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The Future Impact of Nanotechnology Research on Society

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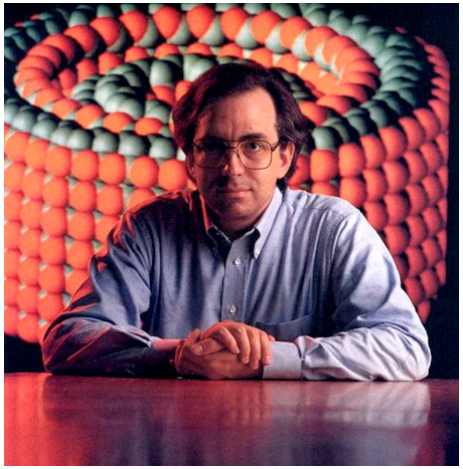
The Scary Future!

*"Nanotechnology will alleviate world hunger, clean the environment, cure cancer, guarantee biblical life spans or concoct super weapons of untold horrors."**

Nano-aliens fight human warfare



Nano-assemblers that will be able to copy and duplicate themselves, self-assemble into anything, including human body parts, in seconds. These nano-assemblers may take control of human race.

Trains and airplanes powered by nano-machines

* Scientific American, Sept., 2001.

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Nanotechnology is showing up in unexpected places

"Nanotech takes new fabric past drip-dry into drip-free"

**USA Today Wednesday, January 10, 2001*

By Kevin Maney

By this summer, you'll be able to have nanotechnology in your pants. Oh, baby.

Really – you'll walk into a store and see pants tagged with the brand name Nano-Dry or Nano-Care, each made with nanotechnology created by Nano-Tex, a 14-person company that's 51% owned by fabric giant Burlington Industries. This might be the first time that nanotech shows up in a mass-market consumer product – a landmark of sorts. You could even say these will be the first true smarty-pants…

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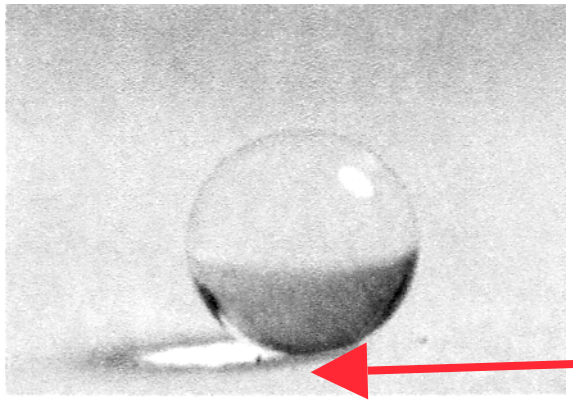
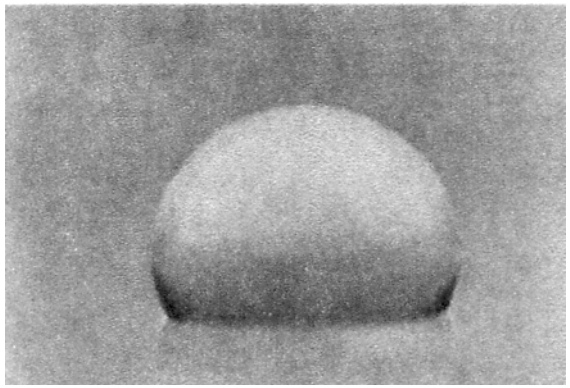
Nice pants, thanks to nanoscience

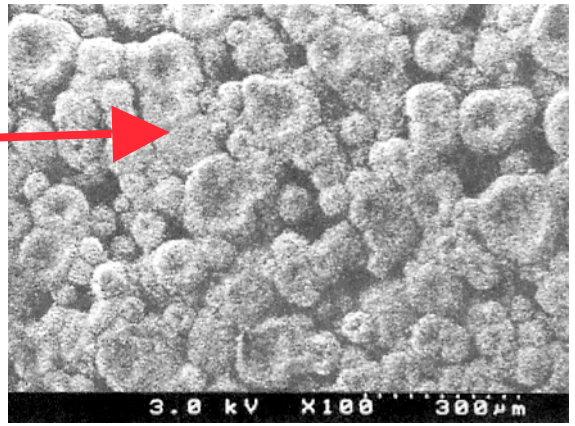
Water Drop on
Fractal Surface





Water Drop on
Smooth Surface

Nano-Roughness
Minimizes Contact



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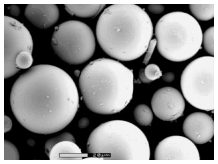
The scale of things Natural…

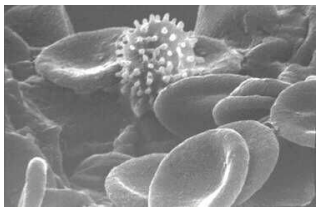
Ant
~ 5 mm

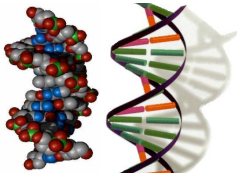
Human hair
~ 10-50 μm wide



Fly ash
~ 10-20 μm

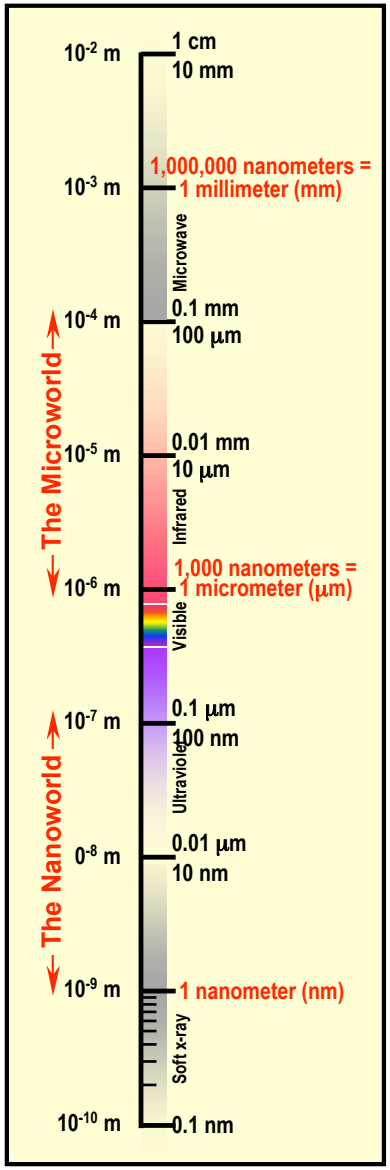
Red blood cells with white cell
~ 2-5 μm





DNA
~2 nm diameter

Atoms of silicon
spacing ~0.2 nm



10^{-3} meter

10^{-6} meter

10^{-9} meter

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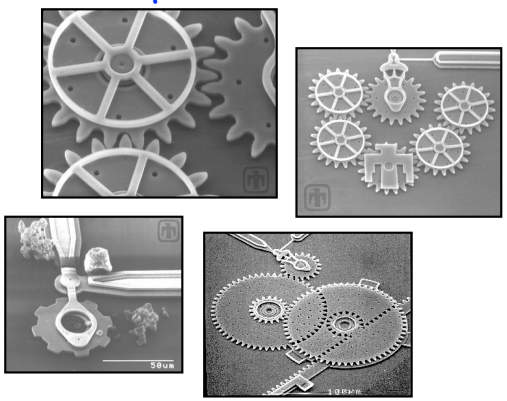
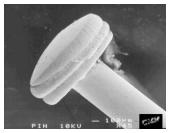
The scale of things Man-made…

