

Engineering is the profession in which a knowledge of mathematical and natural sciences gained by study, experience and practice is **applied with judgment** to develop ways to utilize, economically, the materials and forces of nature **for the benefit of mankind**.

Engineering (of Nanoscale) to Serve Society and How not to become “Engineers as Gods”

*A perspective of societal challenges for engineering
What can we as researchers and citizens do about it? Some
engineering thoughts.*



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This is an engineering conference and the “nano” session.

You are the potential leaders of tomorrow. With the economy the way it is these days, the world around us is not exactly a very happy place. Even in America, the great frontier society of this past century.

You hear quite regularly, if you go to the seminars and the talks, details of many exciting breakthroughs in engineering and science, some very hopeful, sometimes “hyped”. I would like to take a step back, and talk about the great engineering challenges. Engineering is a profession which we enter because we like making things, designing things, things that are useful, things that serve a purpose.

Society’s well being depends on good engineering. Between WWII and 1980, median income in US more than doubled to 50K in 2005 dollars. It was largely flat between 80 and end of 90’s except for a small bump up in mid-90’s. It dropped during this century (even while top 1% increased by 250K between 86 and 2005). Manufacturing matters. The word used often “innovation” matters, but more importantly, manufacturing makes the well being possible for the larger group, and good engineering is central to this. The world has a lot of people, and the brightest everywhere are just as bright; it is the systemic aspects, such as those in manufacturing from engineering, that a sub-group can distinguish its impact.

Great challenges, and there are only some that I can discuss in limited time, are examples of one that you may want to play a role in solving. So, there are seeds of thoughts for research and living that you may want to think about as you make a civilized living.

Since Engineering has this serving society as a part of its act, we also should think about what we do ... and their predictable and unpredictable consequences (most systems are complex) so I will include a few thoughts on “engineers acting as gods”. And I will connect to nano and materials, which are the frontiers of experimental science and engineering these days. Nano is where the atom to bulk transition takes place, and many phenomena, whether quantum mechanical, surface interactions such as in catalysis, ... , the various forms energy takes (electromagnetic e.g.) provides unusual and important changes that we try to harness.

Science and engineering are major social forces

Wheel, fire, agriculture, bridges, tunnels, roofs, engines, roads, machine tools, petroleum, transport, ...

Cave dwellers to agriculture community to urban on rivers to suburban, ...

How one adopts, adapts and uses, matters

Chinese inventions include paper, gunpowder, compass, printing, ...

In 15th century, during Ming dynasty (post Zhang-He), when Chinese were also the leaders in making grand voyages all around (before the Europeans), China chose to look inwards, ..., and declined

Engineers play a central role in society at large (humans, all inhabitants, our environment, business, consumers, ... , ..., our eco-system)

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When romans moved from south to north, the soil changed from good drainage to poor, method of cultivation changed – new yokes, more oxen, community, square rather than rectangular farms,

Science versus engineers

When cooling for nuclear reactors was being debated – you could use gas or liquid. Szilard pushed for exotic coolant liquid Bismuth (he has a patent on refrigerator with Einstein using liquid metal coolant). Wigner, a physicist recommended water following careful analysis. Dupont engineers' preference was for gas. Water was eventually adopted.

Engineers also care about practical knowledge and applicability. Useful in absence of theoretical knowledge as well as presence. Flush riveting in airplanes.

20th Century Engineering Achievements

If you did a Google search, you will see ...

- Electrification
- Automobile
- Airplane
- Water supply and distribution
- Electronics
- Radio and television
- Agricultural technologies
- Computers
- Telephone
- Air conditioning and refrigeration
- Highways
- Spacecraft
- Internet
- Imaging
- Household appliances
- Health technologies
- Petrochemical mechanization
- Laser and fiber optics
- Nuclear technologies
- High-performance materials

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These are achievements where science and engineering connected remarkably.

But, they are also centered on the western world. One would think fertilizers, the mass movement made possible by railways, the mass communications from print and web will be on this list, ahead of others.

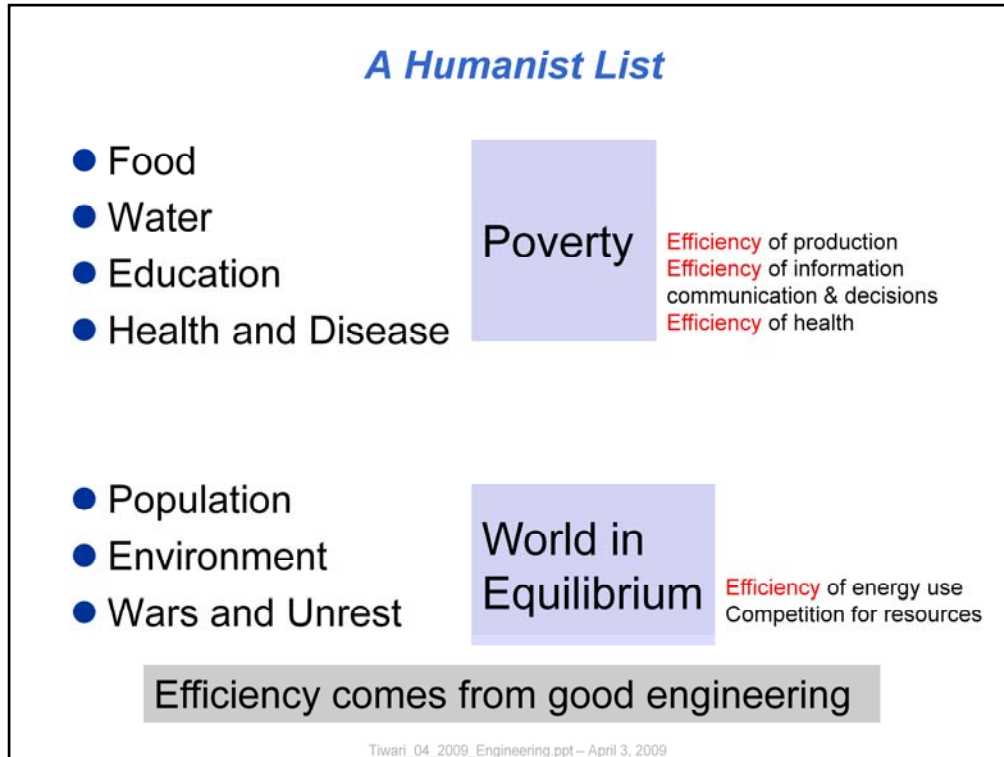
NAE's Grand Challenges (circa 2008)

- Make Solar Energy Economical
- Provide Energy from Fusion
- Develop Carbon Sequestration Methods
- Manage the Nitrogen Cycle
- Provide Access to Clean Water
- Restore and Improve Urban Infrastructure
- Advance Health Informatics
- Engineer Better Medicines
- Reverse-Engineer the Brain
- Prevent Nuclear Terrorism
- Secure Cyberspace
- Enhance Virtual Reality
- Advance Personalized Learning
- Engineer the Tools of Scientific Discovery

A US Perspective!

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The world at large, poor, unhealthy, most children never experiencing the joys of childhood – learning and playing in a civilized way – etc., do not appear as an area for impact on this list.



So, another broader view would be to look at what some of the society's problems are and what role does engineering have to play in them.

Top are interrelated

Bottom are the bigger causes and manifestations in other spheres from them.

And these are related to some central issues where engineering and science (thermodynamics, ...) are intimately connected. Efficiency is what engineering is centrally about.

Few Examples

Education

Open information exchange, access to learning tools,
good learning tools & dedicated people

Communications (internet, ...) & Computing
Information and Communications

Energy

A sustainable fraction that is incident daily on the planet
Efficient use/living

Efficient generation and delivery and use, distributed

Energy Production, Storage, ...

Health

Easy and cheap access to health tools –
personalized & more sophisticated

Easy access to knowledge

Inexpensive diagnostics

Preventive care

Personalized Medicine

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I will focus on a few of these.

