FUNDAMENTALS OF ADVANCED ENERGY CONVERSION

2.996 & 2.994, Spring 04

A Ghoniem (IC), M Kazimi, Y Shao-Horn, J Tester

WHY ? CO2, Terawatts, Needs and Sources,

WHAT ? Few Examples:

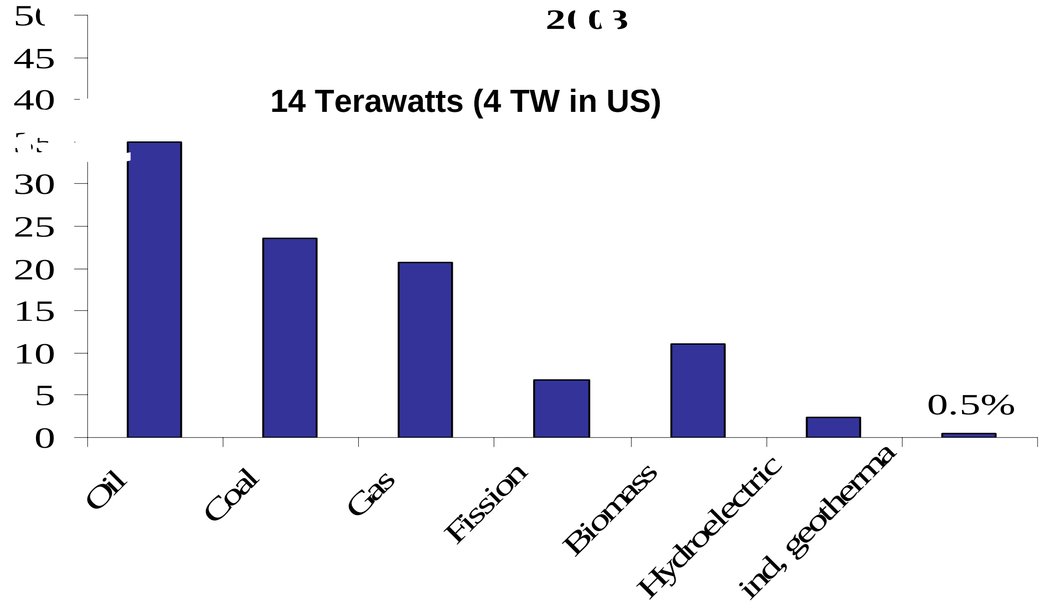
IGCC, fuel reforming and synthesis
Fuel Cells, “fueling the fuel cell”, FC3
Hydrogen Economy: generation and storage
Photoelectricity

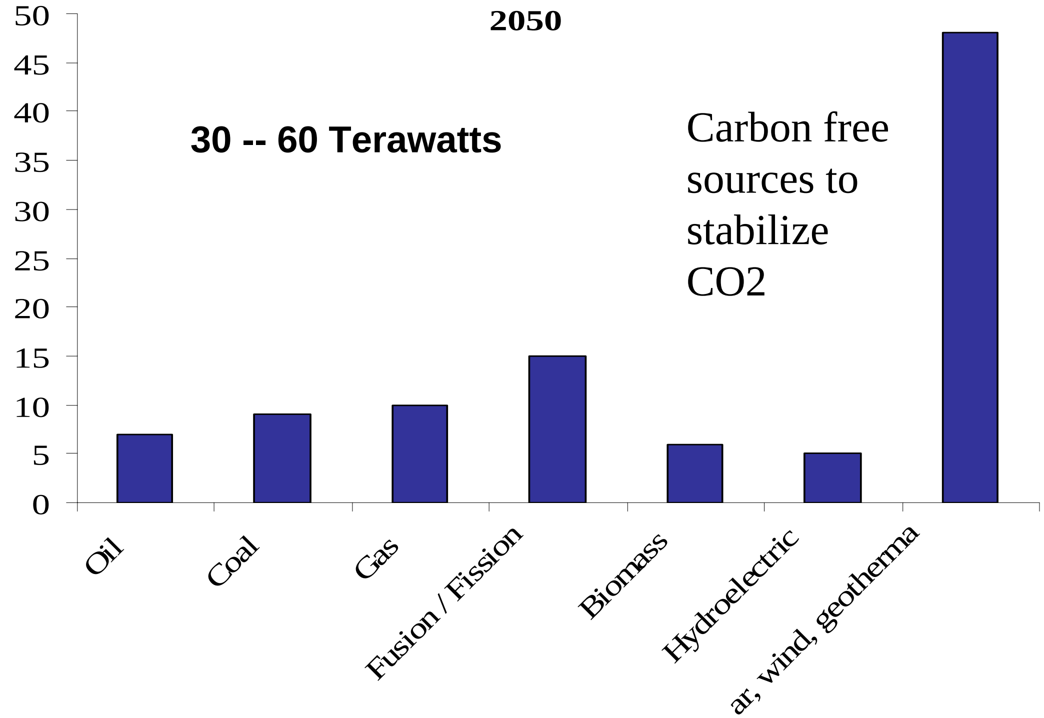
HOW ?

