Our Energy Challenge

AGCI
Aspen, Colorado
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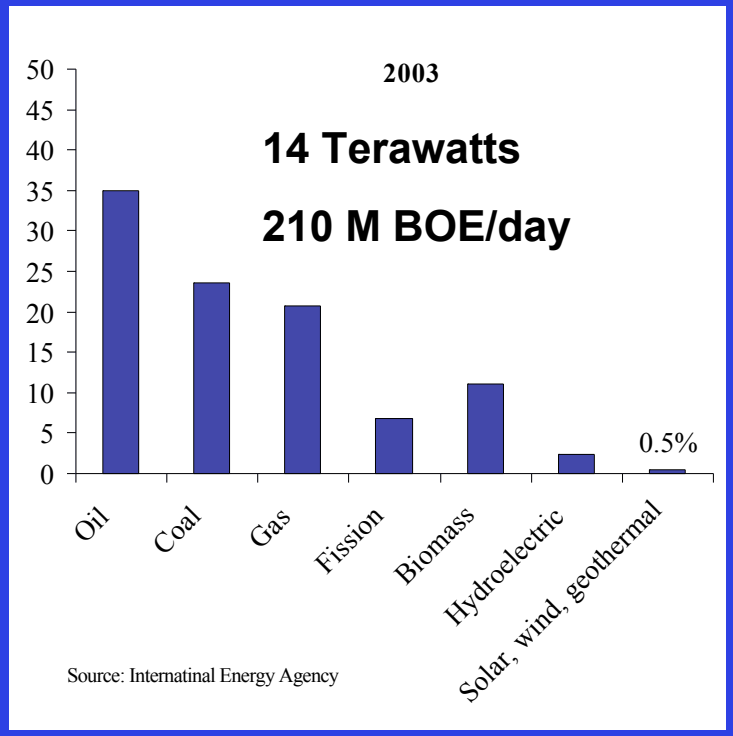
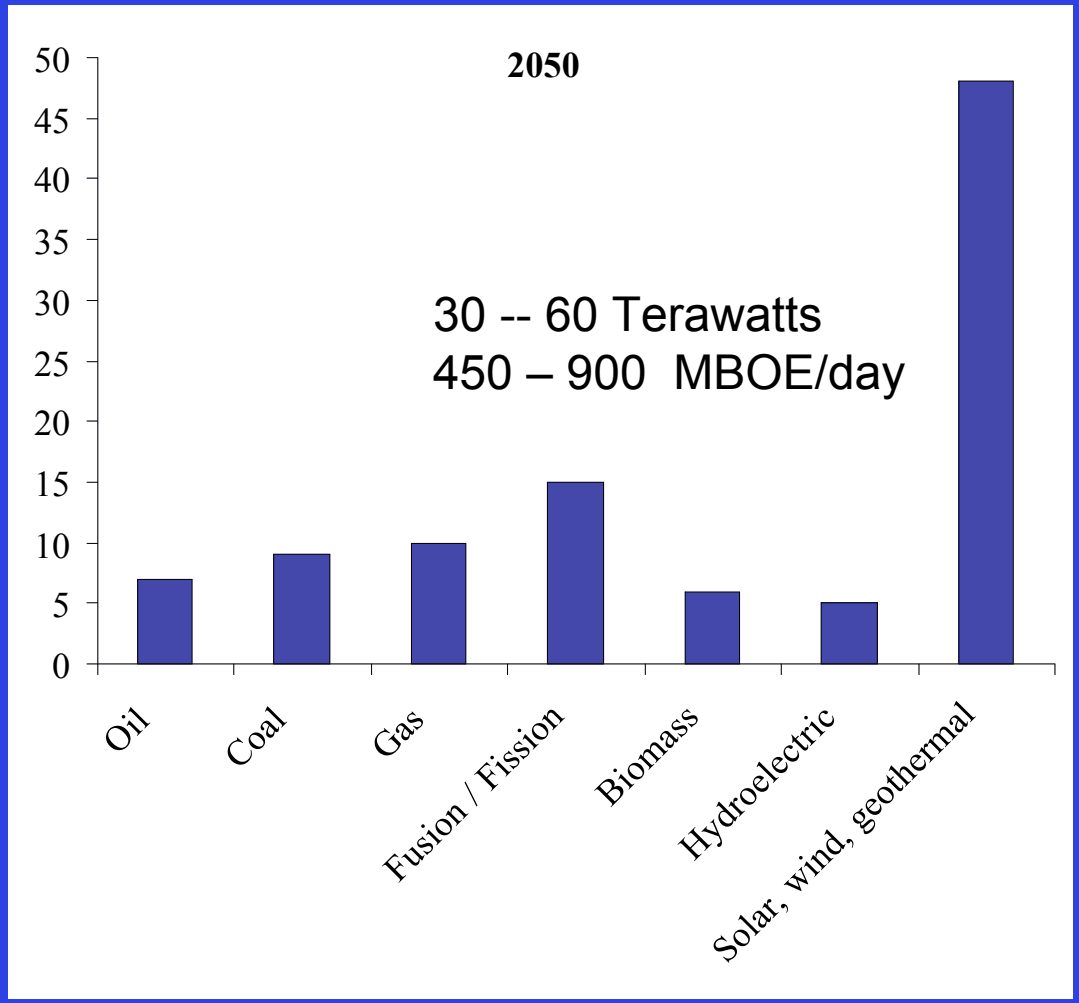
Humanity's Top Ten Problems for next 50 years