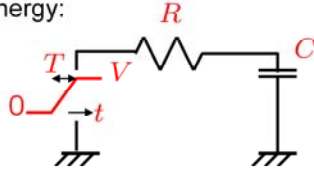
Information & Communication

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The Present Computing Engine

A **central** problem in computing for charge flow and changing EM fields

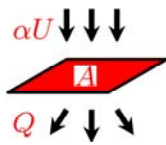
Dissipated
Energy:



$$U = \frac{1}{2}CV^2 \quad \lim_{R \rightarrow 0; T \rightarrow 0}$$

$$U = \frac{1}{2}CV^2 \frac{2RC}{T} \quad \lim_{T \gg RC} \quad \text{Adiabatic}$$

Rapid changes in fields \rightarrow excess charged particle energy loss to medium \rightarrow heat



time constant of energy
consuming operation

$$\tau = \frac{\alpha U}{QA}$$

activity factor
energy per operation
x-section area of heat removal
density of heat removal

1D Heat Spreading: Array regions

$$Q = 10^2 \text{ W/cm}^2 \\ \Rightarrow \tau = 5 \text{ ns}$$

3D Heat Spreading: Logic regions

$$Q = 10^5 \text{ W/cm}^2 \\ \Rightarrow \tau = 5 \text{ ps}$$

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Efficiency and engines.

Carnot – adiabatic cycles.

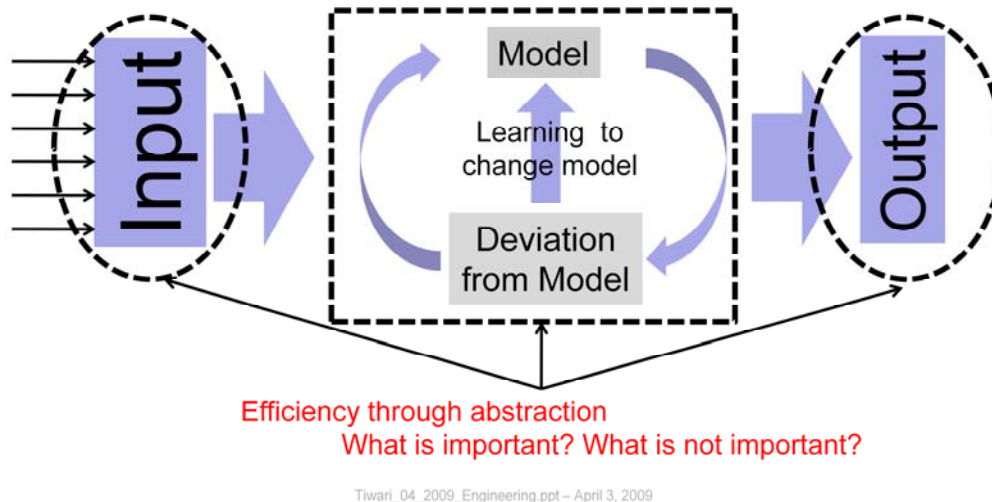
Computing and its efficiency.

Heat as a biproduct of making energy productive – work.

What are the inefficiencies in computing and their connections to nano.

A Very Simplistic View

The Brain operates at 20W and does pretty well for complex problems.



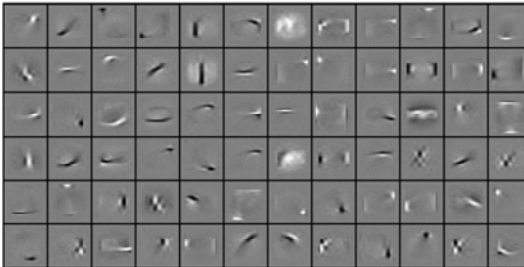
The evolutionary world has built clever systems of its own – brain.

Look for Deviations: Brain & Vision

Efficient **sparse** approaches using self-learning via simpler basis vectors:
edge-like patches

$$\min_a ||x - \sum_{i=1}^n a_i \phi_i||^2 + \lambda \sum_{i=1}^n |a_i|$$

L₁ sparsity term



Learned models ~ correspond ~ to visual recognition region V1 (van Hateren & van de Schaaf, 1998)

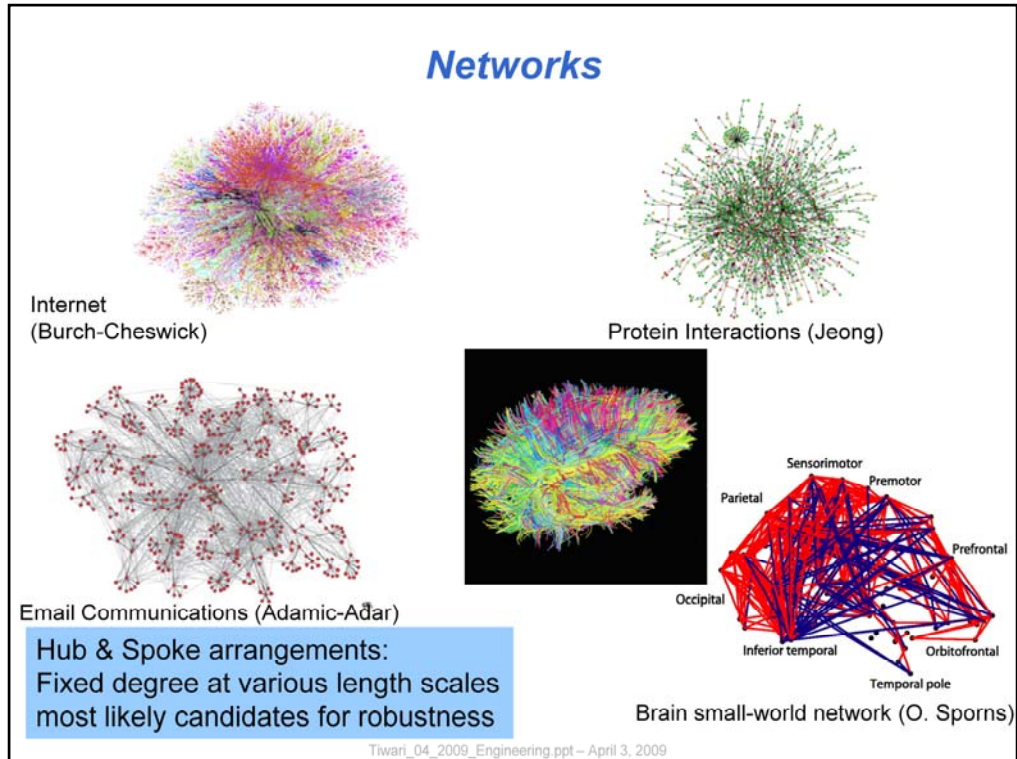
A. Ng, Stanford

Coeff. / Basis learning method	natural image	speech	stereo	Run time
				video
Ng algorithm	260.0	248.2	438.2	186.6
Previous work (LARS+GD)	13085.1	17219.0	12174.6	11022.8

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Look for deviations, don't just compute everything and discard most of the information computed (that is what heat is, and inefficiency is).


Ferret example (Sur, MIT): disconnecting from vision to audio and ferrets could see again. The hardware is similar, the approach of recognition is similar, ...



So interconnects are critically important. For efficiency and robustness of communications.

And nearly all robust systems exhibit the hub and spoke arrangement – a small-world network. Strogatz, Kleinberg, ... work.

