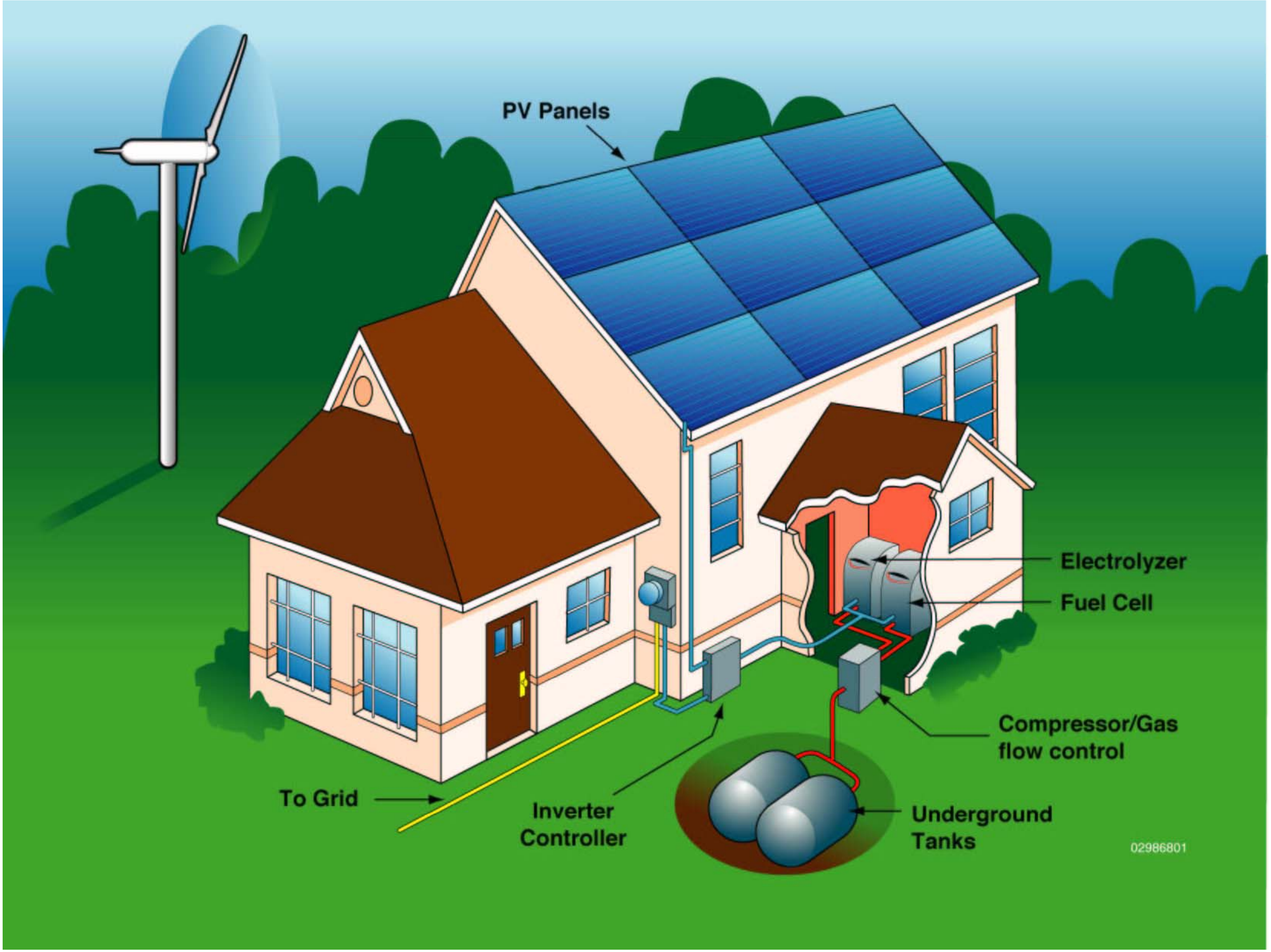


http://www.hydro.com/en/press_room/features/utsira.html

The wind energy – hydrogen – fuel cell system planned at Utsira

The wind mill connected to the grid will supply consumers with power, but also the hydrogen system consisting of electrolyser, hydrogen storage and fuel cells.




