The Energy Challenge

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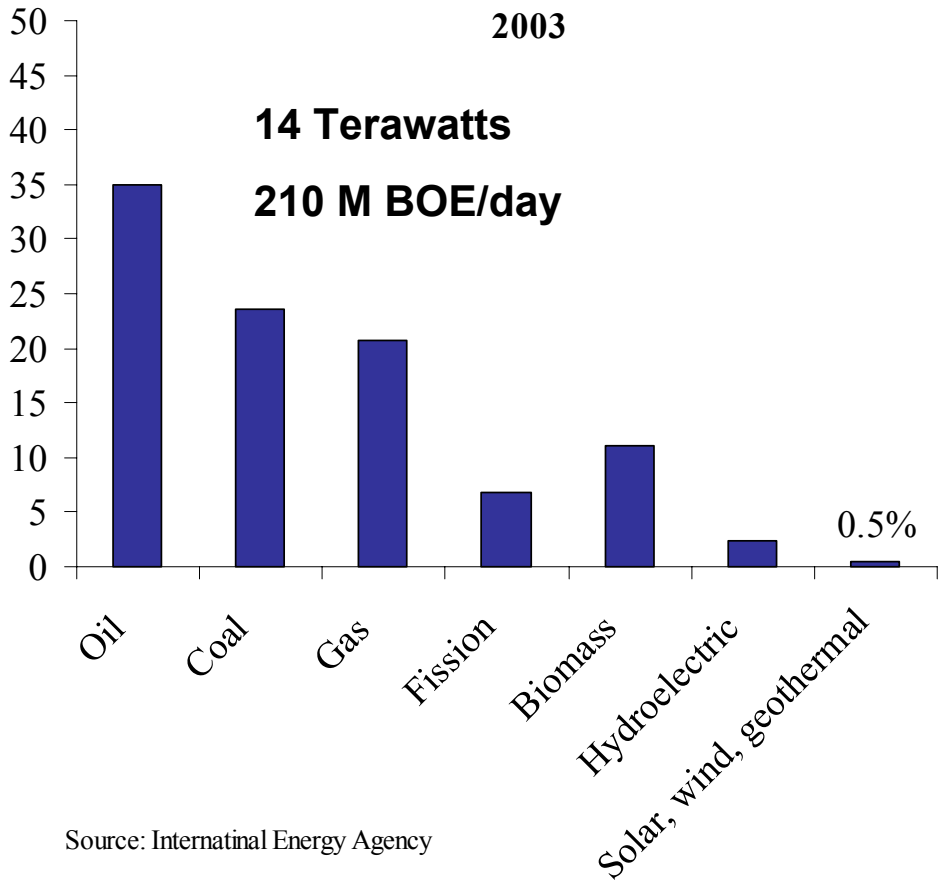
The ENERGY REVOLUTION (The Terawatt Challenge)



Source: Internatinal Energy Agency

2050
30 -- 60 Terawatts
450 – 900 MBOE/day
???

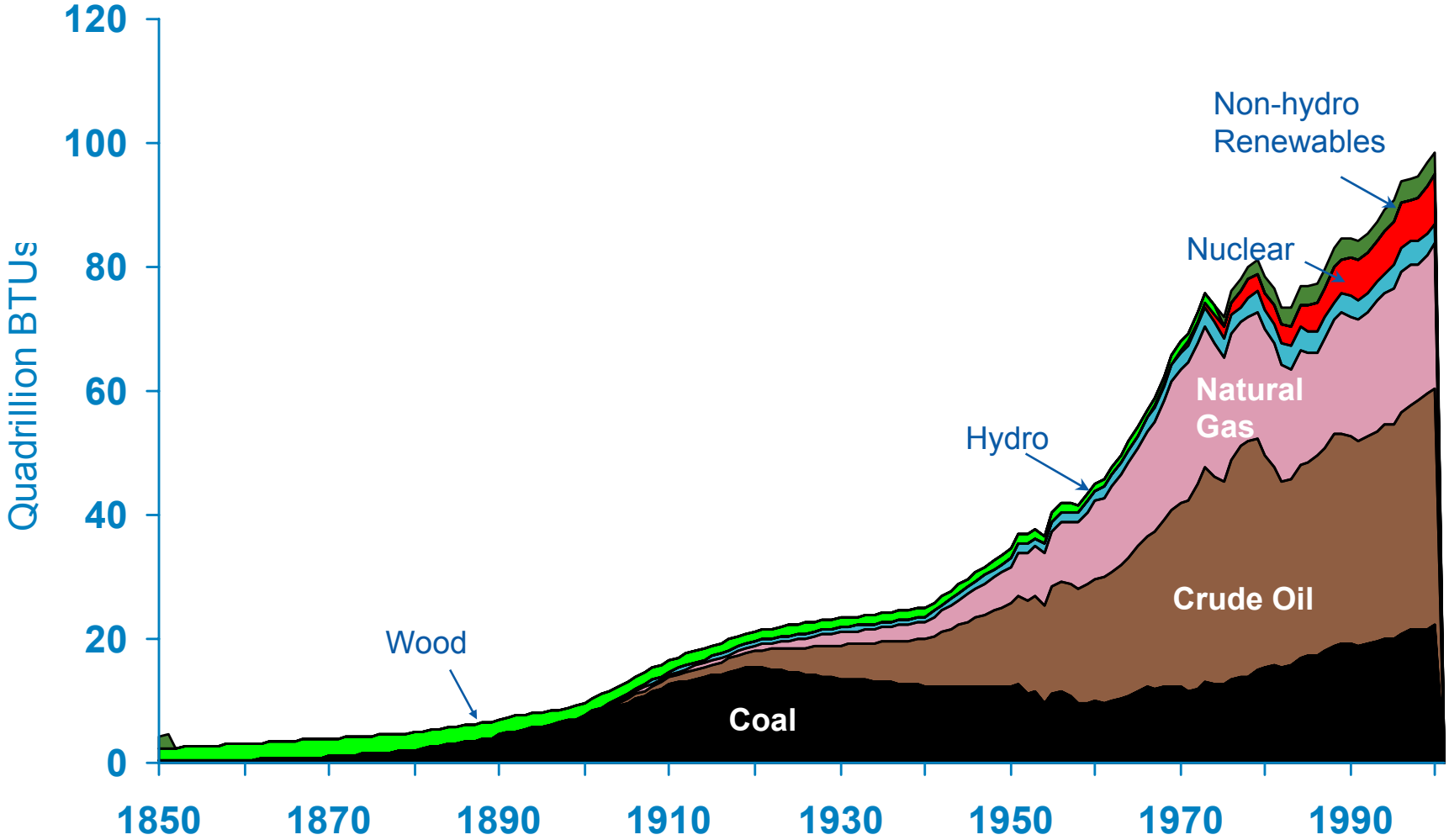
The Basis of Prosperity

20st Century = OIL
21st Century = ??