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

2003	**6.3**	**Billion People**
2050	**8-10**	**Billion People**

The ENERGY REVOLUTION (The Terawatt Challenge)





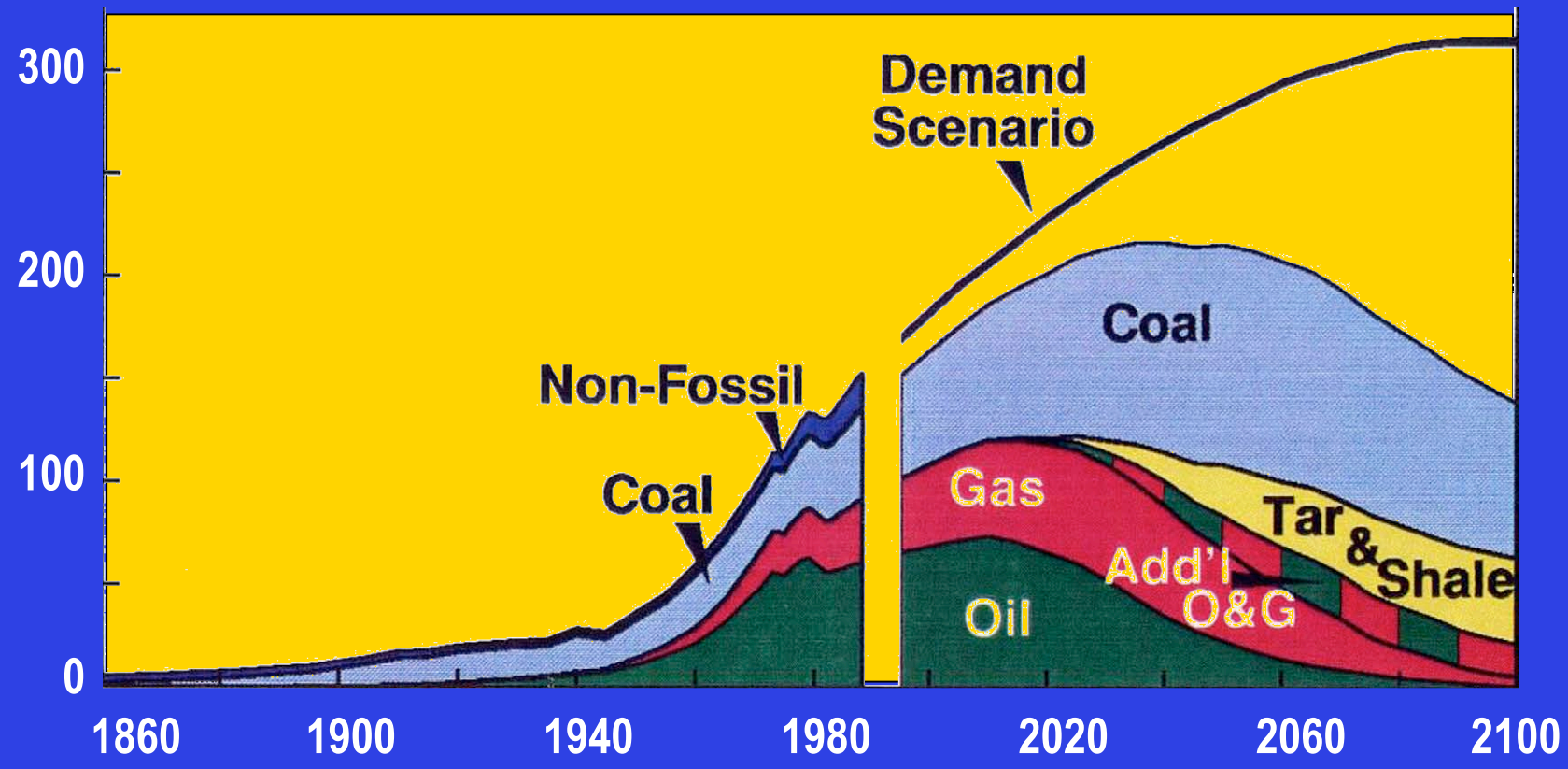
The Basis of Prosperity

20st Century = OIL

21st Century = ??

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).

PRIMARY ENERGY SOURCES
Alternatives to Oil

TOO LITTLE

- **Conservation / Efficiency** -- **not enough**
- **Hydroelectric** -- **not enough**
- **Biomass** -- **not enough**
- **Wind** -- **not enough**
- **Wave & Tide** -- **not enough**