The Terawatt Challenge
*R. Smalley**
Rice University

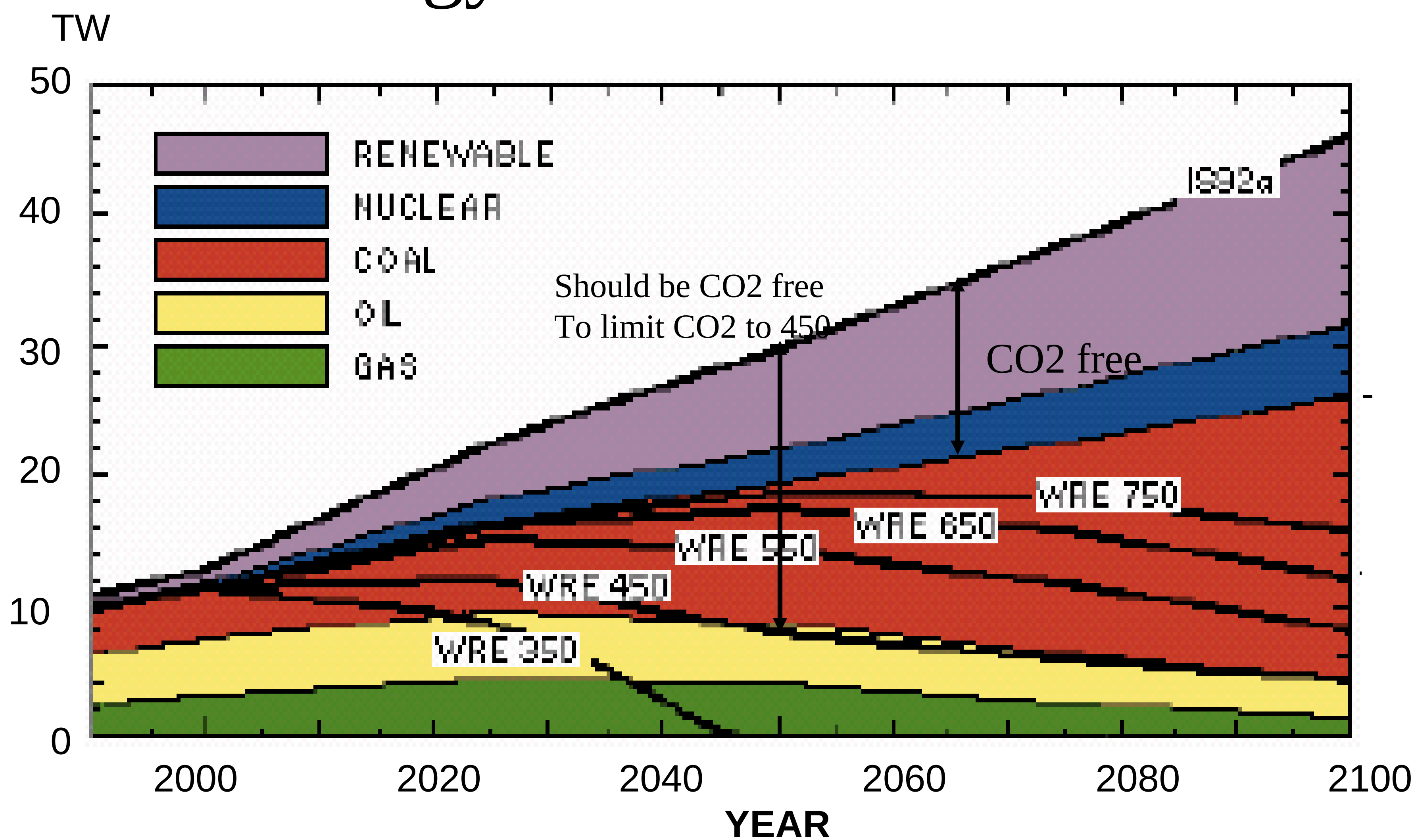
1. **ENERGY**
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

*Noble prize, Chemistry, 1996





Energy Sources and Demand



Source: M.I. Hoffert et. al., *Nature*, **1998**, *395*, 881,

Wigley, Richels and Edmonds, ppmv of CO_2, pre-industrial concentration is 350 ppmv

CO2 emissions and Global Temperature!

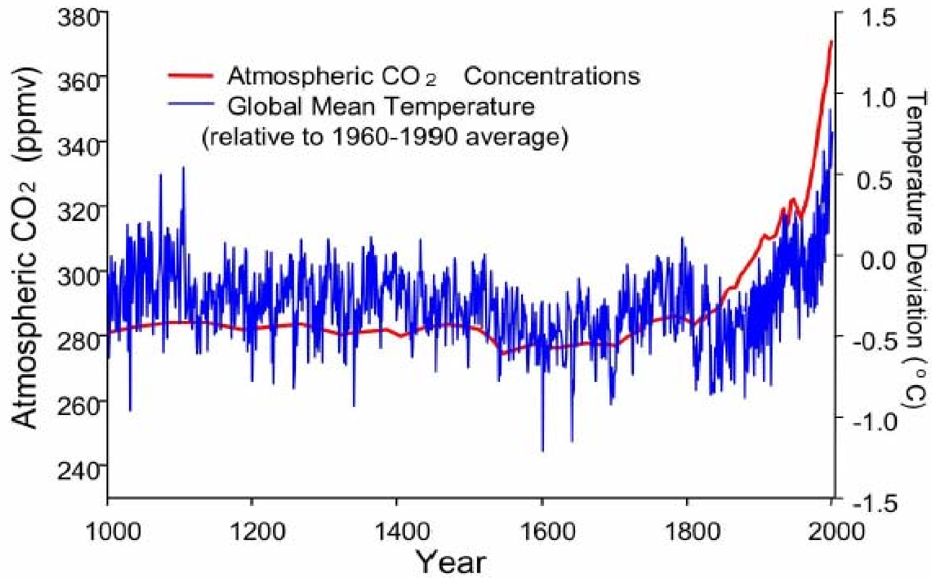


Figure 1b Increased CO_2 Emissions Causing a Rise in Atmospheric CO_2 Associated with a Rise in Global Temperature (Sources: CO_2 data from Ethridge et al. 2001, Keeling and Whorf 2002; temperature data from Jones et al. 1998, Peterson and Vose 1997)