R. Smalley, 2003

U.S. Energy Consumption

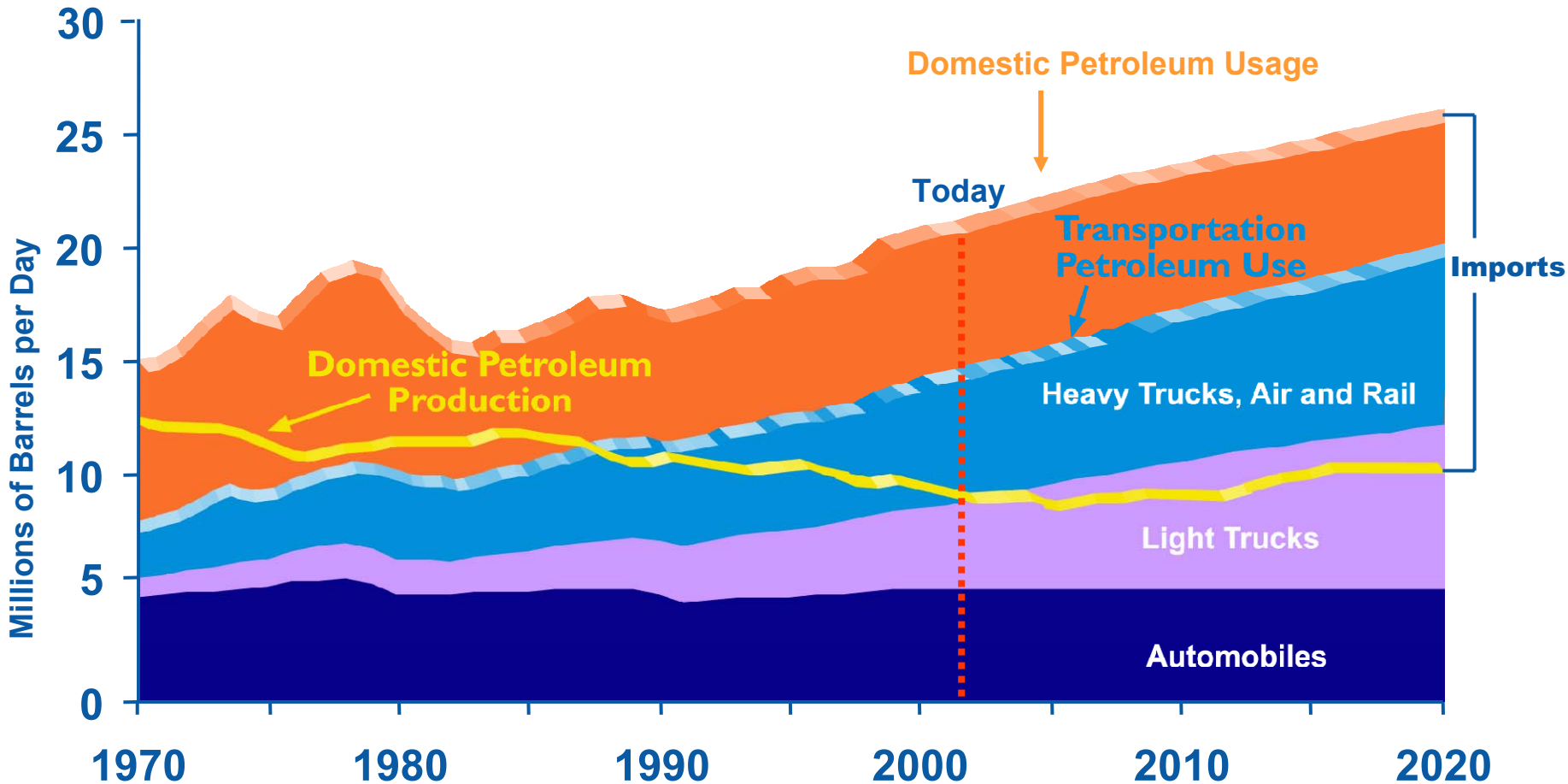
by source - 1850-2000



Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-2000, Annual Energy Review 2000, Table 1.3.

Dependence on Foreign Oil

U.S. Transportation Use of Petroleum



Actual: Annual Energy Review 2000 Tbls 1.2, 5.1 and 5.12
Forecast: Annual Energy Outlook 2002 Tbls 7 and 11
Split between Autos and Lt Truck: Transportation Energy Data Book Edition 21 Tbl 2.6
Updated October 2002