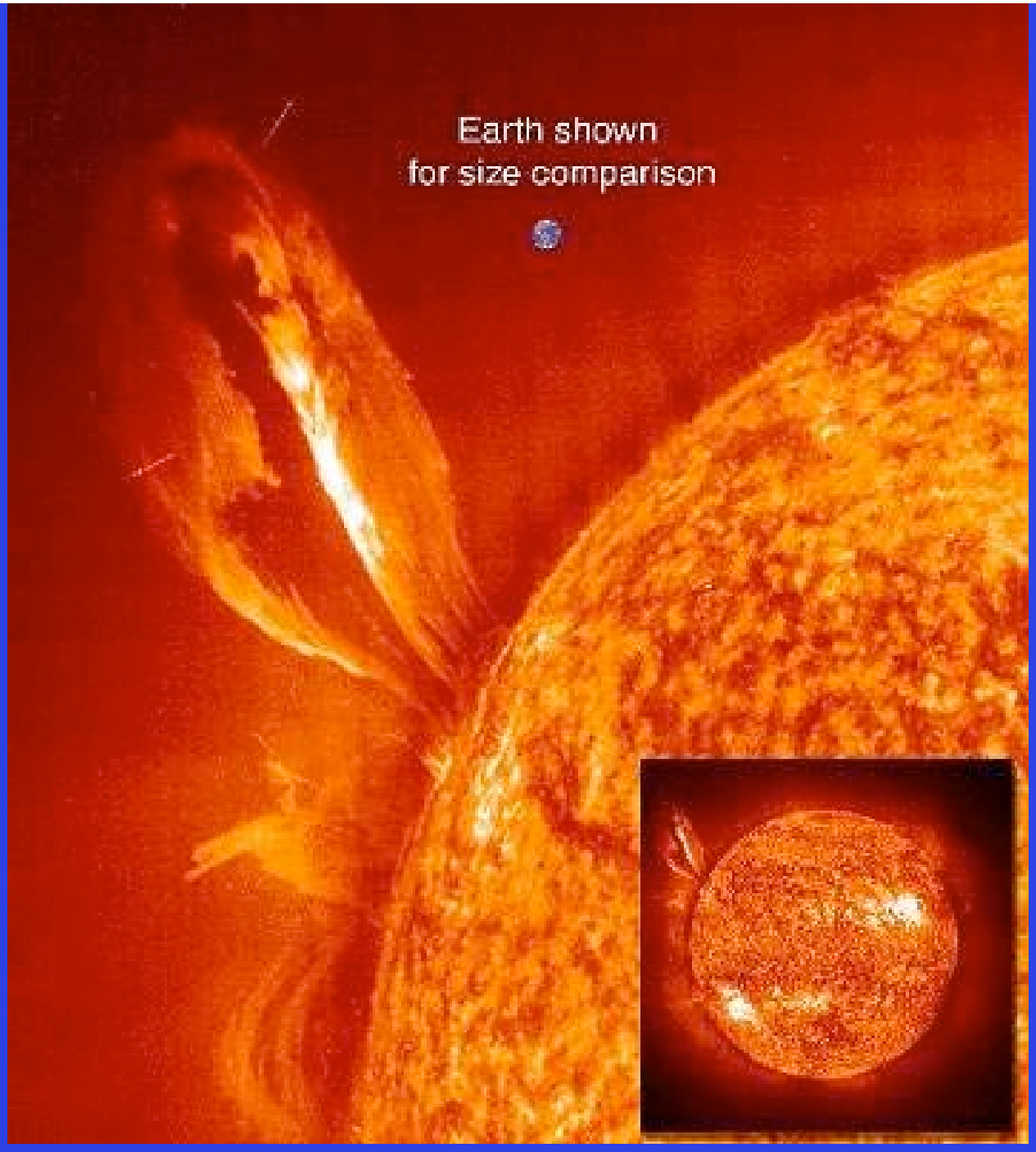
CHEMICAL

- **Natural Gas** -- **sequestration?, cost?**
- **Clean Coal** -- **sequestration?, cost?**