From "Basic Research Need for a Hydrogen Economy", Report of DOE BES Workshop, May 13-15, 2003

CO2 emission reduction:

- Improve plant efficiency
- Use low C fuels
- Use pure H2
- Sequester CO2!
- RENEWABLES

FIGURE 1. GASIFICATION-BASED ENERGY PRODUCTION SYSTEM CONCEPTS

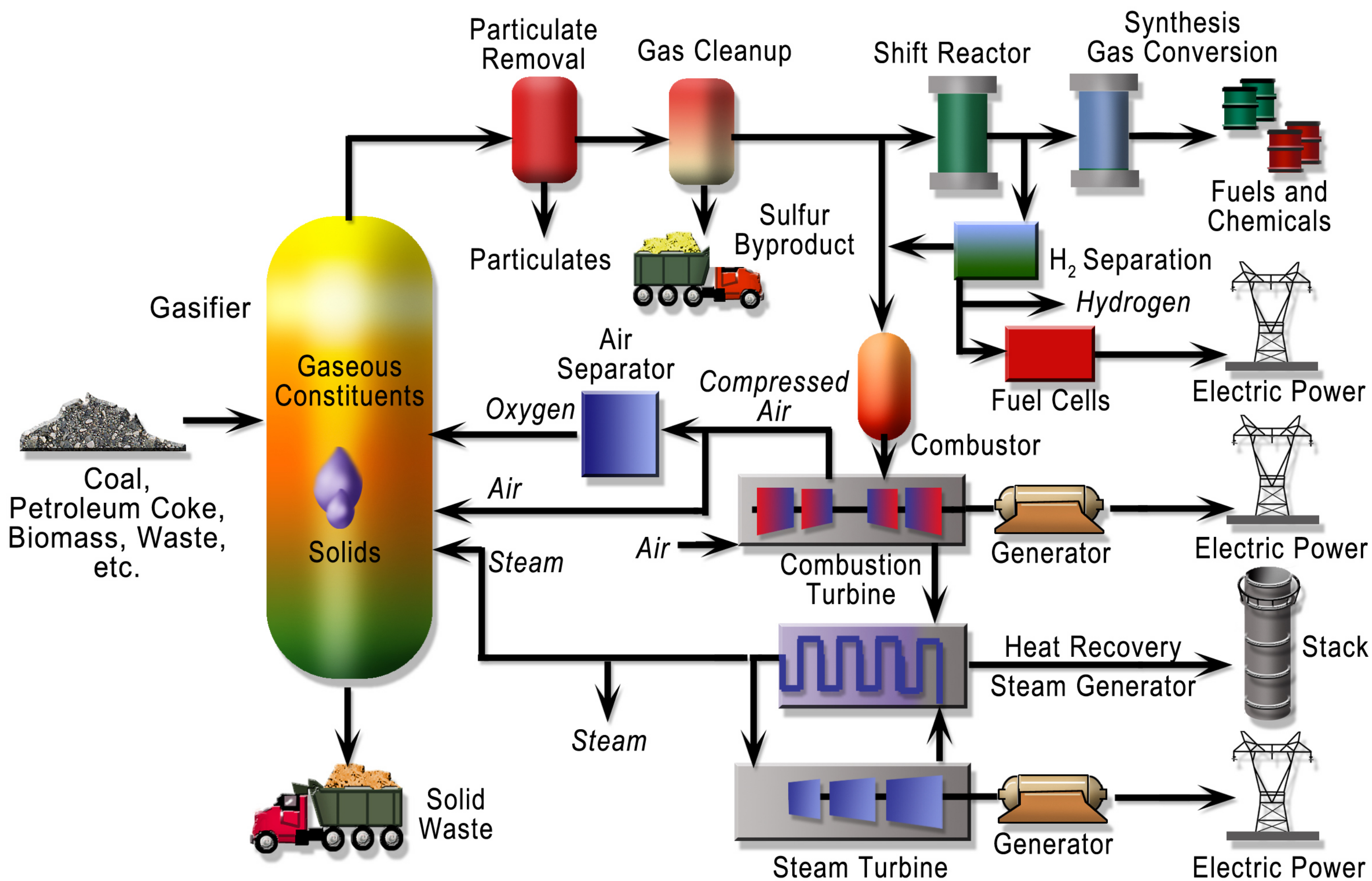


FIGURE 2. GASIFICATION-BASED ENERGY CONVERSION SYSTEM OPTIONS

(Courtesy of Prof. Wilson and Prof. Korakianitis. Used with permission.)