Nanoscale Electronics in Computing

10 nm λ  $7.5 \times 10^{12} \lambda^2$ in 1 inch² $\Rightarrow 10^{12}$ devices/chip

A sea of compute element resources

Power and bandwidth are the scarce resources

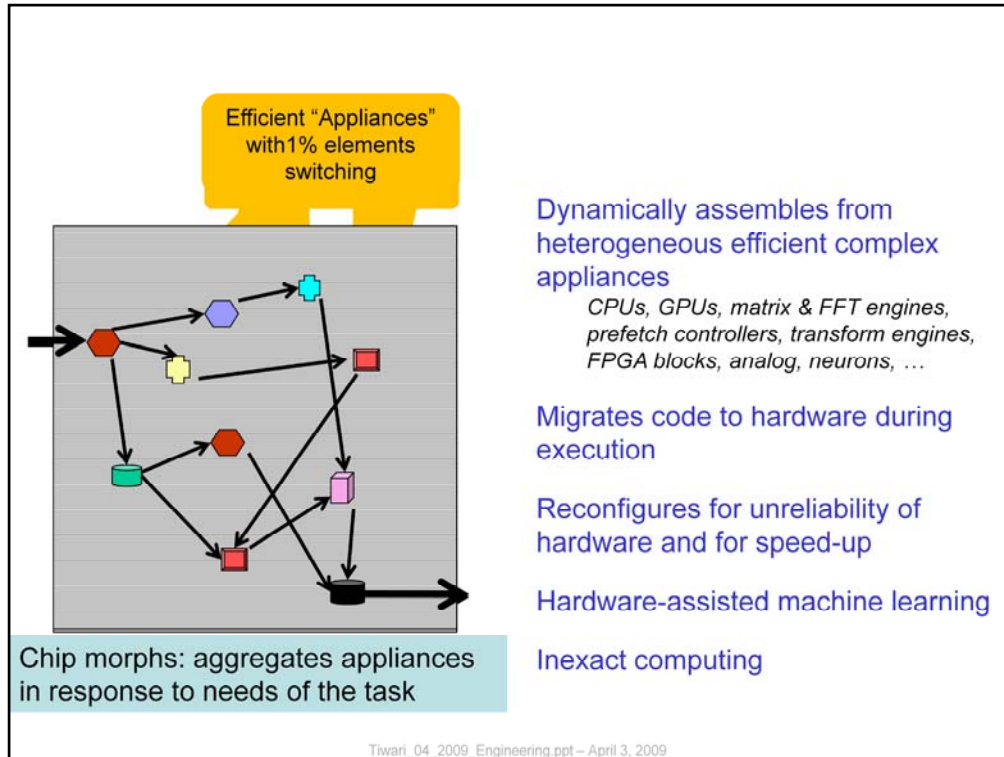
Use the compute resources for different efficient appliances

Turn on, connect, and use only those that are necessary for the task

A multi-tasking chip from a sea of resources

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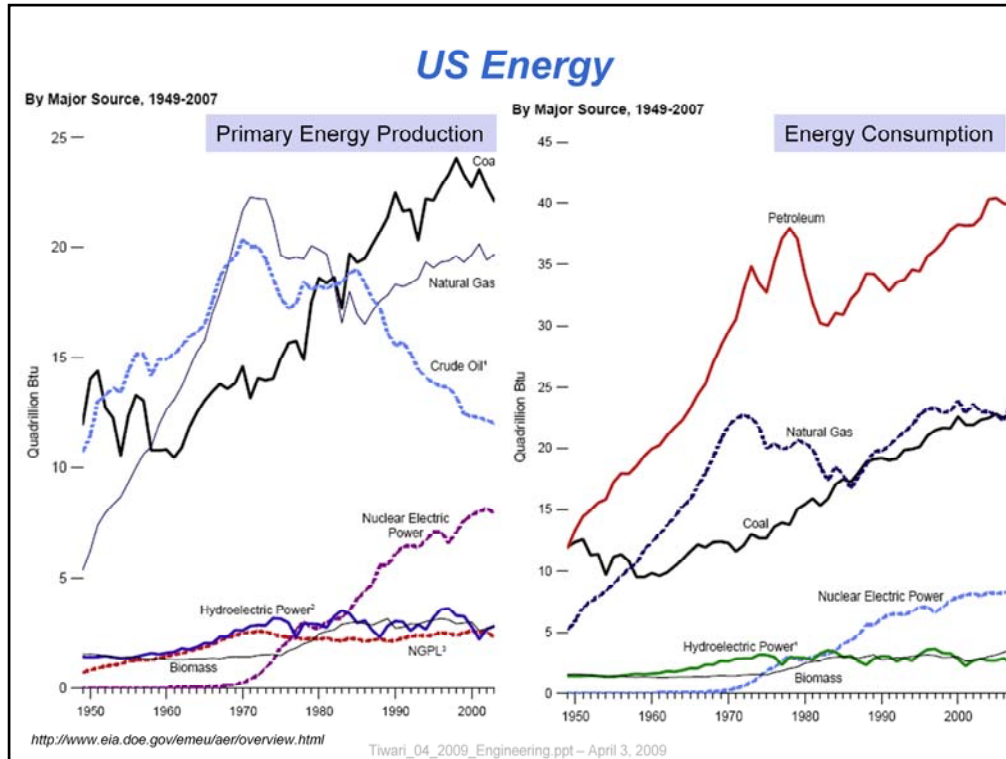
Nano in electronics problem.



A possible solution.

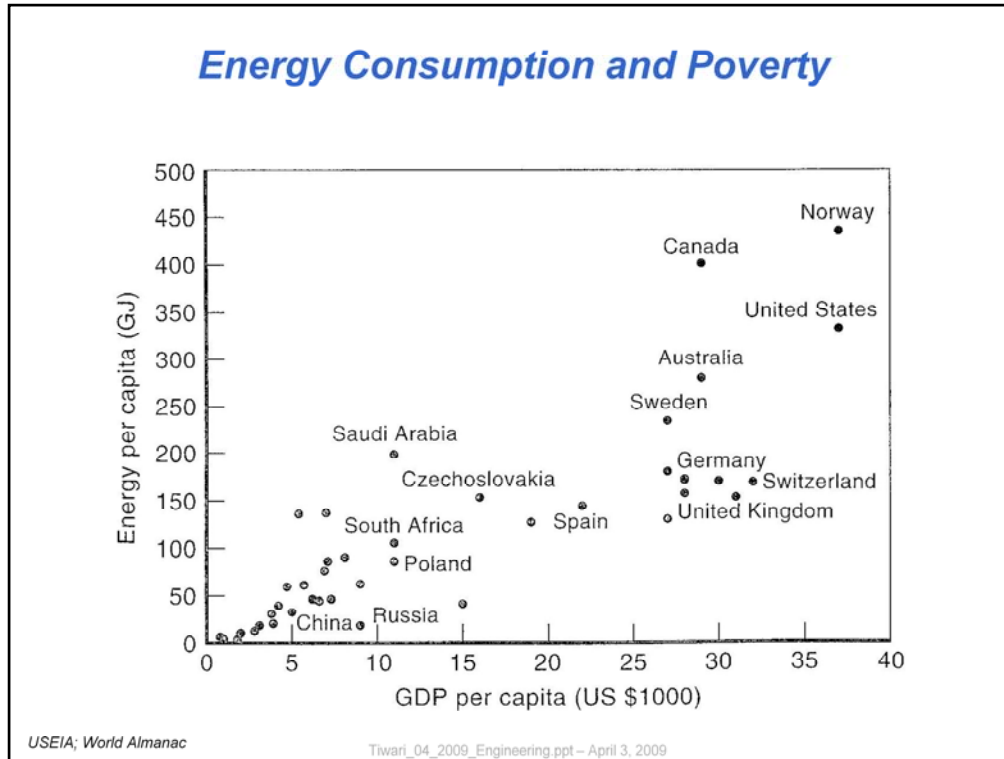
Energy, Environment & Climate

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Petroleum, coal, ... consumption is large and of course that is energy that came over billions of years.

Impact is through climate, for one.



If China or India, or others, reached US, Canada, etc. in their energy per capita, god forbid.

We all, as citizens, as countries, have to play a role in this so that we reach sometime of equilibrium where we consume energy efficiently and so that we are in thermodynamic balance.