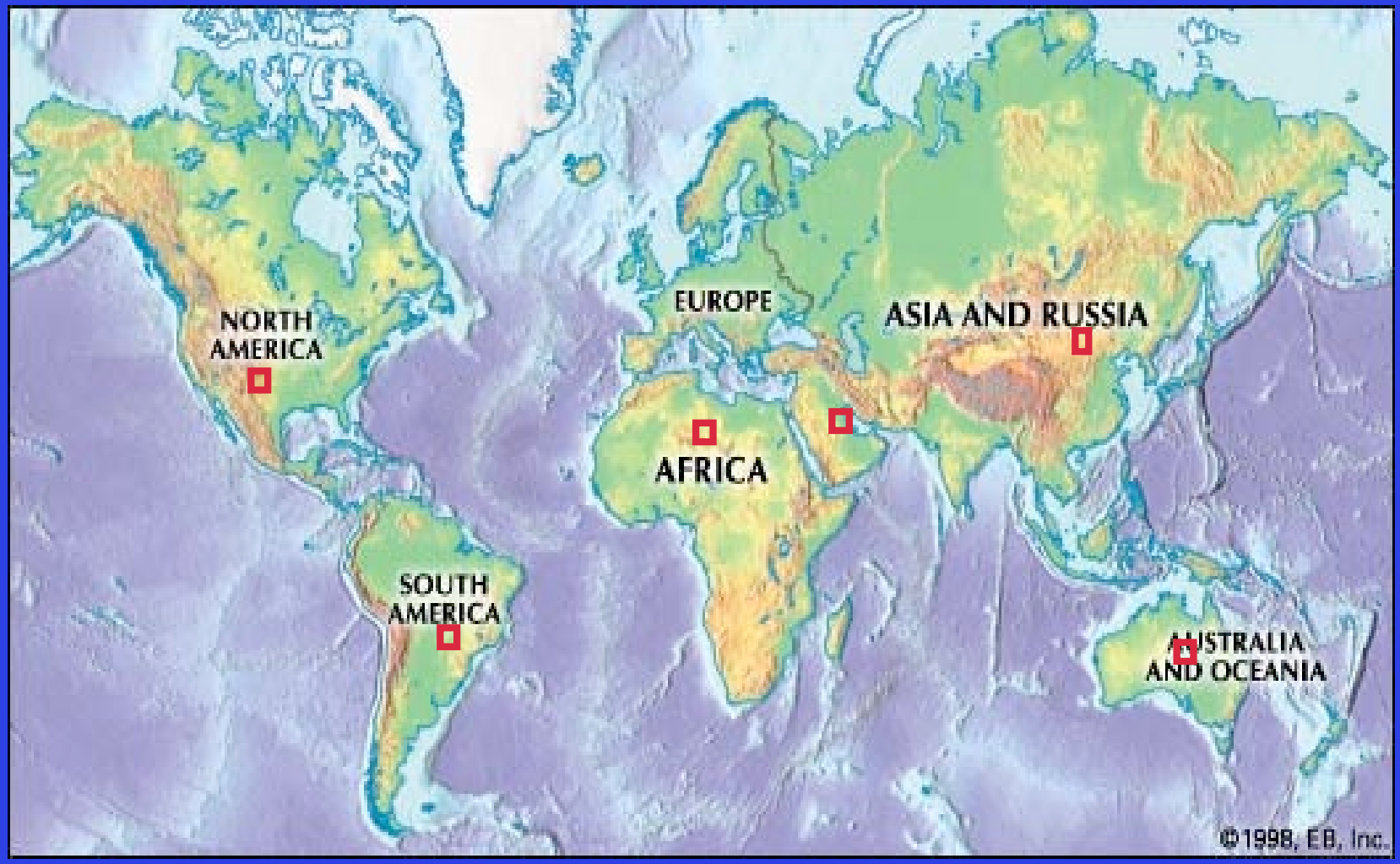
NUCLEAR

- **Nuclear Fission** -- **radioactive waste?, terrorism?, cost?**
- **Nuclear Fusion** -- **too difficult?, cost?**
- **Geothermal HDR** -- **cost ? , enough?**
- **Solar terrestrial** -- **cost ?**
- **Solar power satellites** -- **cost ?**
- **Lunar Solar Power** -- **cost ?**

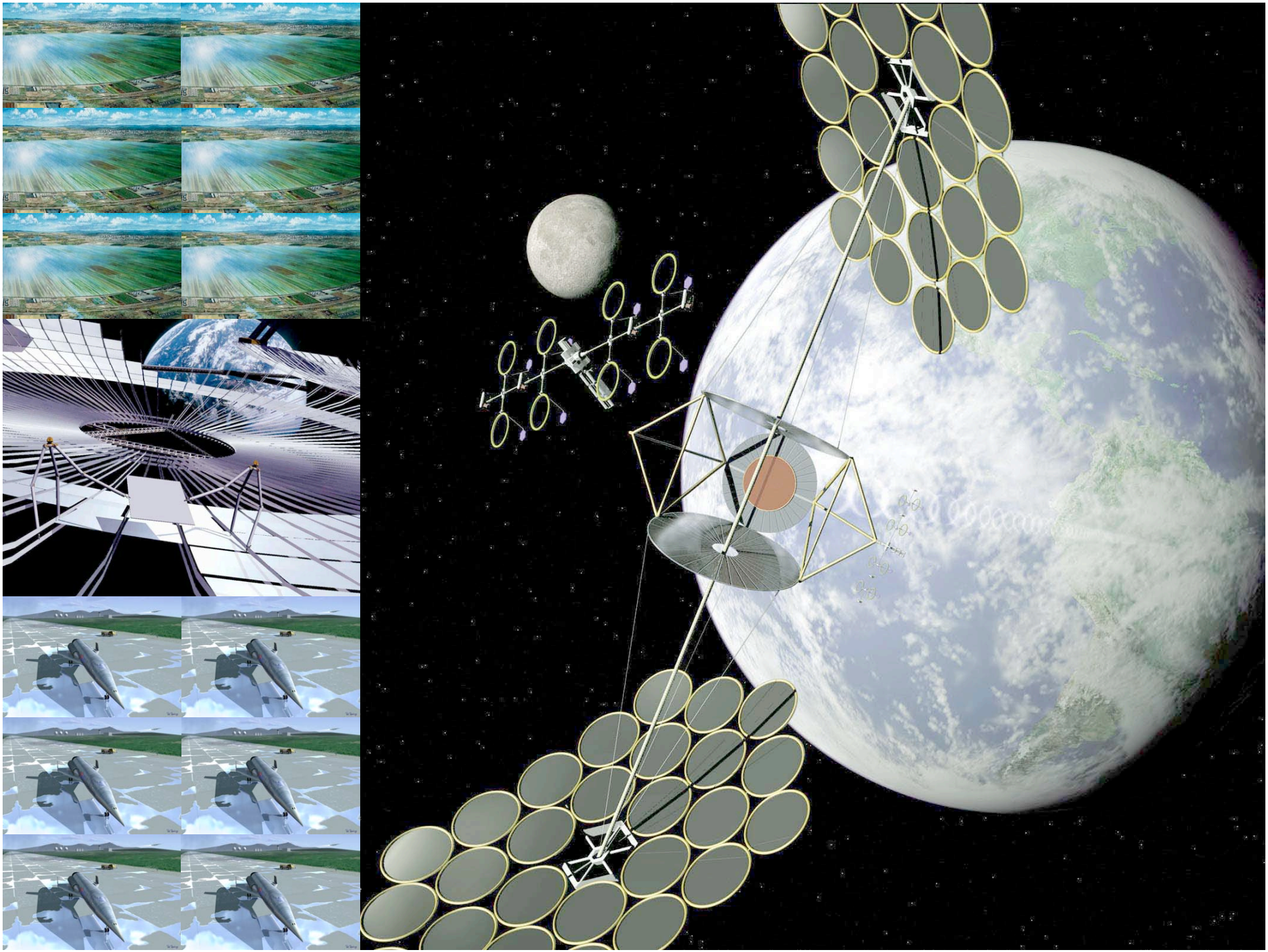
165,000 TW of sunlight hit the earth every day