PV Panels
Electrolyzer
Fuel Cell
Compressor/Gas
flow control
To Grid
Inverter
Controller
Underground
Tanks
02986801

Hydrogen and the Digital Electrical Grid

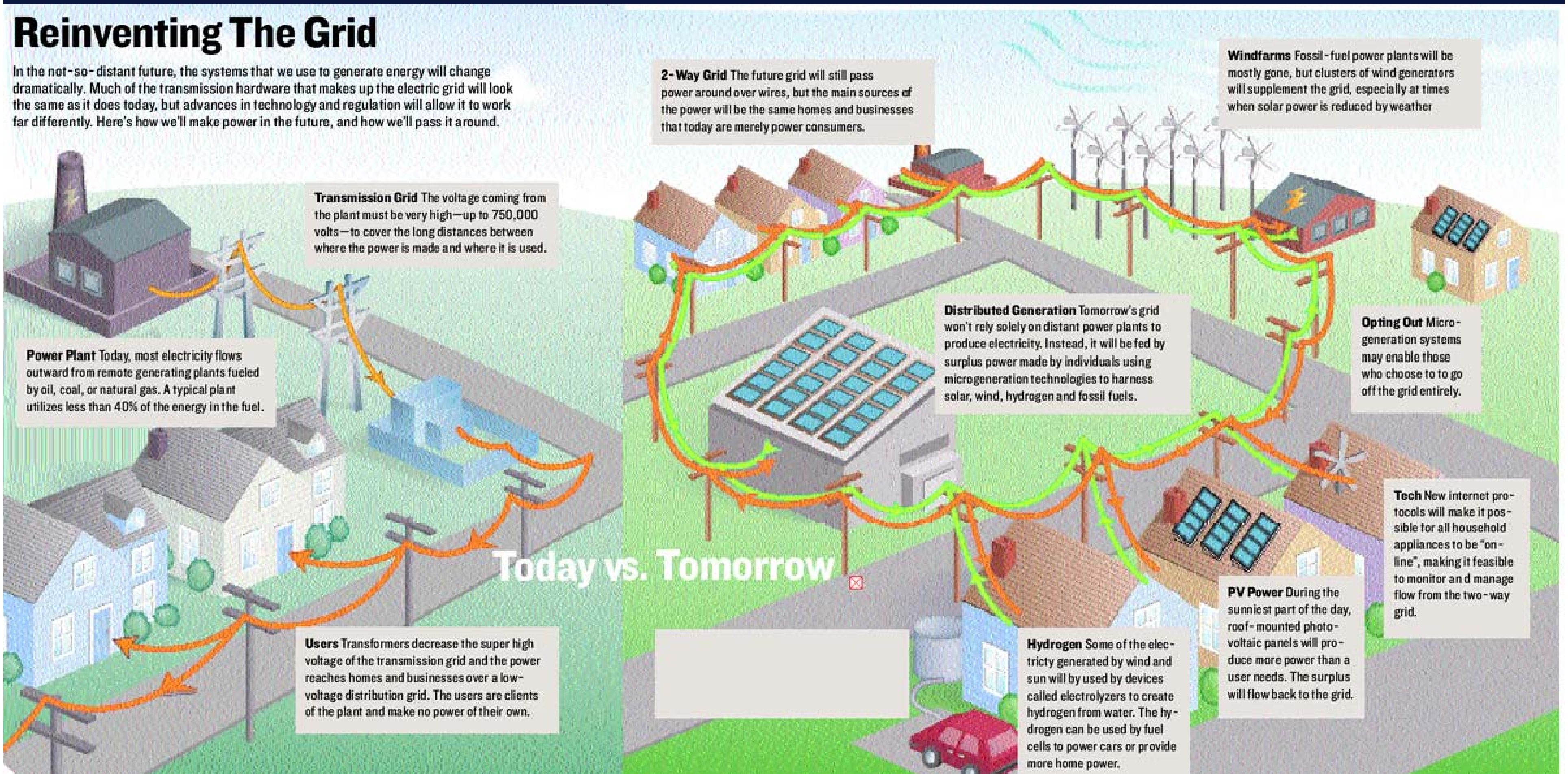


Figure from Newsweek - Description Electronic Design Magazine

http://www.elecdesign.com/Articles/Index.cfm?ArticleID=7022

Mass Production and Sustainable Energy

Current energy generating systems are characterized by large centralized plants, not amenable to mass manufacturing.

- Sustainable energy systems such as wind, PV, fuel cells, and electrolyzers can all be manufactured as smaller units and added together to produce larger systems.
  - High volumes translate into major cost savings.
  - Small (home/village/city) systems can start producing immediately and then can be increased linearly.
- The DaimlerChrysler Saltillo (Mexico) plant makes 1200 engines/day (460,000 per year) a similar plant in Germany makes 3000 en gines/day.

The Path Forward

(J. Turner)

- Push Renewable (Wind) electrons against coal – no sequestration.
  - Solar Cells required on every new home.