U.S. Dependence on Foreign Oil

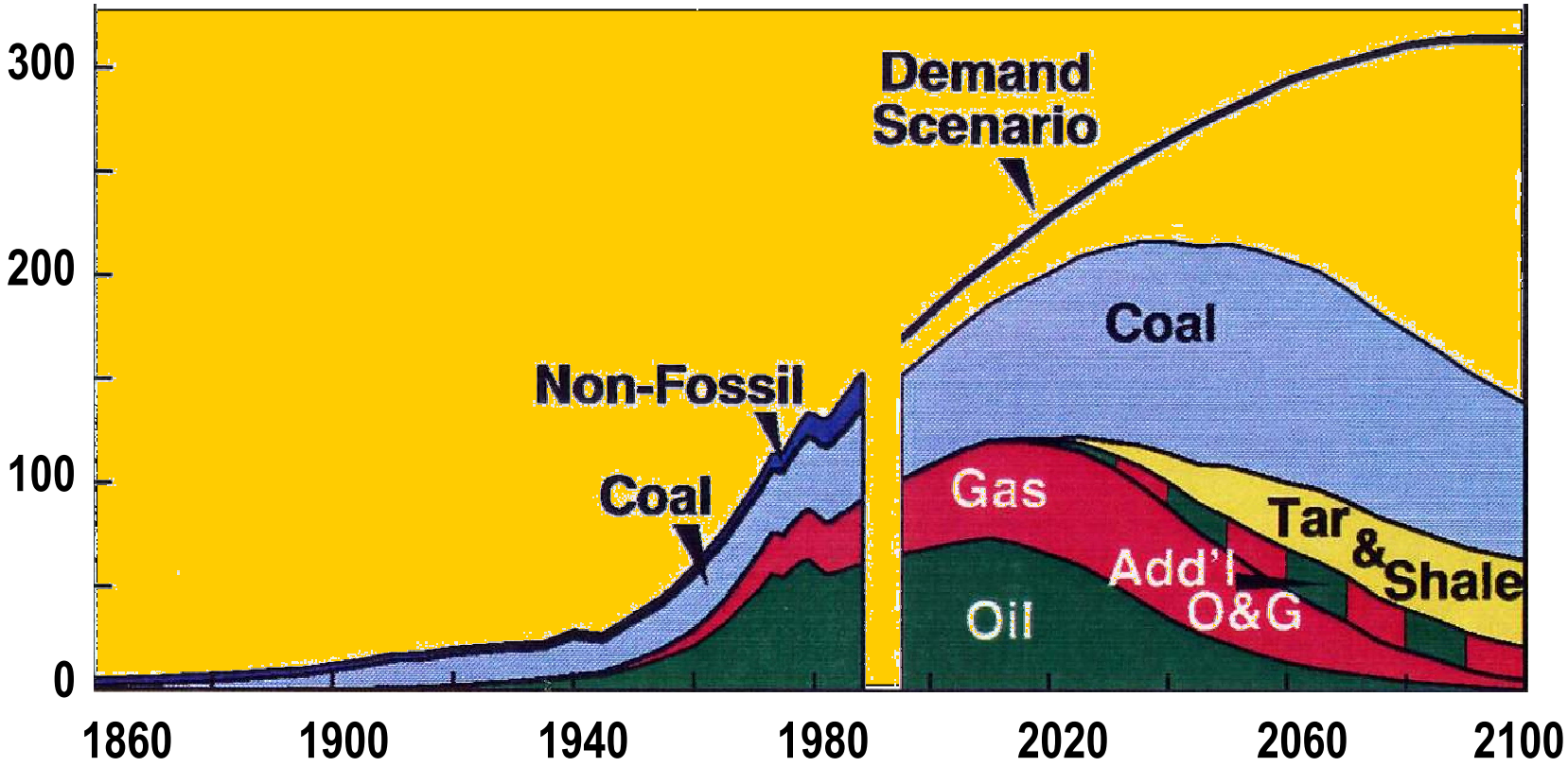
Have Oil		Use Oil	
Saudi Arabia	26%	U.S.	26%
Iraq	11%	Japan	7%
Kuwait	10%	China	6%
Iran	9%	Germany	4%
UAE	8%	Canada	4%
Venezuela	6%	Russia	3%
Russia	5%	Brazil	3%
Libya	3%	S. Korea	3%
Mexico	3%	France	3%
China	3%	India	3%
Nigeria	2%	Mexico	3%
U.S.	2%	Italy	2%

The U.S. uses more than the next 5 highest consuming nations combined.

Updated March 2003. Source: International Energy Annual 2001 (EIA), Tables 11.4 and 11.10.

World Energy

Millions of Barrels per Day (Oil Equivalent)



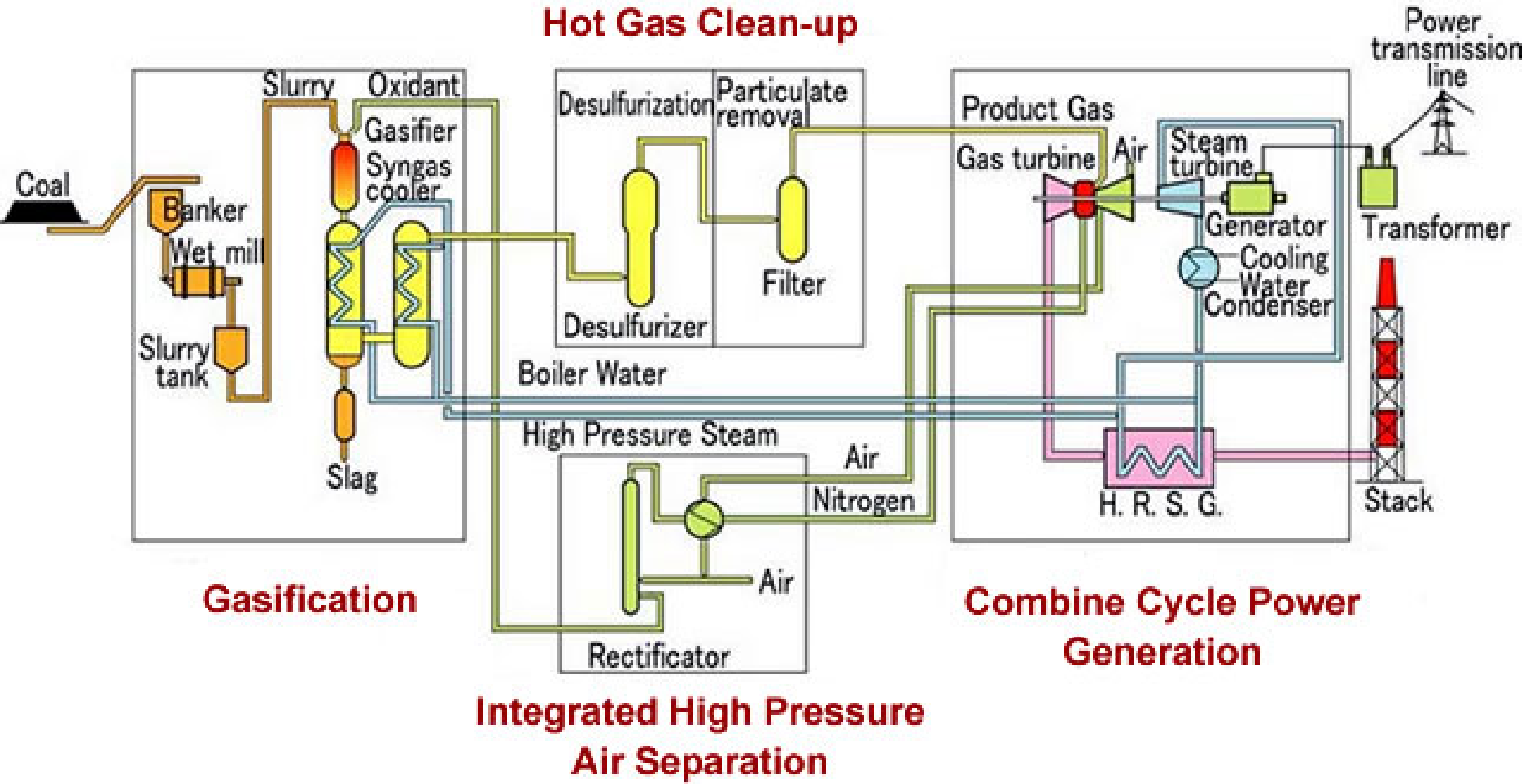
Source: John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC; July 10,1985. Episodes, vol 12, 257-262 (1989).