Solar Cell Land Area Requirements



6 Boxes at 3.3 TW Each = 20 TWe



≥ 20 TWe from the Moon

One World Energy Scheme for 30-60TW in 2050: The Distributed Store-Gen Grid

- Energy transported as electrical energy over wire, rather than by transport of mass (coal, oil, gas)
- Vast electrical power grid on continental scale interconnecting ~ 100 million asynchronous. “local” storage and generation sites, entire system continually innovated by free enterprise
- “Local” = house, block, community, business, town, …
- Local storage = batteries, flywheels, hydrogen, etc.
- Local generation = reverse of local storage + local solar and geo
- Local “buy low, sell high” to electrical power grid
- Local optimization of days of storage capacity, quality of local power
- Electrical grid does not need to be very reliable
- Mass Primary Power input to grid via HV DC transmission lines from existing plants plus remote (up to 2000 mile) sources on TW scale, including vast solar farms in deserts, wind, nimby nuclear, clean coal, stranded gas, wave, hydro, space-based solar…
- Hydrogen is transportation fuel

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.

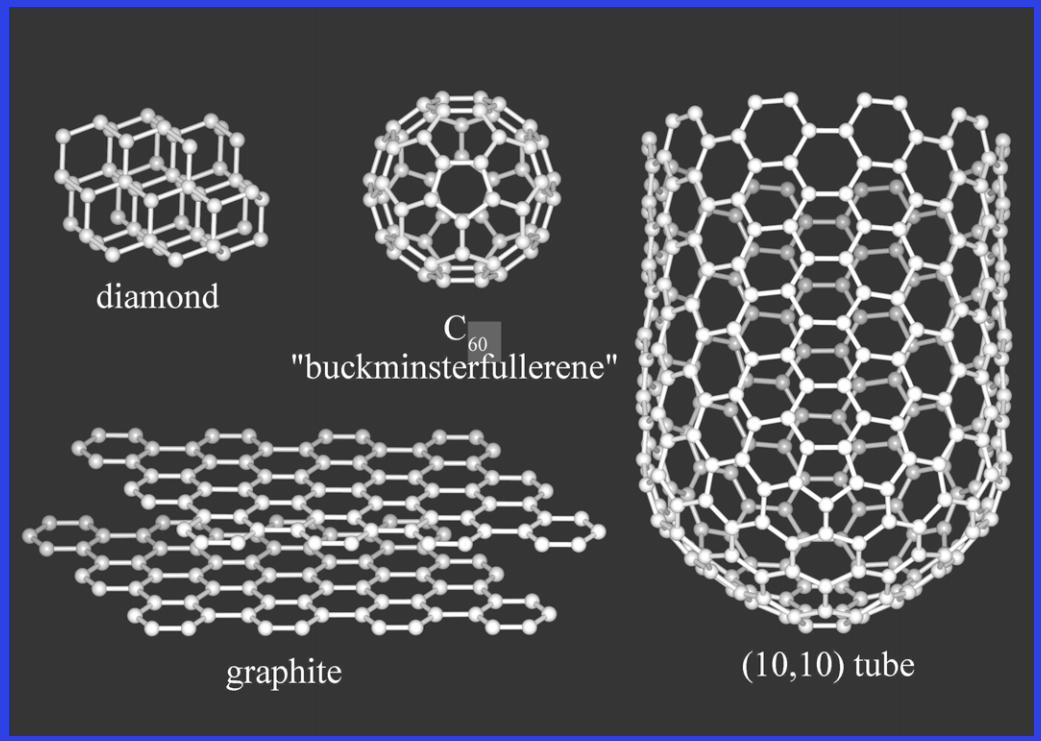
The Wet Side of Nanotechnology

- 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



Enabling Nanotech Revolutions

1. Photovoltaics -- drop cost by 100 fold.
2. Photocatalytic reduction of CO_2 to methanol.
3. Direct photoconversion of light + water to produce H_2.
4. Fuel cells -- drop the cost by 10-100x + low temp start + reversible
5. H_2 storage -- light weight materials for pressure tanks and LH2 vessels, and/or a new light weight, easily reversible hydrogen chemisorption system (material X).
6. Batteries, supercapacitors, flywheels -- improve by 10-100x for automotive and distributed generation applications.
7. Power 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 and generators (especially good if we can eliminate eddy current losses).

An interesting feature of this junction is the sensitive dependence of conductance on the contact length, l. Figure 2 shows the conductance values for armchair-armchair and

