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.

Cornell University

Sandip Tiwari
st222@cornell.edu

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)

When romans moved from south to north, the soild 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 coud 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 evnetually 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

These are achievements where science and engineering connected remarkably.

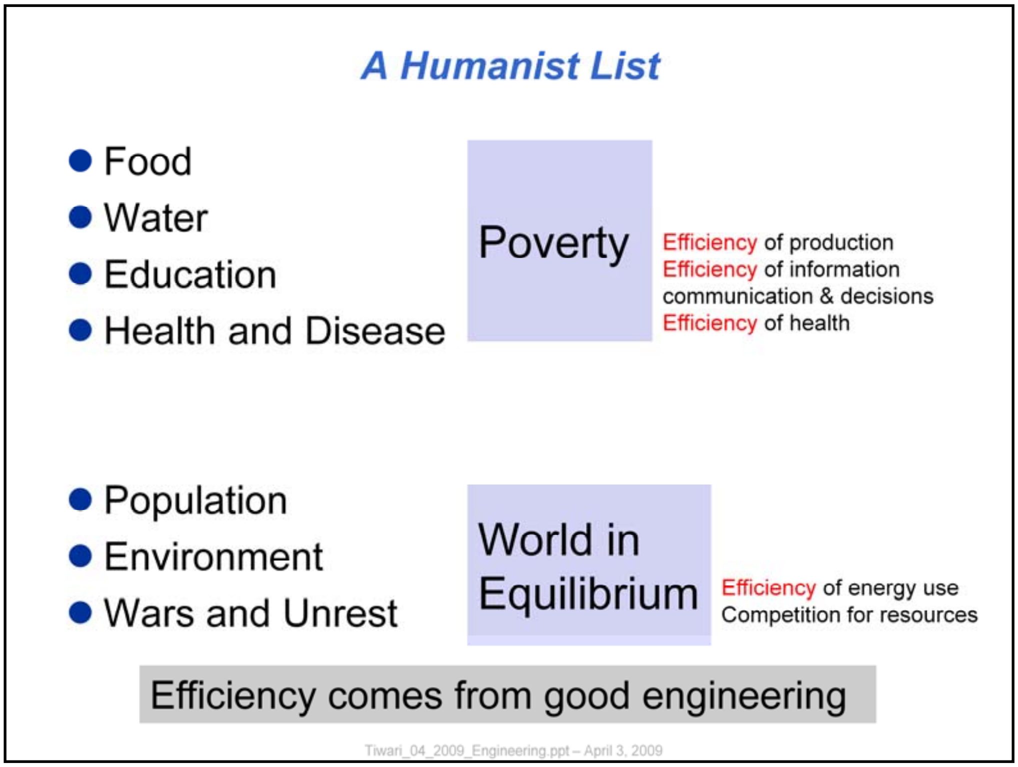
But, they are also centered on the western world. One would think fertilizers, the mass movement made possible by railways, the mass communications from print and web will be on this list, ahead of others.

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!

The world at large, poor, unhealthy, most children never experiencing the joys of childhood – learning and playing in a civilize 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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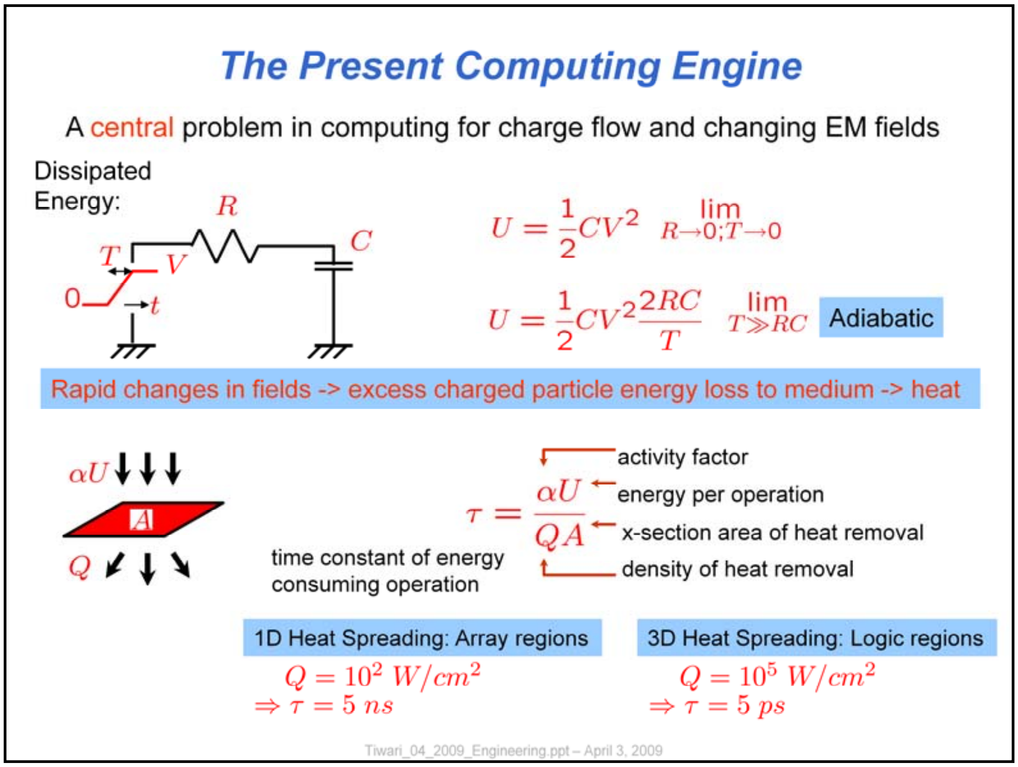
I will focus on a few of these.