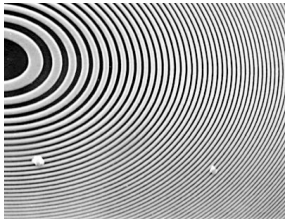
Micro-Machines
10 -100 μm wide

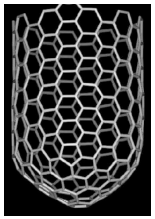




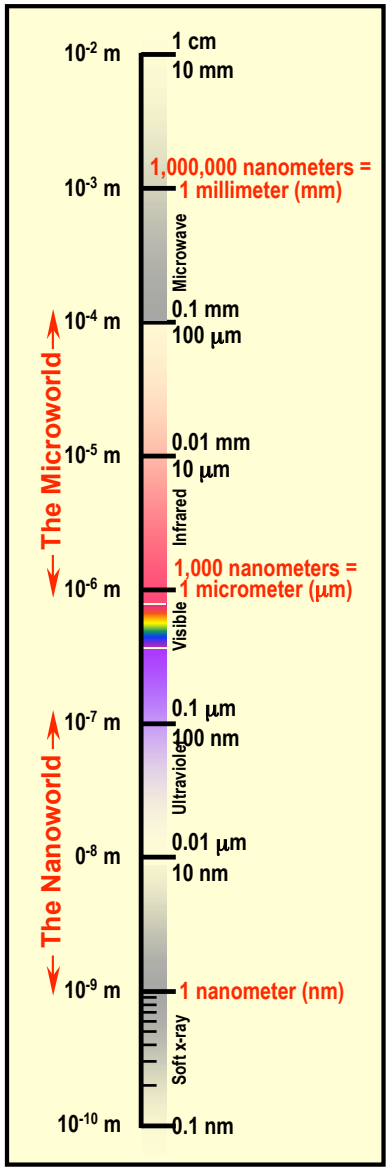
Head of a pin
1-2 mm

X-ray "lens"
ring spacing ~35 nm





Carbon nanotube
~2 nm diameter



10^{-3} meter

10^{-6} meter

10^{-9} meter

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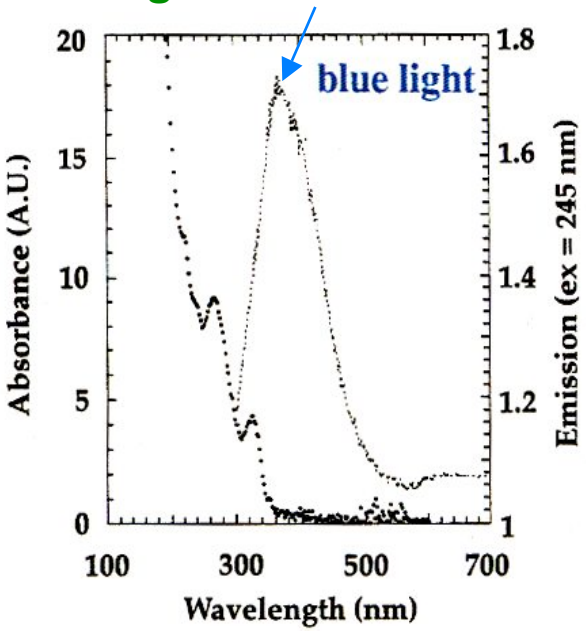
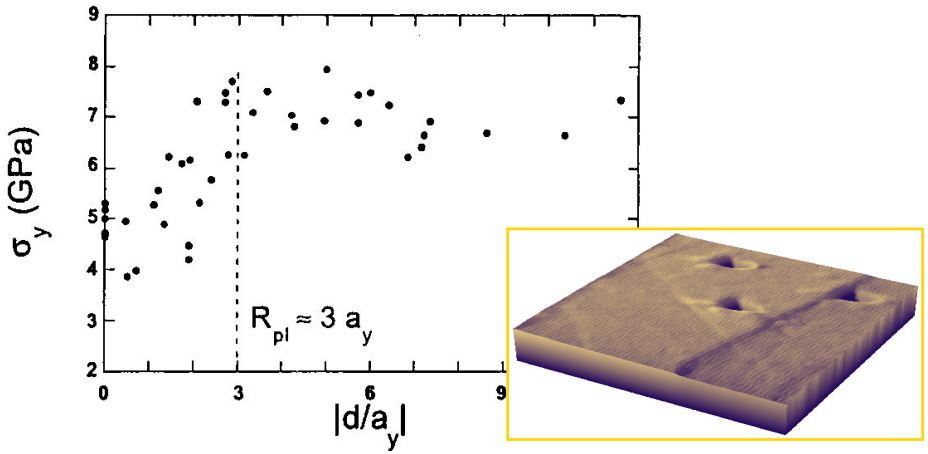
Ordinary materials can behave differently at the nano-scale

Light from Silicon



Steel-like strength from gold



New phenomena from…

- Surfaces and interfaces
- Quantized effects

Lead to…

- New physical effects
- New chemistry
- New mechanical properties

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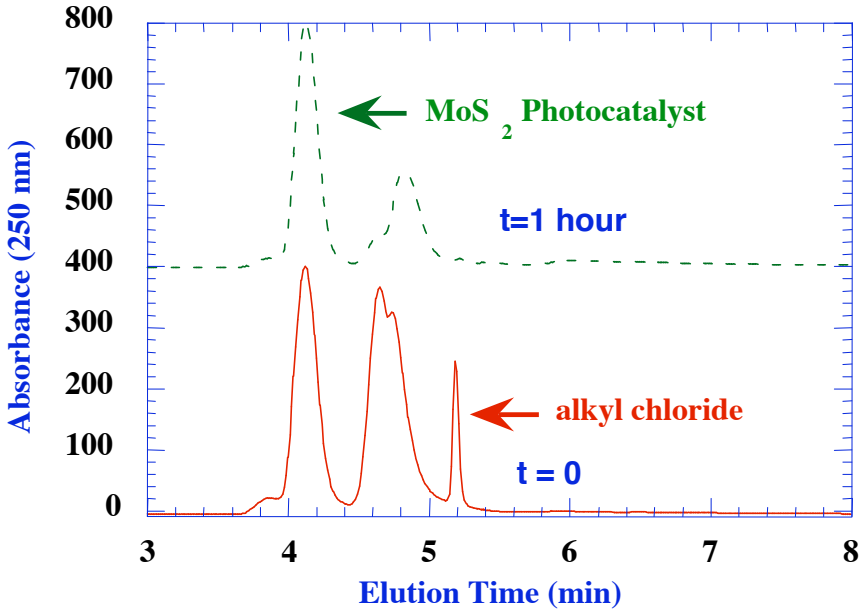
Semiconductor nano-crystals use sunlight to clean up pollutants



MoS_2 nanocrystals photo-oxidize an alkyl chloride using only visible light

- **Environmental remediation**
- **Solar photocatalysis/fuel production**

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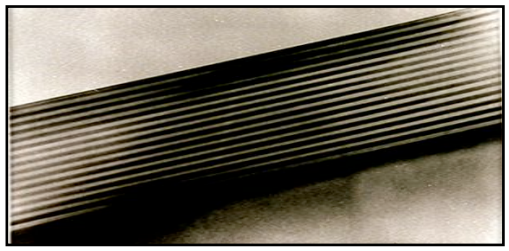
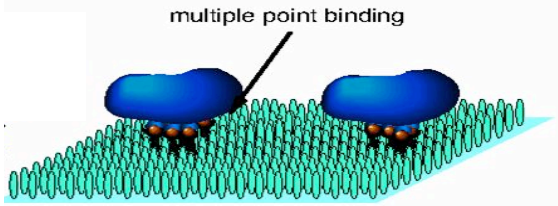
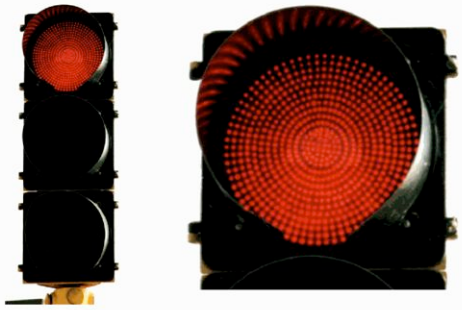
Integrated Nanotechnology will impact our world

Energy

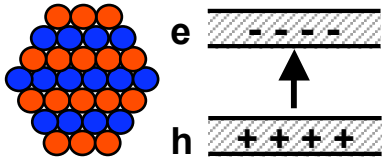


Bio-Medical





Environment



Connecting scientific disciplines and length-scales is key to success

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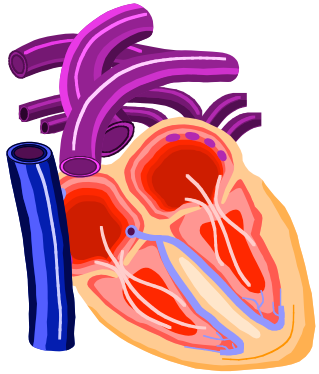
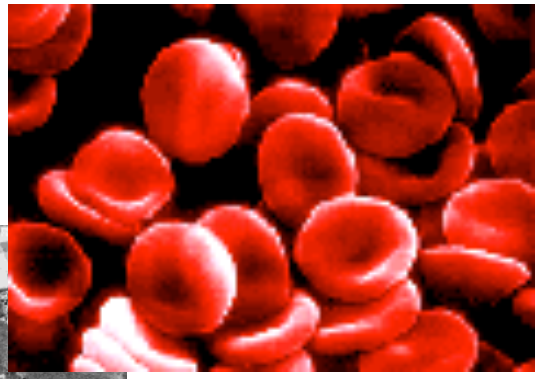
You are the best example of "integrated nanotechnology"

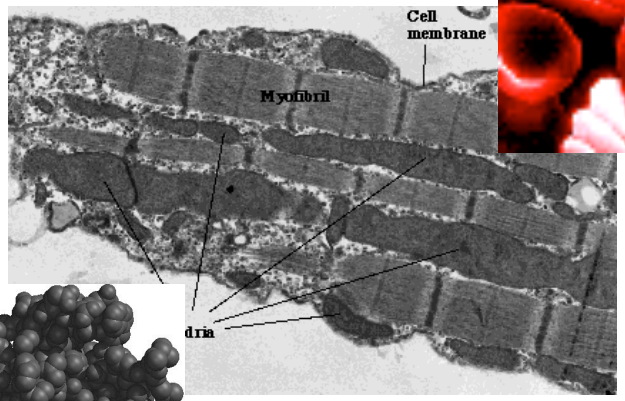
Integrated structures combine multiple length scales and functions.