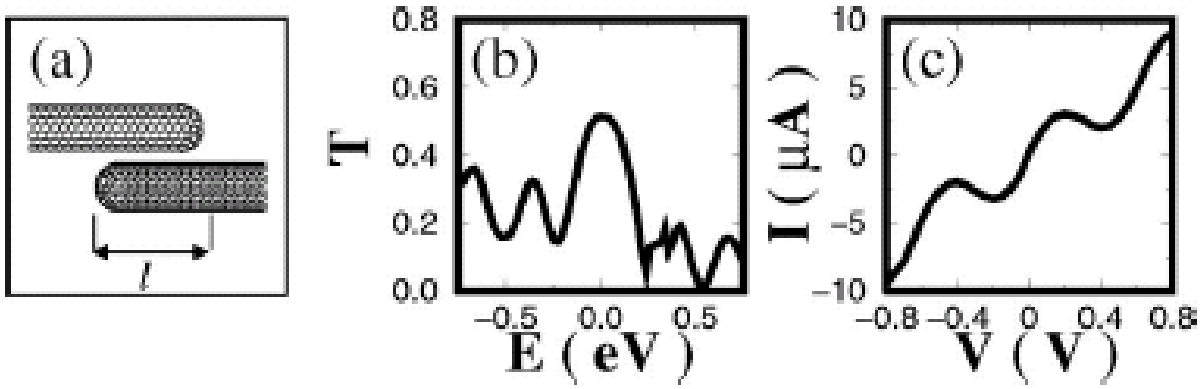


FIG. 1. (a) A two-terminal nanotube junction can be formed by bringing two tubes' ends together in parallel and pointing opposite directions (l is the contact length). (b) The transmission coefficient T of the two armchair tube [(10,10)-(10,10)] junction as a function of energy E for $l = 64$ Å. Interference of electron waves yields resonances in transport. (c) Current-voltage characteristics of the (10,10)-(10,10) junction for $l = 46$ Å.

Alper Buldum and Jian Ping Lu, Phys. Rev. B 63, 161403 R (2001).

Enabling Nanotech Revolutions

8. Nanoelectronics to revolutionize computers, sensors and devices.

9. 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.

10. 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, flywheel energy storage systems, etc.

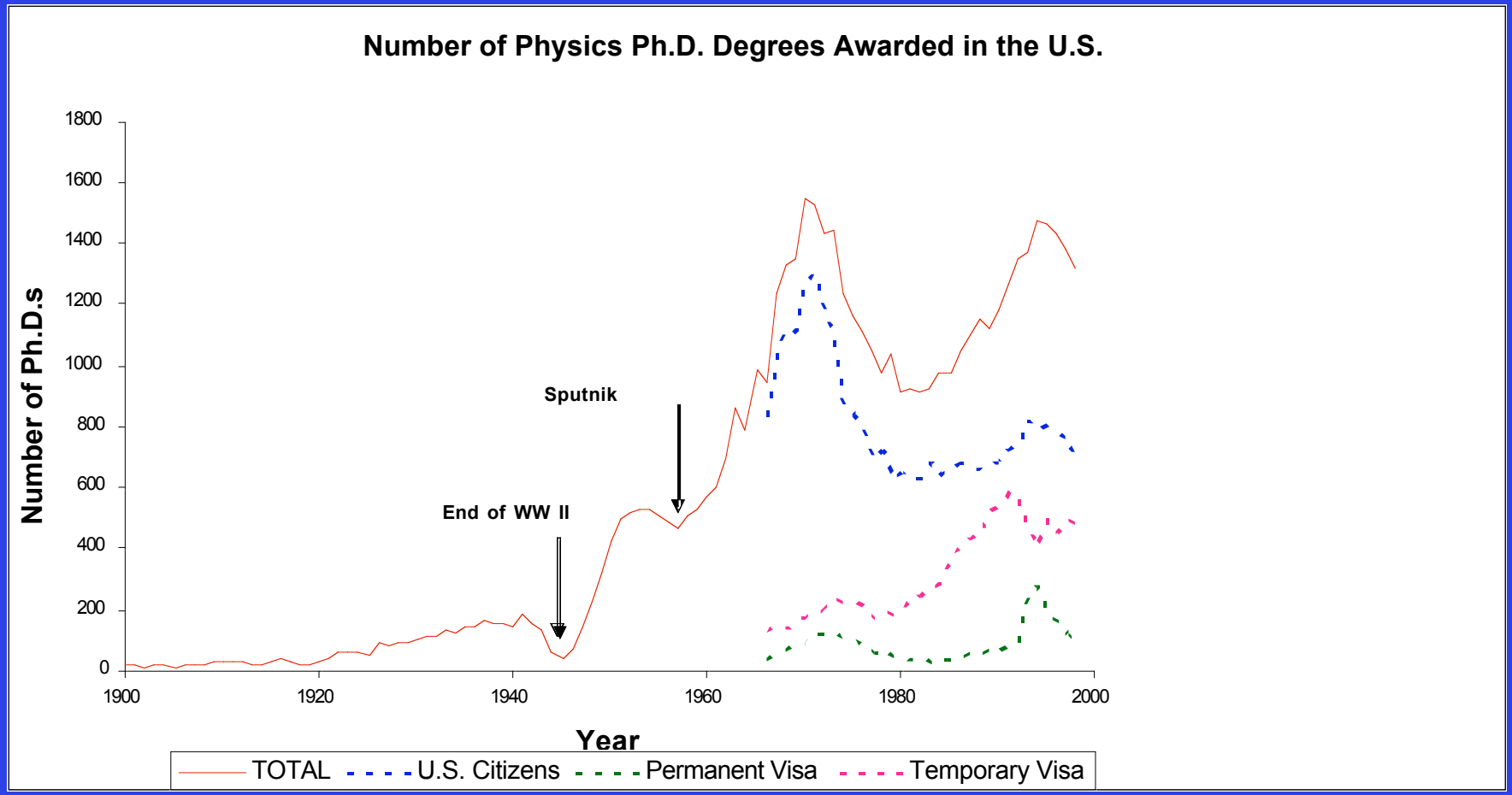
11. Thermochemical catalysts to generate H_2 from water that work efficiently at temperatures lower than 900 C.