The Sun

- 1.2×10^5 TW of global solar energy potential across the planet
- 20 TW from 10% efficient solar farms:
 $2 \times 10^2 / 1.2 \times 10^5 = 0.16\%$ of Globe $\sim 8 \times 10^{11} \text{ m}^2$ ($\sim 9\%$ of US)
- United States:
 - ◆ $\sim 200 \text{ W/m}^2$ average yearly insolation
 - ◆ $\sim 10\%$ conversion efficiency produce 20 W/m^2
 - ◆ For 3 TW production from this source, need
 - $1.5 \times 10^{11} \text{ m}^2 \sim 1.8\%$ of continental US
 - If land used at $\sim 40\%$ coverage, need 4.5% of land

Conversion

Storage

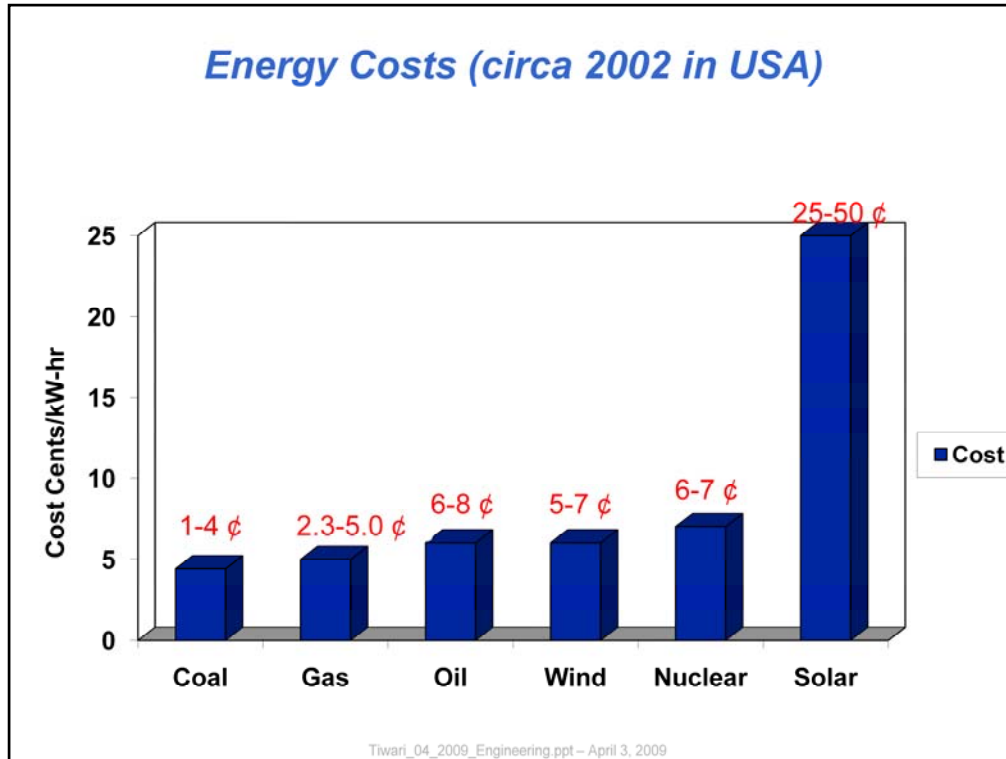
Delivery

Use

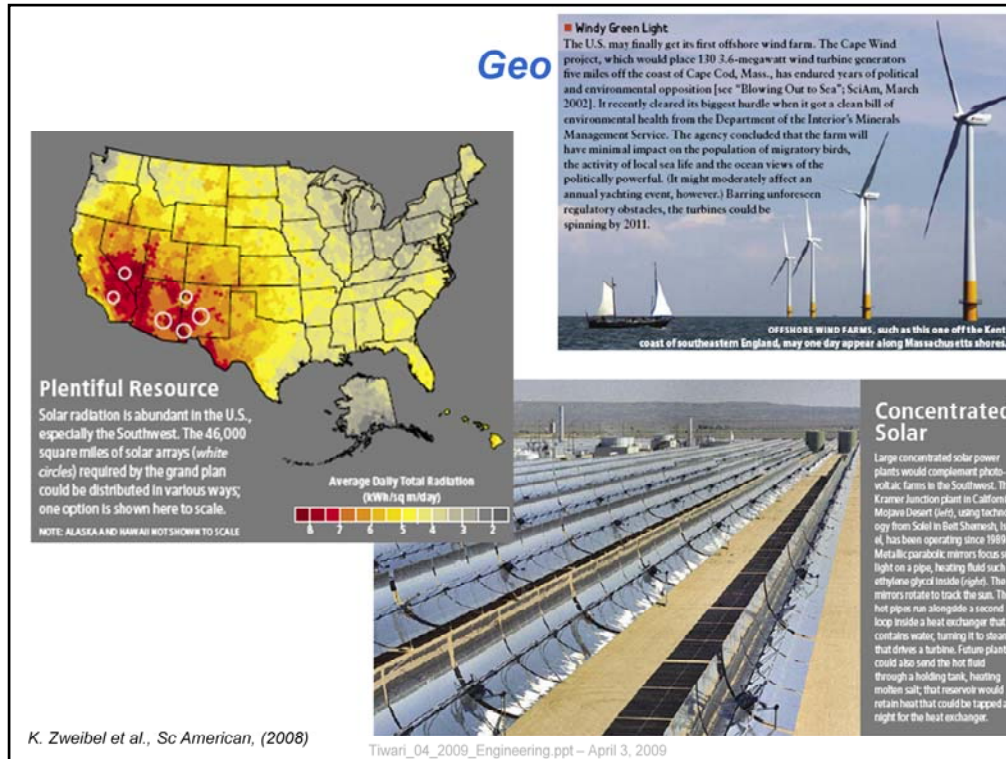
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One such source of energy is the sun.

Discuss light, thermal, winds, electric storms, ocean currents, ...

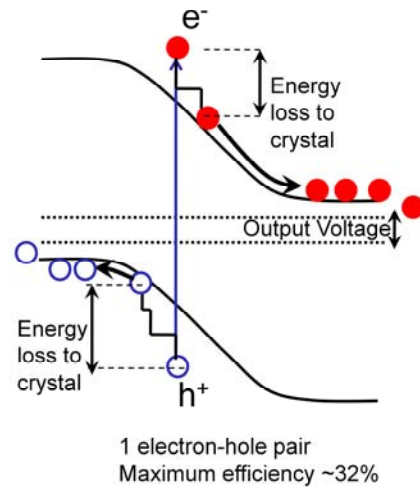
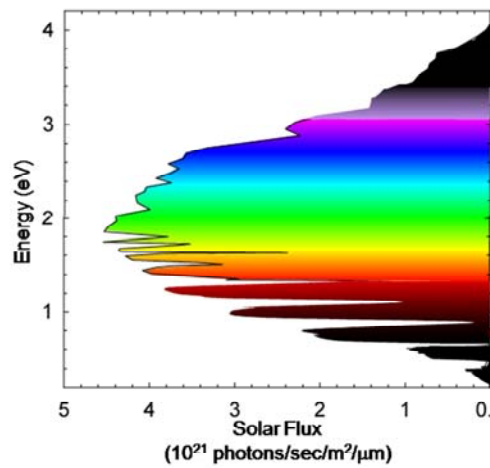


Costs of energy and why fossil resources.



And yet, we are starting to make progress.