Information & Communication



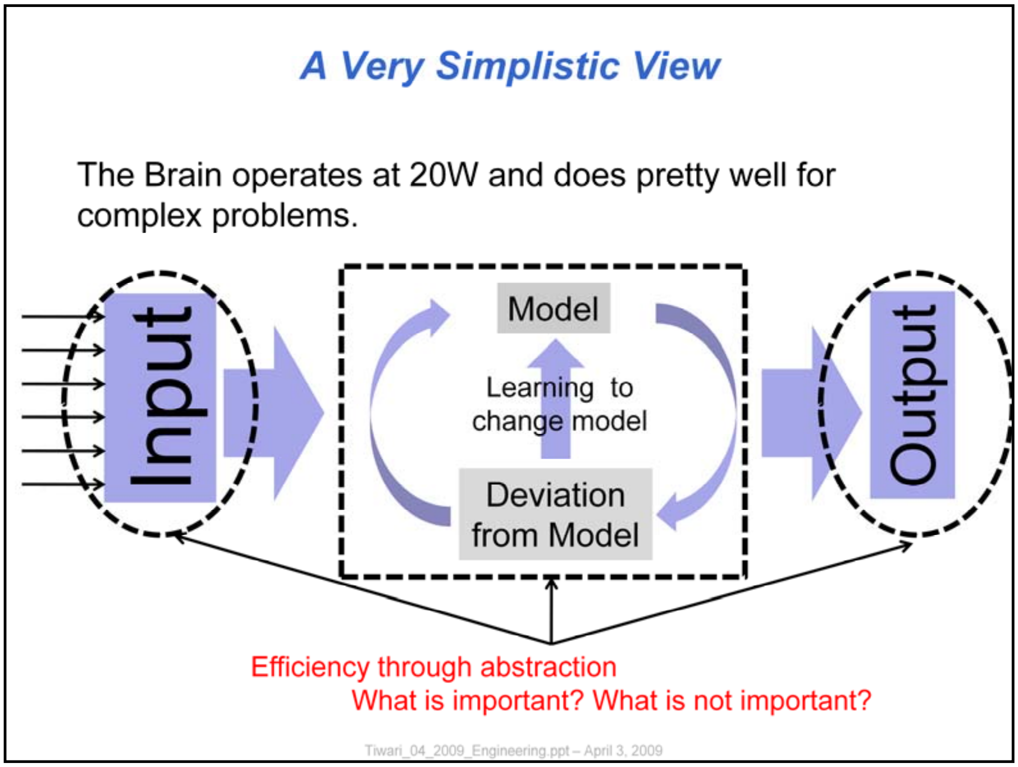
Efficiency and engines.

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.



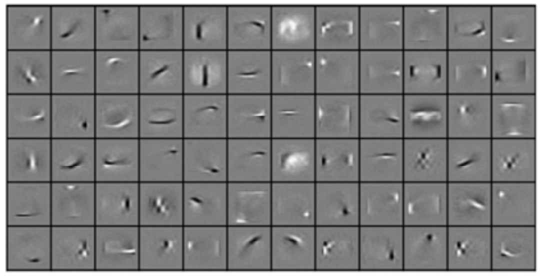
The evolutionary world has built clever systems of its own – brain.

