

# NANOTECHNOLOGY, the S&T Workforce, ENERGY & Prosperity



PCAST  
03/03/03

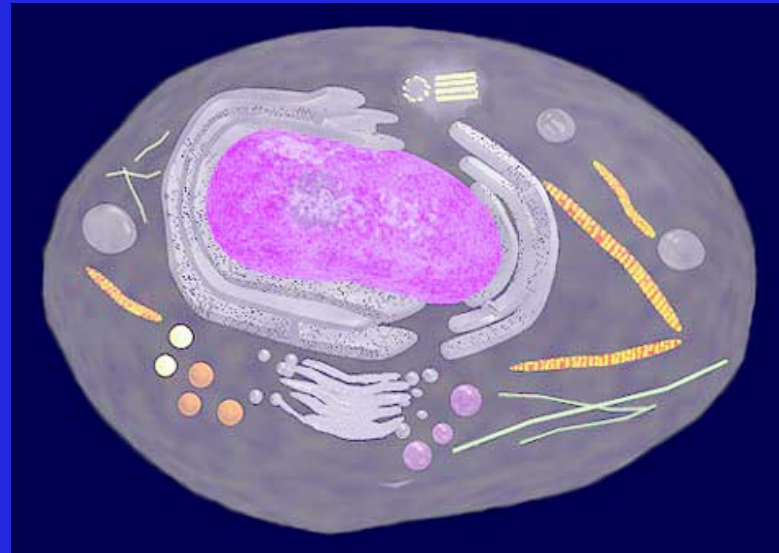
R. E. Smalley  
Rice University

# Nanotechnology

- The art and science of building stuff that does stuff at the nanometer scale
- The ultimate nanotechnology builds at the ultimate level of finesse one atom at a time, and does it with molecular perfection
- It holds the answer, to the extent there are answers, to most of our most pressing material needs.

# The Wet Side of Nanotechnology

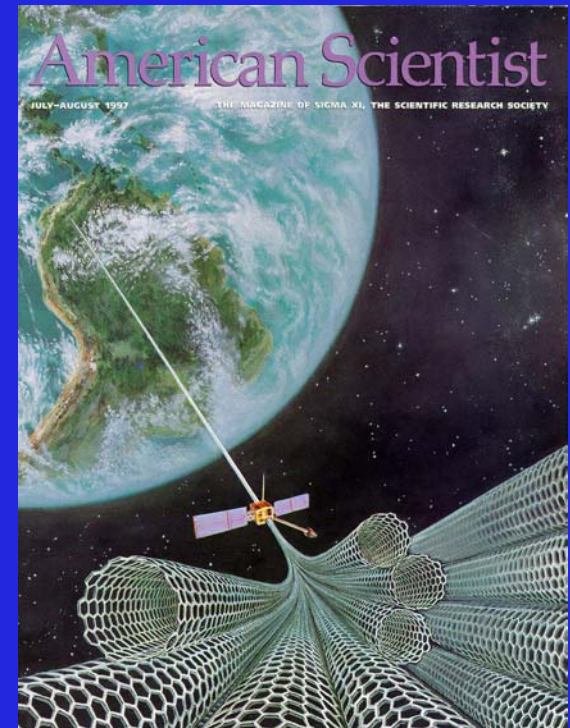
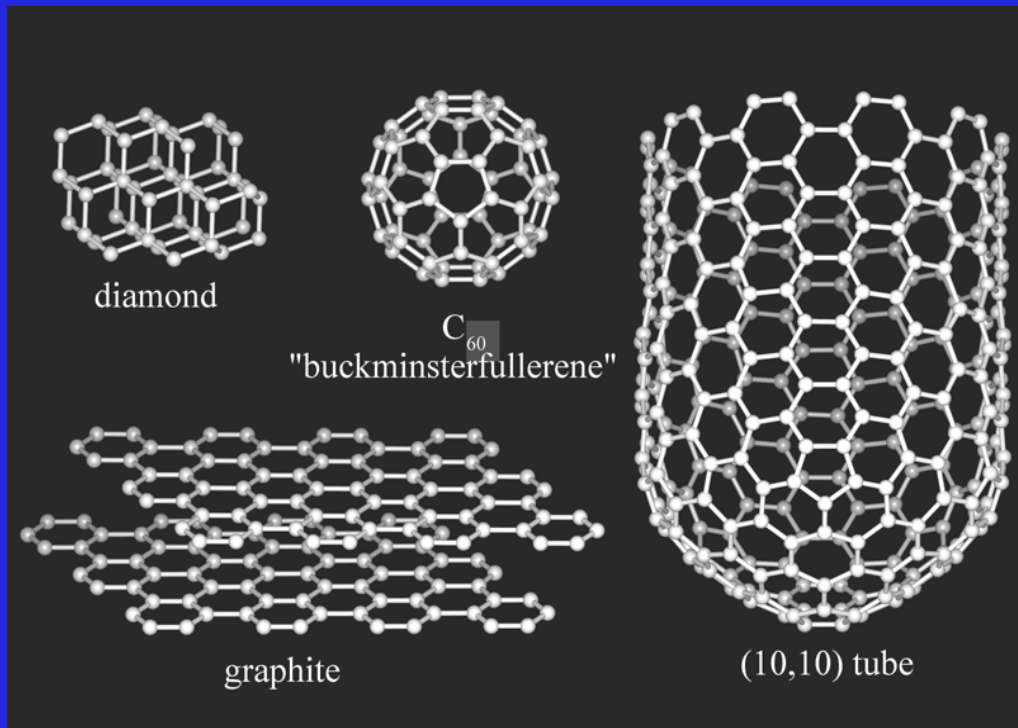
- All the nano-machinery of cellular life (and viruses)



- Biotechnology is a form of Nanotechnology (the wet side)