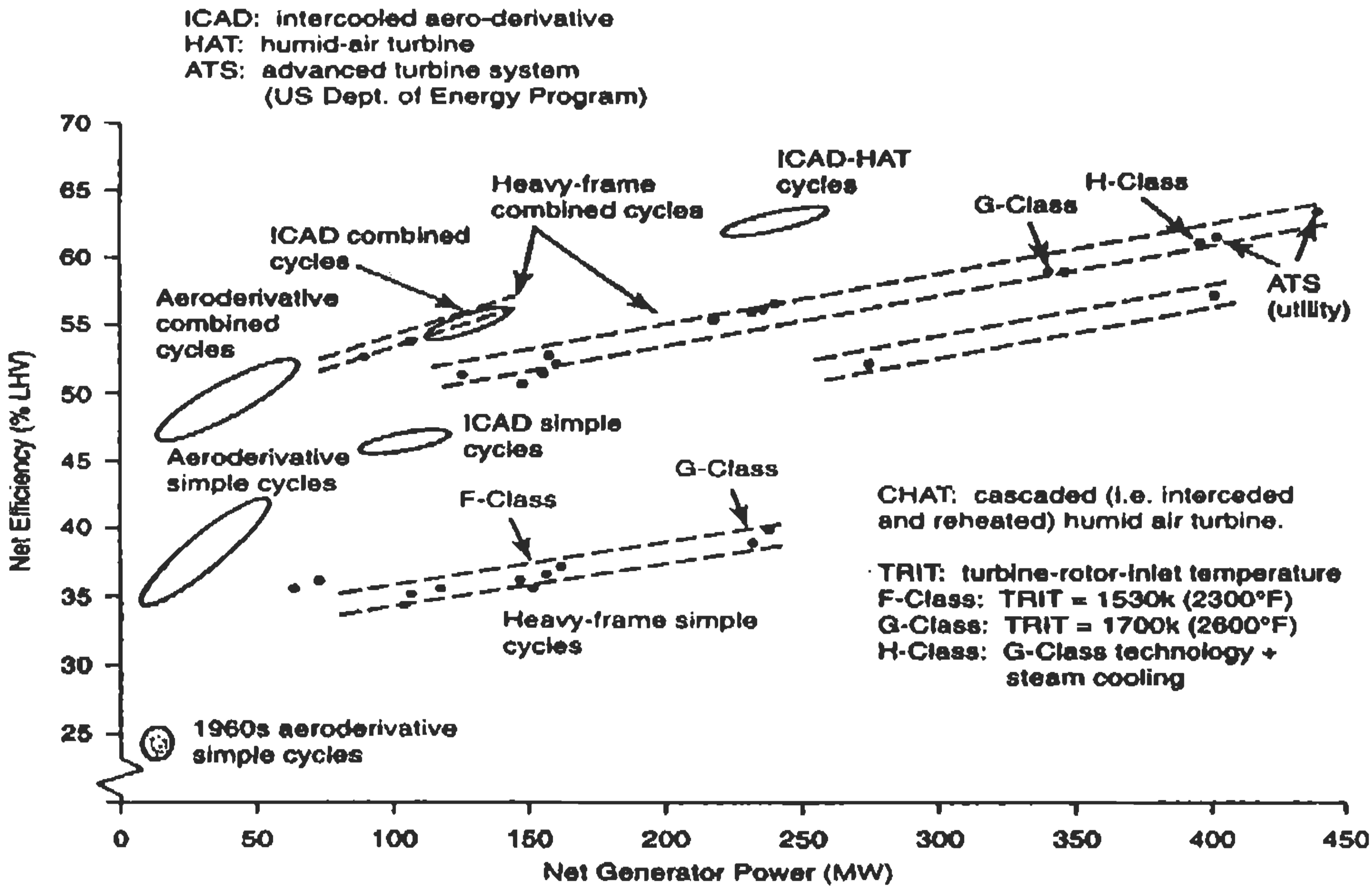


Figure 3. Thermal efficiency versus power of different turbines, and combined cycles (Wilson, and Korakianitis, 1998).

Optimal Hydrogen Utilization: the Fuel Cell

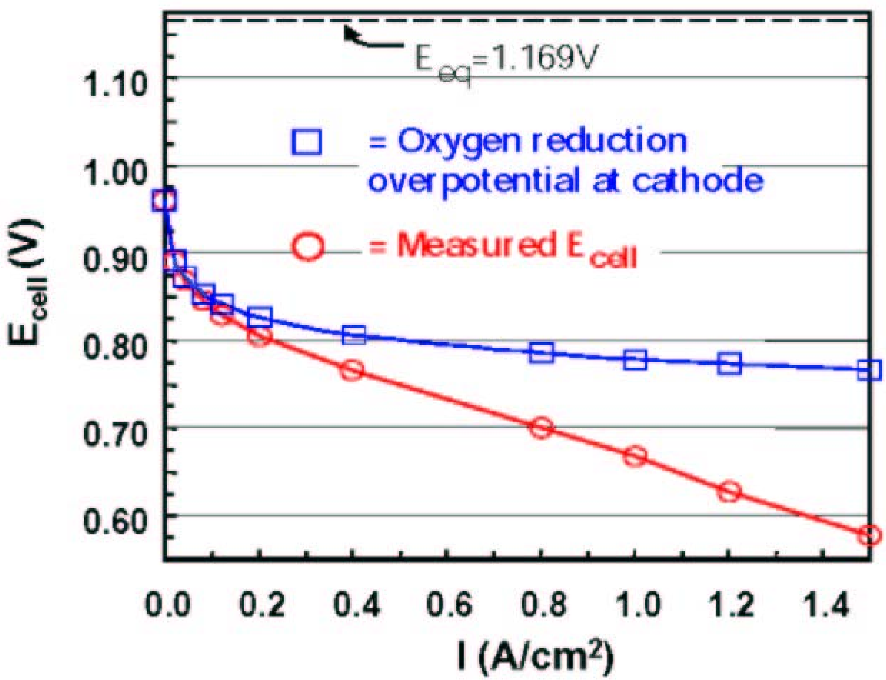
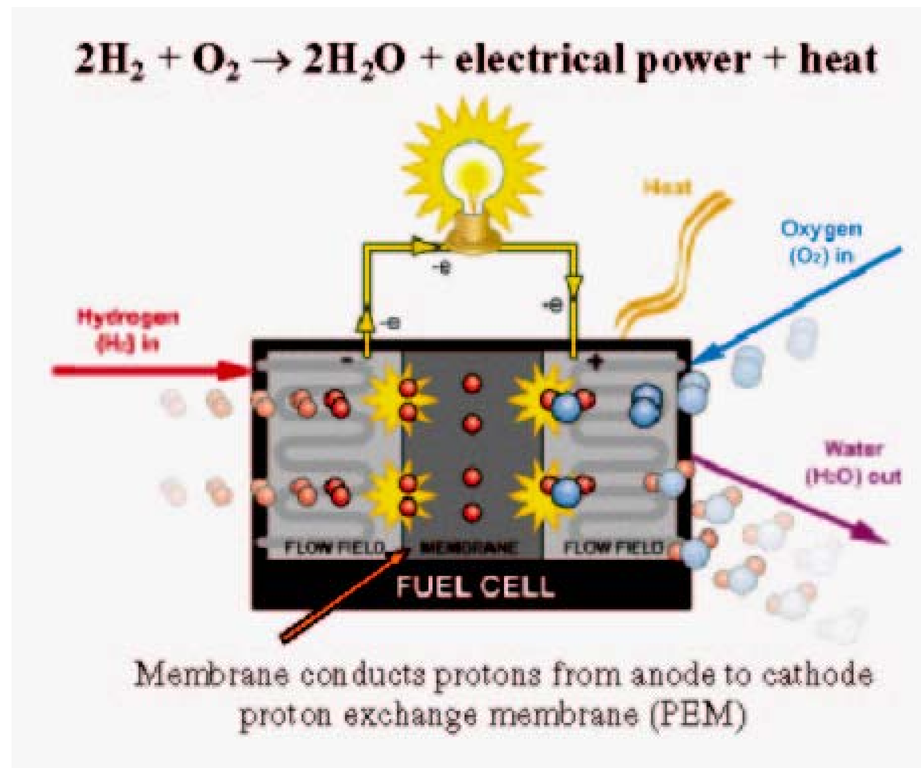


