Energy Challenge and Nanotechnology

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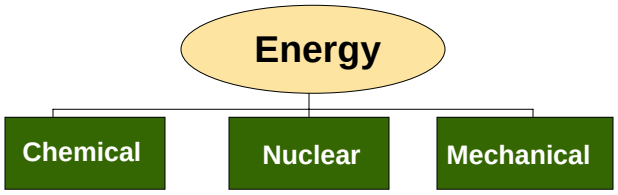
Support: US DOE

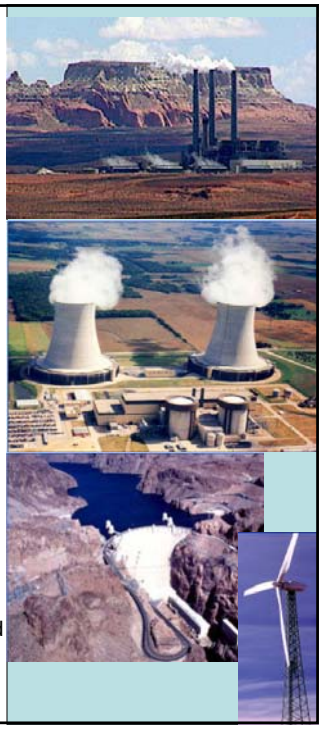
Humanity's Top Ten Problems for next 50 years

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

2004 6.5 Billion People
2050 ~ 10 Billion People

..... R. Smalley, Rice Univ.



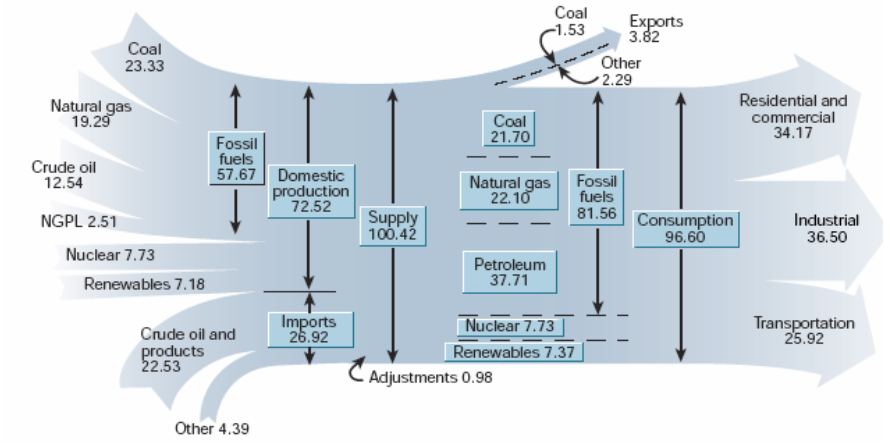


Energy sources

The first derives from chemical or photophysical energy that relies on oxidizing some reduced substance, usually a hydrocarbon, or absorbing sunlight to generate either heat or electricity. The energy involved is that of a chemical bond or fractions of an electron volt (eV).

The second involves nuclear reactions that release energy either by splitting heavy nuclei or by fusing light nuclei. The energy involved in nuclear reactions is in the region of 106 electron volts (MeV) per nuclear reaction.

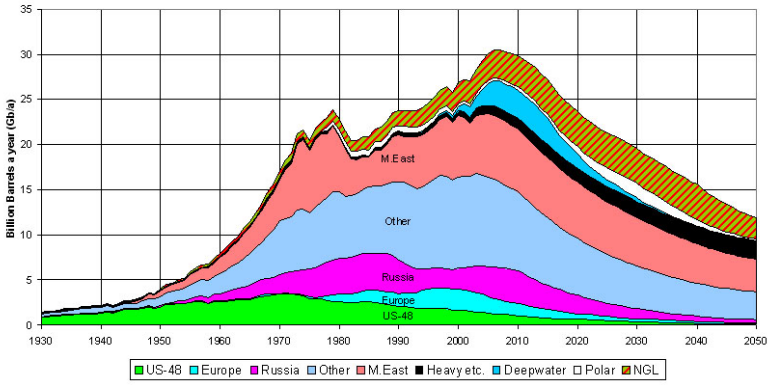
The third is thermomechanical in the form of wind, water, or geological sources of steam or hot water. The energy involved is in the milli-electron-volt (meV) region from, for example, water falling several tens of meters.



Energy flow diagram for the United States for 1999, in quads (1 quad = 10^{15} British thermal units = 2.92×10^{11} kWh). The average energy consumption in the United States is 0.42×10^{-6} quads per person per year, and the US population is about 5% of that on planet Earth. Energy consumption is large compared with food consumption (1.22×10^{4} kJ per day per person , which translates to only 0.42×10^{-8} quads per person per year). Some corresponding numbers for world energy consumption for 1999, in quads, are: petroleum 149.7; natural gas 87.3; coal 84.9; nuclear 25.2; hydro, geothermal, solar, wind and other renewables 29.9; total world energy production is 377.1 quads.