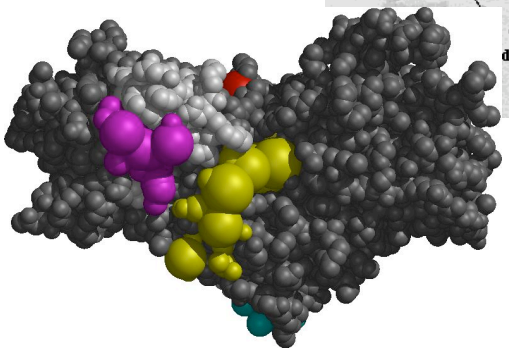
Organs and Tissues



Cells



Sub-cellular mechanical structure



Molecules and Chemical Pathways

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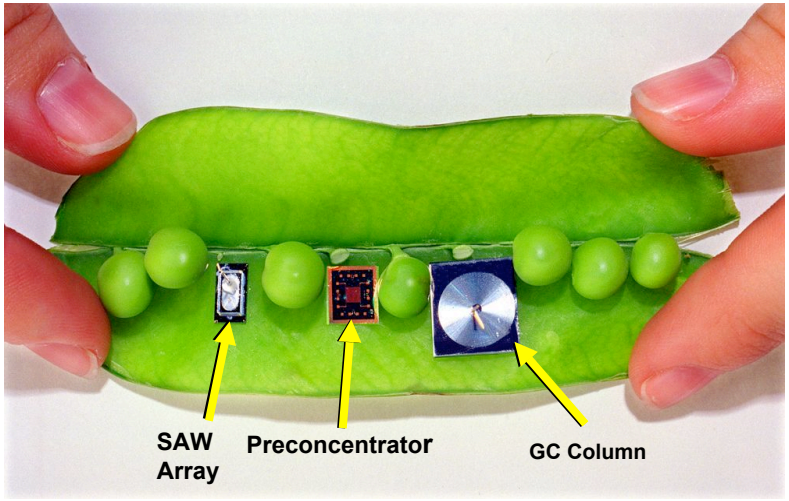
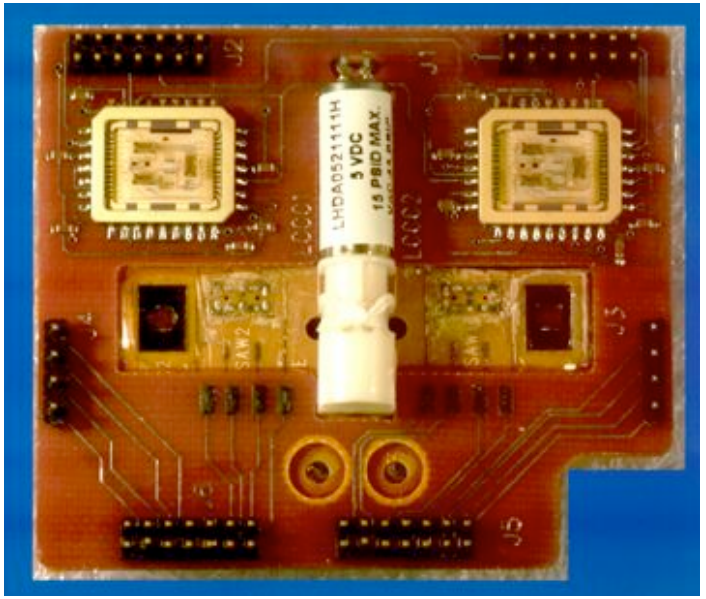
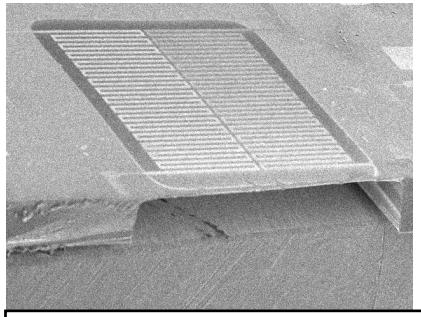
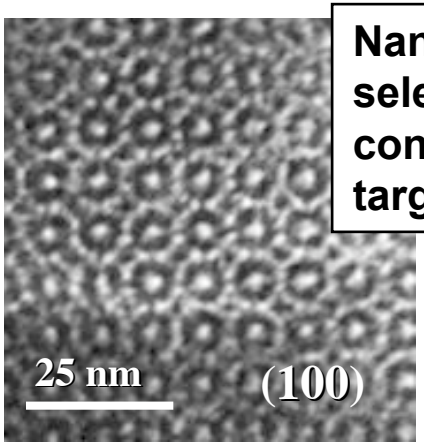
µChemLab™ is engineered down to the molecular level







Micro-scale heater



Nanoporous film selectively concentrates target analytes.

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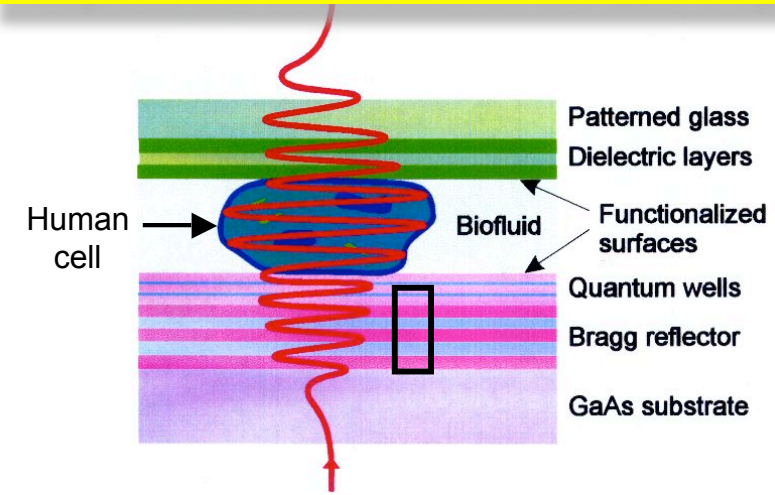
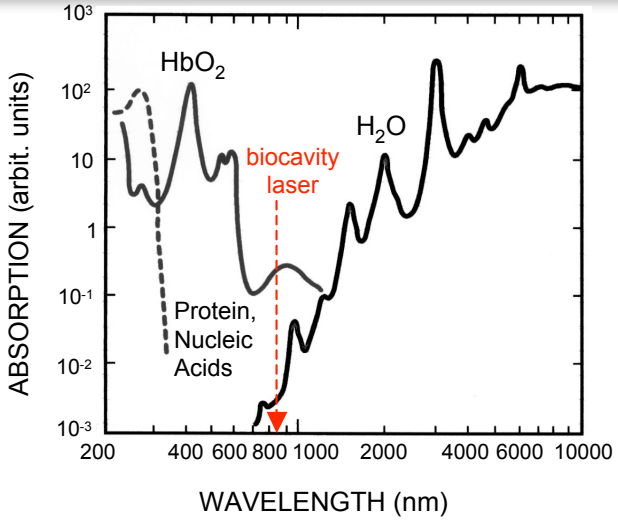
The BioCavity Laser combines nano and micro technologies

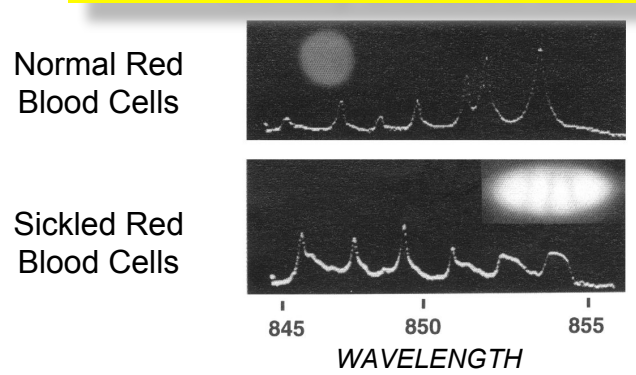
Biological cells form part of a semiconductor laser and impress cell information on the laser's optical output