Solar Cells: pn junctions



Single junction device, band gaps of 1.0 to 1.5 eV give near 30% without concentration of light

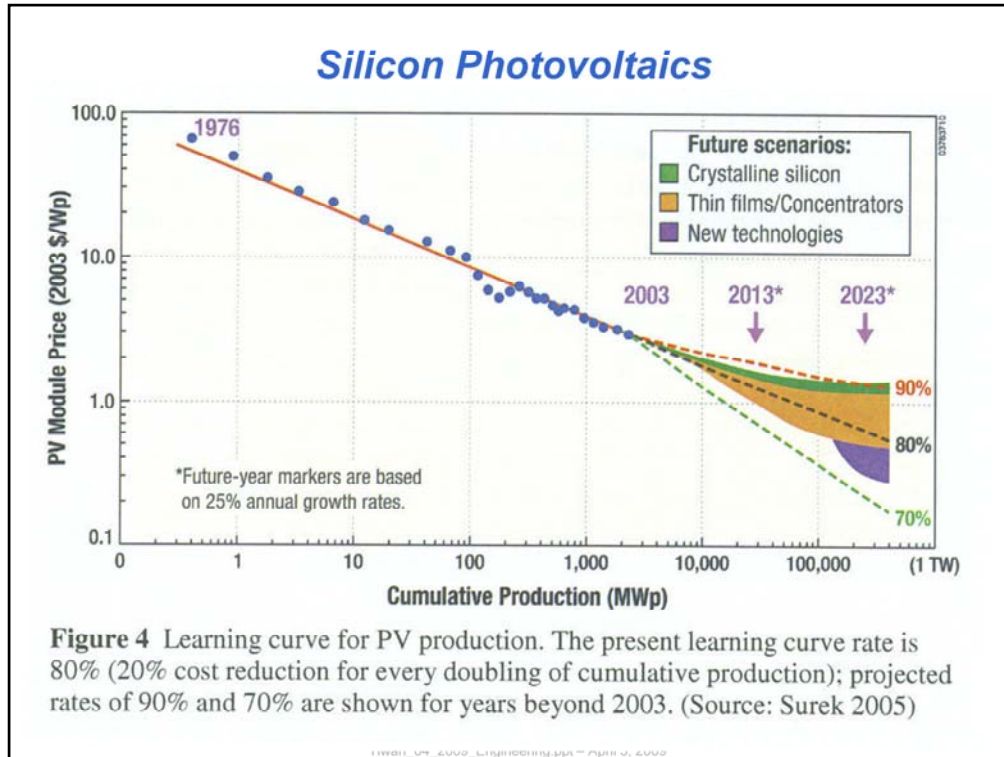
Multi junctions are better

Best efficiency for single crystal silicon is about 25%.

Cheaper devices made from from multi-crystalline materials are 13 -15 % efficient

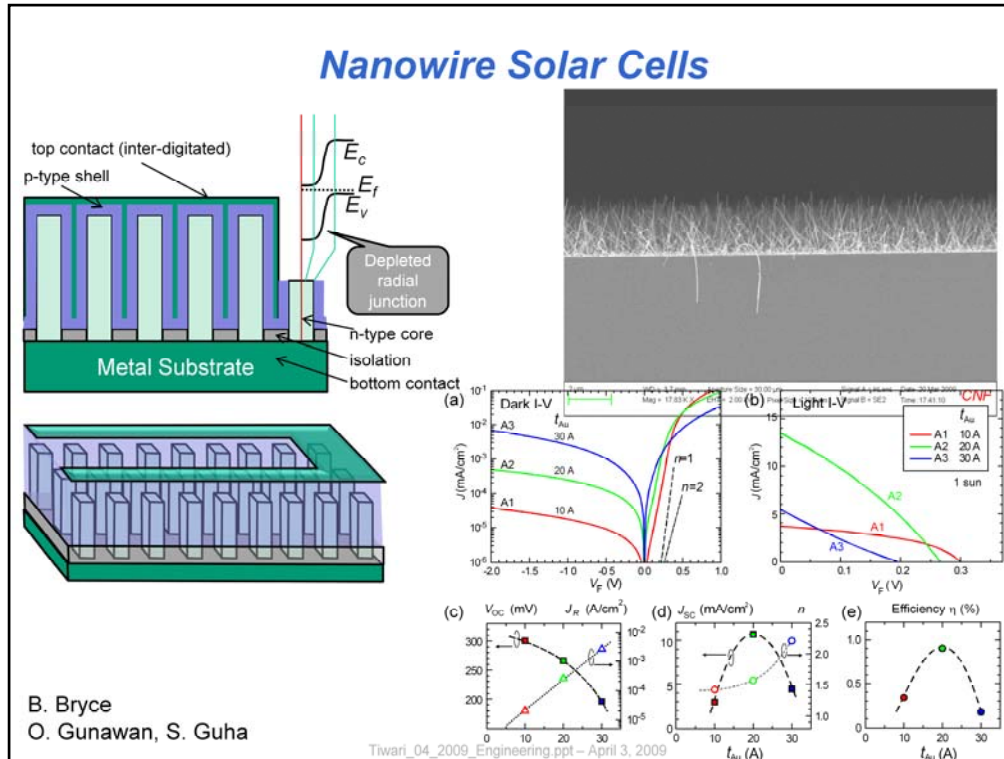
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How solar cells, a simple one, work.



Importance of learning and energy.

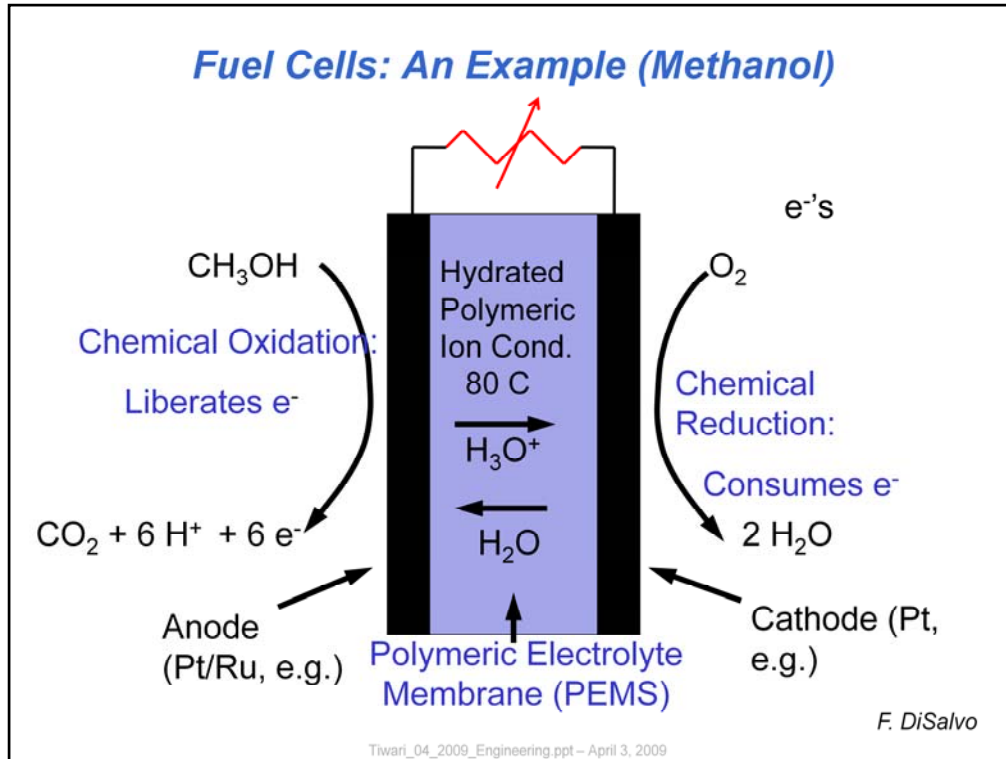
Importance of consuming very little energy, and very little materials in fabrication.



One example

Form Brian Bryce at Cornell, and Supratik Guha's group at IBM.

Connection of nano, materials, energy of production, use of materials.

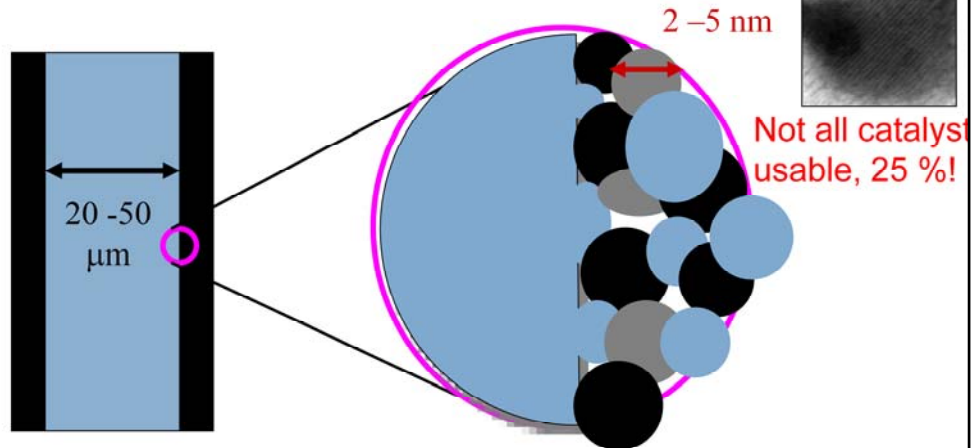


Another example related fuel cells – means of converting chemical to electrical.
Materials – movement of ions, catalytic reactions at surfaces, ...