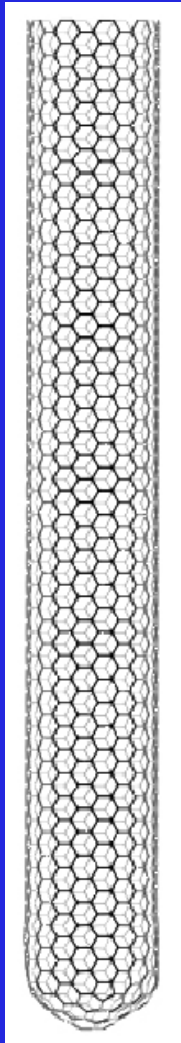
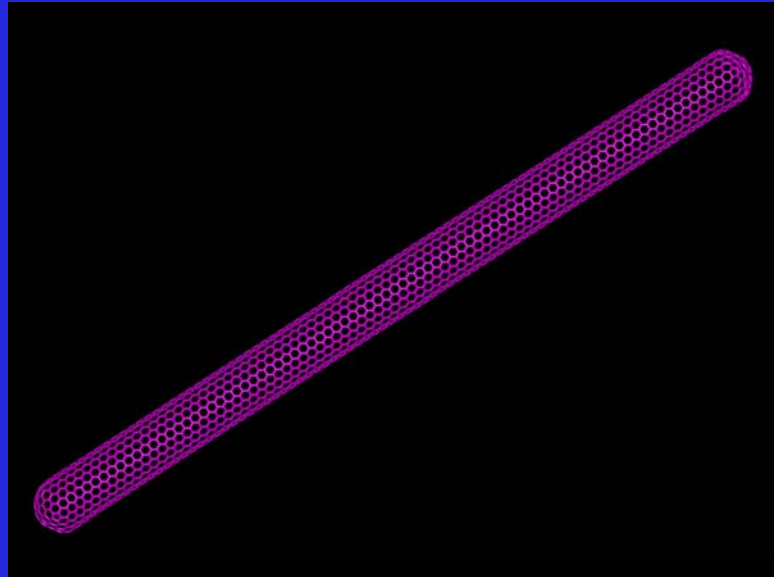
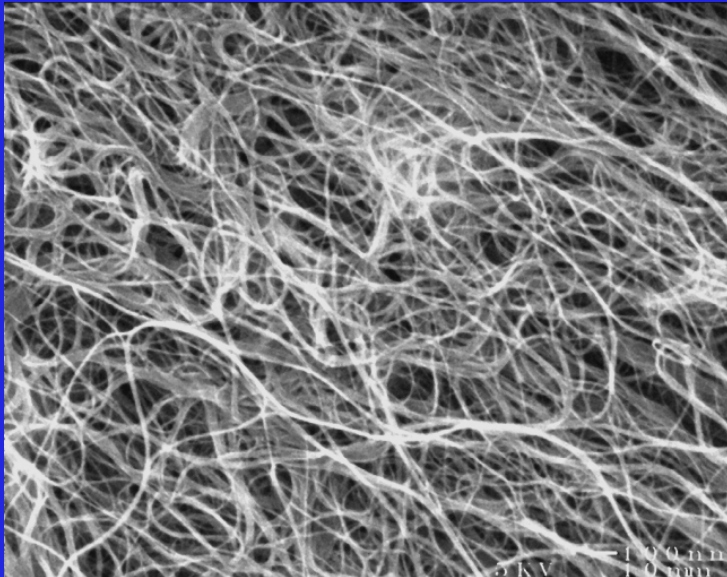
# The Dry Side of Nanotechnology

- Electrical & thermal conduction
- Great strength, toughness, high temperature resistance, etc



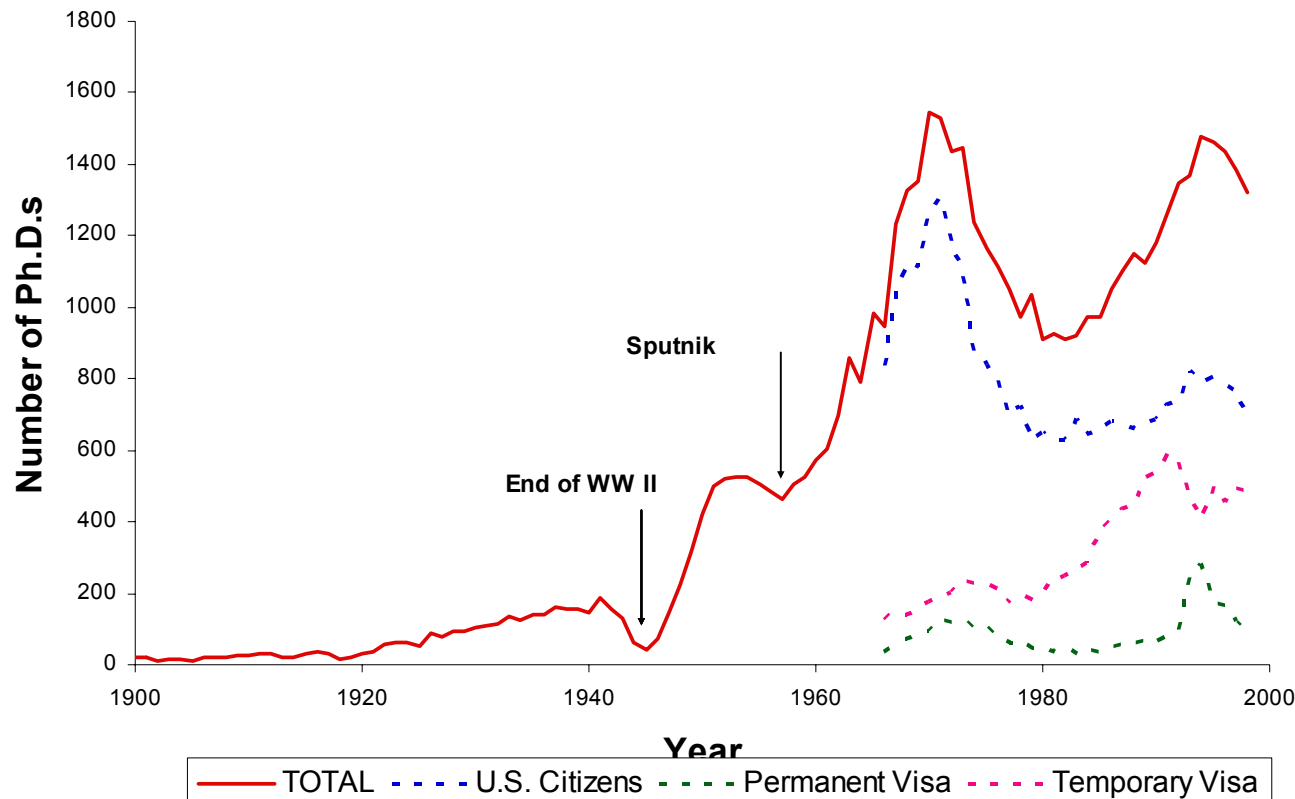
# MOLECULAR PERFECTION: The FULLERENE IDEAL

- The Strongest fiber that will ever be made.
- Electrical Conductivity of Copper or Silicon.
- Thermal Conductivity of Diamond.
- The Chemistry of Carbon.
- The size and perfection of DNA.