Fossil Fuel Reserves

	Recoverable Reserves, GTC	Reserve Life @Current Rate, Yr	Reserve Life @Projected GDP Growth, Yr
Oil	120	35	25
Natural Gas	75	60	45
Coal	925	400	100
Tar Sands Oil Shale	?	Recovery challenges (heat to 100-150ºC, etc.)	

J. Siirola, 2005

IGCC Units
Integrated gasification combined cycle



www.coal21.com.a/IGCC.php

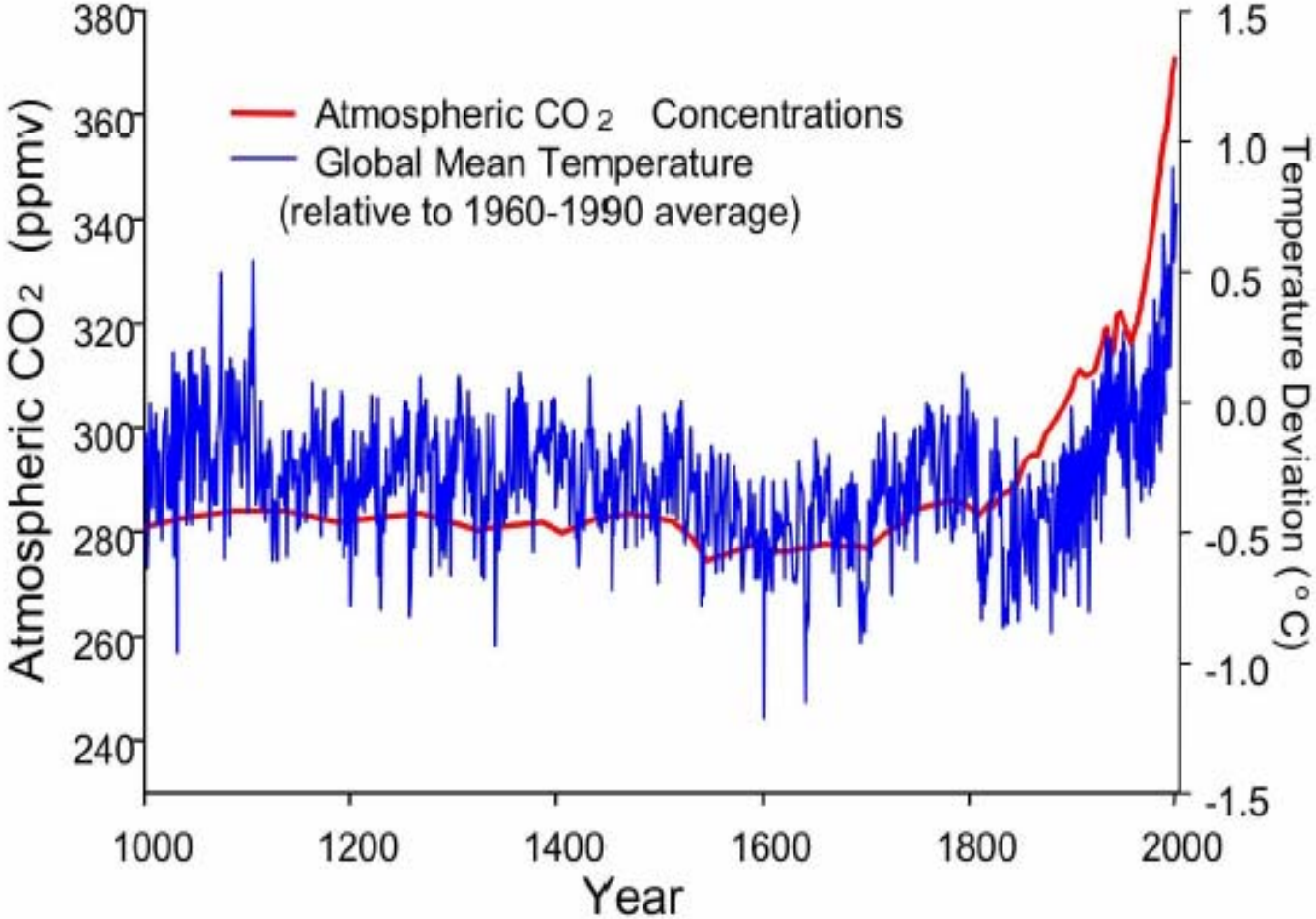
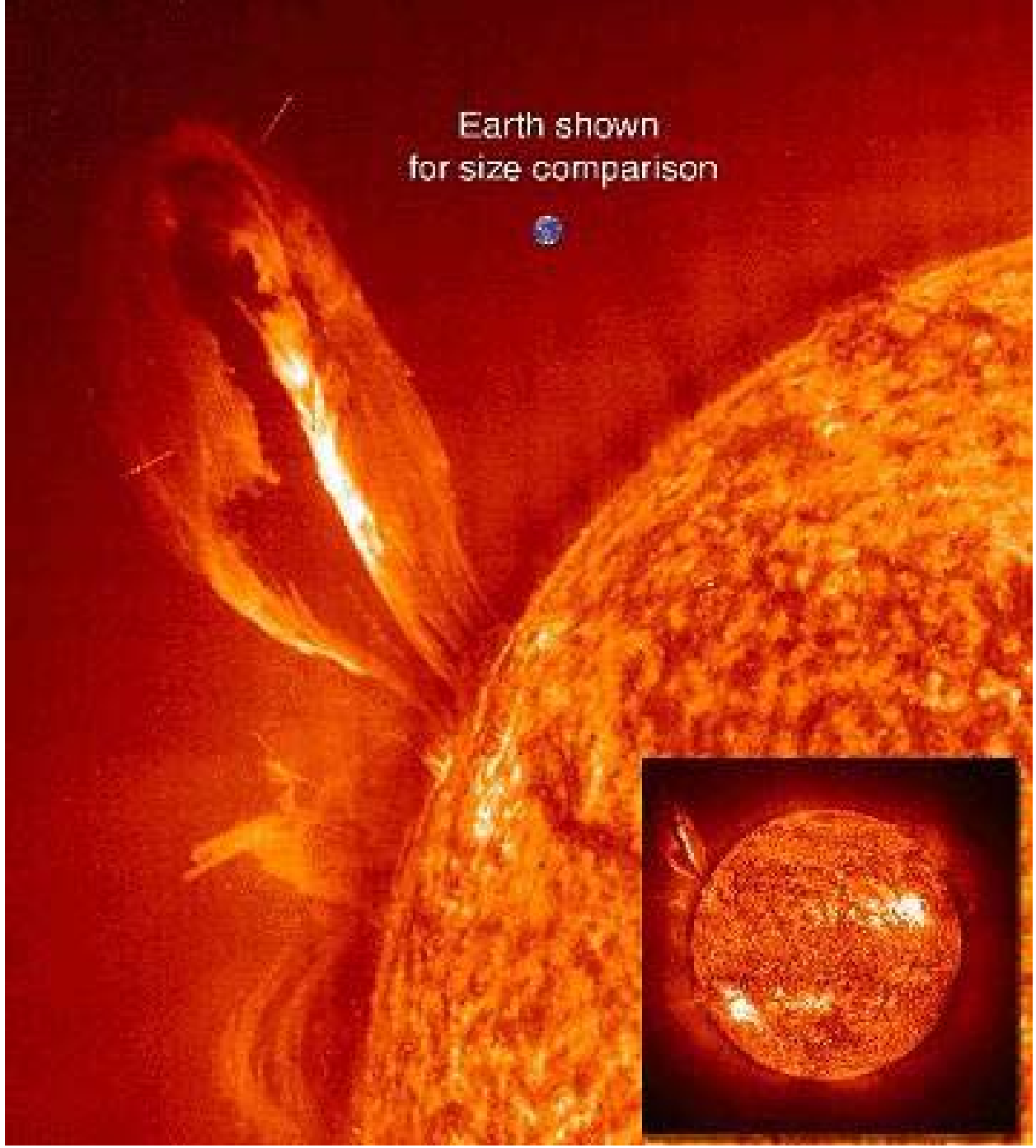