Look for Deviations: Brain & Vision

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

L_1 sparsity term

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



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

A. Ng, Stanford

Run time

Coeff. / Basis learning method	natural image	speech	stereo	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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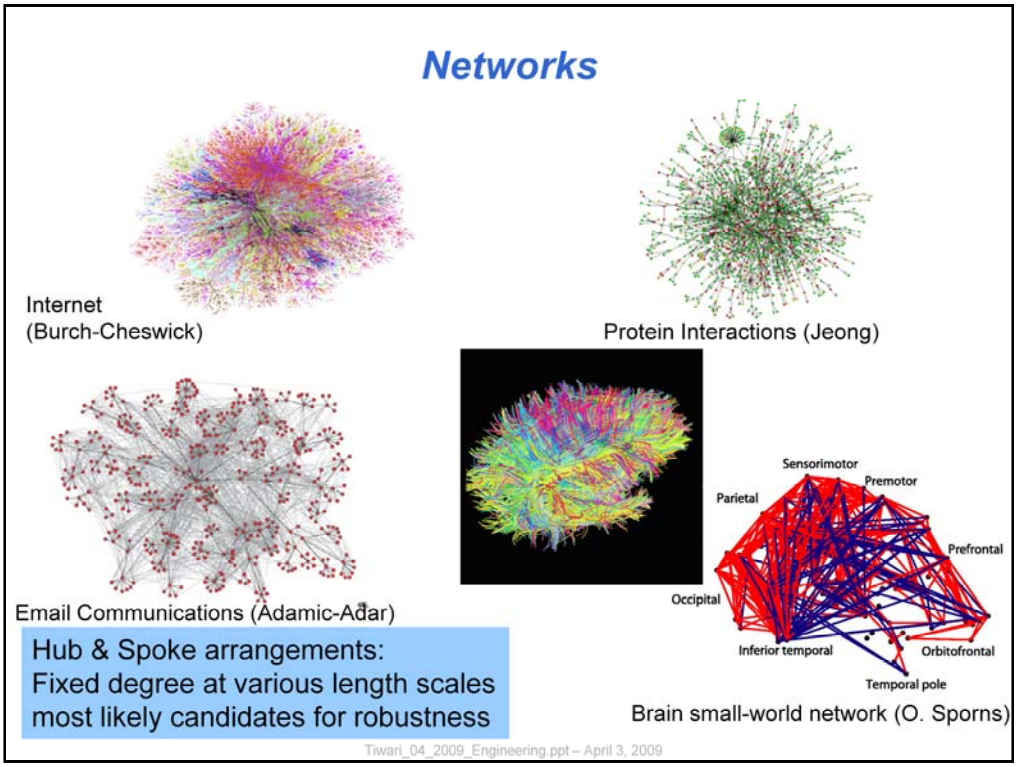
Look for deviations, don't just compute everything and discard most of the information computed (that is what heat is, and inefficiency is).