Electrodes

F. DiSalvo

Electrodes need to support several percolation networks:
electronic, ionic, fuel/oxidizer/product access



Inexpensive synthesis techniques of the right materials!

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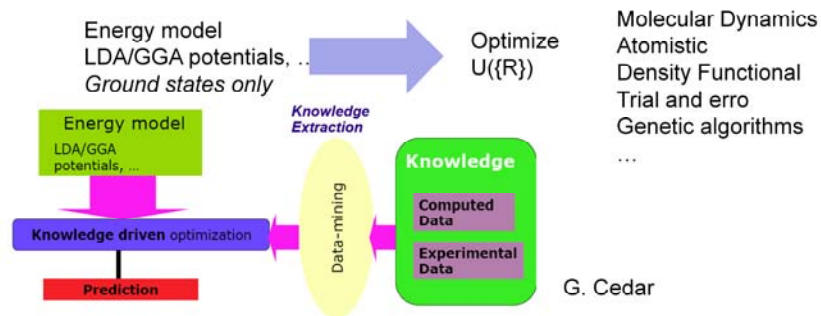
Connection of nano

A Common Challenge to Energy: Materials By Design

Data mining for materials

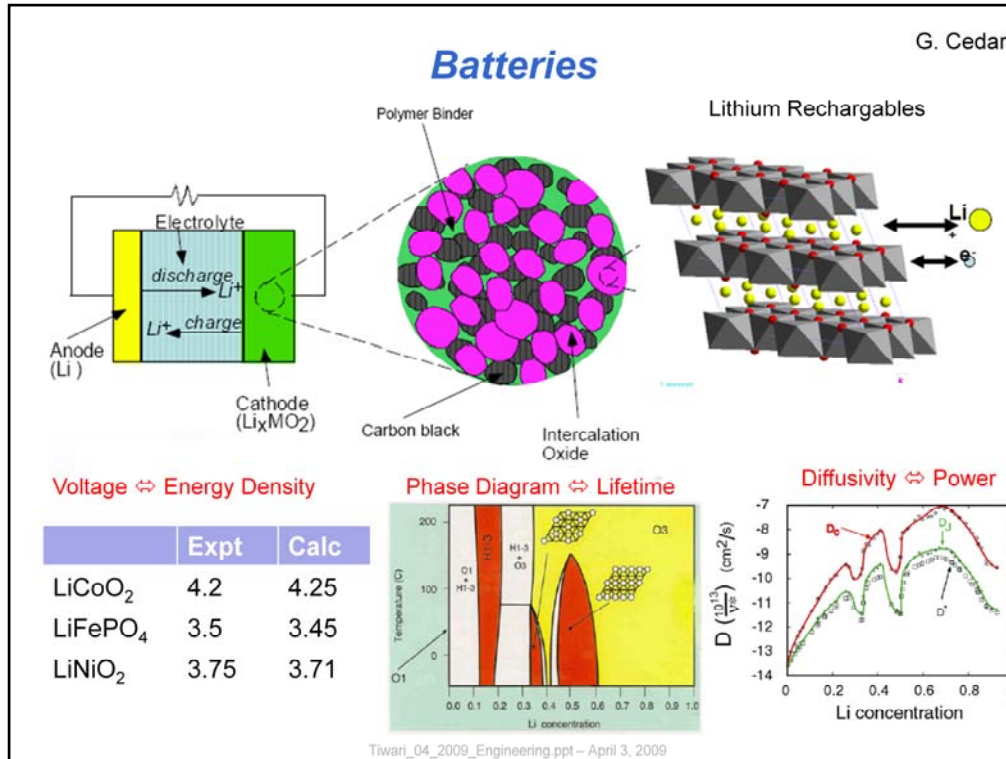
Minima in energy space are not random
Result from underlying physical and chemical principles

Can we learn about underlying physics in nature without making it explicit?
Can we do this in mathematically rigorous way using mathematical intuition via statistical learning, data mining and soft artificial intelligence?



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We have created new materials, made efficient processes – Bosch-Haber process, ...
Can we make new materials and design. A grand challenge, but a worthy one.



Properties are related to use and one can design from engineering principles.
Discuss various connections.

Climate Change: A Truly Grand Challenge

Scientific American, Nov. 2008

GEENGINEERING

A Sunshade for Planet Earth

Global warming has become such an overriding emergency that some climate experts are willing to consider schemes for partly shielding the planet from the sun's rays. But no such scheme is a magic bullet **By Robert Kunzig**

KEY CONCEPTS

- Many scientists now support serious research into "geoengineering," artificial actions taken to slow or reverse global warming.
- Of the various geoengineering proposals, the one that shields the earth from the sun could bring about the most immediate effects. But all of them have drawbacks and risks, effects that probably cannot be anticipated.
- Pumping sulfur dioxide into the atmosphere, as volcanoes do, is the most well established way to block the sun. Yet it poses all the dangers of triggering climate over the centuries by taking you off the sun's atmospheric and heating a nucleus in space.

—The Editors

When David W. Keith, a physicist and energy expert at the University of Calgary in Alberta, gives lectures these days on geoengineering, he likes to point out how old the idea is. People have been talking about deliberately altering climate to counter global warming, he says, for as long as they have been worrying about global warming itself. As early as 1965, when Al Gore was a freshman in college, a panel of distinguished environmental scientists named President Lyndon B. Johnson that surface albedo (CO₂) increases from that surface albedo "would change in climate" that "would be deleterious." Yet the scientists did not go so far as to consider the possibility of reducing emissions. Instead they considered one idea: "spreading very small reflective particles" over about five million square miles of ocean, so as to bounce about 1 percent more sunlight back to space—"a weak geoengineering solution," Keith says, "that doesn't even work."

In the decades since, geoengineering ideas have died, but they did get pushed to the fringe—they were widely mentioned by scientists and commentators alike as silly and even immoral attempts to avoid addressing the root of the problem of global warming. Three recent developments have brought them back into the mainstream.

First, despite years of talk and international treaties, CO₂ emissions are rising faster than the worst-case scenario projected as recently as 2007 by the Intergovernmental Panel on Climate Change. "The trend is upward and toward an ever increasing reliance on coal," says Ken Caldeira, a climate researcher at the University of Illinois at Urbana-Champaign.

Second, we are making faster than ever progress in the field of climate change. It is now clear that climate change is a tipping point, in the current version of the science, had thought.

And third, Paul Crutzen wrote an essay. The 2006 paper in the journal *Climatic Change* by the eminent Dutch atmospheric chemist, in which with Jerry Raman, he suggested serious consideration of geoengineering.

Keith says, "that doesn't even work."

In the decades since, geoengineering ideas have died, but they did get pushed to the

CLIMATE OF "TRANSITION" IN SPACE, as shown in this artist's conception of a sunshade, might ease the warming of our world.

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So, now let us talk about climate which is intimately connected to energy.

A recent Sc. Am. Article – that helps me make the point about complexity and unpredictability and therefore issues of engineers as gods.