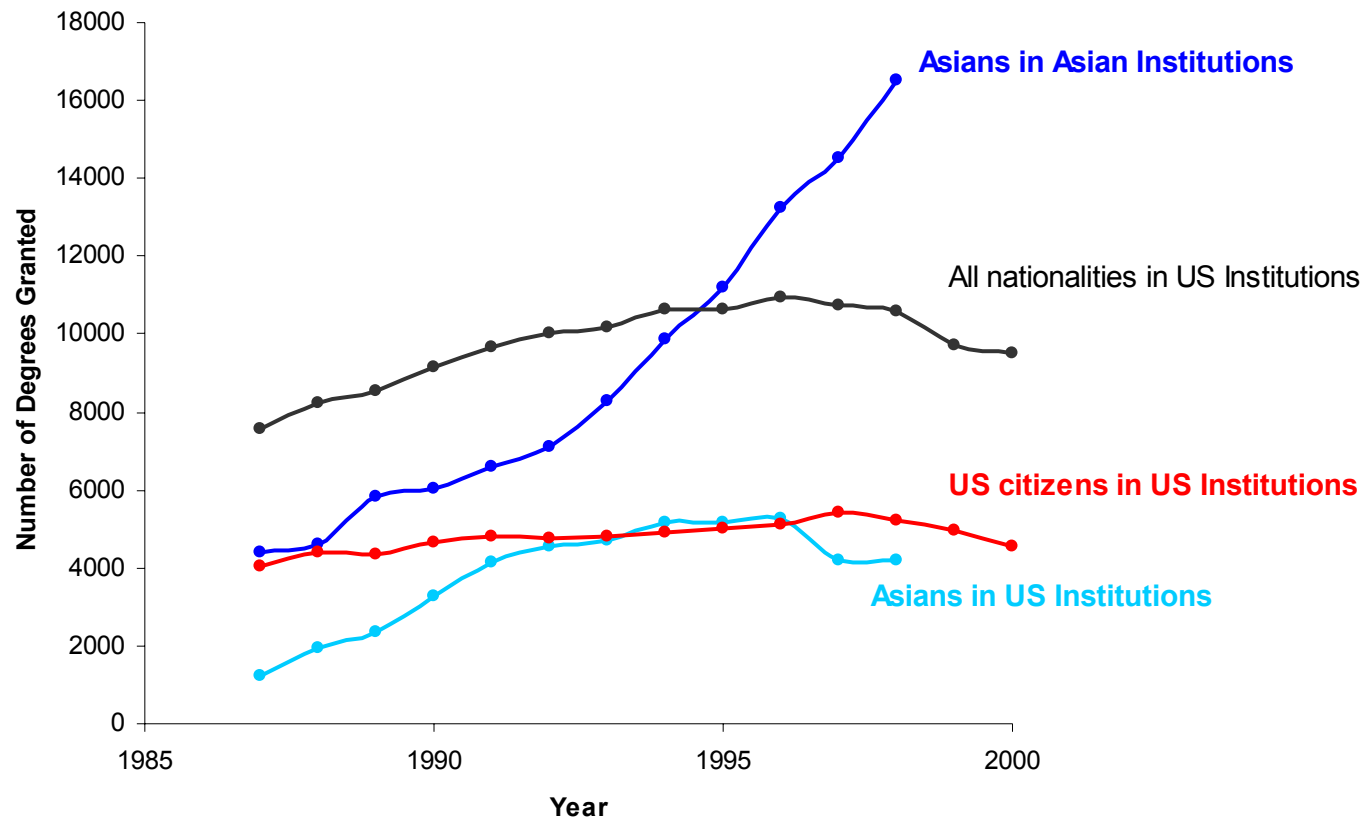


# The S&T Workforce Problem

Number of Physics Ph.D. Degrees Awarded in the U.S.



## Physical Science & Engineering PhD Degrees



Source: Science and Engineering Doctorate Awards, 1996 and 2000, NSF; Science and Engineering Indicators, NSB, 2002