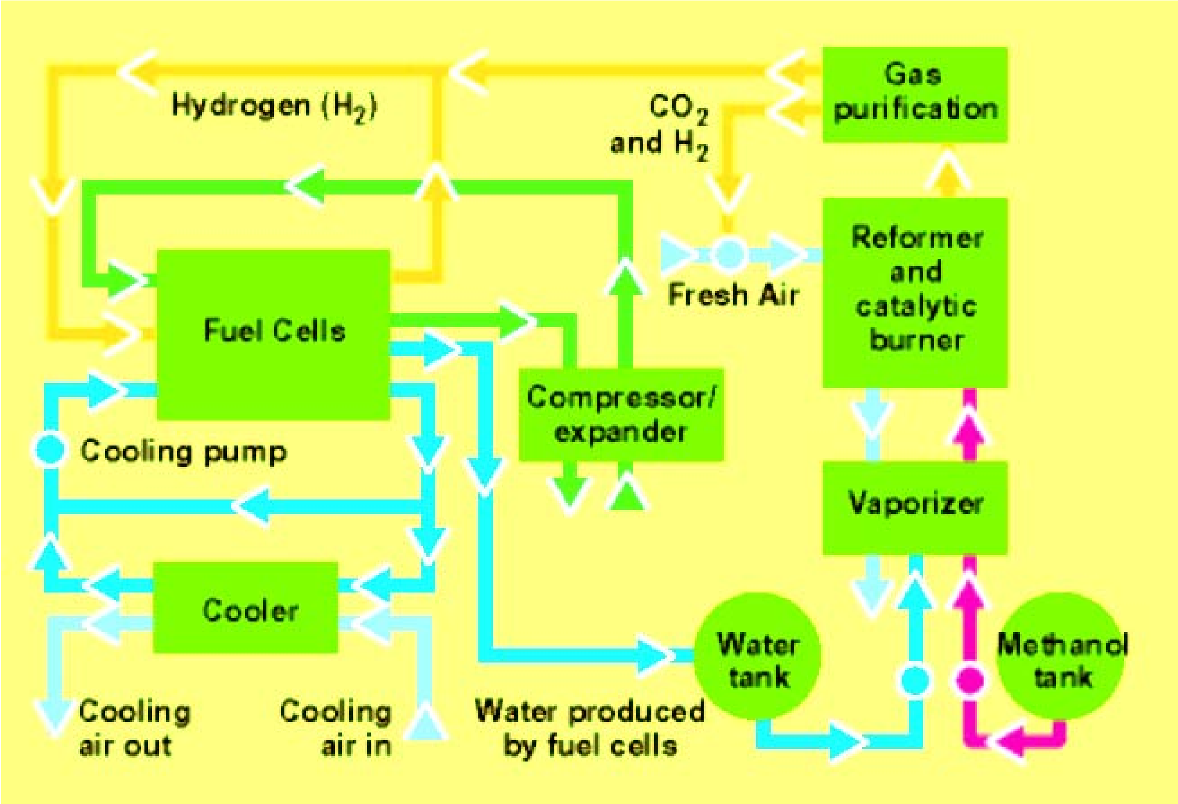
Figure 10 (Lower curve) Cell Voltage (E_{cell}) of a State-of-the-art H_2/Air Membrane Electrode Assembly Operated at 80°C versus the Current Drawn from the Cell (in amp/cm^2) (Gasteiger and Mathias 2002) (The equilibrium [theoretical] cell voltage [1.169 V] is shown by the dashed line at the top of the figure.) (Upper curve) Reduction from the Theoretical Value Caused by the Oxygen Reduction Overpotential at the Cathode Alone (Note that the overpotential is large at all but the very lowest currents. The remaining loss in potential at a given current is caused by internal resistance in the cell and to O_2 gas transport limitations through the air in the porous cathode composite.)



Basic Energy Needs for the Hydrogen Economy, May 2003, DOE

How to Fuel the Fuel Cell Engine?