The semiconductors are tailored to emit where the cells are transparent



Unique emission signatures identify diseased cells



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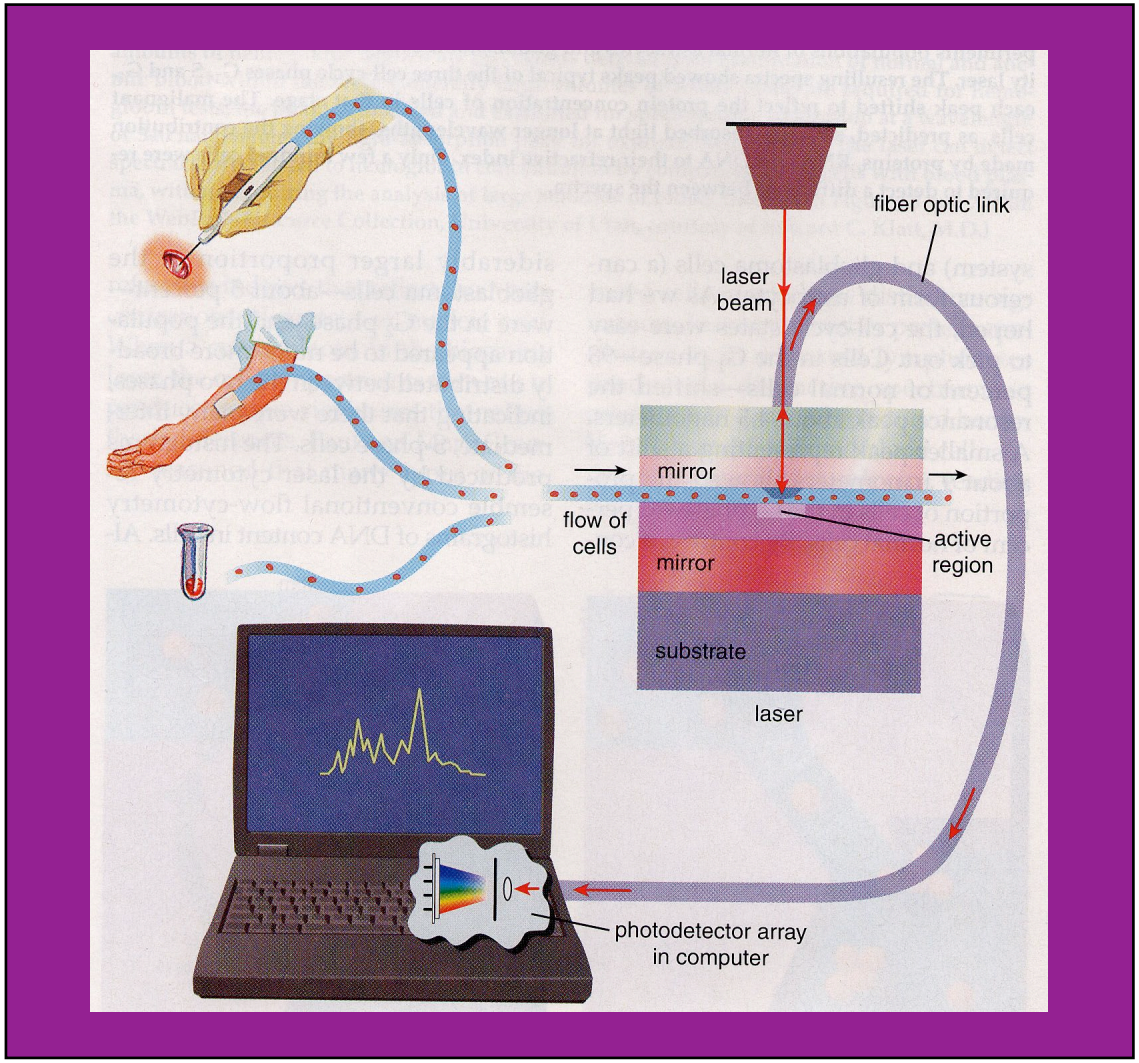
Biocavity laser technology could combine detection and treatment



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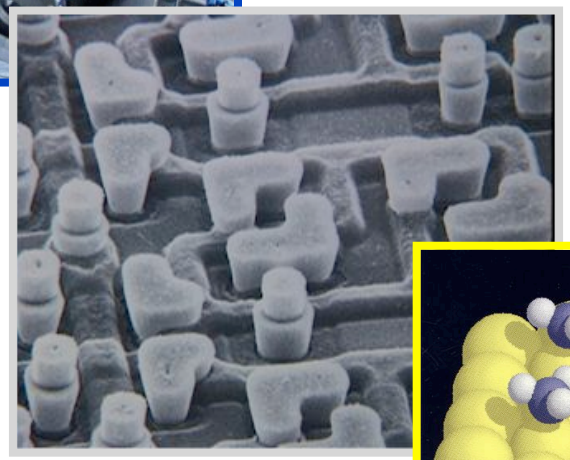
How is nano-technology different from micro-technology?

Conventional Machines

Build and assemble

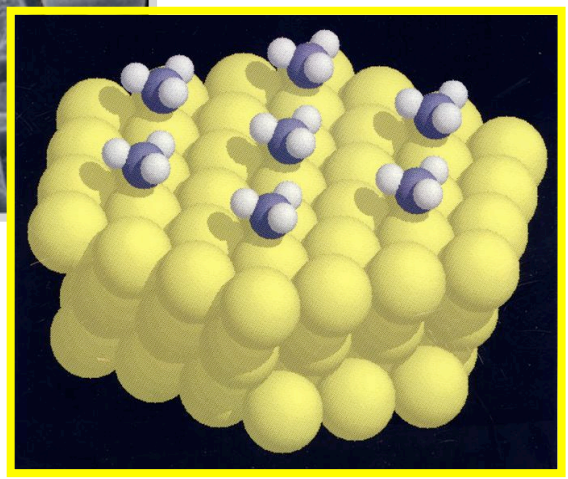
(m - mm)



Microelectronics

Top down - build in place

(10 - 0.1 µm)



Nanotechnology

Bottom up - self assembled

(1- 100 nm)

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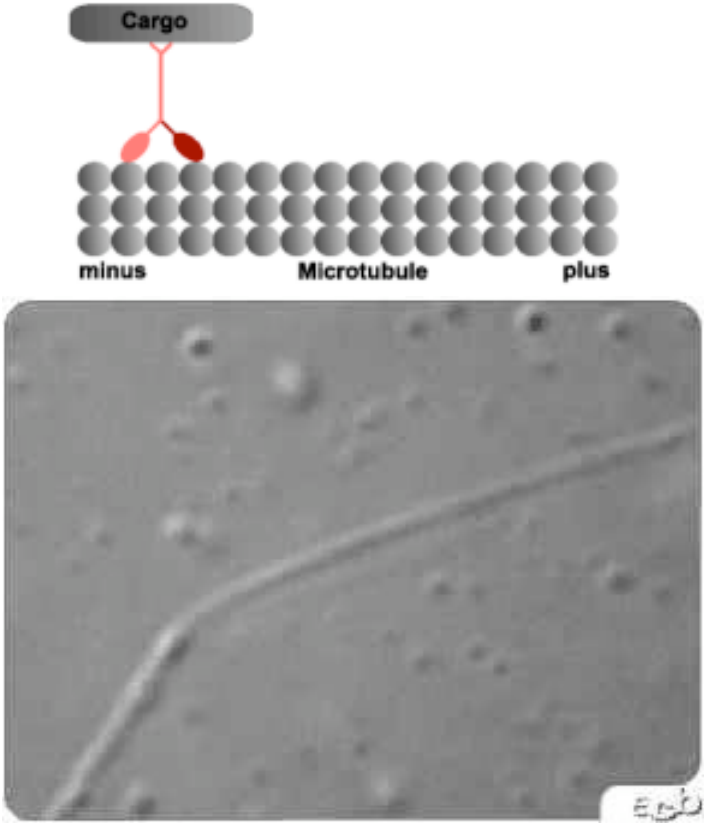
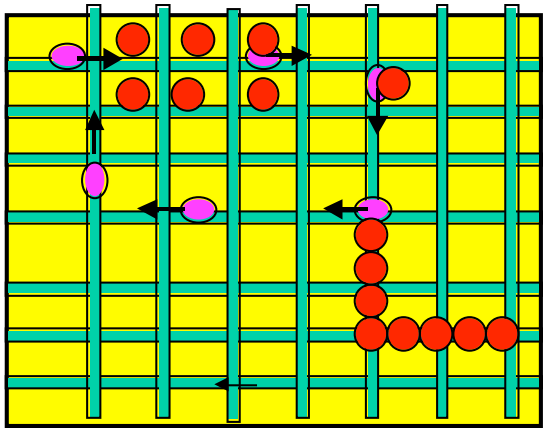
How Nature moves things…

Directed translation of molecular cargo as a result of energy consumption;
Nature's solution to diffusion problems.