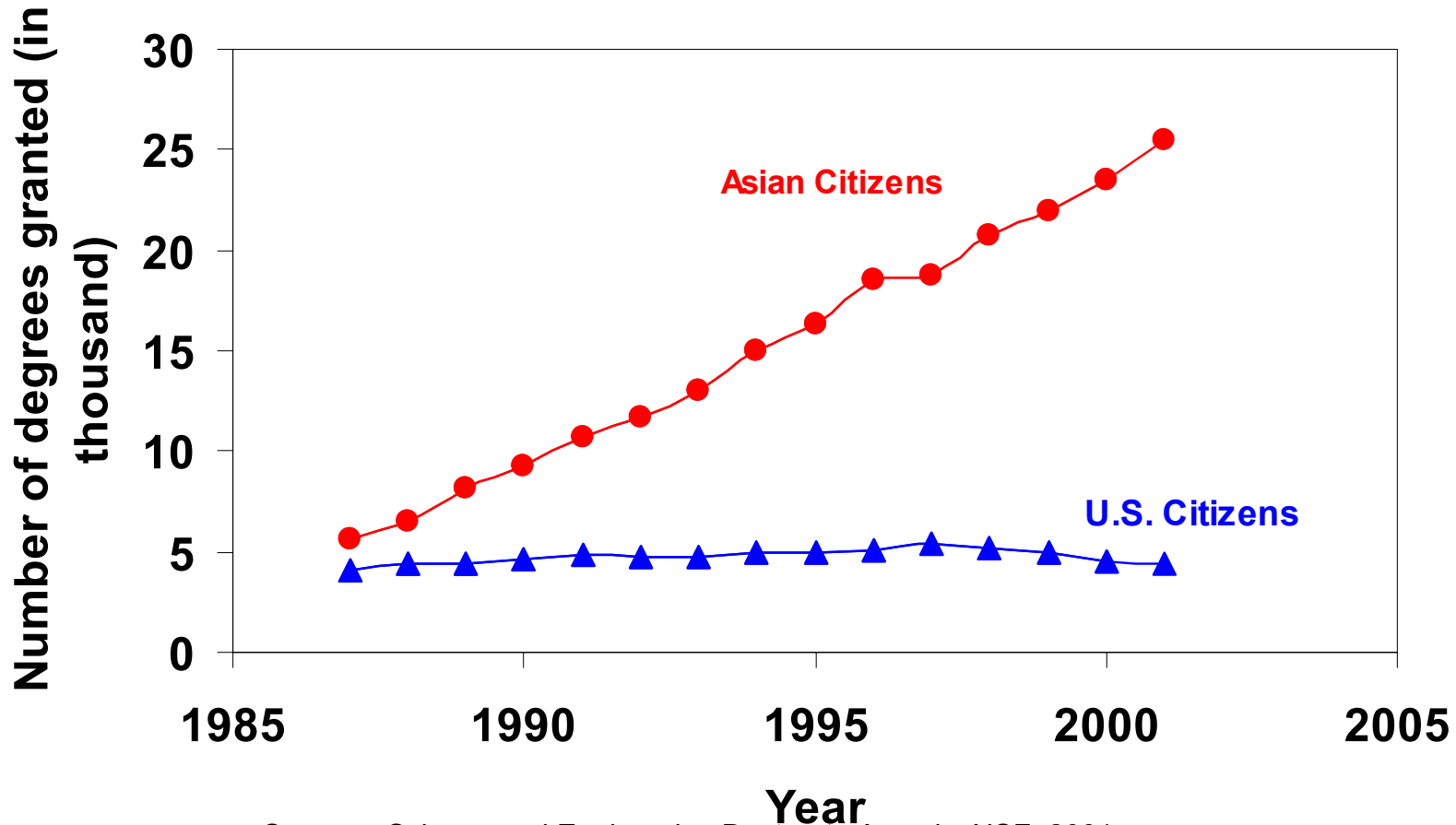
Sciences = Physics, chemistry, astronomy, earth, atmospheric, and ocean sciences

Engineering = Aeronautical, astronautical, chemical, civil, electrical, industrial, material, metallurgical, and mechanical.

By 2010, if current trends continue,  
over 90% of all physical scientists and engineers in the world  
will be Asians working in Asia.



# Ph.D. Degrees in Physical Science and Engineering



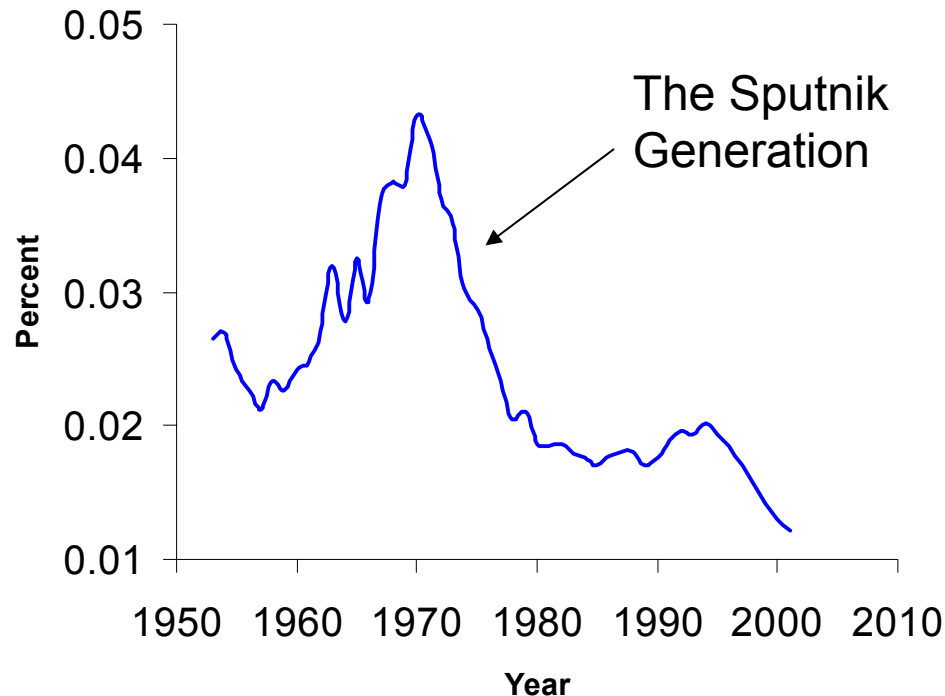
Sources: Science and Engineering Doctorate Awards, NSF, 2001.  
Science and Engineering Indicators, NSB, 2002.

Sciences = Physics, chemistry, astronomy, earth, atmospheric, and ocean sciences

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### Ph.D. Degrees in Physics as a Percentage of GDP



GDP is expressed in constant 1996 dollars (in million)  
Source: American Institute of Physics & National Science Board,  
Science and Engineering Indicators, 2002.

We Need a New  
Sputnik Event to  
inspire US citizens into  
the Physical Sciences  
and Engineering.

We have one:

**9/11**

Physical Scientist Production in the US is not keeping up with GDP  
even though the physical sciences are the basis of most wealth creation.