  - Improve conservation and energy efficiency everywhere.
- Develop fuel cells for transportation (hydrogen from natural gas).
- Implement electrolysis as electricity from coal diminishes and sustainable energy increases.

Talk about it!!

Hydrogen from Non-fossil Domestic Resources

If 50% of the US light-duty fleet were converted to hydrogen fuel cell vehicles with an efficiency twice the current average, it would require approximately 40 million tons of hydrogen per year. To produce that, you would need:

- ✓ Wind: 555 GW (current 6.7 GW) (16 years @ 28%)
- ✓ PV: 740 GW (current ~0.2 GW) (22 years @ 30%)
- ✓ Nuclear: 216 GW (current 98 GW)

*Assuming all the hydrogen was produced solely by 70% efficient electrolysis powered by that resource.

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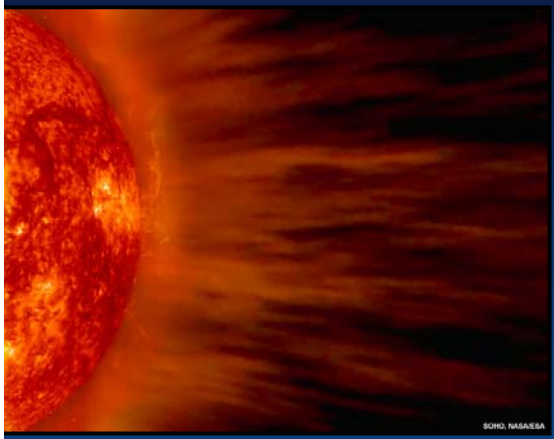
Hydrogen From Sunlight and Water



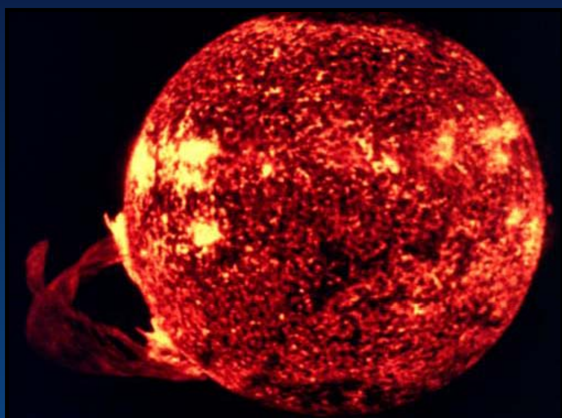
Visible light has enough energy to split water (H_2O) into hydrogen (H_2) and oxygen (O_2).

However water is transparent and does not absorb this energy (fortunately).