Climate Control? *Engineers as Gods!* Scientific American, Nov. 2008

<p>CONSIDERATIONS OF THE PROS AND CONS Sulfur in the Stratosphere The idea of spraying sulfur into the stratosphere to cool the planet has been around for decades. It was first proposed by Paul Crutzen, a Nobel Prize-winning chemist, in the 1980s. The idea is to mimic the natural cooling effect of volcanic eruptions like Mount Pinatubo in 1991. Sulfur dioxide is released into the stratosphere, where it forms aerosols that reflect sunlight and cool the planet. The idea is to spray sulfur into the stratosphere at a rate of about 100,000 tons per year to offset the warming caused by greenhouse gases.</p> <p>PROS AND CONS PROS: Could offset some of the warming caused by greenhouse gases. Could be deployed relatively quickly. Could be used as a weapon. CONS: Could destroy the ozone layer. Could cause acid rain. Could cause crop failures. Could cause respiratory problems. Carbon still needs to be controlled.</p>	<p>CONSIDERATIONS OF THE PROS AND CONS Sea Mist in the Troposphere The idea of spraying sea salt into the troposphere to cool the planet has been around for decades. It was first proposed by Paul Crutzen, a Nobel Prize-winning chemist, in the 1980s. The idea is to mimic the natural cooling effect of sea salt aerosols. Sea salt is released into the troposphere, where it forms aerosols that reflect sunlight and cool the planet. The idea is to spray sea salt into the troposphere at a rate of about 100,000 tons per year to offset the warming caused by greenhouse gases.</p> <p>PROS AND CONS PROS: Could offset some of the warming caused by greenhouse gases. Could be deployed relatively quickly. Could be used as a weapon. CONS: Could cause respiratory problems. Could cause crop failures. Carbon still needs to be controlled.</p>	<p>CONSIDERATIONS OF THE PROS AND CONS Disk in the Trillion in Space The idea of placing a large disk-shaped reflector in space to cool the planet has been around for decades. It was first proposed by Robert Zubrin, a NASA engineer, in the 1980s. The idea is to place a large disk-shaped reflector in space that would reflect sunlight away from the Earth and cool the planet. The idea is to place a large disk-shaped reflector in space at a distance of about 1.5 million miles from the Earth to offset the warming caused by greenhouse gases.</p> <p>PROS AND CONS PROS: Could offset some of the warming caused by greenhouse gases. Could be deployed relatively quickly. Could be used as a weapon. CONS: Could be very expensive. Could cause orbital debris. Could cause climate change. Carbon still needs to be controlled.</p>
<p>Predictability of weather patterns Reduced evaporation => less global rain Destruction of ozone layer Cheap – could be used as a weapon Maintenance Carbon still needs to be controlled</p>	<p>Predictability and wider changes of Temp Clouds with smaller drops => less rain Not understood – magnitude of effect Cheap – could be used as a weapon Continual maintenance Carbon still needs to be controlled</p>	<p>Cost - \$5 Trillion estimate Long construction time Unpredictable weather patterns Reduced evaporation => less rain Replacement of fliers Potential of use as a weapon</p>

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Reflecting energy back – early ideas from U. Arizona to reflect back 2% of light through a mirror in sky.

Sulphur, Salt, and reflectors.

Discuss issues.

Solar: energy in energy out, contamination, recycling, lifetime, ...

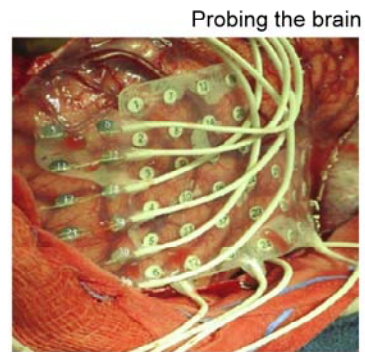
Wind power: Energy removed from what makes the climate work, ..., has consequences. Dead zones behind wind farms – dead zones underneath farm salmon.

Health

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One area where engineering has had just an enormous impact by placing tools in doctor's and people's hands.

Health



J. Viventi & B. Litt

Cochlear prosthesis bypasses damaged hair cells in the auditory system

Provides direct electrical stimulation of the auditory nerve
60,000 cochlear prosthesis

Movie of monkey!

Other examples: bone graft, coronary stent, heart valves, pacemakers, ...

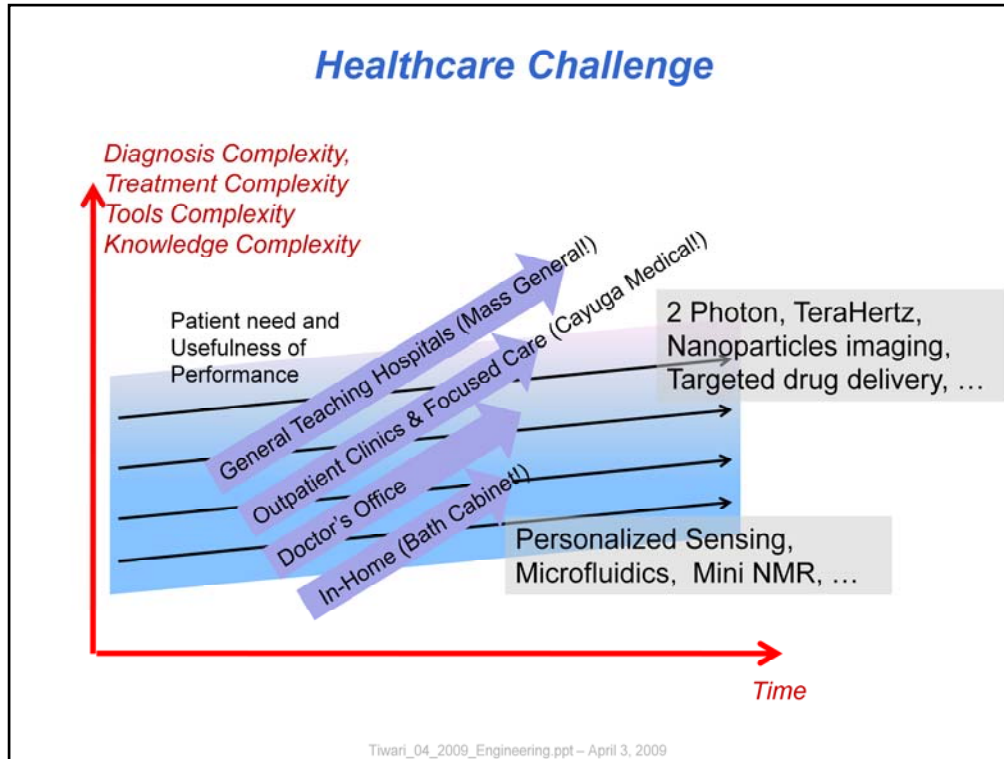
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Examples of some where life has been changed just entirely.

...

And we can now probe and connect to brains and are starting to understand how some of the broader principles are at work.

Show monkey eating banana movie.



Importance of how health care and costs arise and how engineering can help.

Discuss ideas where interesting developments are taking place.


Importance of personalized, and in people's hands, ..., and its impact on preventive care, and through use by many, on costs.

Paper based tests, ...

Microfluidics, cheap, ...

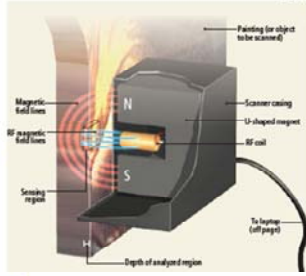
Personalization

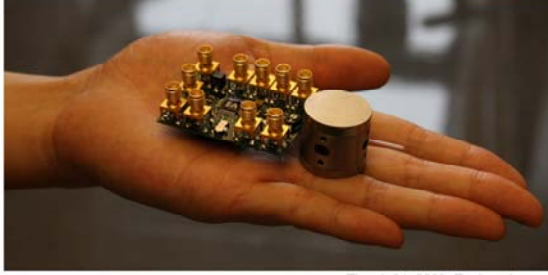
MRI



<http://www.sciencelearn.org.nz>

B. Blumich





Miniaturized NMR

U-shaped magnet that with an RF coil in its gap.

Sense the composition of matter where the magnetic field lines of the magnet and of the RF coil cross each other and by moving analyze slices at different depths.

D. Ham, Harvard

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An example from imaging.