Especially for mobile applications, fuel cells may work with a reformer (although direct methanol cells are also under development) ……



HYDROGEN & THE HYDROGEN ECONOMY

- *Energy carrier*: must be produced, stored, transported & charged.

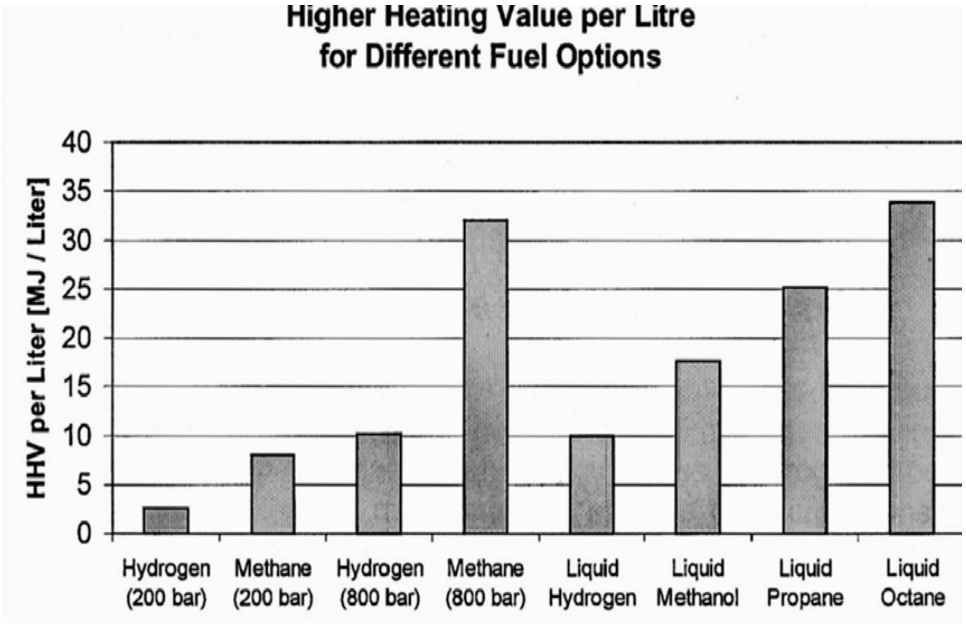
- Like electricity: expensive to produce, transport, not easy to store.
- Provides a good link with renewables or "non-exhaustables."

- Can be produced by:
  - Oxygen or steam Reforming of hydrocarbon, or,
  - Splitting water electrolytically or thermo-chemically.

- Compression/liquefaction (20 K, 1 bar/293 K, 800 bar) energies are high.
- Has low volumetric energy density (even in liquid form)

- Storage: metal fiber tanks, cryogenic container, or in metal hydrides (solids): through physical or chemical sorption.

The Mobile Storage Problem: Fuel Cell may be the easiest piece of the puzzle!



The Future of the Hydrogen Economy, Bright or Bleak"
Eliasson (\BB) and Bossel (Fuel Cell Consultant), 2003

Table 1 FreedomCAR Hydrogen Storage System Targets

Targeted Factor	2005	2010	2015
Specific energy (MJ/kg)	5.4	7.2	10.8
Hydrogen (wt%)	4.5	6.0	9.0
Energy density (MJ/L)	4.3	5.4	9.72
System cost ($/kg/system)	9	6	3
Operating temperature (°C)	-20/50	-20/50	-20/50
Cycle life-time (absorption/desorption cycles)	500	1,000	1,500
Flow rate (g/s)	3	4	5
Delivery pressure (bar)	2.5	2.5	2.5
Transient response (s)	0.5	0.5	0.5
Refueling rate (kg H_2/min)	0.5	1.5	2.0

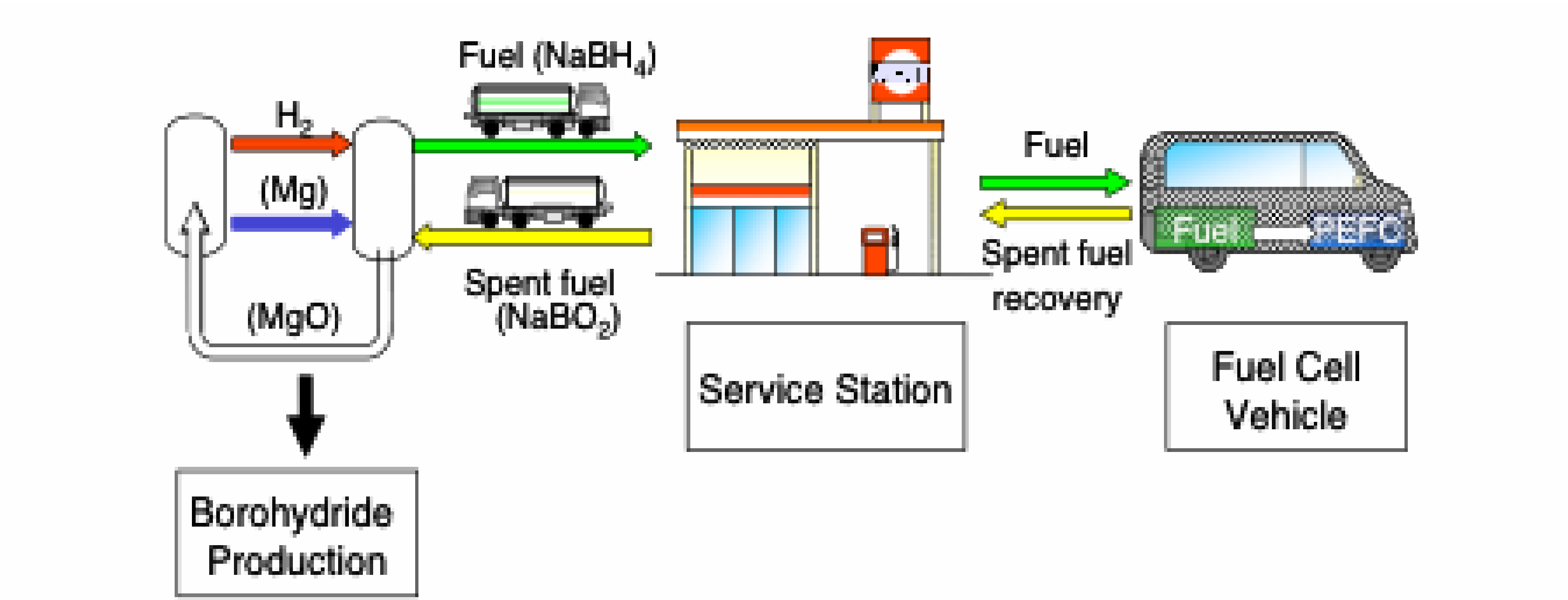
[a] Source: Milliken (2003).