Figure 1b Increased CO_2 Emissions Causing a Rise in Atmospheric CO_2 Associated with a Rise in Global Temperature (Sources: CO_2 data from Ethridge et al. 2001, Keeling and Whorf 2002; temperature data from Jones et al. 1998, Peterson and Vose 1997)

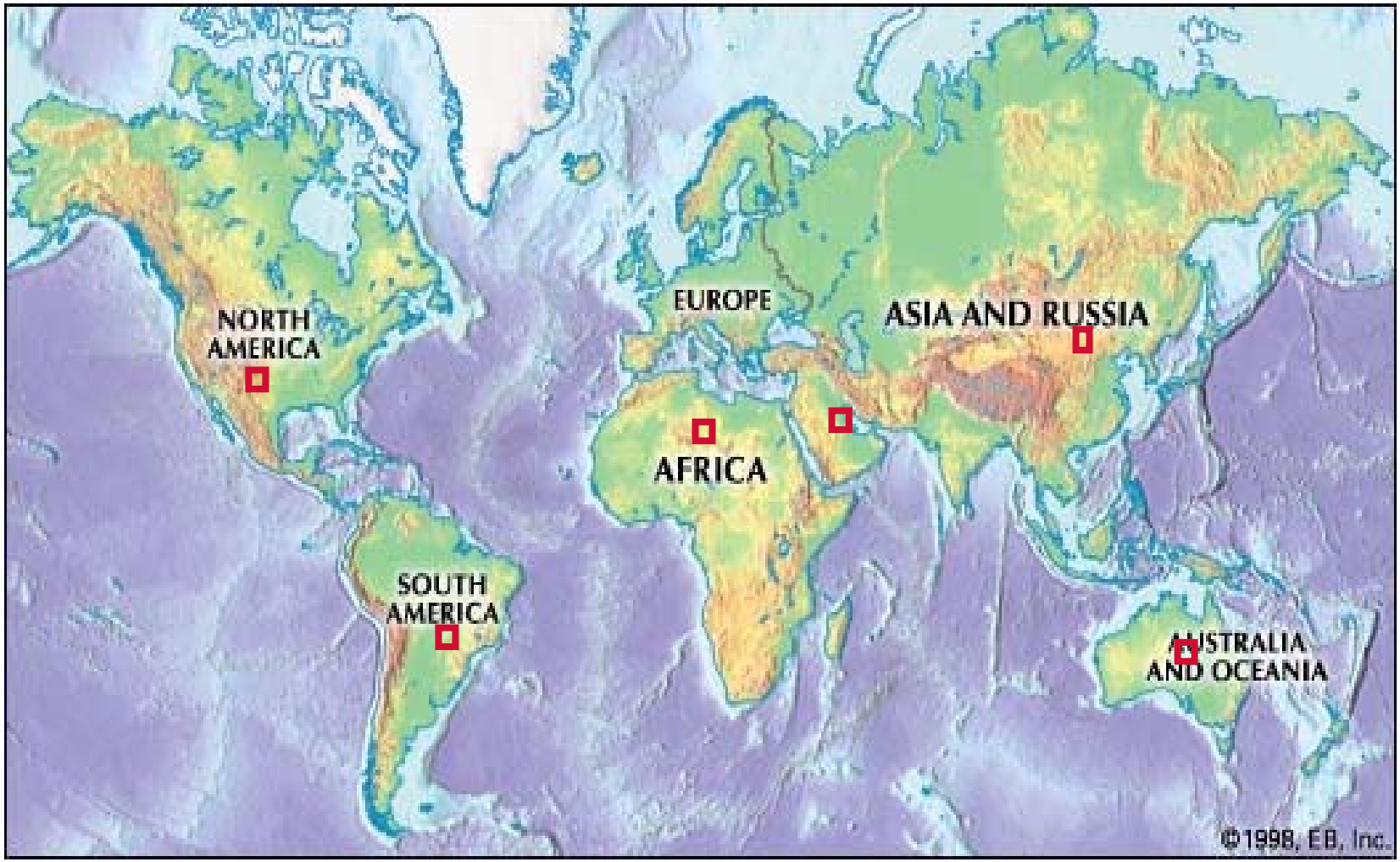
Renewables

- Conservation/efficiency
  - Not enough; already built in to projections
- Wind, Geothermal, Hydrothermal, Tides
  - Not enough
  - Wind fastest growing renewable
- Biomass
  - Not enough
- Nuclear
  - No CO_2
  - Waste storage challenge
  - Resurgence due to changing demographics
- Solar