*From: Alberts et al. (1998)
"Essential Cell Biology."

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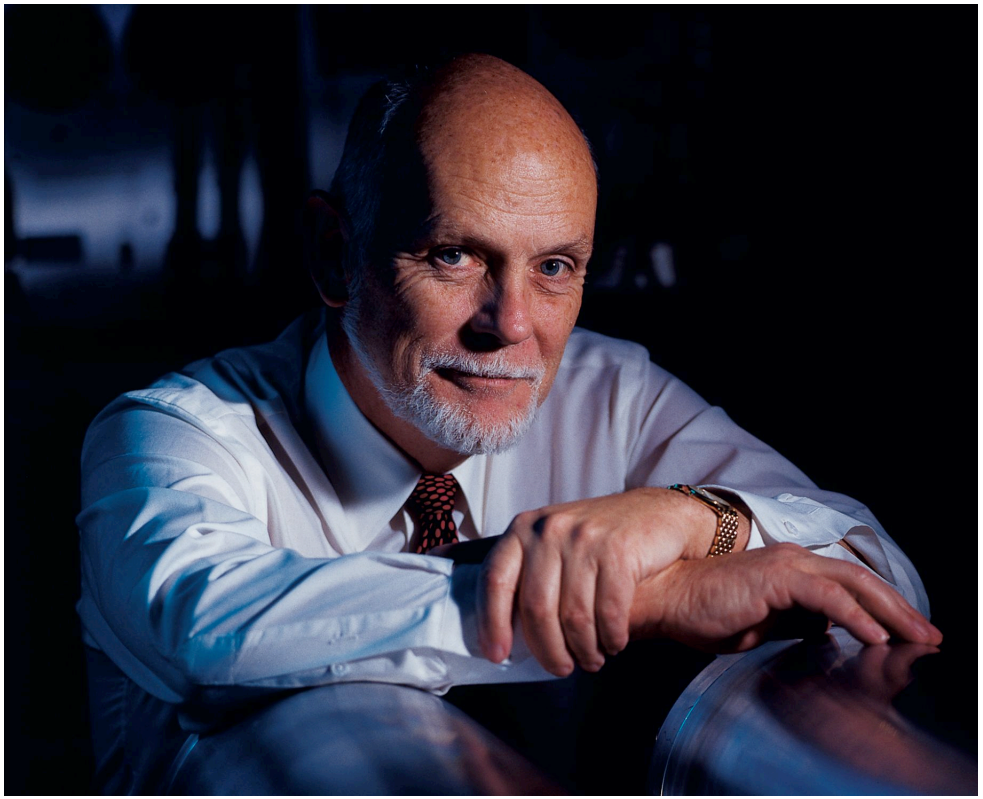
What are the really big challenges for humankind?



Richard Smalley
1943-2005

"How many of them could be solved with inexpensive energy?"

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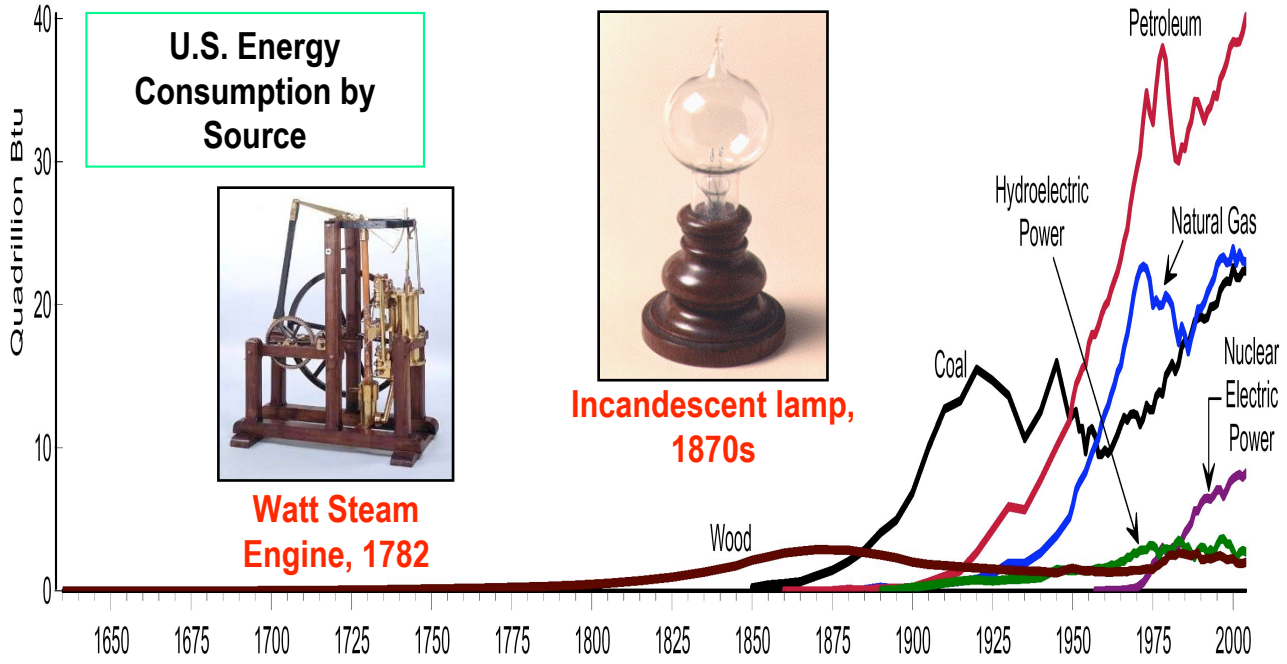
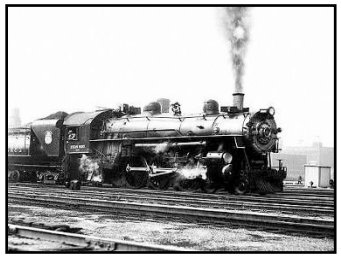
Technology, Energy, and Society are inextricably intertwined



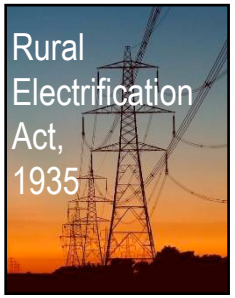
Watt Steam Engine, 1782

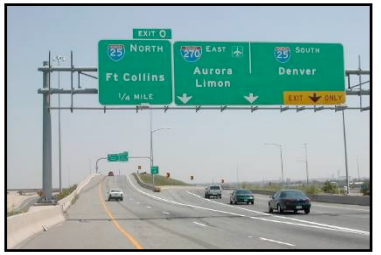
Incandescent lamp, 1870s

Wind, water, wood, animals, (Mayflower,1620)