GM's HyWire

Basic Energy Needs for the Hydrogen Economy, May 2003, DOE

HYDROGEN STORAGE IN THE SOLID STATE
e.g., Sodium borohyrdride Cycle

$$NaBH_4 + 2H_2O \xrightarrow{catalysis} 4H_2 + NaBO_2$$



Typical fuel: 30% NaBH4+3%NaHO+67%H2, has 6.6%H2, all by wt.
OR 66 gH2/L compared to 70 g/L liquid H2 and 23 g/L gas (at 350 bar).

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Nuclear Hydrogen Production

Thermochemical Cycle for Hydrogen Production: Sulfur-iodine process:

Non-electrolytic water splitting

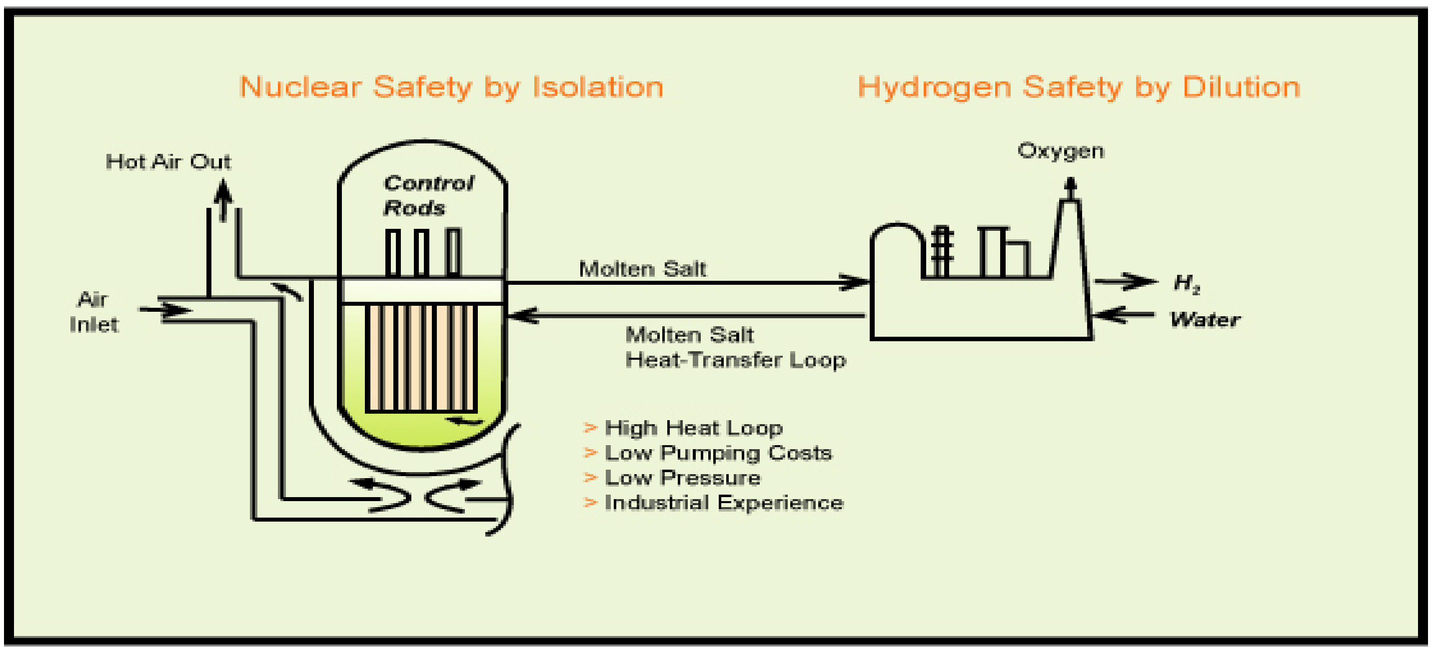
$$2\left[I_2 + SO_2 + 2H_2O \xrightarrow{-Q@120C} 2HI + H_2SO_4\right]$$