**The biggest single challenge for the next few decades:**

# **ENERGY**

**for  $10^{10}$  people**

- **At MINIMUM we need 10 Terawatts (150 M BOE/day) from some new clean energy source by 2050**
- **For worldwide peace and prosperity we need it to be cheap.**
- **We simply can not do this with current technology.**
- **We need Boys and Girls to enter Physical Science and Engineering as they did after Sputnik.**
- **Inspire in them a sense of MISSION  
( BE A SCIENTIST      SAVE THE WORLD )**
- **We need a bold new APOLLO PROGRAM  
to find the NEW ENERGY TECHNOLOGY**



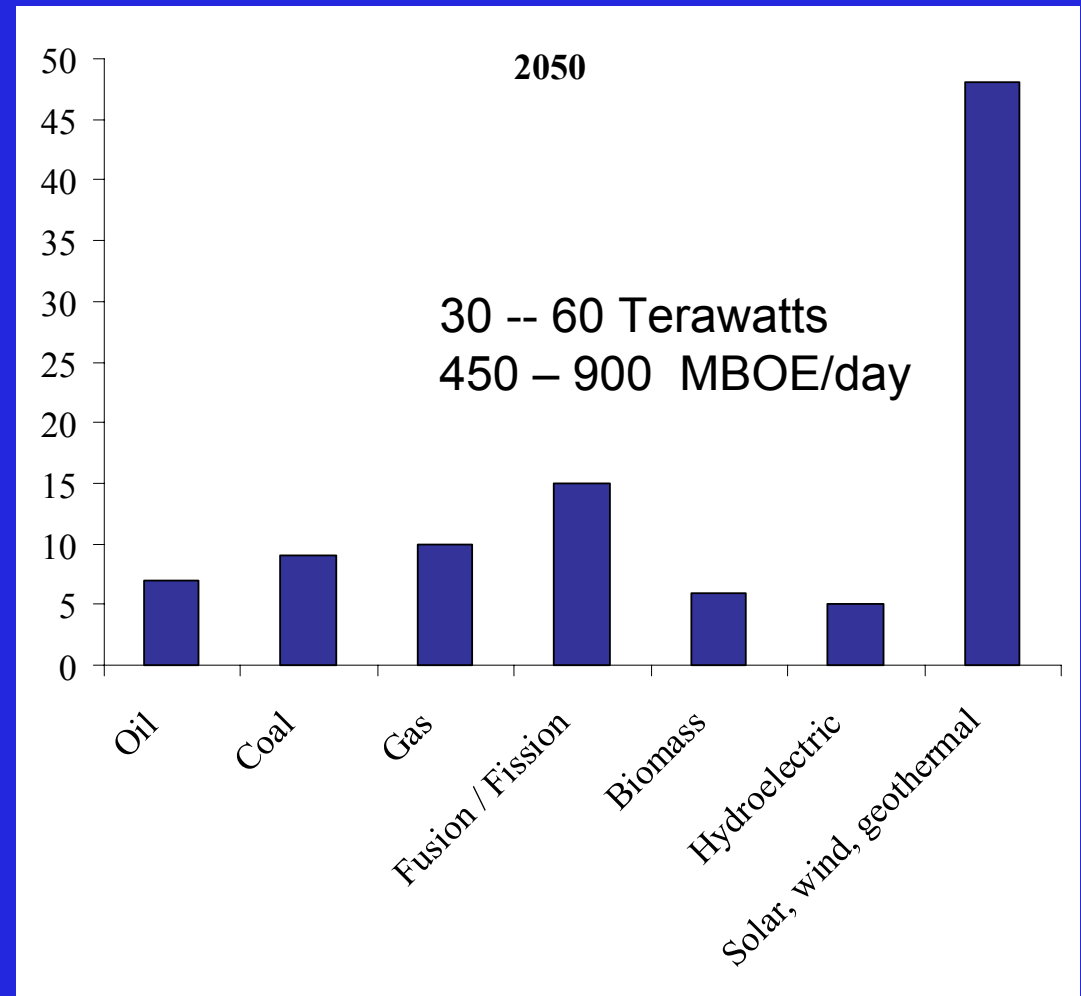
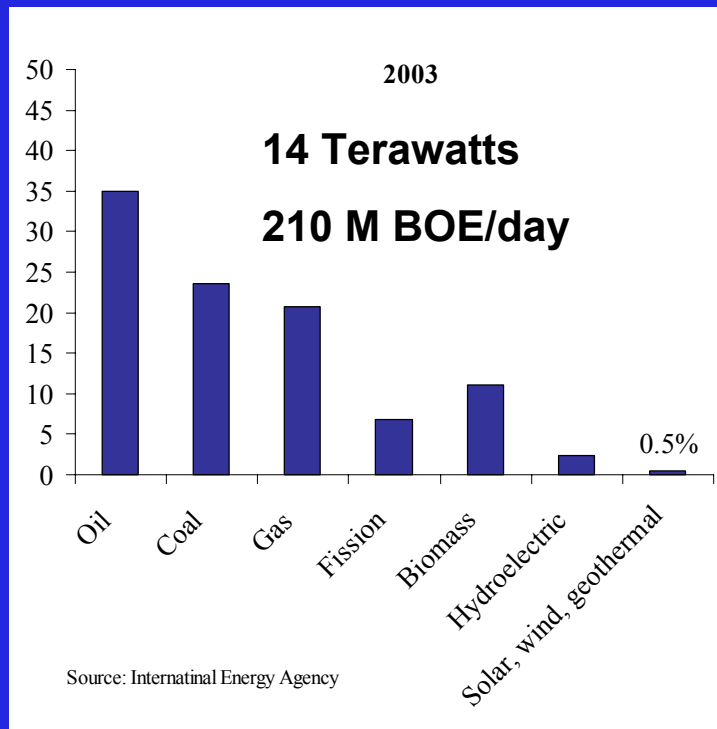
# Humanity's Top Ten Problems for next 50 years

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



<b>2003</b>	<b>6.3</b>	<b>Billion People</b>
<b>2050</b>	<b>9-10</b>	<b>Billion People</b>

# The ENERGY REVOLUTION (The Terawatt Challenge)



**The Basis of Prosperity**

**20<sup>st</sup> Century = OIL**

**21<sup>st</sup> Century = ??**

# PRIMARY ENERGY SOURCES

## Alternatives to Oil

- Conservation / Efficiency -- not enough
- Hydroelectric -- not enough
- Biomass -- not enough
- Wind -- not enough
- Wave & Tide -- not enough
  
- Natural Gas -- sequestration?, cost?
- Clean Coal -- sequestration?, cost?
  
- Nuclear Fission -- radioactive waste?, terrorism?, cost?
- Nuclear Fusion -- too difficult?, cost?
  