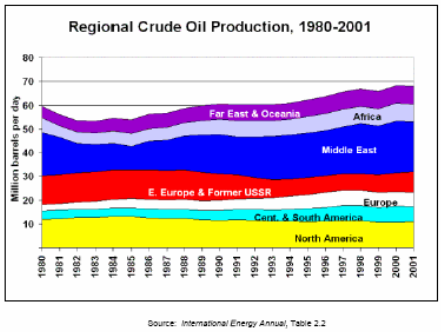
Energy Information Administration Office of Energy Markets and End Use. *Annual Energy Review 1999* <http://www.eia.doe.gov/aer> (US Department of Energy, Washington DC, 2000); Dresselhaus, M. S. and Thomas, I. L., *Alternative energy technologies.* Nature, **2001**, *414*, 332-337

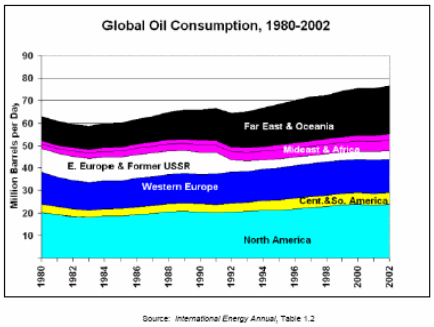
OIL AND GAS LIQUIDS
2004 Scenario



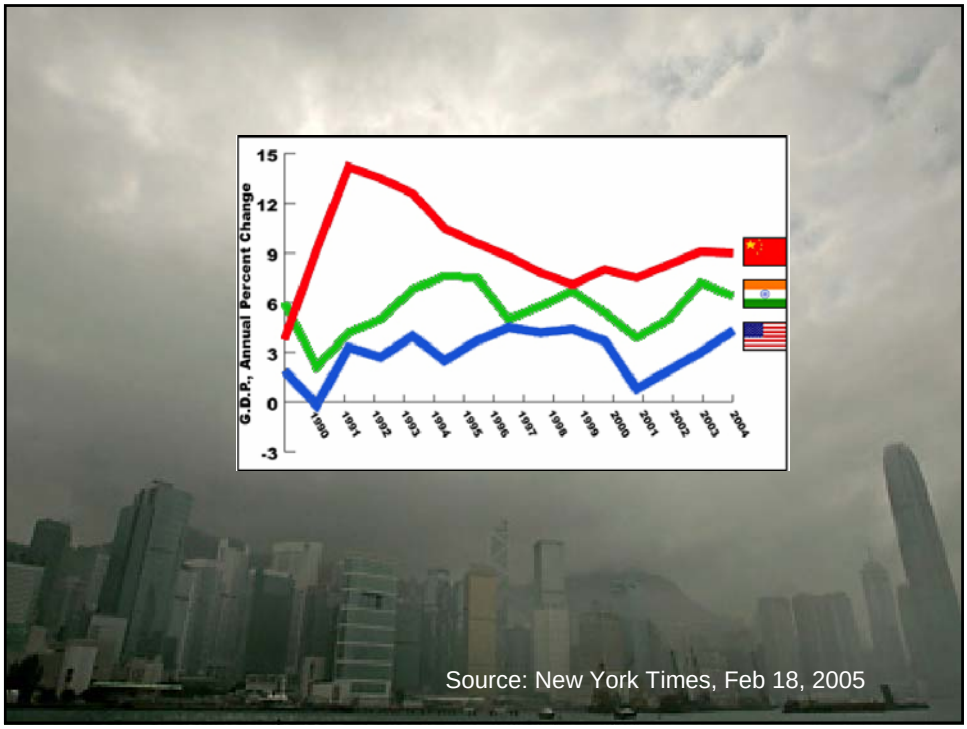
Uppsala Hydrocarbon Depletion Study Group
OIL AND GAS LIQUIDS 2004 Scenario