165,000 TW of sunlight hit the earth every day

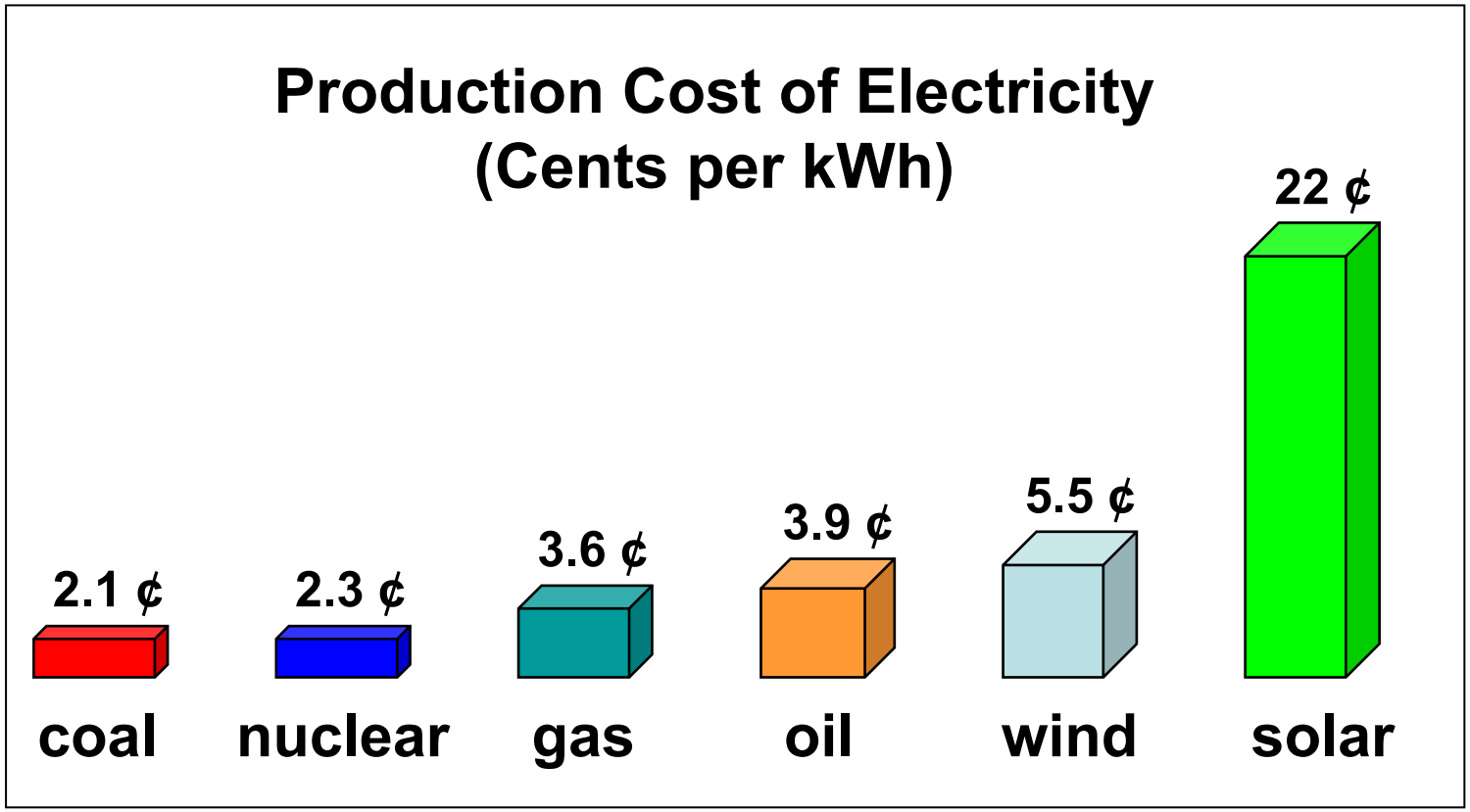


Solar Cell Land Area Requirements



6 Boxes at 3.3 TW Each = 20 TWe

Solar Power Too Expensive



Source: N. Lewis

Solar Energy Needs

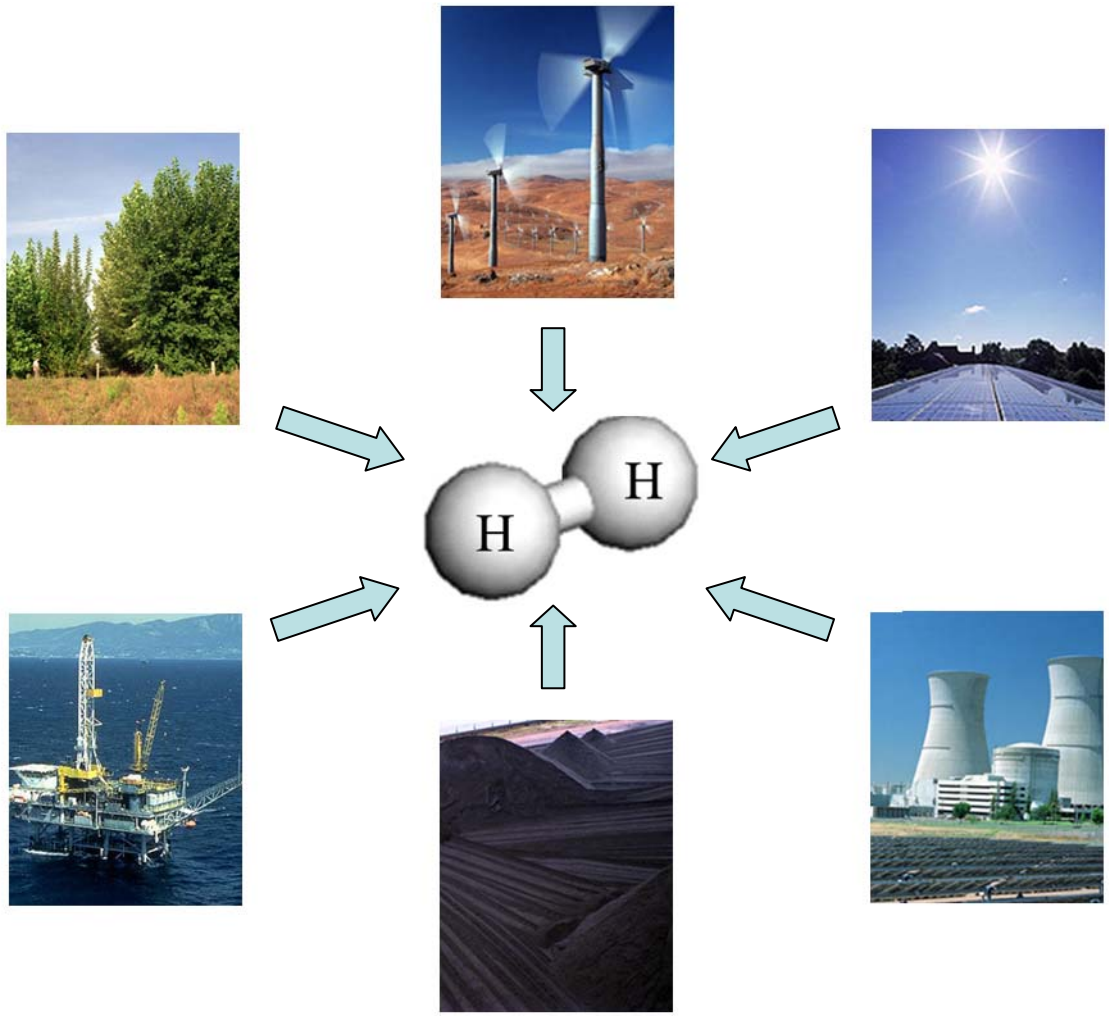
- Improve efficiency
- Drop cost/watt by 20-50x
- Direct splitting of water

DOE BES Solar Workshop report

Question – What secondary energy carrier?

- Electricity
- Hydrogen
- Something else?