- Geothermal HDR -- cost ?
- Solar terrestrial -- cost ?
- Solar power satellites -- cost ?
- Lunar Solar Power -- cost ?

# New Energy Research Program

## (The Nickel & Dime Solution)

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- For FY04-FY09 collect **5 cents** from every gallon of oil product  
Invest the resultant > \$10 Billion per year as additional funding in  
frontier energy research distributed among DOE, NSF, NIST, NASA,  
and DoD.
- For the next 10 years collect **10 cents** from every gallon;  
invest the >\$20 Billion per year in frontier energy research.
- Devote a third of this money to New Energy Research Centers  
located adjacent to major US Research Universities.
- At worst this endeavor will create a cornucopia of new technologies  
and new industries.
- At best, we will solve the energy problem before 2020,  
and thereby lay the basis for peace and prosperity worldwide.

# 14 Enabling Nanotech Revolutions

1. Photovoltaics -- a revolution to drop cost by 10 to 100 fold.
2. H<sub>2</sub> storage -- a revolution in light weight materials for pressure tanks, and/or a new light weight, easily reversible hydrogen chemisorption system
3. Fuel cells -- a revolution to drop the cost by nearly 10 to 100 fold
4. Batteries and supercapacitors -- revolution to improve by 10-100x for automotive and distributed generation applications.
5. Photocatalytic reduction of CO<sub>2</sub> to produce a liquid fuel such as methanol.
6. Direct photoconversion of light + water to produce H<sub>2</sub>
7. Super-strong, light weight materials to drop cost to LEO, GEO, and later the moon by > 100 x, to enable huge but low cost light harvesting structures in space; and to improve efficiency of cars, planes, etc.
8. Nanoelectronics to revolutionize computers, sensors and devices.



# 14 Enabling Nanotech Revolutions

9. High current cables (superconductors, or quantum conductors) with which to rewire the electrical transmission grid, and enable continental, and even worldwide electrical energy transport; and also to replace aluminum and copper wires essentially everywhere -- particularly in the windings of electric motors (especially good if we can eliminate eddy current losses).
10. Thermochemical catalysts to generate  $H_2$  from water that work efficiently at temperatures lower than 900 C.
11.  $CO_2$  mineralization schemes that can work on a vast scale, hopefully starting from basalt and having no waste streams.
12. Nanoelectronics based Robotics with AI to enable construction maintenance of solar structures in space and on the moon; and to enable nuclear reactor maintenance and fuel reprocessing.
13. NanoMaterials/ coatings that will enable vastly lower the cost of deep drilling, to enable HDR (hot dry rock) geothermal heat mining.
14. Nanotech lighting to replace incandescent and fluorescent lights

# Projected Demand for Carbon-Free Energy

- M.I. Hoffert et. al., *Nature*, **1998**, 395, 881, “Energy Implications of Future Atmospheric Stabilization of CO<sub>2</sub> Content”

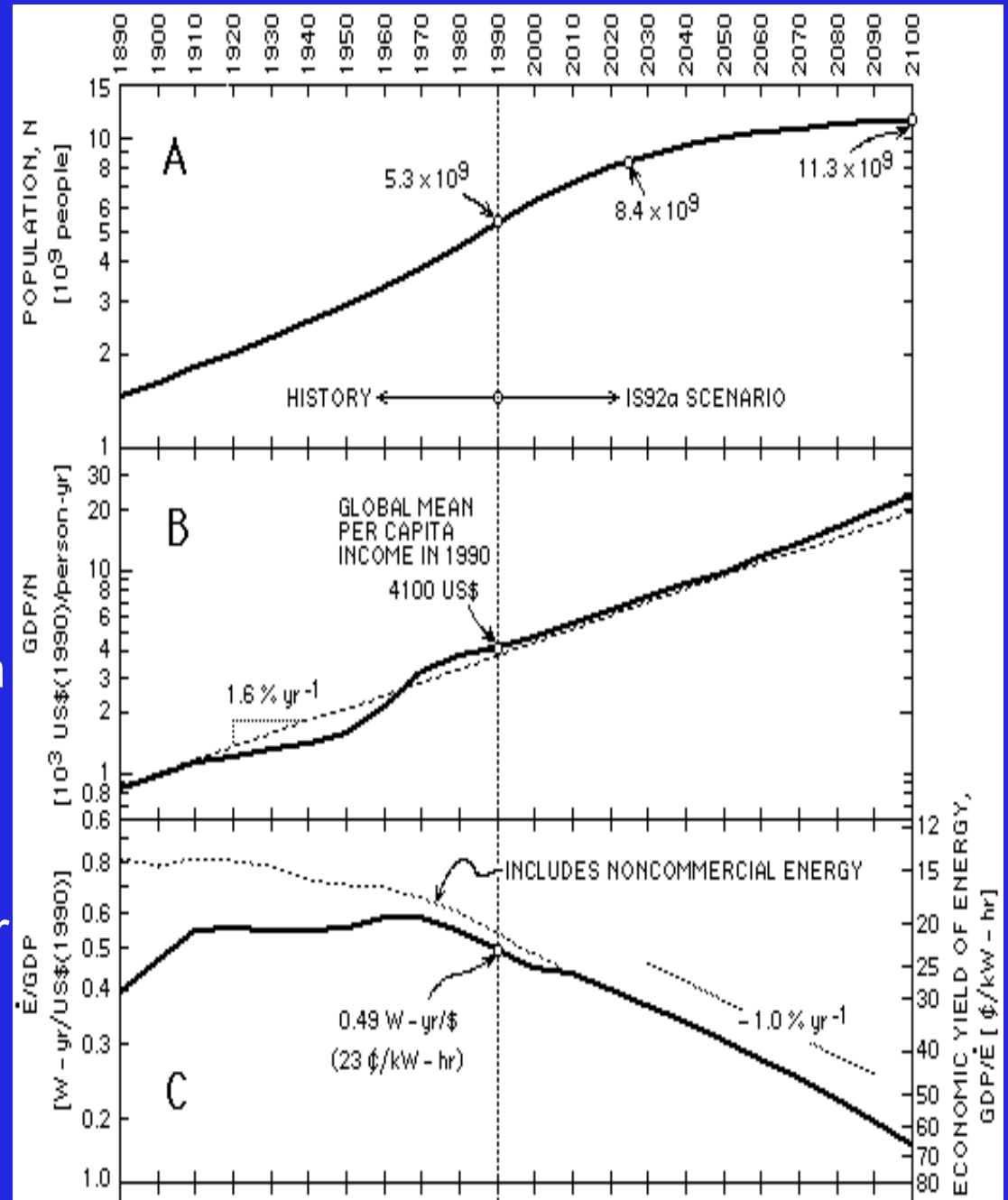
# Possible Sources of Carbon-Free Energy