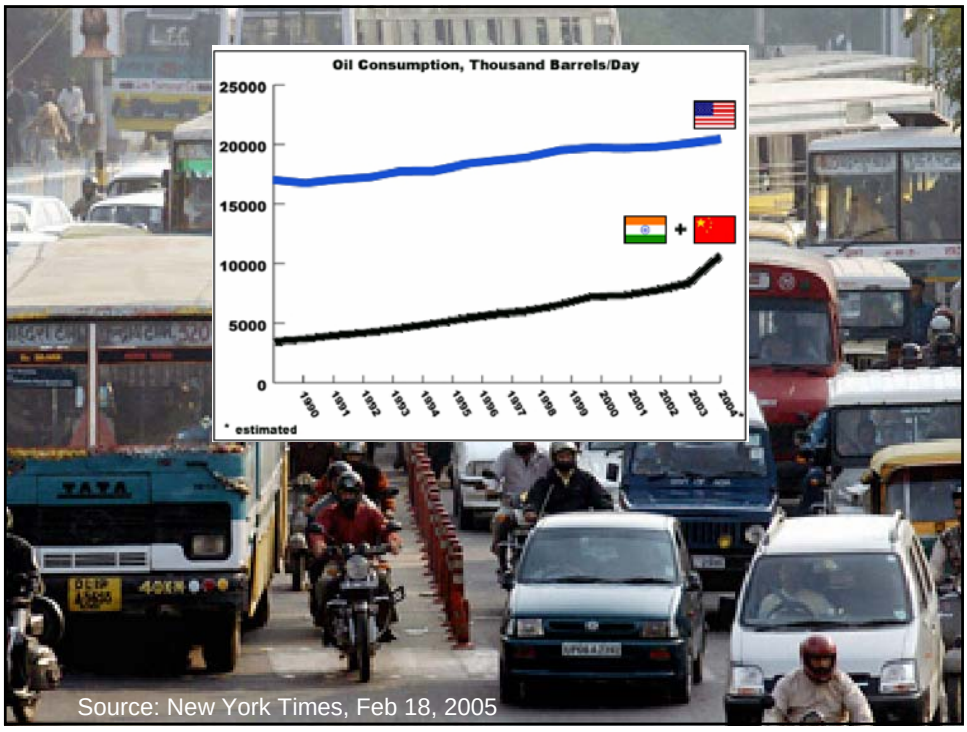
http://ww.peakpoil.net

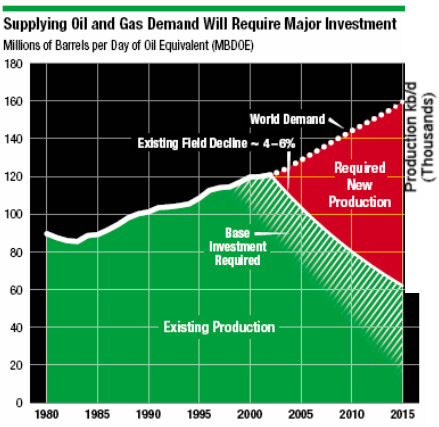




http://www.eia.doe.gov


G.D.P., Annual Percent Change
15
12
9
6
3
0
-3
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Source: New York Times, Feb 18, 2005

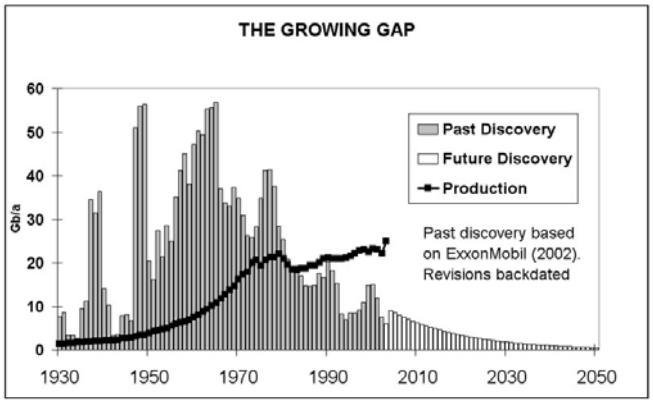

Oil Consumption, Thousand Barrels/Day
25000
20000
15000
10000
5000
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004*
* estimated
+
Source: New York Times, Feb 18, 2005

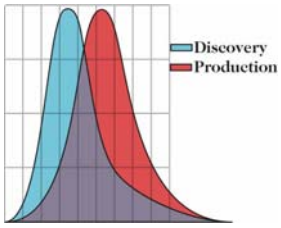


Graph: World Oil Production 1950-2050
Source: Dr. C.J. Campbell

"Understanding depletion is simple. Think of an Irish pub. The glass starts full and ends empty. There are only so many more drinks to closing time. It's the same with oil. We have to find the bar before we can drink what is in it."

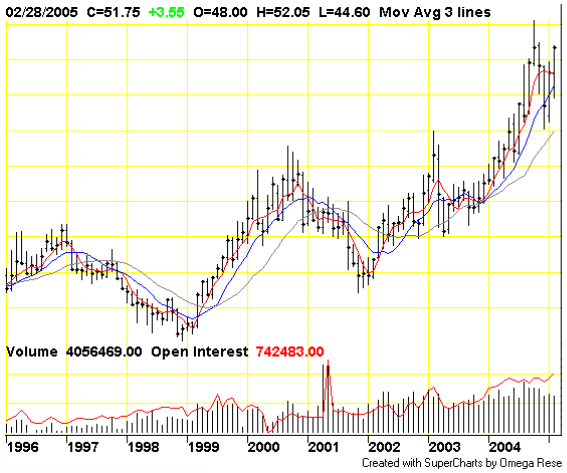
Campbell

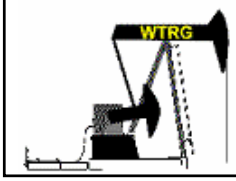




http://ww.peakpoil.net

Increasing demand is driving oil prices higher





The old way to address the problem …….