12. Nanotech lighting to replace incandescent and fluorescent lights

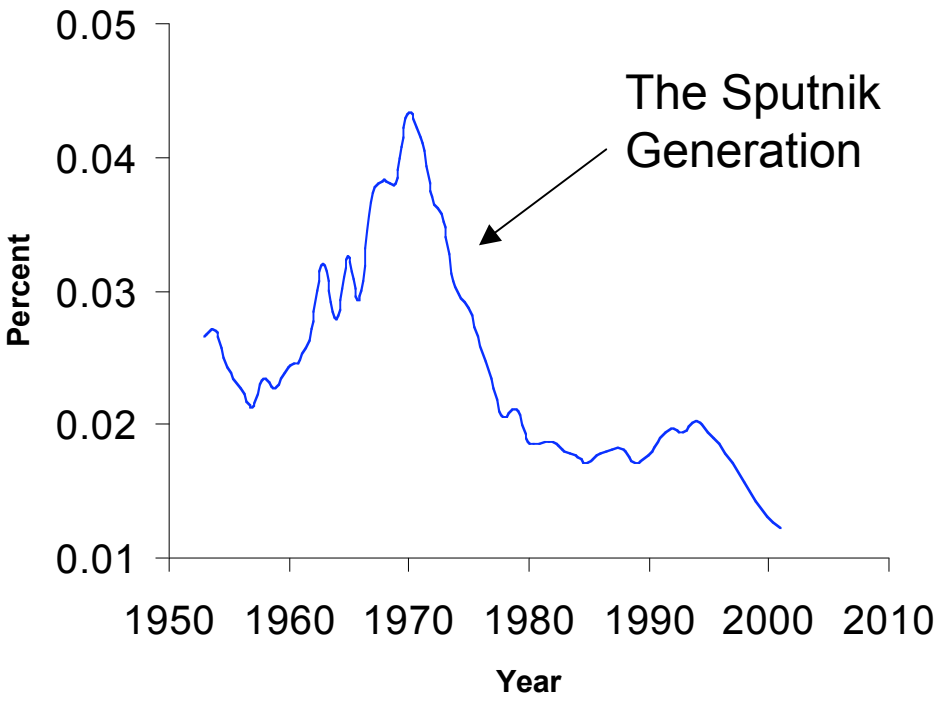
13. NanoMaterials/ coatings that will enable vastly lower the cost of deep drilling, to enable HDR (hot dry rock) geothermal heat mining.

14. CO_2 mineralization schemes that can work on a vast scale, hopefully starting from basalt and having no waste streams.

The S&T Workforce Problem



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.

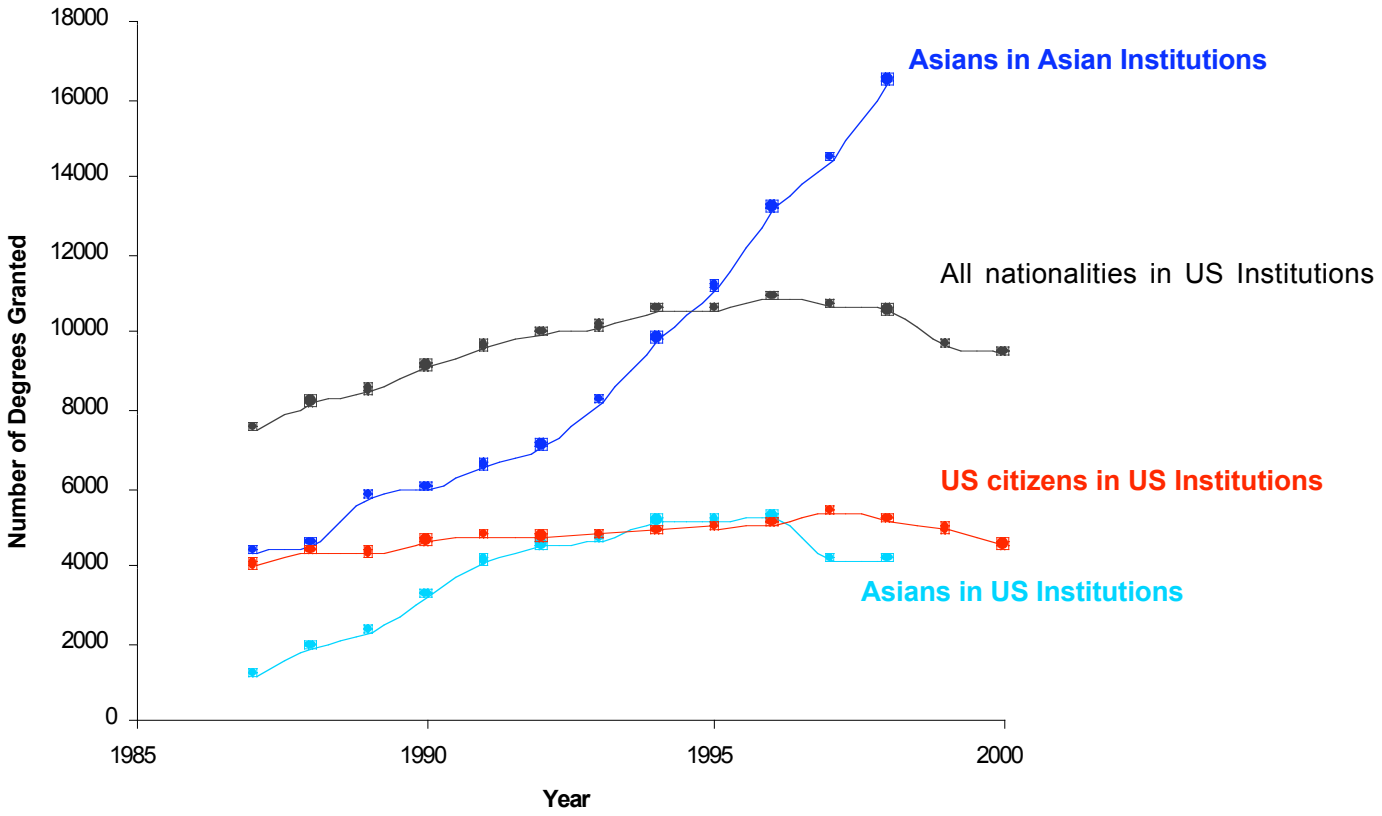
We Need a New Sputnik Event to inspire US citizens into the Physical Sciences and Engineering.