- M.I. Hoffert et. al., *Science*, **2002**, 298, 981, “Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet”

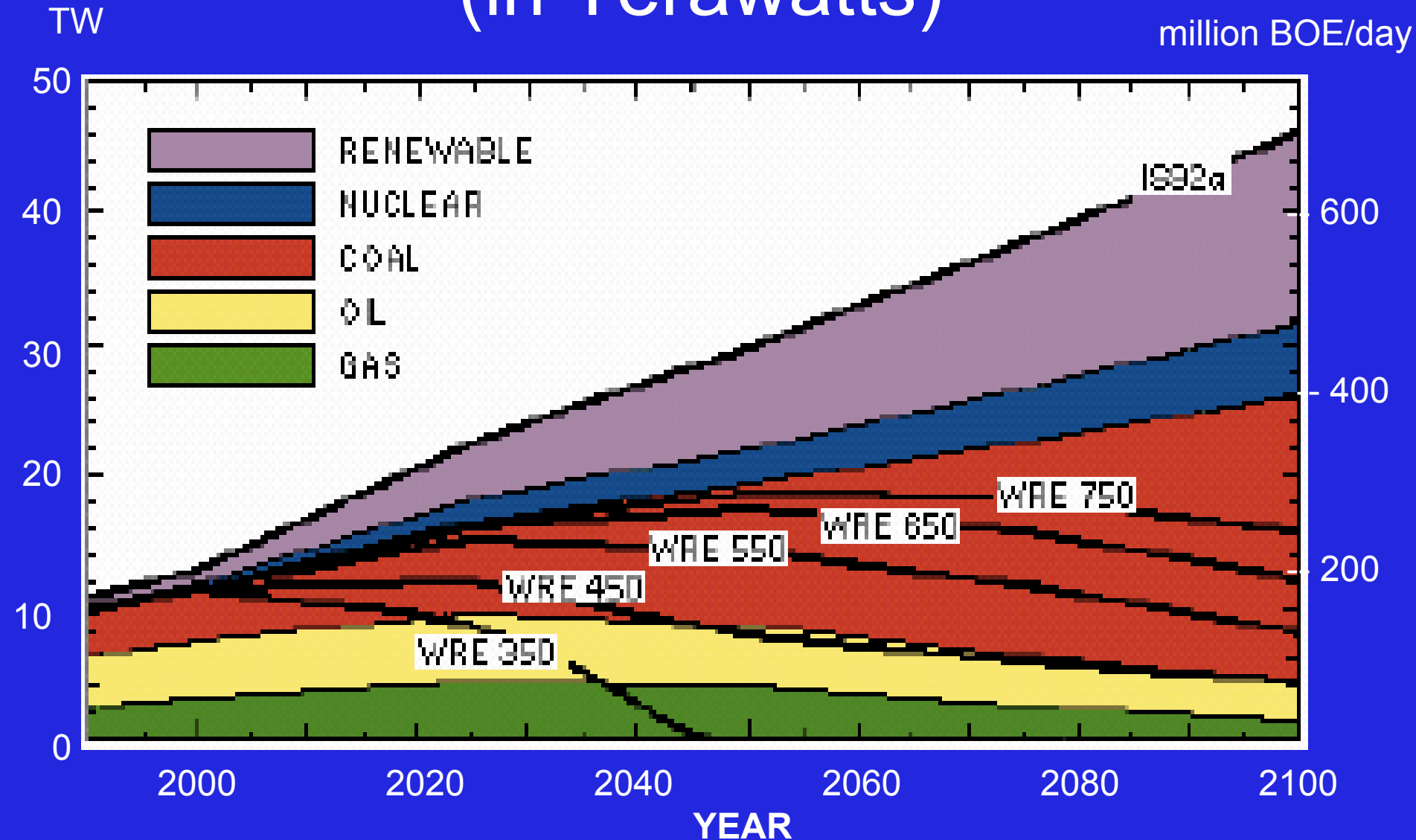
Population Growth to  
10 Billion People in  
2050

Per Capita GDP Growth  
at 1.6% yr<sup>-1</sup>

Energy consumption per  
Unit of GDP declines  
at 1.0% yr<sup>-1</sup>



# Energy Demand & Source (in Terawatts)



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

# Tonight's Reading Assignment

“Hubbert's Peak” by Kenneth Deffeyes (2001)

- King Hubbert predicted US oil production would peak in 1970. It did.
- The same approach predicts World Oil production will peak within this decade. It will.
- The days of cheap energy from oil will then be gone.