Gerald Herbert/Associated Press

Bush Meets With Saudi Leader
The president said he wanted to discuss the capacity of the Saudis to pump more oil. Go to Article

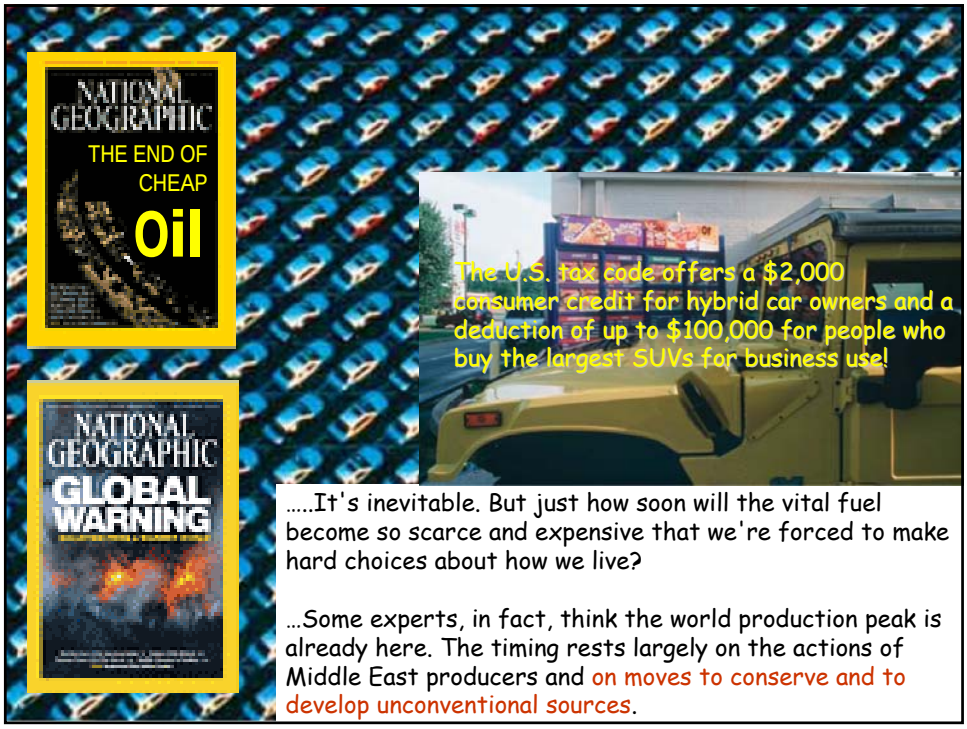
New York Times April 25, 2005

But will it work this time?

Saudis are already pumping oil at rates closer to their maximum sustainable capacity than during previous price spikes, leaving them less leeway to increase the supply on the global market.

In 2002 Saudi Aramco, the state owned oil company, says it produced 6.8 million barrels of oil per day. The Saudis now produce about 9.5 million barrels a day.

The spare capacity available to the Saudis is estimated to be down to about 1.2 million barrels a day.



News Quotes from April 01, 2005**

9 a m U.S. used an average of 8.9 million barrels of gasoline a day this year, up 2.2 percent from the same period in 2004, Energy Department data shows.

Goldman Sachs predicted a "super spike" in oil prices, to $105 a barrel by 2007. The forecast helped push oil futures prices sharply higher.

"With OPEC capacity only a million barrels a day away from their limits and demand rising, add a major outage somewhere and sure it's possible," said Tom Bentz, an analyst at BNP Paribas Commodity Futures.

Gasoline prices would have to reach $4 a gallon to stop American consumers from driving gas-guzzling vehicles, Goldman Sachs concludes.

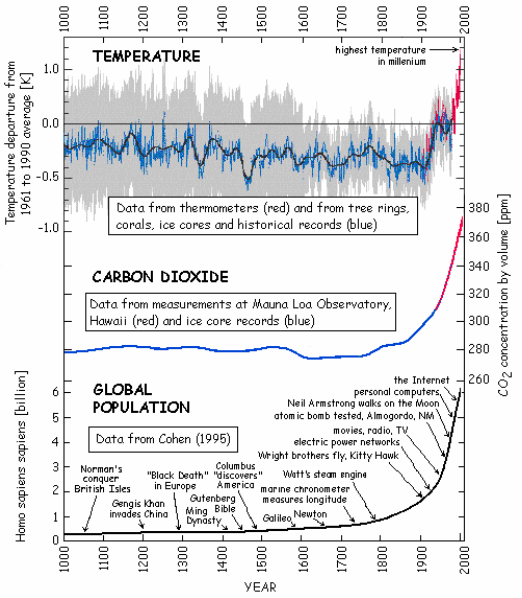
5 p m Oil prices rallied to a record close above $57 a barrel Friday, sparked by a surge in gasoline futures that could send the average retail cost of gasoline above $2.25 a gallon within a few weeks.

*** Note: These are not April Fool Jokes! These are real news clips of the day*

Global warming over the past millennium

Very rapidly we have entered uncharted territory -– what some call the *anthropocene* climate regime. Over the 20th century, human population quadrupled and energy consumption increased sixteenfold. Near the end of the last century, we crossed a critical threshold, and global warming from the fossil fuel greenhouse became a major, and increasingly dominant, factor in climate change. Global mean surface temperature is higher today than it's been for at least a millennium.