Intercontinental Rail System, mid 1800s





Eisenhower Highway System, 1956

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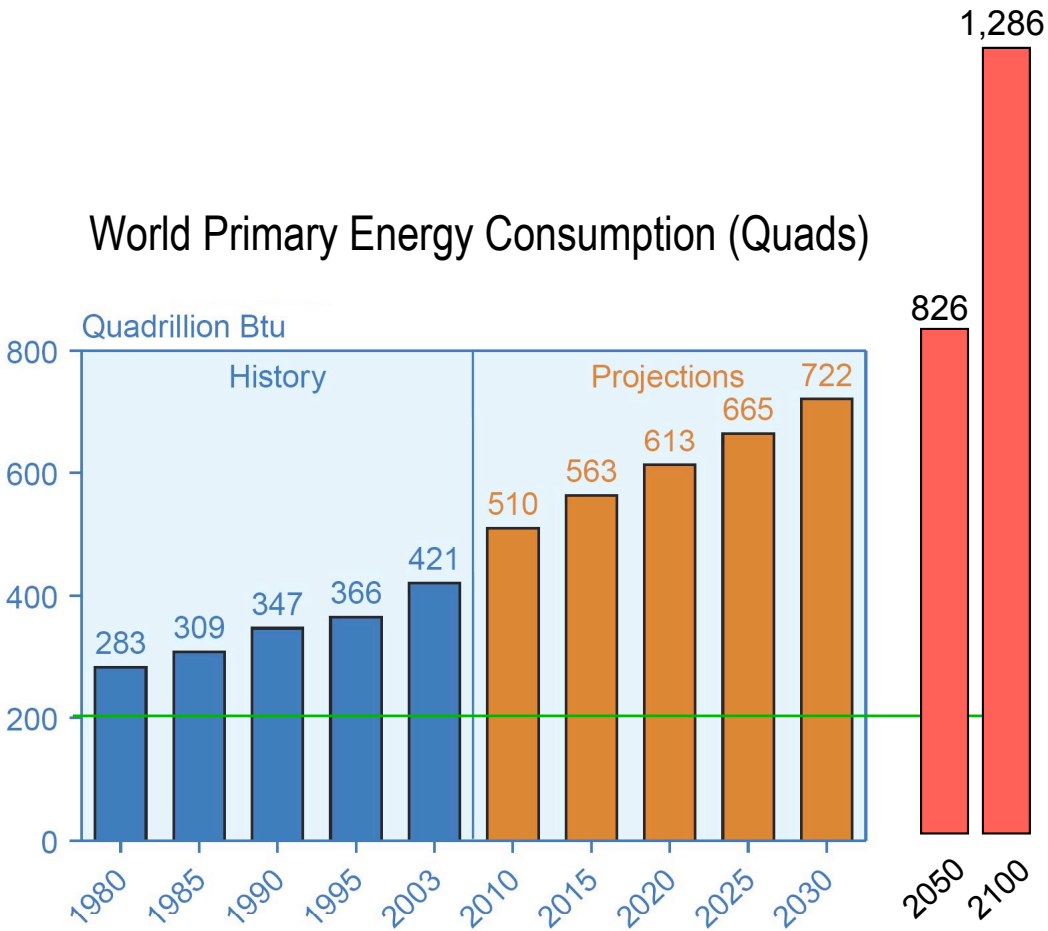
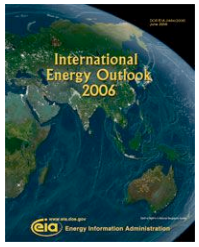
World Energy Needs will Grow Significantly



Projections to 2030 are from the Energy Information Administration, International Energy Outlook, 2006.

Projections for 2050 and 2100 are based on a scenario from the Intergovernmental Panel on Climate Change (IPCC), an organization jointly established in 1988 by the World Meteorological Organization and the United Nations Environment Programme. The IPCC provides comprehensive assessments of information relevant to human-induced climate change.



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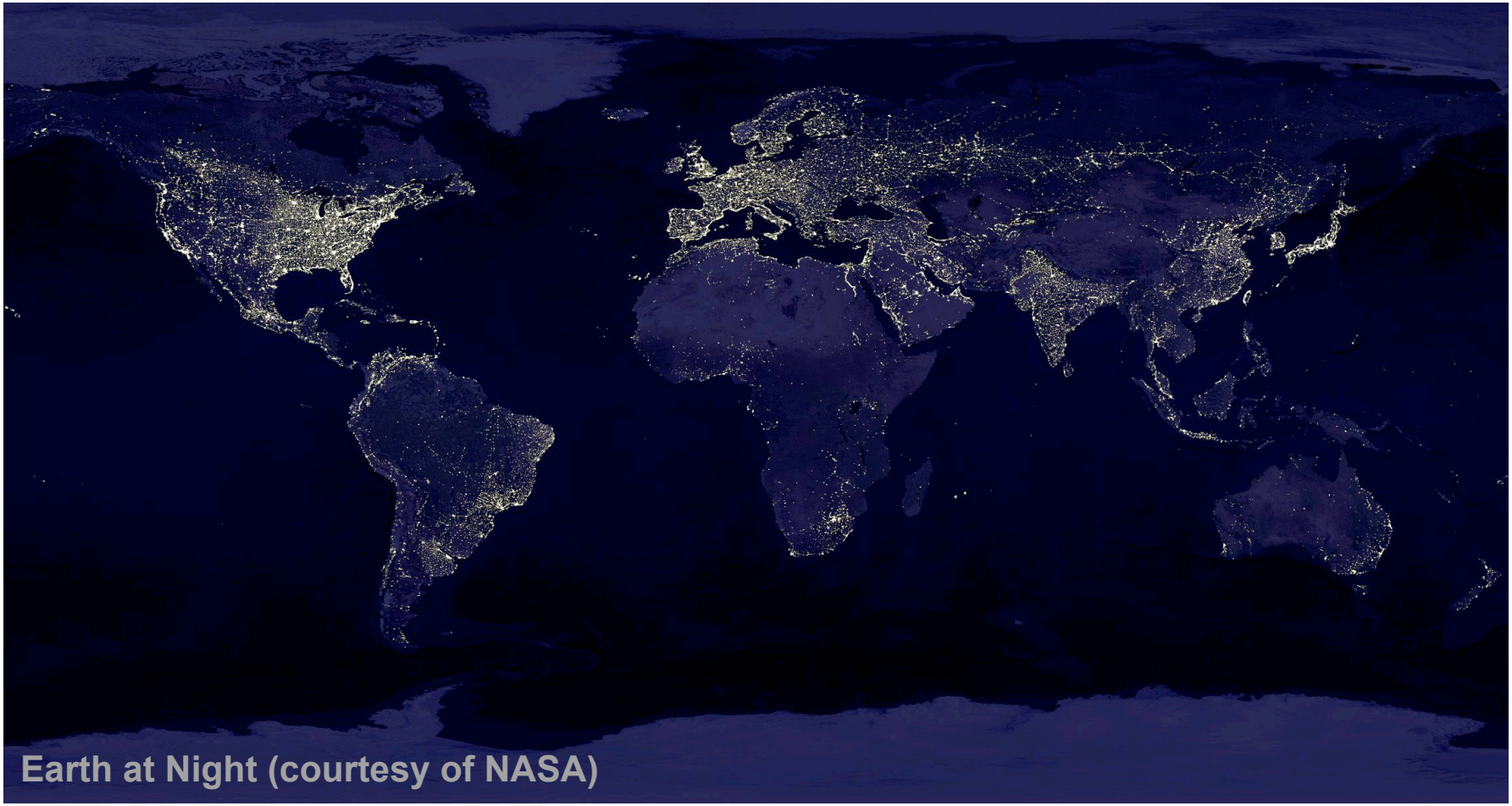
Lighting the Earth



Earth at Night (courtesy of NASA)

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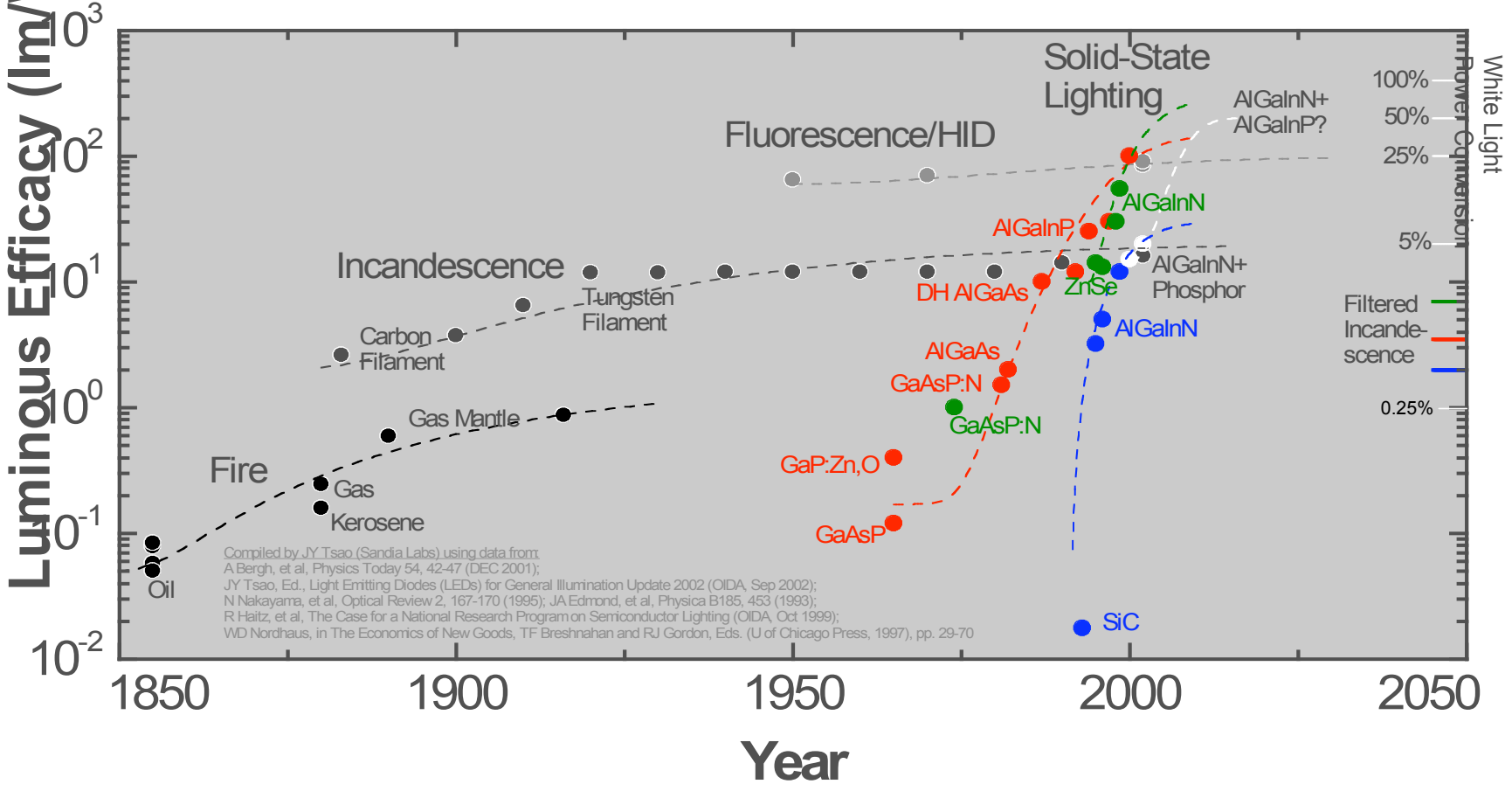
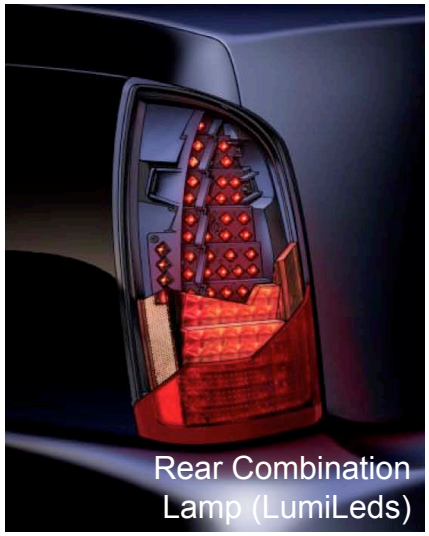
History of Lighting Technology