Ferret example (Sur, MIT): disconnecting from vision to audio and ferrrets 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 ⟺ $7.5\times10^{12}\ \lambda^2$ in 1 inch^2 => 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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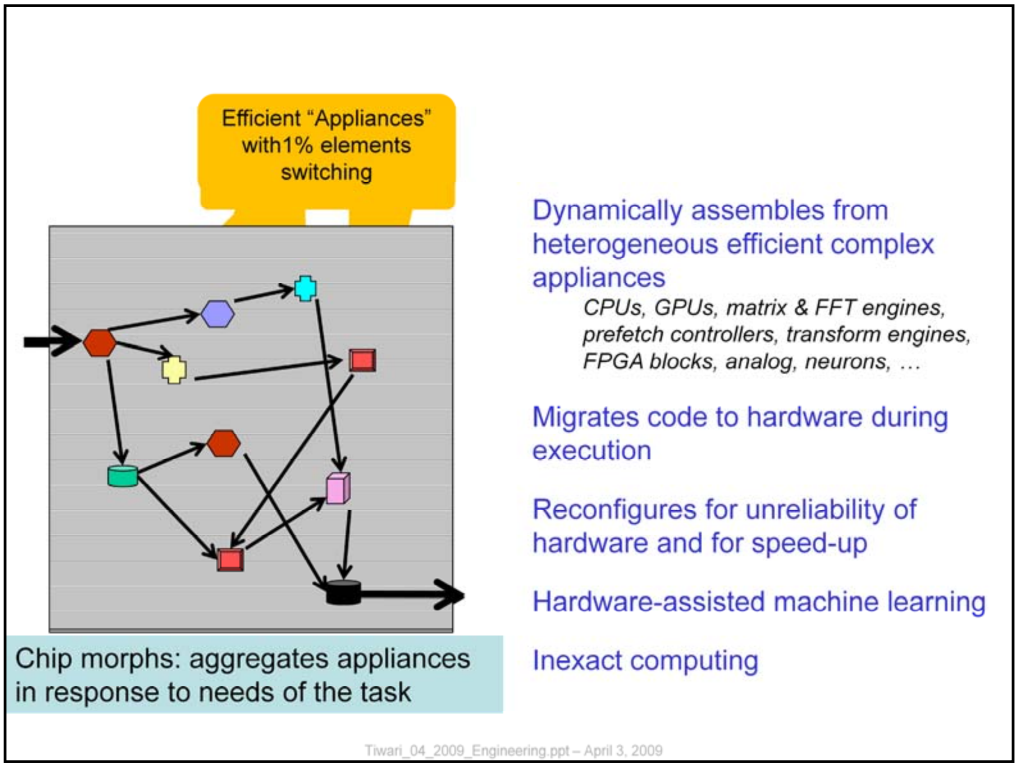
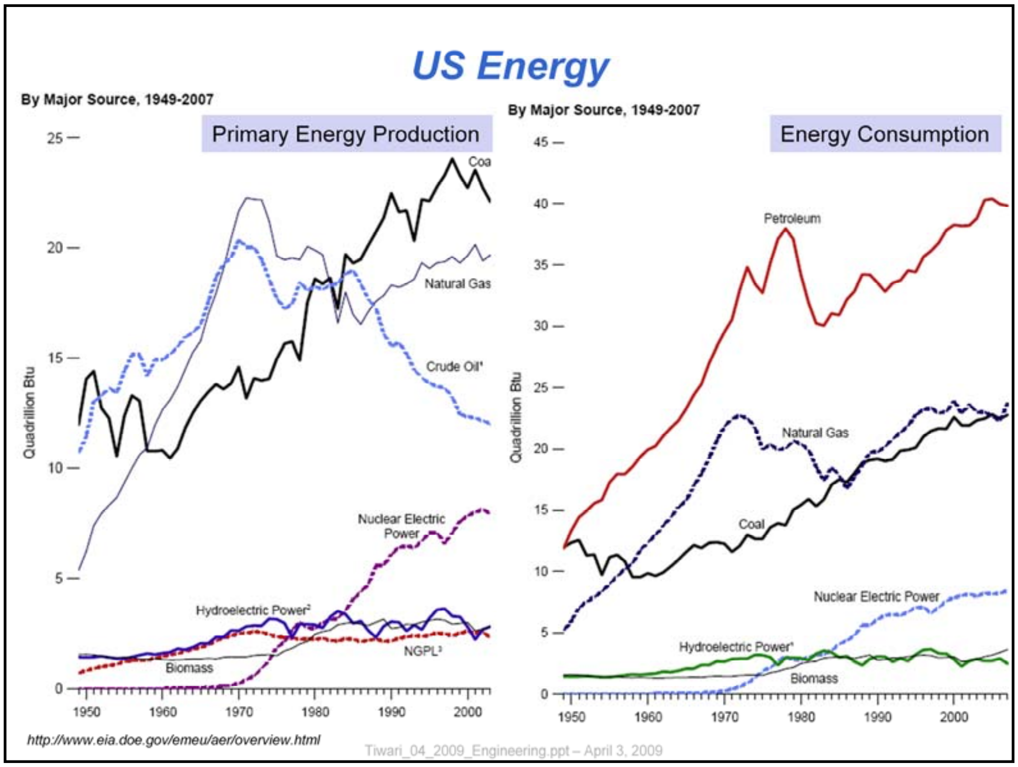
Nano in electronics problem.