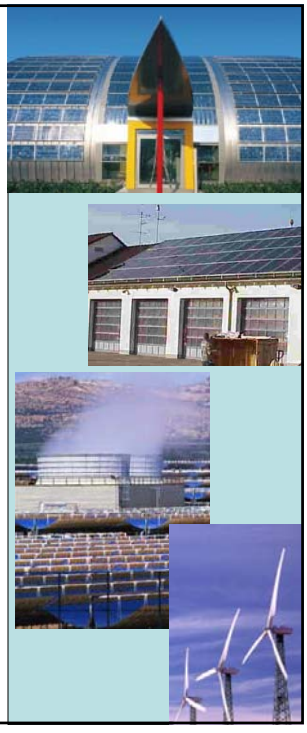
…… Marty Hoffert NYU



The United Nations Framework Convention on Climate Change calls for ''stabilization of greenhouse-gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system . . .''. A standard baseline scenario that assumes no policy intervention to limit greenhouse-gas emissions has 10 TW (10 x 10^{12} watts) of carbon-emission-free power being produced by the year 2050, equivalent to the power provided by all today's energy sources combined.

……..NATURE, VOL 395, 881,1998

Decarbonization, CO_2 sequestering ….
Improved energy efficiency in motor vehicles, buildings and electrical appliances
Beyond 2010 new carbon-free primary power technologies will increasingly be needed (~10TW by 2050)



The Silver Lining …….

The earth receives more energy from the sun in just one hour than the world uses in a whole year.

Cumulative solar energy production accounts for less than 0.01% of total Global Primary Energy demand.

Solar Energy demand has grown at about 25% per annum over the past 15 years (hydrocarbon energy demand typically grows between 0-2% per annum). Worldwide photovoltaic installations increased by 927 MW in 2004, up from 574 MW installed during the previous year.

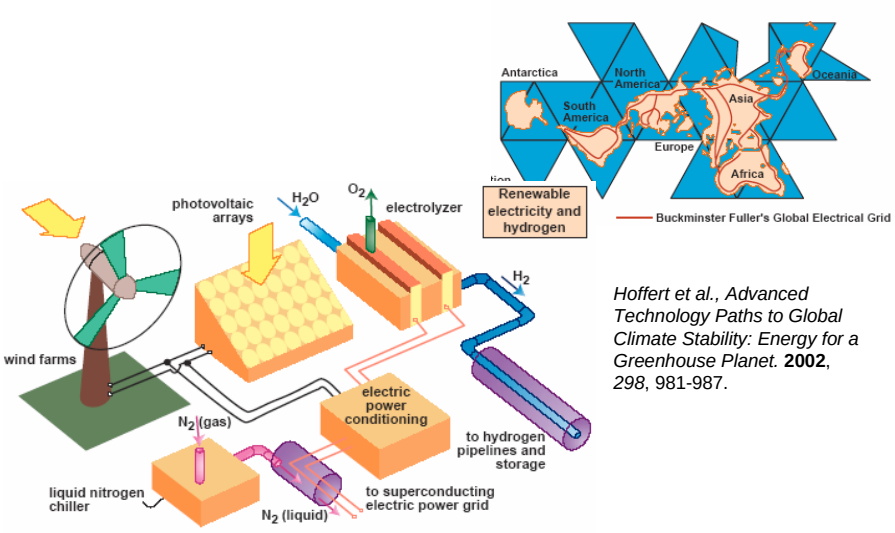
An average crystalline silicon cell solar module has an efficiency of 15%, an average thin film cell solar module has an efficiency of 6%. (*Thin film manufacturing costs potentially are lower, though.)*

Solar Energy (photovoltaic) prices have declined on average 4% per annum over the past 15 years.

For the Fiscal Year 2002, the Japanese solar roof top program received applications from 42,838 households.
Without incentive programs, solar energy costs (in an average sunny climate) range between 22-40 cents/kWh for very large PV systems. (installation costs $8-$10 with no government incentives)

Japan has taken over from the United States as the largest net exporter of PV cells and modules. Around 50 % of the world's solar cell production was manufactured in Japan in 2003. United States accounted for 12%.

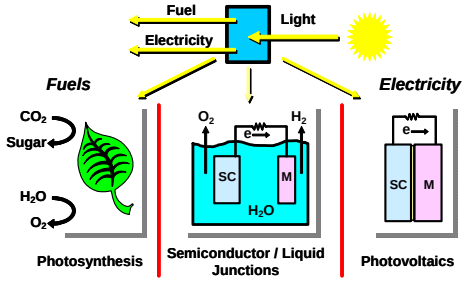
Boxes showing land area requirements to produce 3 TW or 20 TW of photovoltaic energy at 10% efficiency.



Hoffert et al., Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet. **2002**, *298*, 981-987.