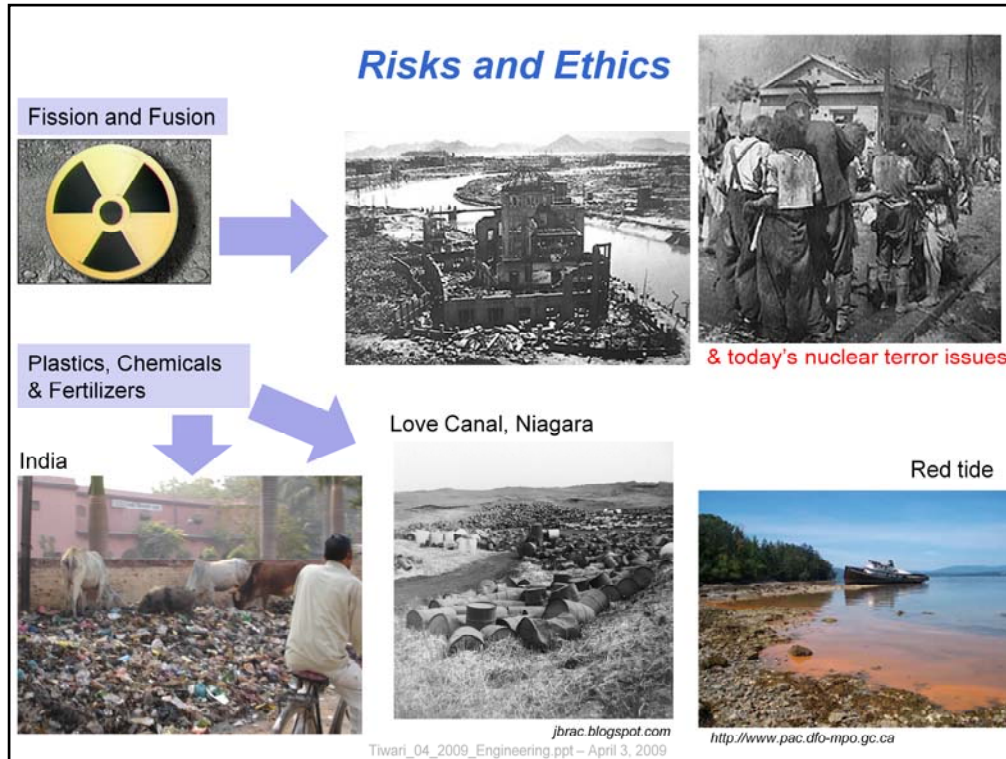
Purcell, ..., spin – identification of species, Hydrogen, imaging, ...

MRI, fMRI, ..., as important non-invasive tools.

Miniaturization.

Summary Commentary

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When I was young, in the 60's, fascinated by radioactivity.

Its impact, visit to Hiroshima, use when it was needed, so social structure and decision making versus what scientist and engineer does.

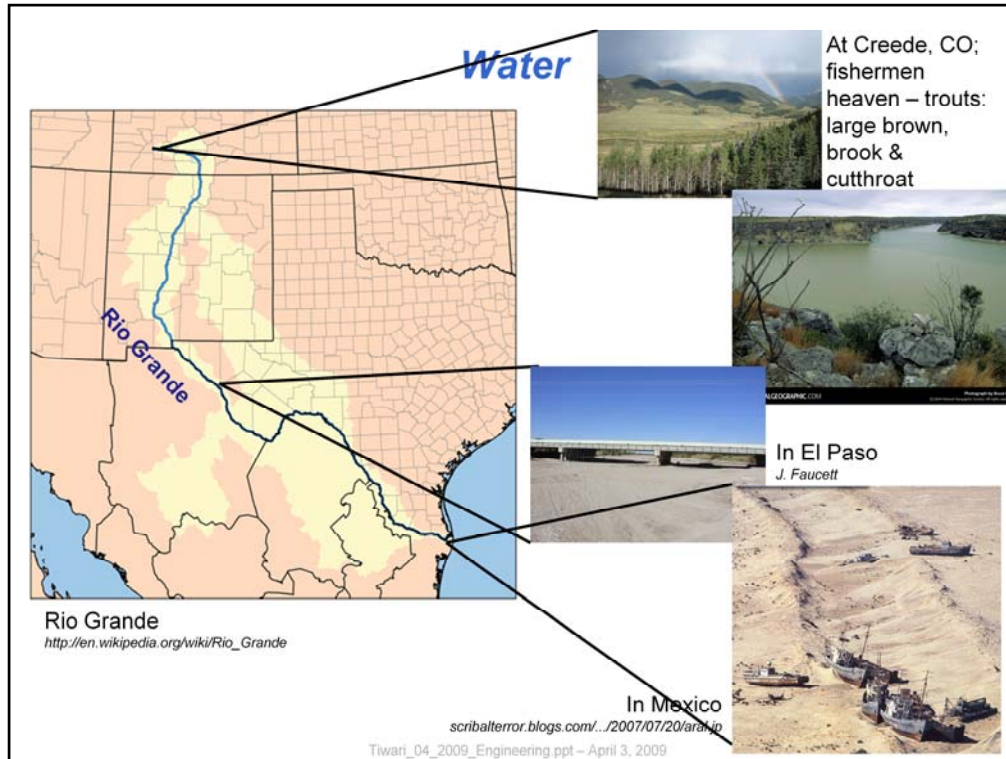
Today's nuclear issues.

Others that have had a big impact in recent times.

Plastics – India – Bombay floods, drainage clogged by plastics, their long life.

Chemicals, so essential, and how we use them – Love Canal, cancer, few hundred miles from here in Niagara.

Fertilizers, which make the 7x population beyond what it would be in their absence, and N, P, run-offs and the red tides, and others.



Competition for resources – water, which is tied to our everyday life.

Rio Grande, ...

The roots of the Texas-Mexican water dispute go back to the 1944 [Mexican Water Treaty](#), which determined how water from the Colorado, Tijuana and Rio Grande drainage basins would be divided between Texas and Mexico. Article 4 of the treaty stipulates that one third of the water reaching the Rio Grande from the Conchos, San Diego, San Rodrigo, Escondido, Las Vacas Arroyo and Salado rivers is allotted to the United States. If this amount of water turns out to be less than 350,000 acre feet annually, however, Mexico is to make up the difference. In times of drought, an allowance is made for the Mexicans to pay their water debt at the end of a five-year cycle. – from <http://www.thetrumpet.com/index.php?q=4822.3085.0.0>

... the Rio Grande has stopped flowing in Big Bend National Park," biologist Raymond Skiles wrote in a "daily report" e-mail distributed from the park's Panther Junction headquarters. "The river is now a series of isolated pools separated by dry, white gravel with no flow. You can walk across without getting your shoe soles wet. The whiteness of river bed gravel feels like a bleached skeleton lying in the sun." ... <http://www.offthekuff.com/mt/archives/001970.html>

Dams and population and usage as issues.

Some Notes on Engineering

- Engineering is most effective when improving human life (infrastructure, health, daily life, agriculture, ...) i.e. when social systems and technology complement
 - ◆ Best when formulating a response to a social need rather than a technological quick fix.
- Engineering fails when social system is hostile or unwilling to modify itself to allow technology to operate under the best conditions for beneficial results
 - ◆ e.g. hunger, illiteracy, and health care
- Engineering should still work on correcting a social purpose it perceives as detrimental
 - ◆ This is very difficult to do, witness unbridled consumerism in market economies or technological reinforcement of authoritarian regimes

Engineering is a noble profession, immensely satisfying because it bridges pure intellectual pursuit ("science") and use in society

You are lucky. Make the most of the opportunities and make them for yourself

*But, remember that technology is not the answer to everything.
You are not god!*

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...

Do great science and engineering, take challenging problems, but also think and consider the predictable and unpredictable consequences.

...

Nature has seniority over us. Give it its due respect.

... you do not know all, you are not god, ... predictability and unpredictability is inherent in complexity that engineering deals with.