# Tomorrow's Reading Assignment

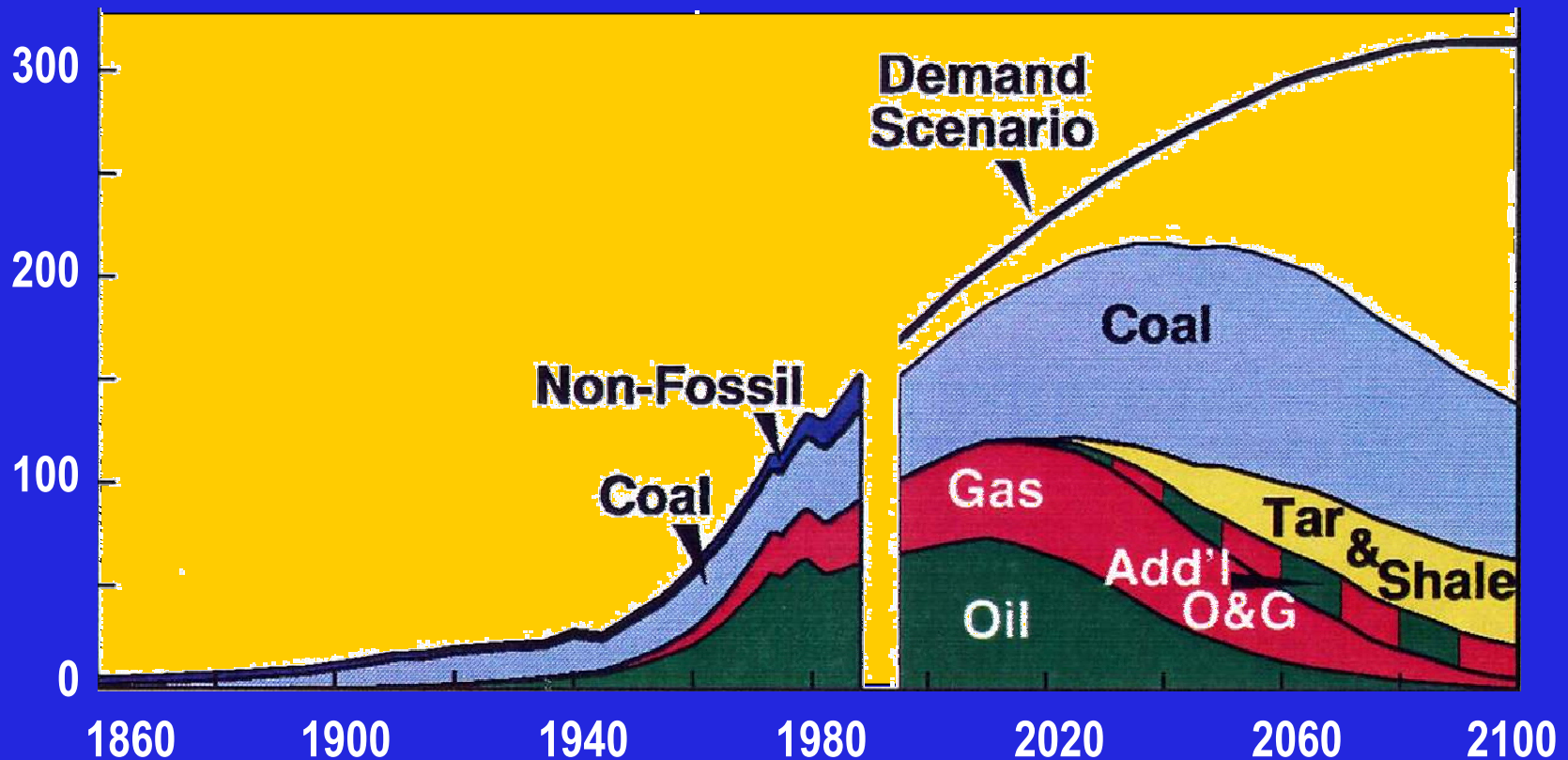
“The Hydrogen Economy: The Next Great Economic Revolution” by Jeremy Rifkin  
(Tarcher/Putnam, 2002)

H<sub>2</sub> is not a primary energy source.

But, after natural gas, it probably will be  
our future transportation fuel  
and energy storage medium.

# World Energy

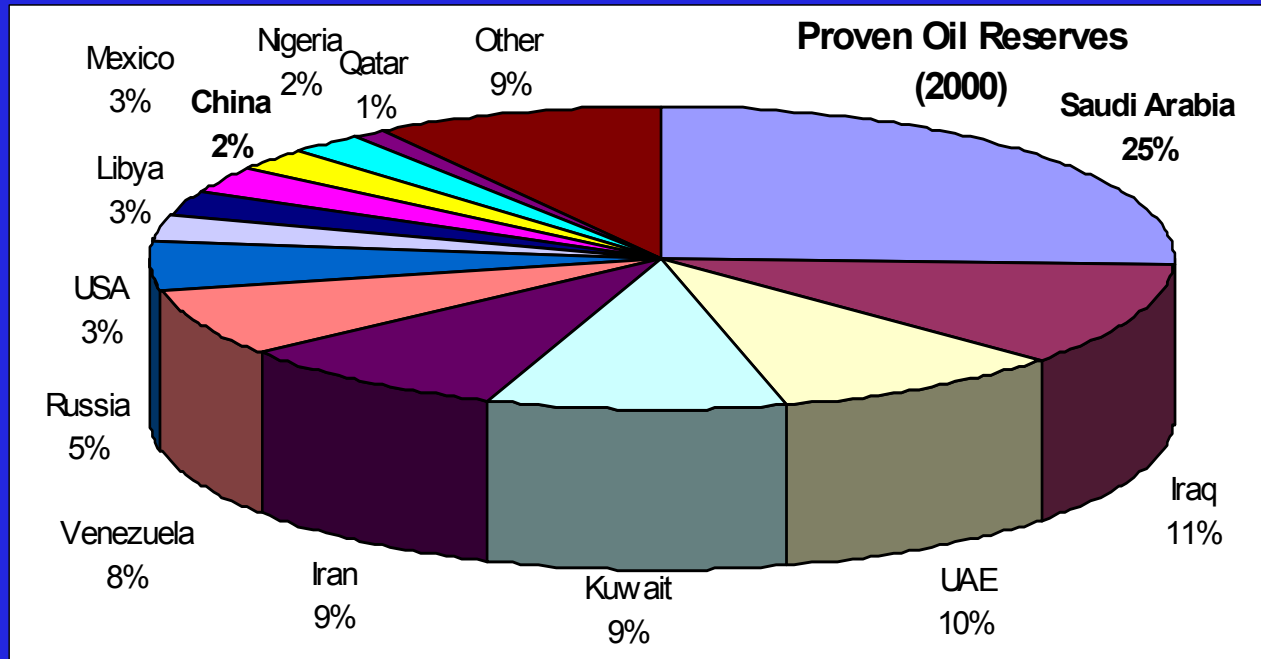
Millions of Barrels per Day (Oil Equivalent)



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).



# *World Proven Oil Reserves*



**THE REMAINING OIL RESERVES ARE NOT WHERE WE WANT THEM.**

**FOR TRANSPORTATION FUELS WE CURRENTLY HAVE NO CHOICE.**