Mass-produced widely distributed PV arrays and wind turbines making electrolytic H2 or electricity may eventually generate 10 to 30 TW emission-free. The global grid proposed by R. Buckminster Fuller with modern computerized load management and high-temperature superconducting (HTS) cables could transmit electricity from day to night locations

Energy Conversion Strategies

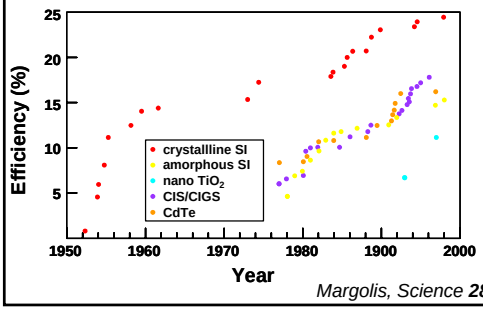


Need for alternative energy sources –Solar Energy

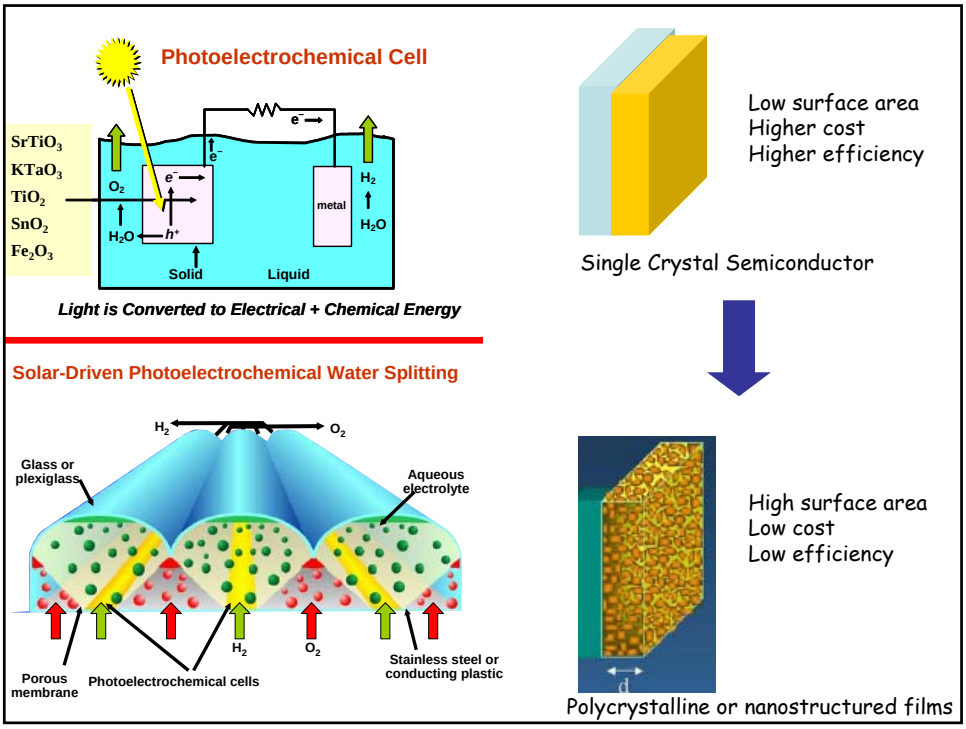
Overcome the environmental issues – Greenhouse effect

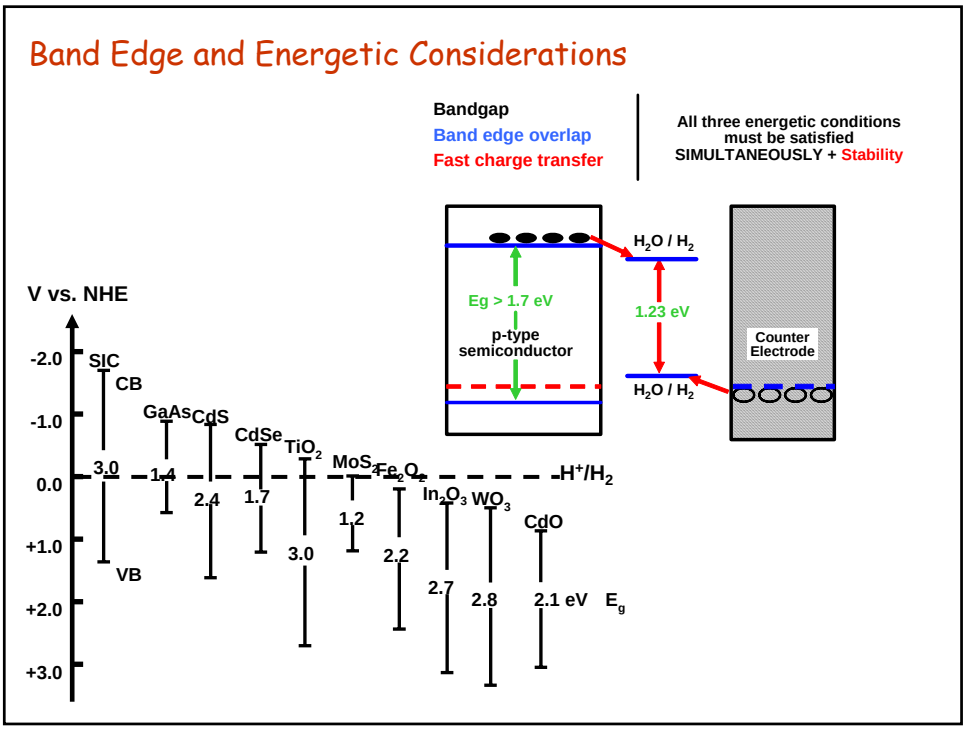
Decrease the cost per watt by improving the efficiency –solar paint, flexible cells