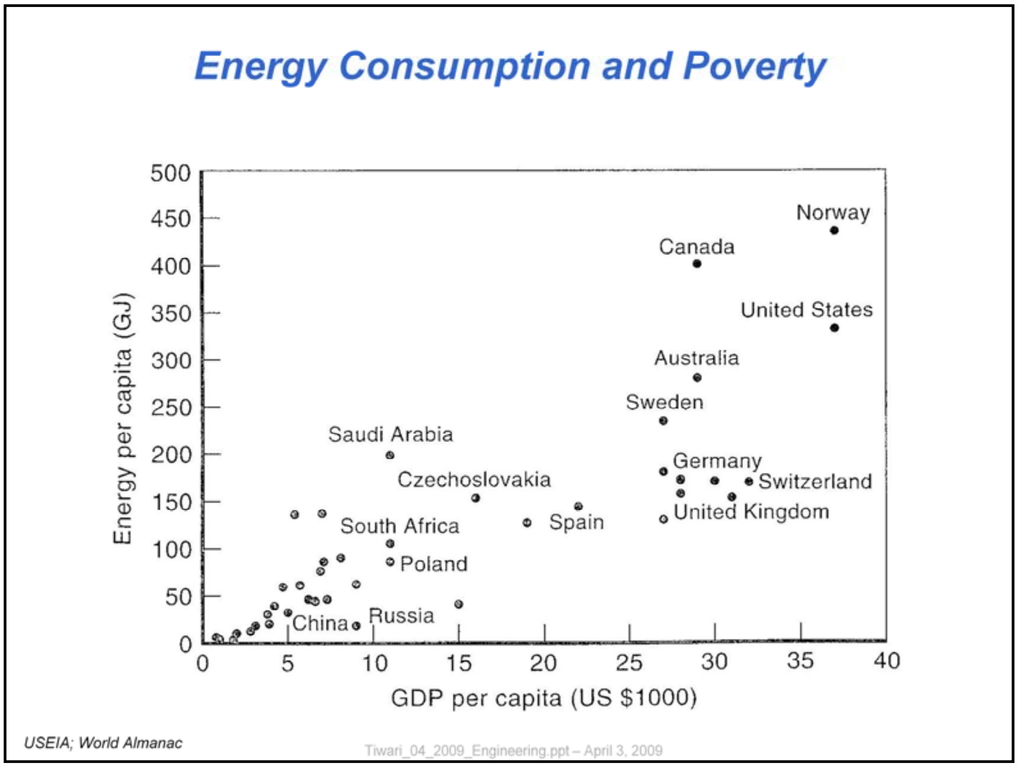
A possible solution.

Energy, Environment & Climate



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.

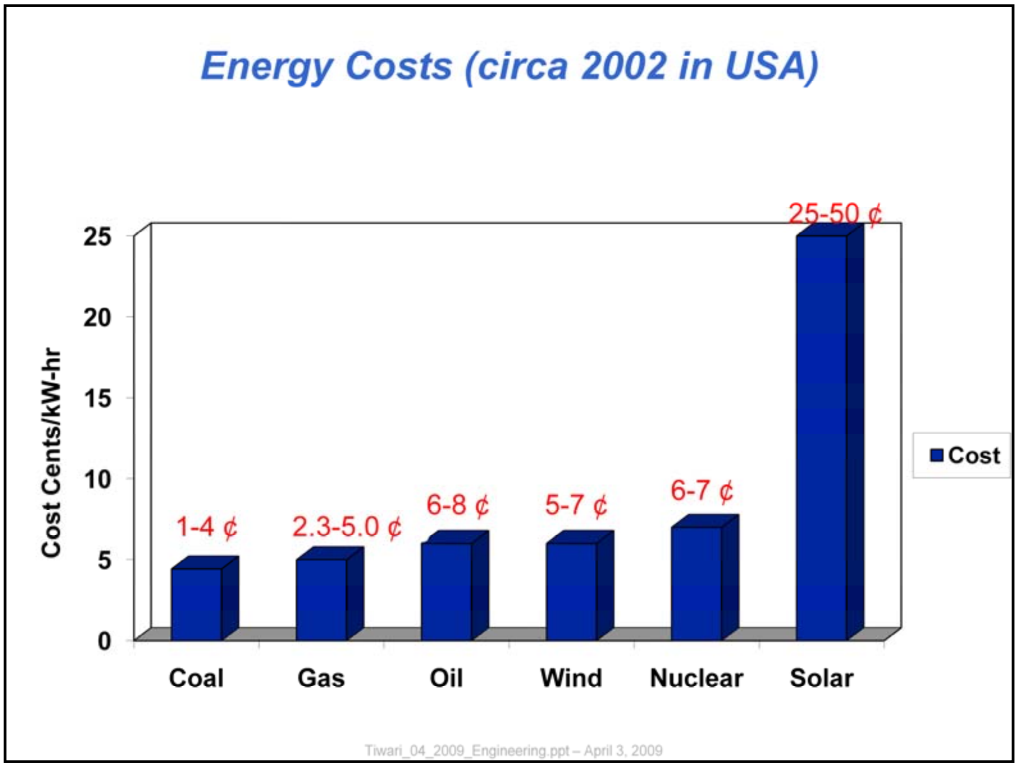
We all, as citizens, as countries, have to play a role in this so that we reach sometime of equilibrium where we consume energy efficiently and so that we are in thermodynamic balance.