$$2H_2SO_4 \xrightarrow{+Q@800\text{-}950C} 2SO_2 + 2H_2O + O_2$$

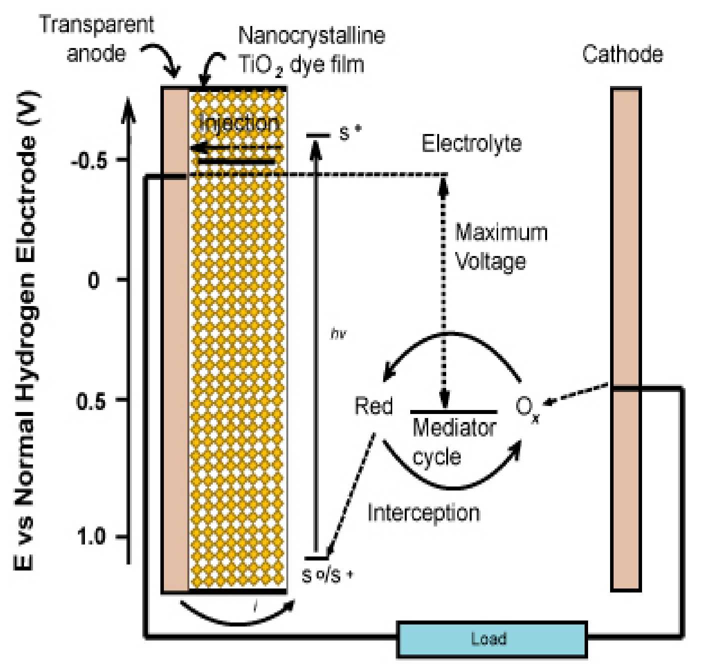
$$2\left[2HI \xrightarrow{+Q@450C} I_2 + H_2\right]$$

$$\Big\} \quad 2H_2O \xrightarrow{+Q\,@\,850\,C} 2H_2 + O_2$$

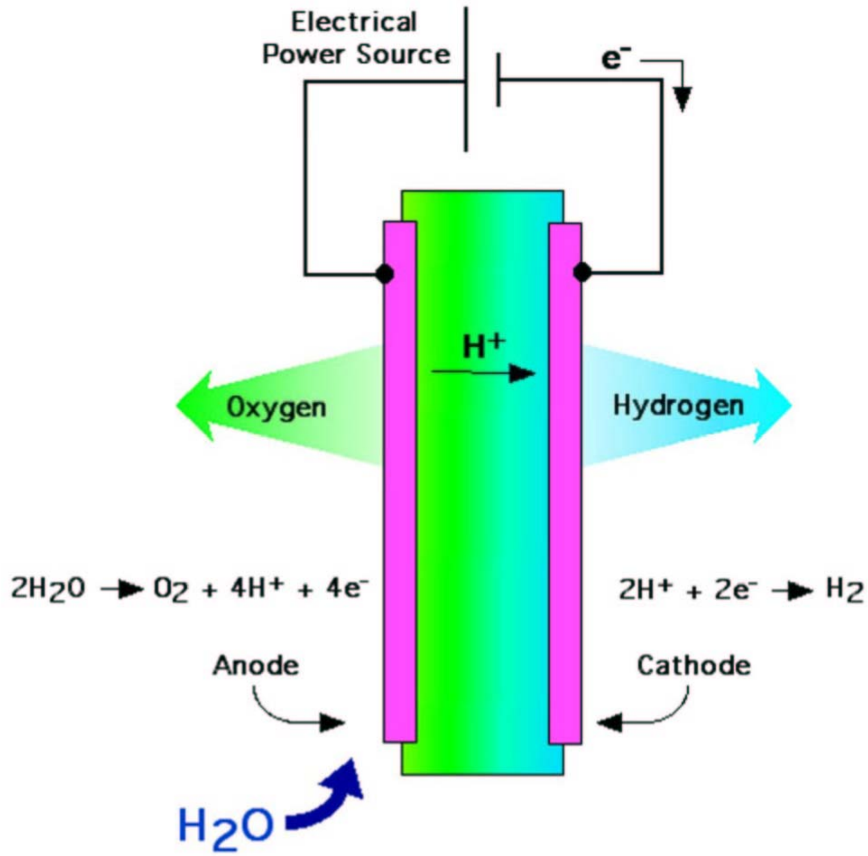
$$\eta \approx 50\%$$



Solar Hydrogen Production
Capture/conversion + Electrolysis



Dye-Sensitized Photoelectrochemical
Solar Graetzel cell



Basic Energy Needs for the Hydrogen Economy,
May 2003, DOE.

Spring 04, subject is offered as 2.996 (G) and 2.994 (U)

FUNDAMENTALS OF ADVANCED ENERGY CONVERSION
(2.60j, 2.62j,10.392j, 22.40j)
Perquisite: 2.006 or permission of instructor
G (Spring)
4-0-8 H-LEVEL Grad Credit,

A.F. Ghoniem (IC), M. Kazimi, Y. Shao-Horn, J. Tester.

Fundamentals of thermodynamics, chemistry, transport processes in energy systems. Analysis of energy conversion in thermo-mechanical, thermo-chemical, electrochemical, and photoelectric processes in existing and future power and transportation systems, with emphasis on efficiency, environmental impact and performance. Systems utilizing fossil fuels, hydrogen, nuclear and renewable resources, over a range of sizes and scales are discussed. Applications include fuel reforming, hydrogen and synthetic fuel production, fuel cells and batteries, combustion, catalysis, supercritical and combined cycles, photovoltaics, etc. Energy storage and transmission. Optimal source utilization and fuel-life cycle analysis.

From matter and Energy (1912) by Frederick Soddy - Noble Prize in Chemistry, 1921.

“The laws expressing the relations between energy and matter are not solely of importance in pure science. They necessarily come first..... In the whole record of human experience, <u>and they control, in the last resort, the rise or fall of political systems, the freedom or bondage of nations, the movements of commerce and industry, the origin of wealth and poverty and the physical welfare of the race</u>. If this has been imperfectly recognized in the past, there is no excuse, now that these physical laws have become incorporated into everyday habits of thought, for neglecting to consider them first in questions relating to the future”