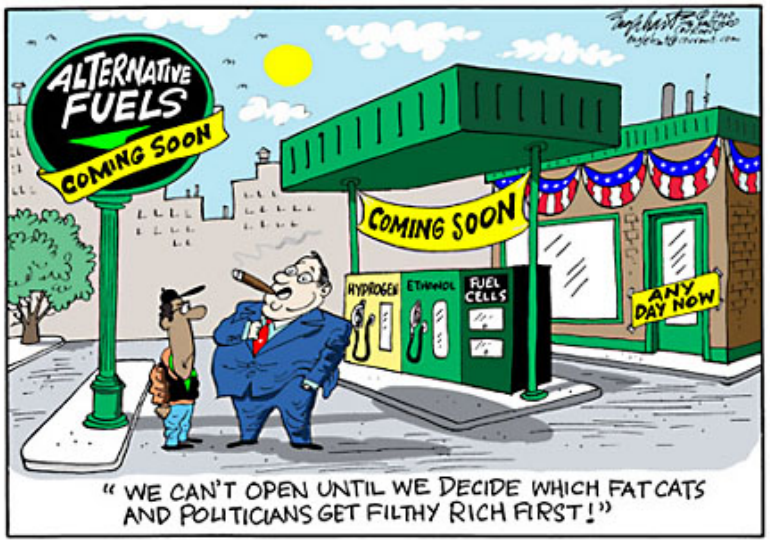
Efficiency of Photovoltaic Devices



*Margolis, Science **285**, 690, 1999)*

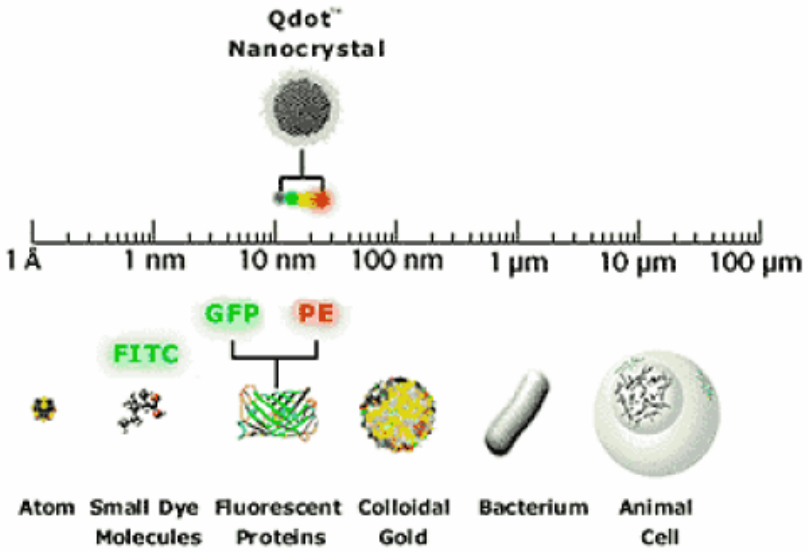

Photoelectrochemical Cell
$SrTiO_3$
$KTaO_3$
TiO_2
SnO_2
Fe_2O_3
O_2
H_2O
e^-
h^+
metal
H_2
H_2O
Solid
Liquid
Light is Converted to Electrical + Chemical Energy
Low surface area
Higher cost
Higher efficiency
Single Crystal Semiconductor
Solar-Driven Photoelectrochemical Water Splitting
H_2
O_2
Glass or plexiglass
Aqueous electrolyte
Porous membrane
Photoelectrochemical cells
Stainless steel or conducting plastic
High surface area
Low cost
Low efficiency
Polycrystalline or nanostructured films


Band Edge and Energetic Considerations
Bandgap
Band edge overlap
Fast charge transfer
All three energetic conditions must be satisfied SIMULTANEOUSLY + Stability
V vs. NHE
-2.0
-1.0
0.0
+1.0
+2.0
+3.0
SiC
CB
VB
3.0
GaAs
1.4
CdS
2.4
CdSe
1.7
TiO_2
3.0
MoS_2
1.2
Fe_2O_3
2.2
In_2O_3
2.7
WO_3
2.8
CdO
2.1 eV
E_g
H^+/H_2
Eg > 1.7 eV
p-type semiconductor
H_2O / H_2
1.23 eV
H_2O / H_2
Counter Electrode



How can we address the energy challenge with advances in Nanotechnology?

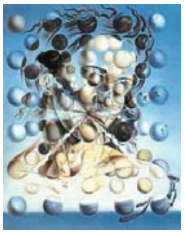
Nanoworld



Nature Materials, February 2005 Commentary

To be nano or not to be nano?

CHRISTIAN JOACHIM



Galatée aux Sphères
(Salvador Dali, 1952).