The Sun

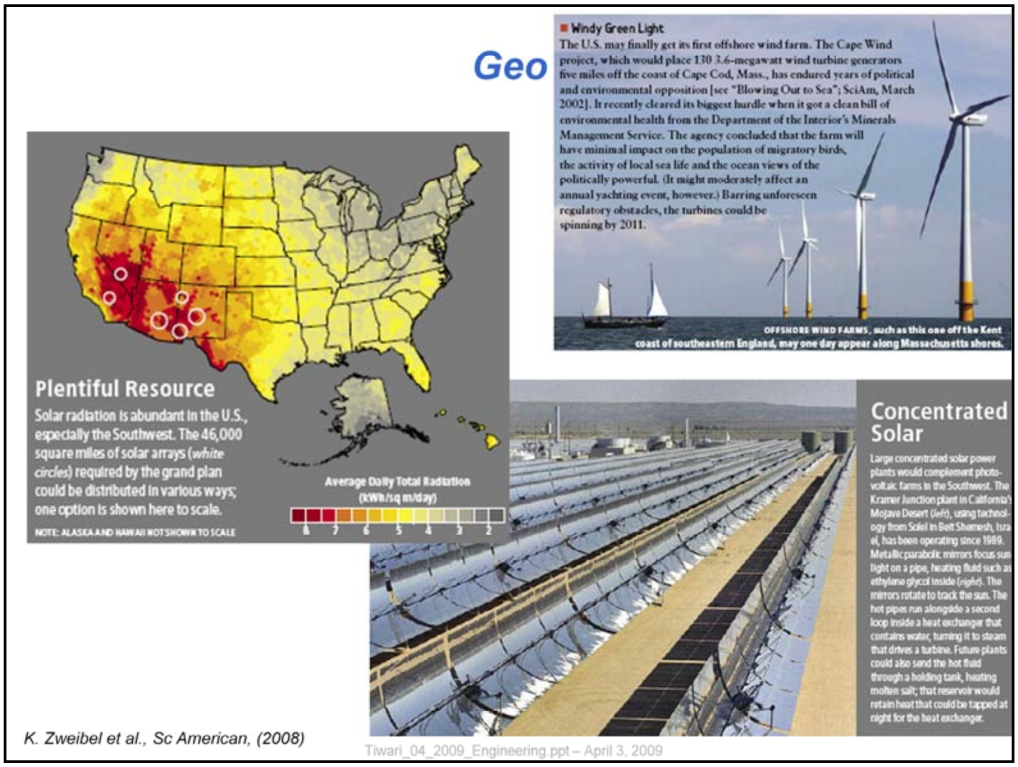
- 1.2×10^5 TW of global solar energy potential across the planet
- 20 TW from 10% efficient solar farms:
  $2 \times 10^2 / 1.2 \times 10^5$ = 0.16% of Globe ~ 8×10^{11} m^2 (~9% of US)
- United States:
  - ~200 W/m^2 average yearly insolation
  - ~10 % conversion efficiency produce 20 W/m^2
  - For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

Conversion	Storage	Delivery	Use

One such source of energy is the sun.
Discuss light, thermal, winds, electric storms, ocean currents, …