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.

Physical Science & Engineering PhD Degrees

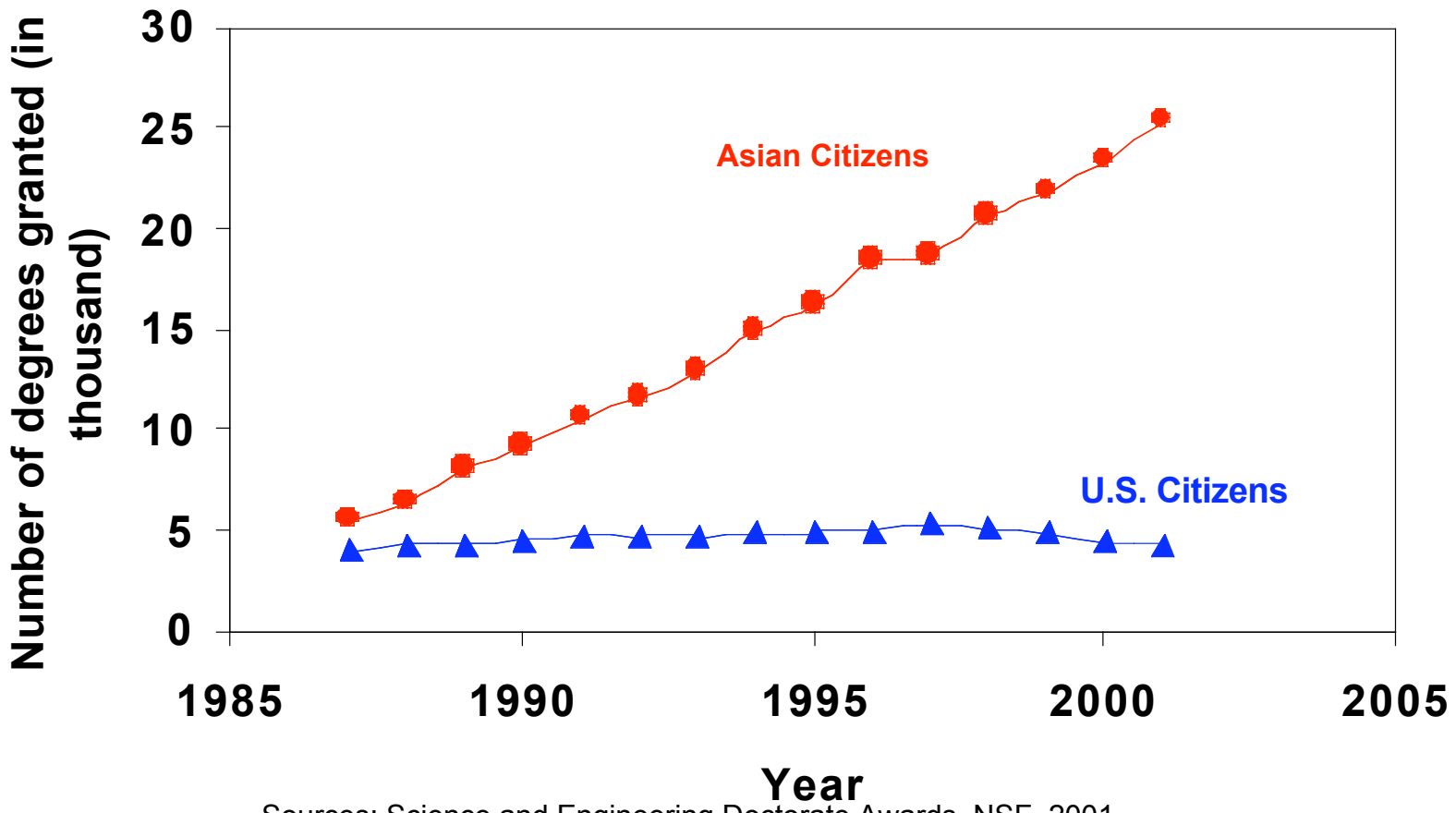


Source: Science and Engineering Doctorate Awards, 1996 and 2000, NSF; Science and Engineering Indicators, NSB, 2002

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.

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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

WHAT ARE WE WAITING FOR?

- An Energy Crisis ?
- A Global Warming Disaster?
- A New Administration?
- An Asian Technology Boom?

(or)

Leadership

New Energy Research Program

(The Nickel & Dime Solution)

- **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.

Reading Assignments

- 2002 State of the Future,
  (see www.stateofthefuture.org)
- The Hydrogen Economy, Jerry Rifkin
- Twenty Hydrogen Myths, Amory Lovins
  (see www.rmi.org)
- Hubbert's Peak, Kenneth Deffeyes
- The Prize, Daniel Yergin
- M.I. Hoffert et. al., *Science*, **2002**, 298, 981,