Applications for Colored LEDs

Red Traffic Light



Rear Combination Lamp (LumiLeds)

NASDAQ's Giant Video Display in Times Square, New York (Jeff Tsao)

Programmable Lights on Ben Franklin Bridge, Philadelphia (Color Kinetics)

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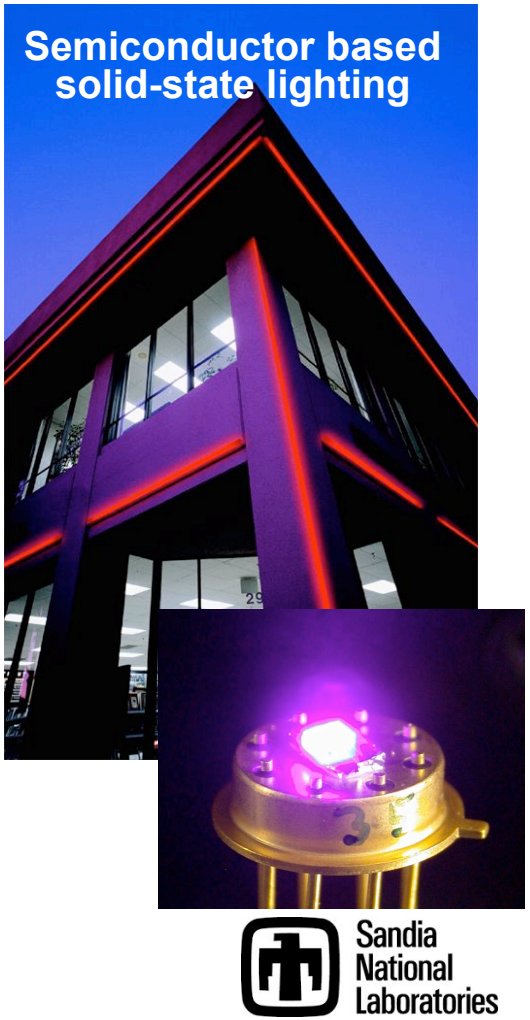
Solid-State Lighting can be part of the answer

- **Solid State Lighting will achieve 50% efficiency by 2025, *reducing the nation's electricity consumption by 10%***

- **To achieve 50% efficiency, we need to understand:**
  - ***Charge carrier transport at the nanoscale***
  - ***Quantum confinement***
  - ***Radiative & non-radiative recombination***
  - ***Point and extended defects***
  - ***How molecular structure controls function***

The obstacles to achieving 50% energy efficient SSL are *nanoscience problems.*



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After the energy challenge is solved…

"Nations have gone to war over oil, but there are substitutes for oil. There is no substitute for water. We have about 300 million people who are living in areas of serious to severe water shortages right now. Twenty years from now, that will be 3 billion. It is just overwhelming."

Sen. Paul Simon, "Tapped Out"

"Whiskey is for drinking. Water is for fighting."
Mark Twain

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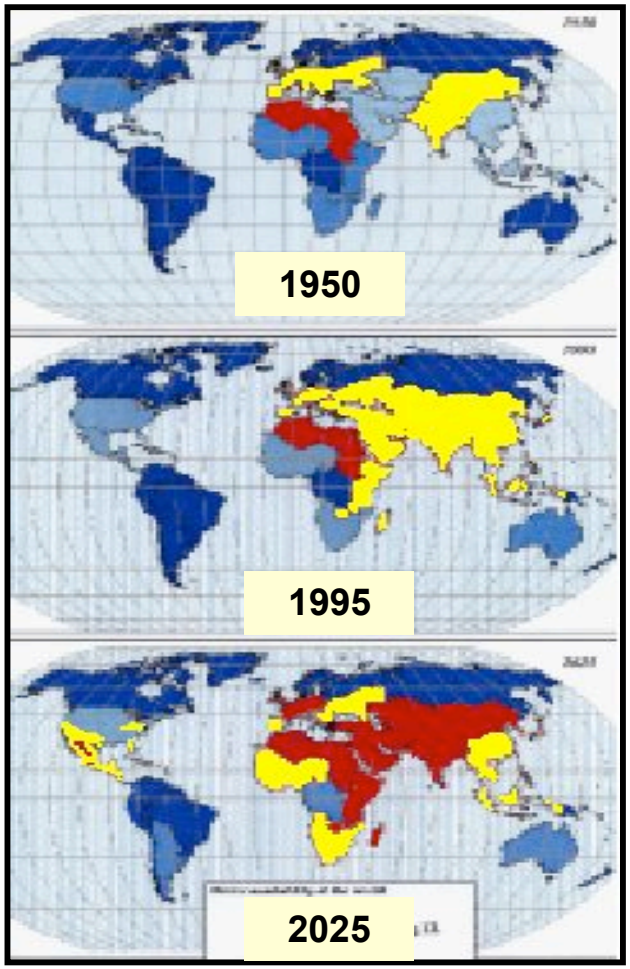
Over half the world's population will face severe water shortage in 50 years.

- In 1990, poor water supply and sanitation was the 2nd leading cause of death and disability worldwide.
- Over 50% of world's major rivers are dry or heavily polluted.
- By 2025, 20% more fresh water will be needed for irrigation and 40% more for cities to maintain current per capita water levels.
- Access to fresh water will increasingly become a national security concern and source of potential conflict



"Water promises to be to the 21st century what oil was to the 20th century: the precious commodity that determines the wealth of nations."