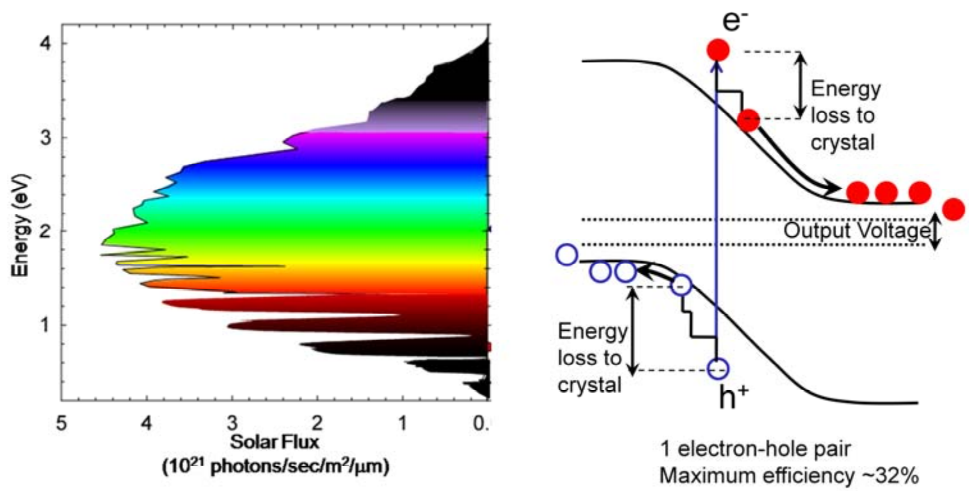


Costs of energy and why fossil resources.



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

How solar cells, a simple one, work.

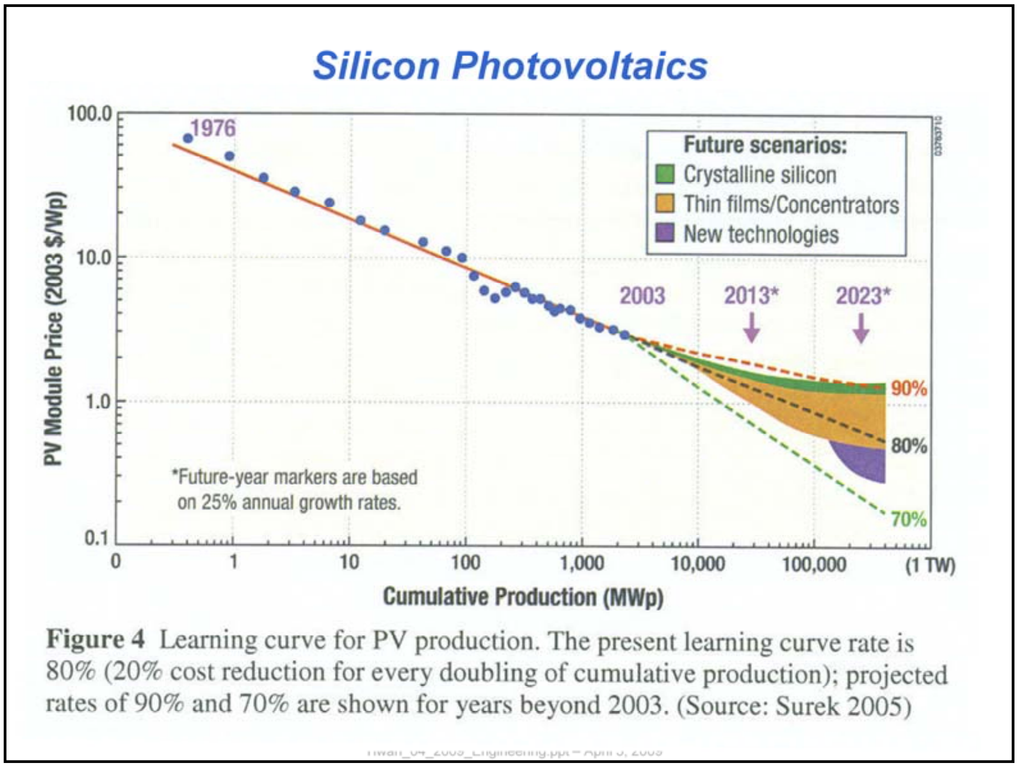
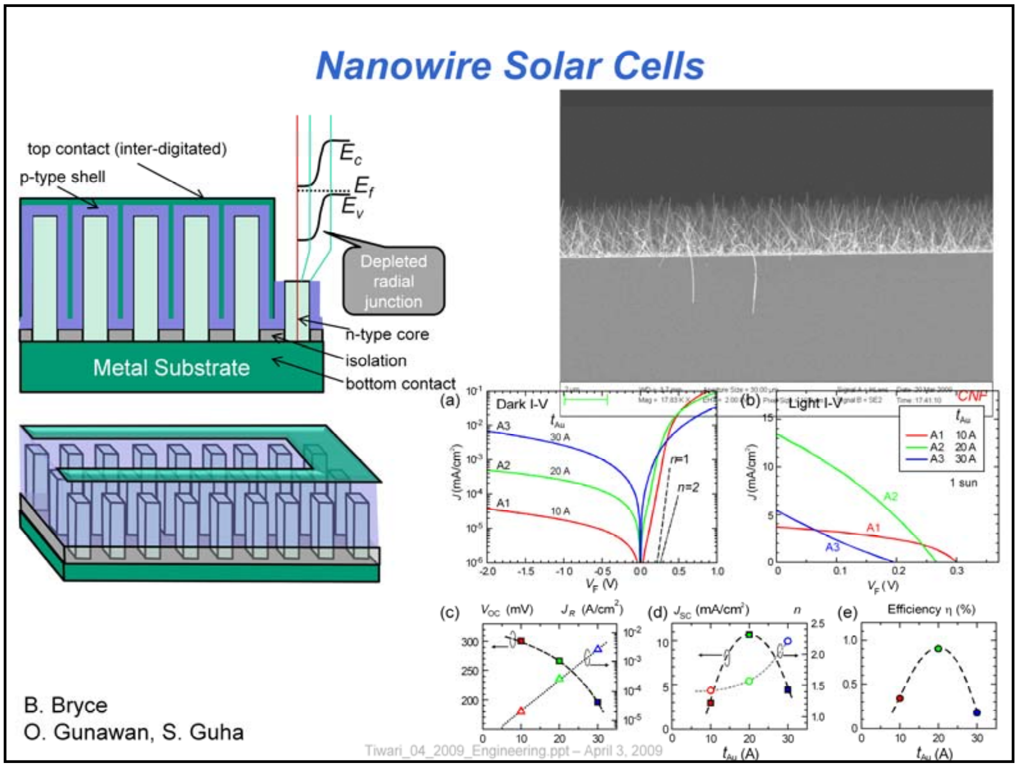