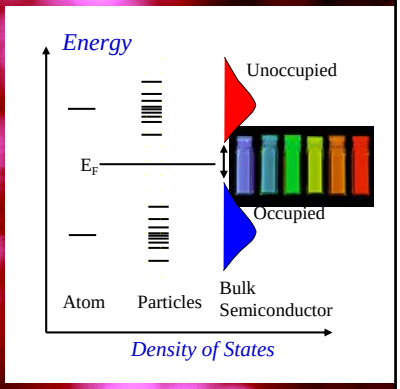
Nanomaterials, nanostructures, nanostructured materials, nanoimprint, nanobiotechnology, nanophysics, nanochemistry, radical nanotechnology, nanosciences, nanooptics, nanoelectronics, nanorobotics, nanosoldiers, nanomedecine, nanoeconomy, nanobusiness, nanolawyer, nanoethics to name a few of the nanos. We need a clear definition of all these burgeoning fields for the sake of the grant attribution, for the sake of research program definition, and to avoid everyone being lost in so many nanos.

Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale.

…….Royal Society of London report *Nanoscience, and Nanotechnology: Opportunities and Uncertainties*, 2004

Unique Aspects of nanostructures

- Organization of molecular-particle composites
- 2- and 3-D assemblies
- Control of electronic and surface properties

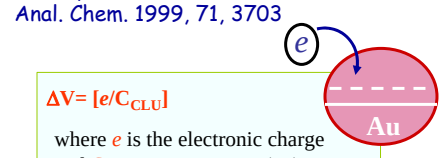


Applications

- Optoelectronics, photonics, displays
- Chemical and biosensors
- Catalysis, photovoltaics and fuel cells

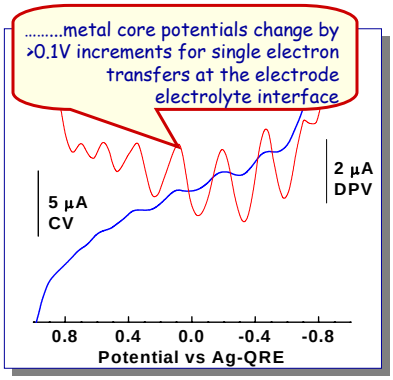
Quantized double layer charging effects

Murray et al. Science, 1998, 280, 2098 and Anal. Chem. 1999, 71, 3703



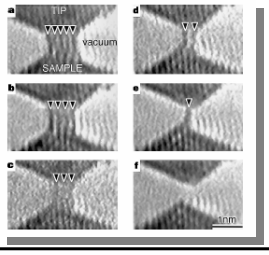
$\Delta V = [e/C_{CLU}]$

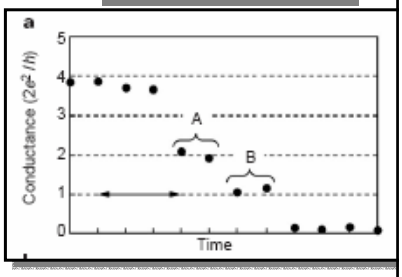
where e is the electronic charge and C_{CLU} is capacitance (aF)



Quantized conductance through individual rows of suspended gold atoms

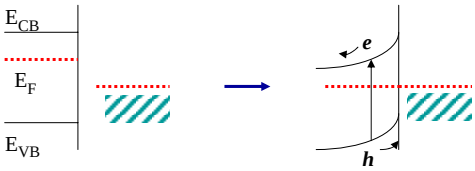
H. Ohnishi, Y. Kondo & K. Takayanagi Nature, 395, 780 (1998)

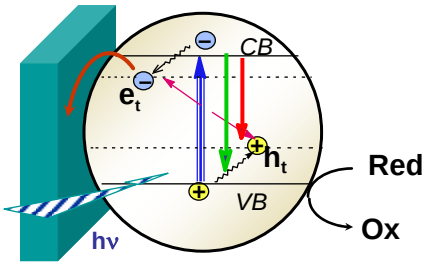




unit conductance $G_0 = 2e^2/h$.

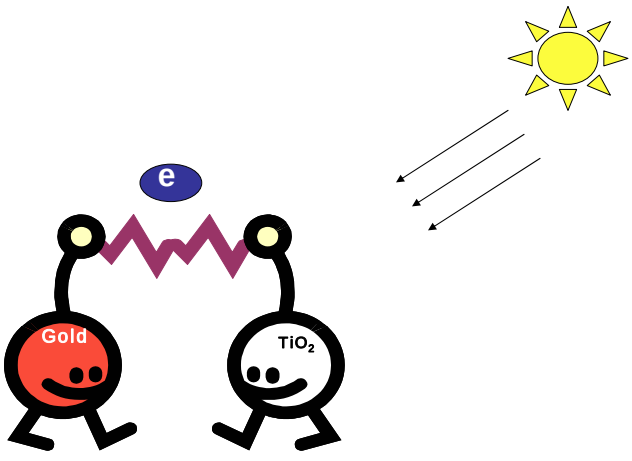
Semiconductor (bulk)/metal (or redox couple)





Issues: Charge separation and charge transport

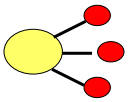
Molecular Engineering of Inorganic-Organic Hybrid Assemblies

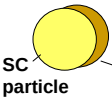


Simple assemblies of elementary nanoobjects

Wire connected to Metal
or SC Nanoparticle

Particles
connected
by small
molecules





Metal capped
Particles

SC
particle

Metal,
Catalyst