- Photosynthetic algae and photoelectrochemical processes can use this light to produce hydrogen from water.

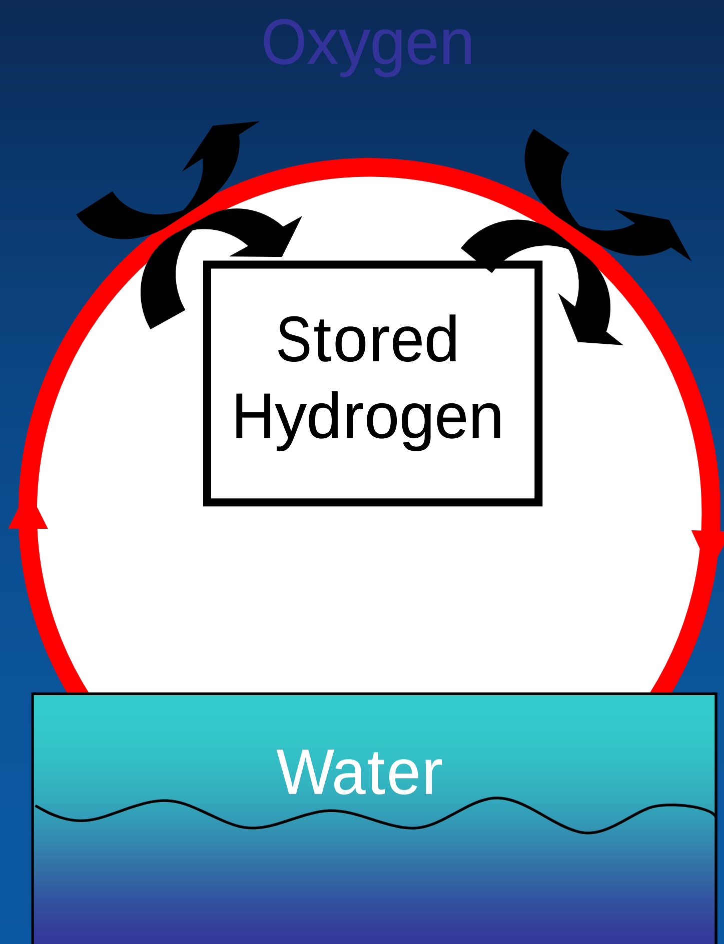
$$2H_2O \rightarrow 2H_2 + O_2$$

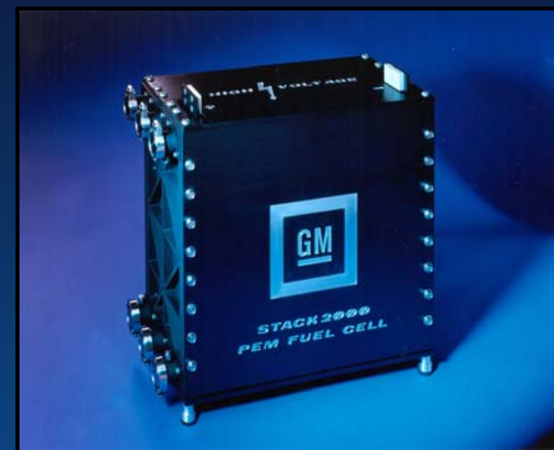
Hydrogen Economy
Closed Energy Cycle



Inputs:

Solar Energy and Water





Outputs:

Electricity, Heat and Water

Hydrogen Energy

BENEFITS

- ✓ No harm to the environment.
- ✓ Small or large systems available.
- ✓ Energy supply is endless.
- ✓ Costs will come down when mass production begins.

CONCERNS

- ✓ Currently more expensive than fossil fuels.
- ✓ Most of the costs involved are for start-up infrastructure.