Fortune Magazine, May 15, 2000

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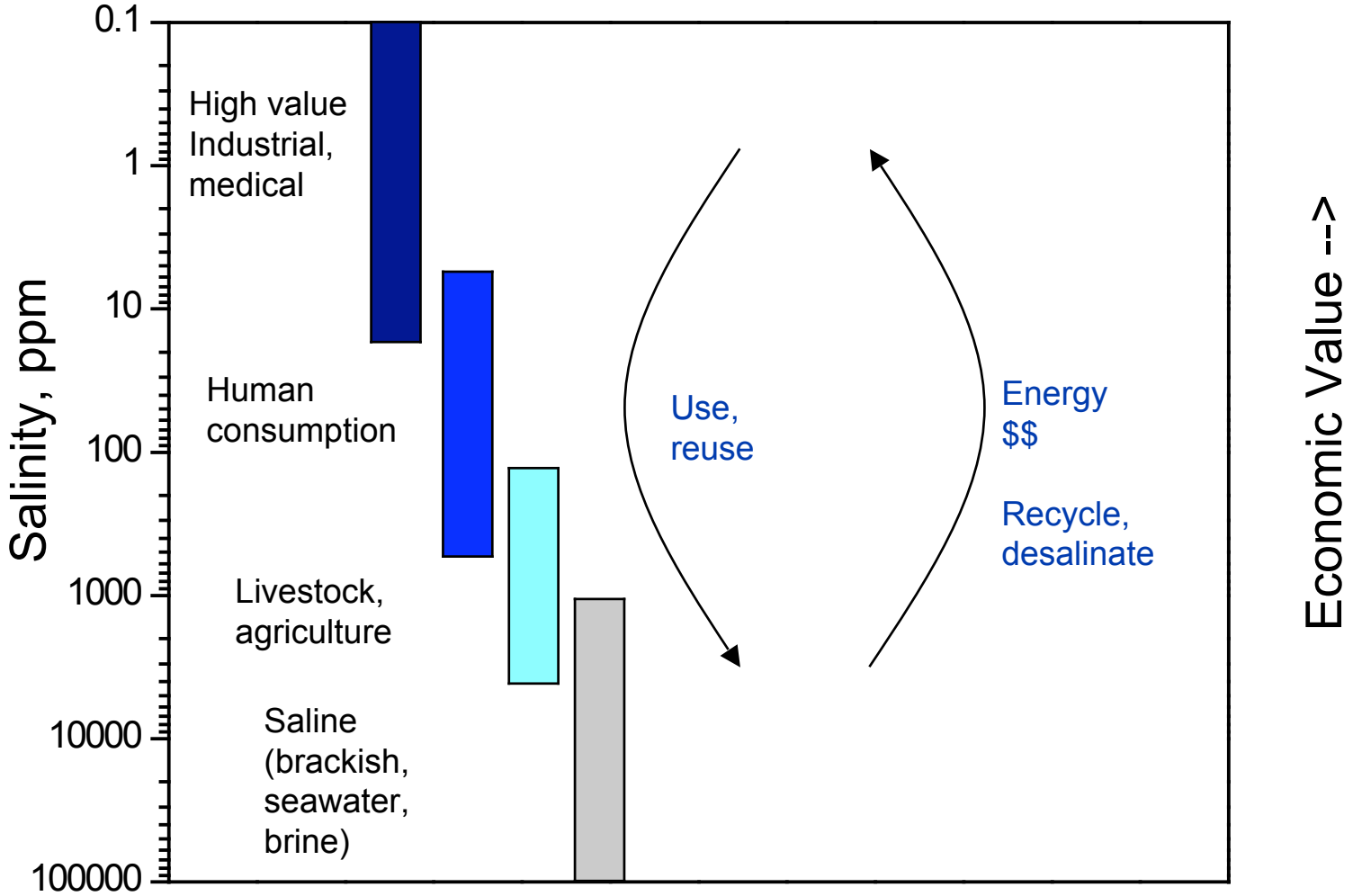
Water is infinitely recyclable, …at a cost



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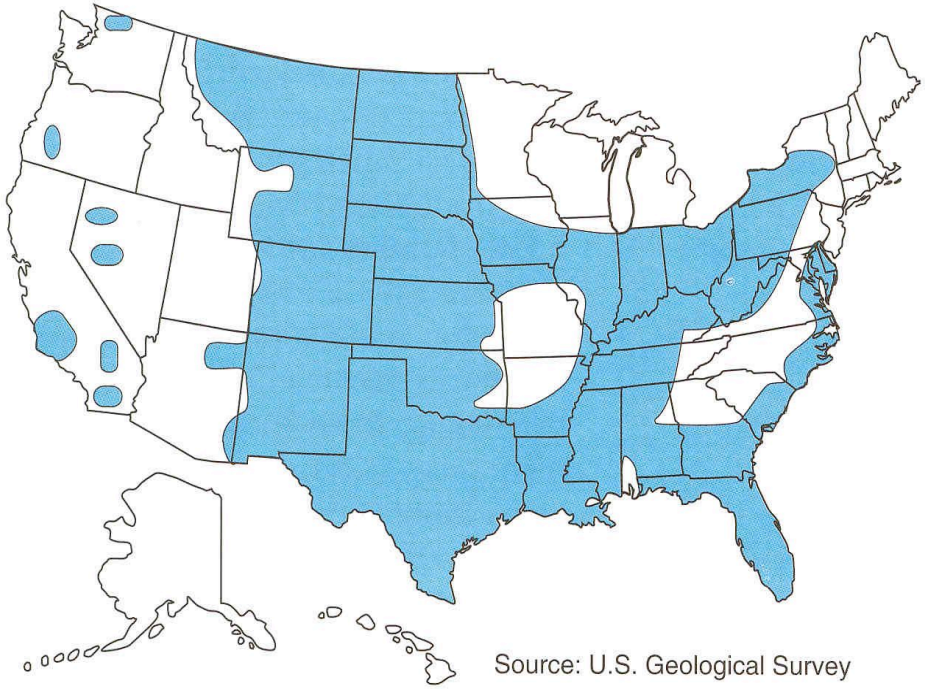
Opportunity: Technologies to use inland saline waters

- Inland desalination is a becoming a necessity
  - Surface water fully allocated, increasingly polluted
  - No new fresh groundwater resources
- Inland issues include brine disposal, saline water variability, and inland process scale
- Desalination costs and environmental issues of brine disposal need to be reduced

US Saline Aquifers



Source: U.S. Geological Survey

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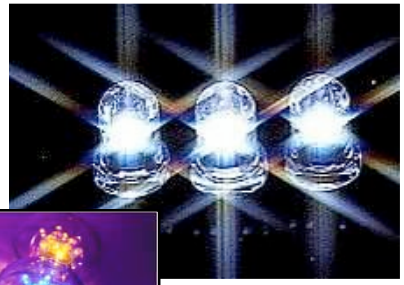
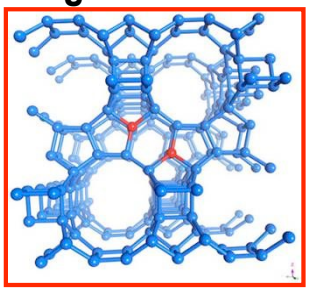
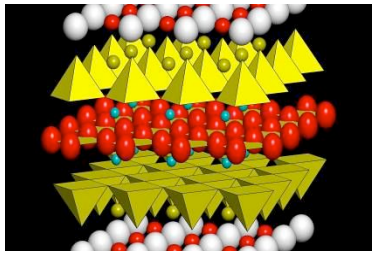
What Will the 21st Century Bring?



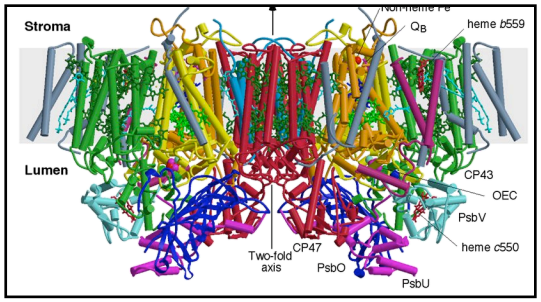
Solid-state lighting and other applications of quantum confinement and low-dimensionality

Designer molecules

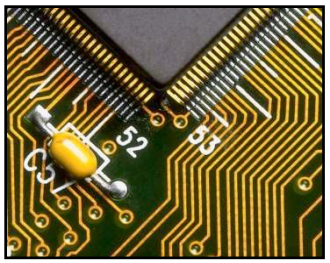




High Tc superconductors



Bio-inspired nanoscale assemblies – self-repairing and defect-tolerant materials and selective and specific chemical reactivity.



Peta-scale computing

21st Century Science and Technology Will Exert Control at the Atomic, Molecular, and Nanoscale Levels

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Challenge: overcoming fear factors

- Involuntary: Products containing nanomaterials
- Unfamiliar or novel sources
- Results from man-made sources
- Causes hidden and irreversible damage
- Poorly understood by science or responsible agencies
- Described in contradictory statements from responsible sources; Utopian and apocolyptic representations of nano abound

(Sources: Nordan, 2005; Bennett & Calman, 1999)

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A Message for Scientists

House Science Committee Chairman Boehlert,
Washington Summit on Climate Stabilization, September 18-21, 2006

"… So scientists have to engage. And what scientists say needs to be clear and accurate and modulated and persuasive. Hyperbolic claims will only diminish scientific credibility over time. Scientists have to be clear about what we know, and about what we don't. They need to be 'up front' about uncertainties - and about the potential costs of waiting until all uncertainties are resolved."

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