Our Energy Challenge

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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 energy prosperity and peace 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
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 energy prosperity & peace worldwide.
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 6.5 Billion People
2050 8-10 Billion People
The ENERGY REVOLUTION
(The Terawatt Challenge)

The Basis of Prosperity
20th Century = OIL
21st Century = ??
World Energy

Millions of Barrels per Day (Oil Equivalent)

Figure 1b  Increased CO₂ Emissions Causing a Rise in Atmospheric CO₂ Associated with a Rise in Global Temperature (Sources: CO₂ data from Ethridge et al. 2001, Keeling and Whorf 2002; temperature data from Jones et al. 1998, Peterson and Vose 1997)
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
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…”EVERYBODY PLAYS”
- Hydrogen is transportation fuel
Enabling Nanotech Revolutions

1. Photovoltaics -- drop cost by 100 fold.
2. Photocatalytic reduction of CO₂ to methanol.
3. Direct photoconversion of light + water to produce H₂.
4. Fuel cells -- drop the cost by 10-100x + low temp start + reversible
5. H₂ 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

\[ \text{(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 \( l = 64 \, \text{Å} \). Interference of electron waves yields resonances in transport. (c) Current-voltage characteristics of the \((10,10)-(10,10)\) junction for \( l = 46 \, \text{Å} \).} \]
Cloning Project

1. Cut to short lengths (< 20 nm)
2. Purify
3. Sort by end and side chemistry
4. Attach catalyst
5. Inject into reactor and grow clone
6. Cut to desired length
7. Purify
8. Season to taste

But these organic molecules conduct electricity!

Same old chemistry.
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 H₂ 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. CO₂ mineralization schemes that can work on a vast scale, hopefully starting from basalt and having no waste streams.
The S&T Workforce Problem

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

- **TOTAL**
- **U.S. Citizens**
- **Permanent Visa**
- **Temporary Visa**

- **Sputnik**
- **End of WW II**

Year:
- 1900
- 1920
- 1940
- 1960
- 1980
- 2000

Number of Ph.D.s:
- 0
- 200
- 400
- 600
- 800
- 1000
- 1200
- 1400
- 1600
- 1800
Physical Scientist Production in the US is not keeping up with GDP even though the physical sciences are the basis of most wealth creation.

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

We have one: 9/11
PhD Degrees in Science and Engineering

Asians citizens
All fields of Science & Engineering

US citizens, all fields of Science and Engineering, (excluding psychology & social sciences)

US citizens, Physical Sciences and Engineering only

Source: Science and Engineering Indicators, National Science Board, 2002
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We Know We Have to do this: Revolutionize Energy

WHAT ARE WE WAITING FOR?

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

(or)
consensus in the S&T establishment, DoD, IC, State Dept.
and
POLITICAL LEADERSHIP
Reading Assignments

- **The Prize**, Daniel Yergin
- **Hubbert’s Peak**, Kenneth Deffeyes
- **The Hydrogen Economy**, Jeremy Rifkin
- **Twenty Hydrogen Myths**, Amory Lovins ([www.rmi.org](http://www.rmi.org))