Hydrogen Fuel Cell Car Competition
National Middle School Science Bowl
Golden, Colorado June 2005

Final Tune Ups


SCIENCE
SCIENCE
Solving the Puzzle of Life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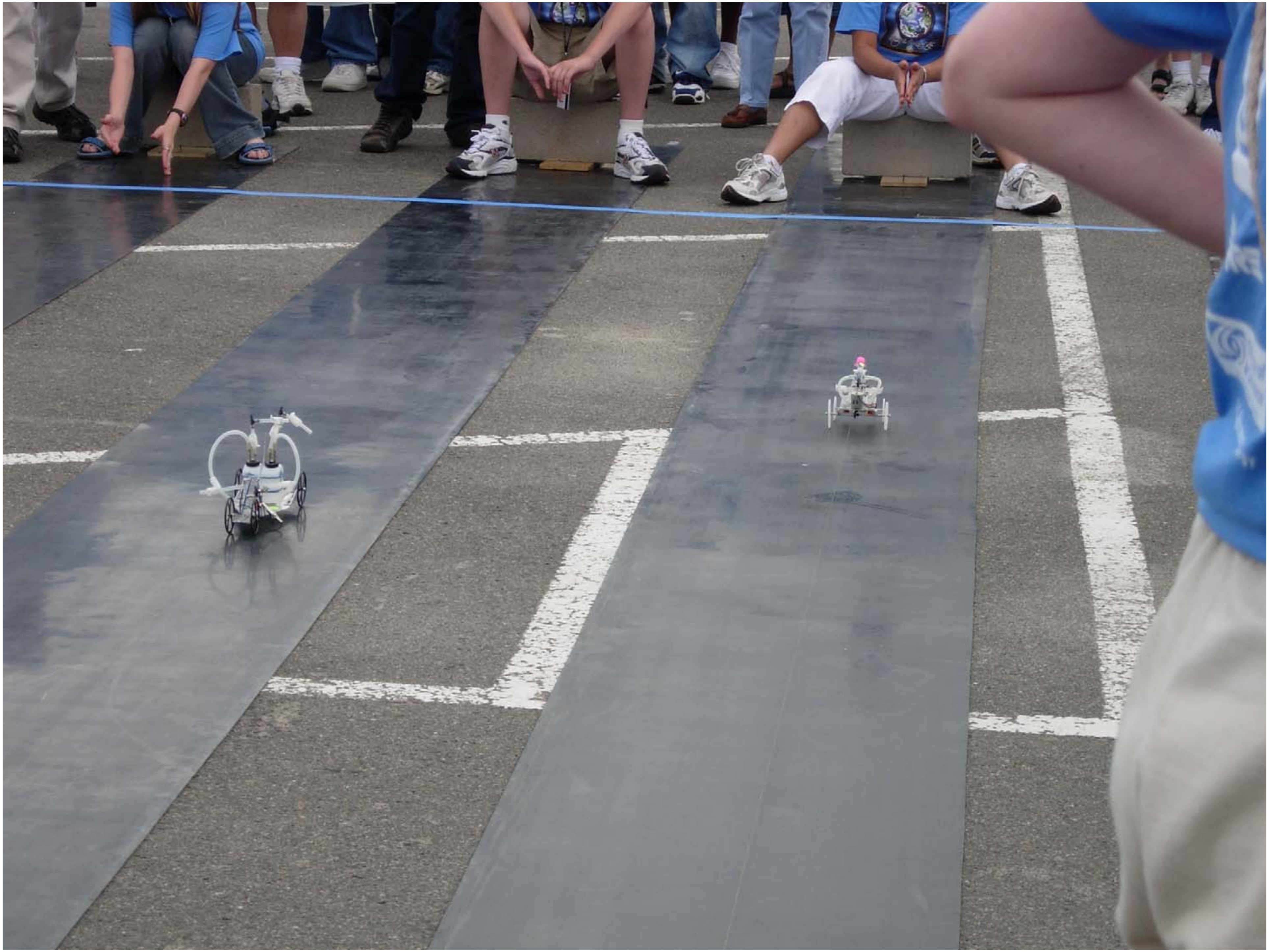


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Team B
Captain