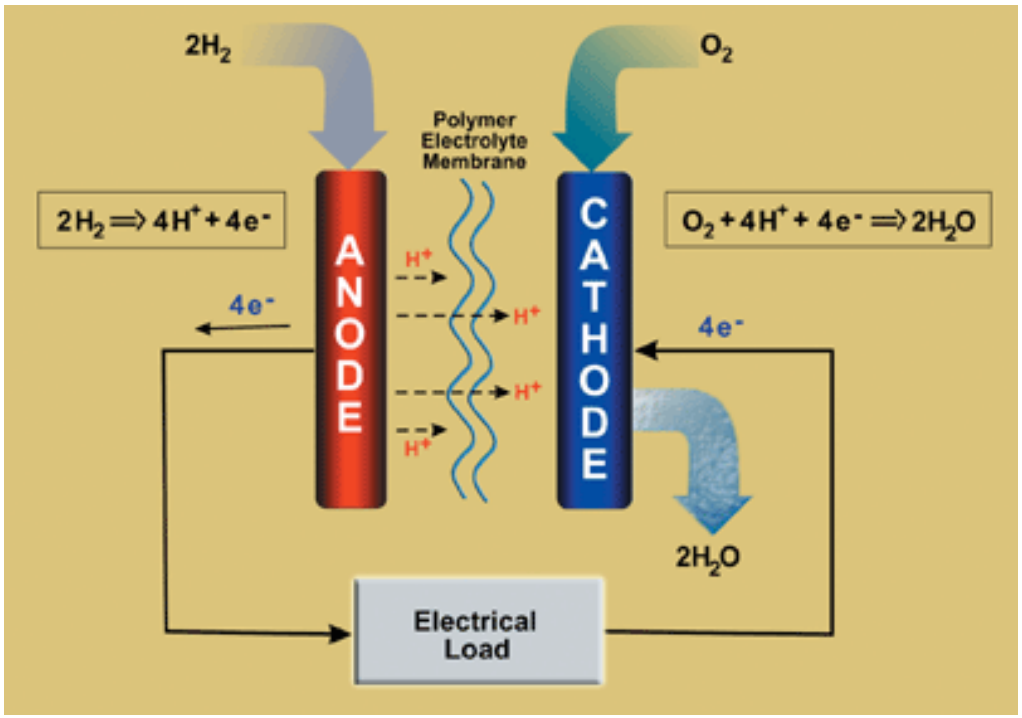
Hydrogen



Agrawal, 2005

The Promise of Hydrogen

Fuel Cell



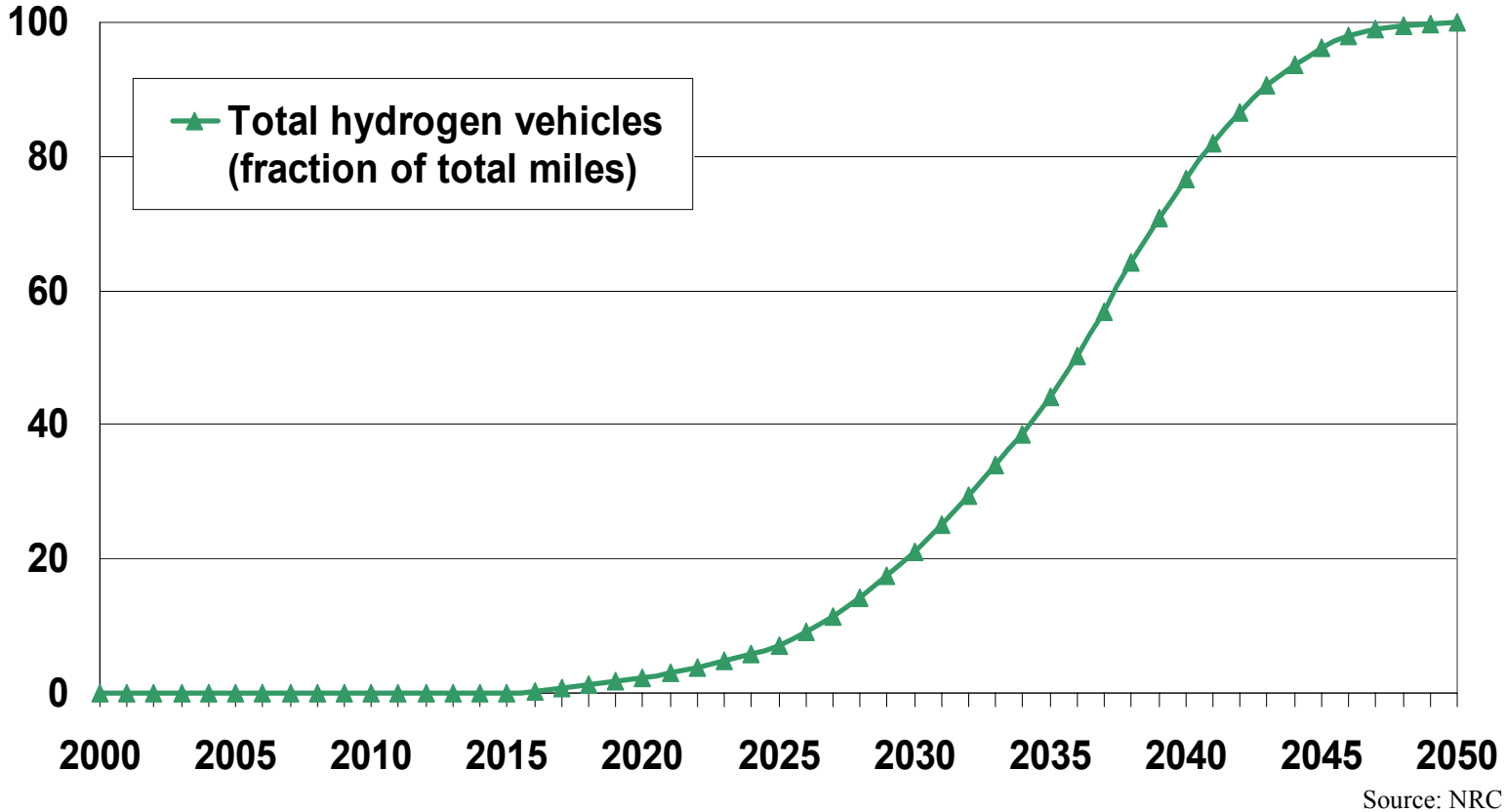
Source: EPA

Clean and efficient conversion to power

No pollutants – only water as byproduct

Agrawal, 2005

Penetration Curves for Fuel Cell Vehicles (USA); Optimistic Case



Complete replacement of ICE vehicles with fuel cell vehicles in 2050

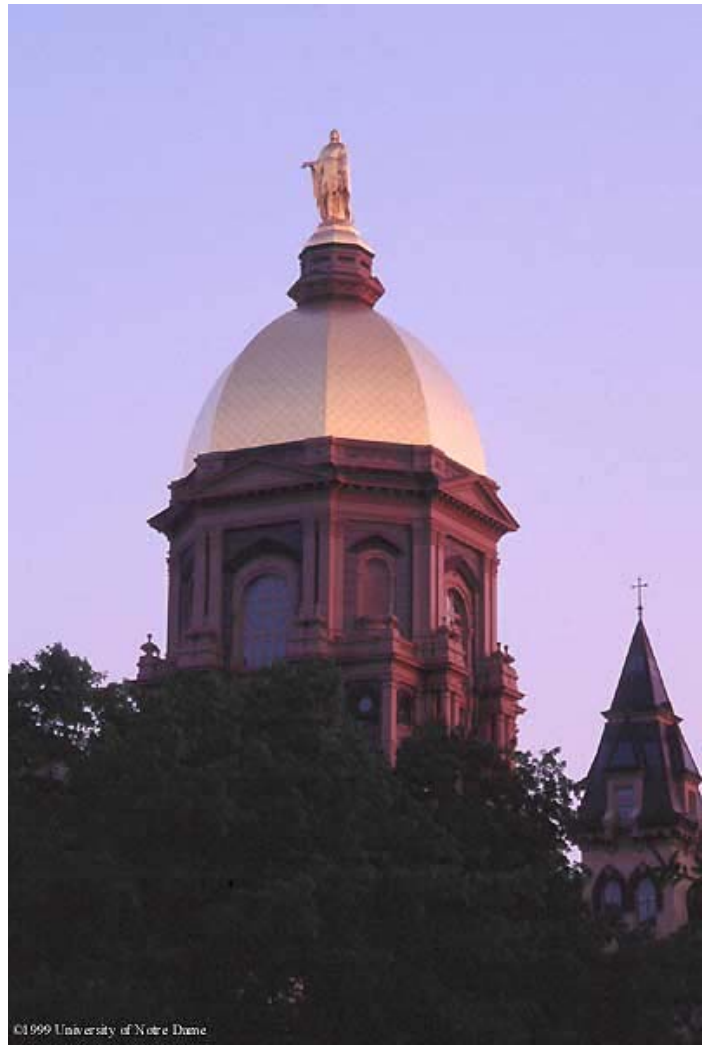
NRC Committee on Alternatives and Strategies for Future Hydrogen Production and Use

Challenges for the Hydrogen Economy

- Can produce H_2 from natural gas, coal and nuclear at price comparable to gasoline
  - Solar will require “breakthrough” technology
  - Biomass would require all US crop and grazing land
- Need fuel cell improvements
  - Drop cost from $2000/kw to $100/kw
  - Increase lifetime from 1000 hr to 5000 hr
  - Expand operating temperature range
- Solution to onboard H_2 storage
- H_2 distribution infrastructure challenges

Summary

- Energy is one of the grand challenges of our time
- Clean coal utilization is absolutely necessary for the next few decades
- Alternative energy sources (SOLAR) must be developed; must start NOW
- H_2 economy will not happen anytime “soon”
- Need scientific and engineering breakthroughs to get from here to there
- Need YOU

Acknowledgments

- Richard Smalley, Rice Univ.
- Jeff Siirola, Eastman Chemical
- Stanley Bull, NREL
- Rakesh Agrawal, Purdue Univ.