Figure 4 Learning curve for PV production. The present learning curve rate is 80% (20% cost reduction for every doubling of cumulative production); projected rates of 90% and 70% are shown for years beyond 2003. (Source: Surek 2005)

Importance of learning and energy.

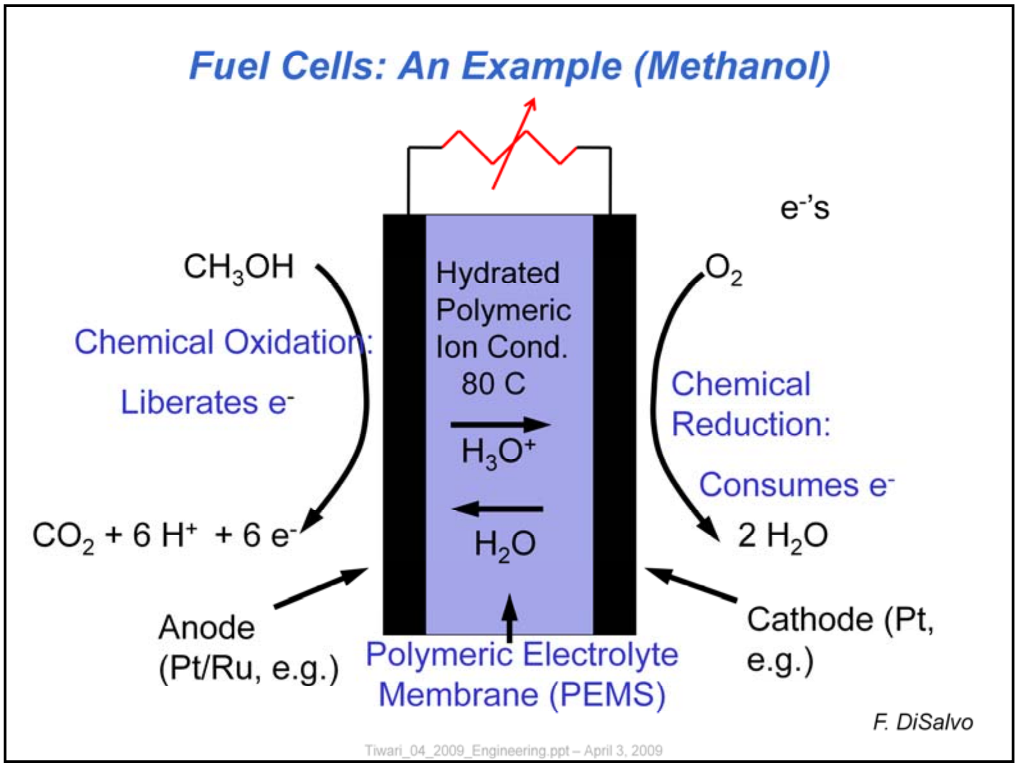
Importance of consuming very little energy, and very little materials in fabrication.



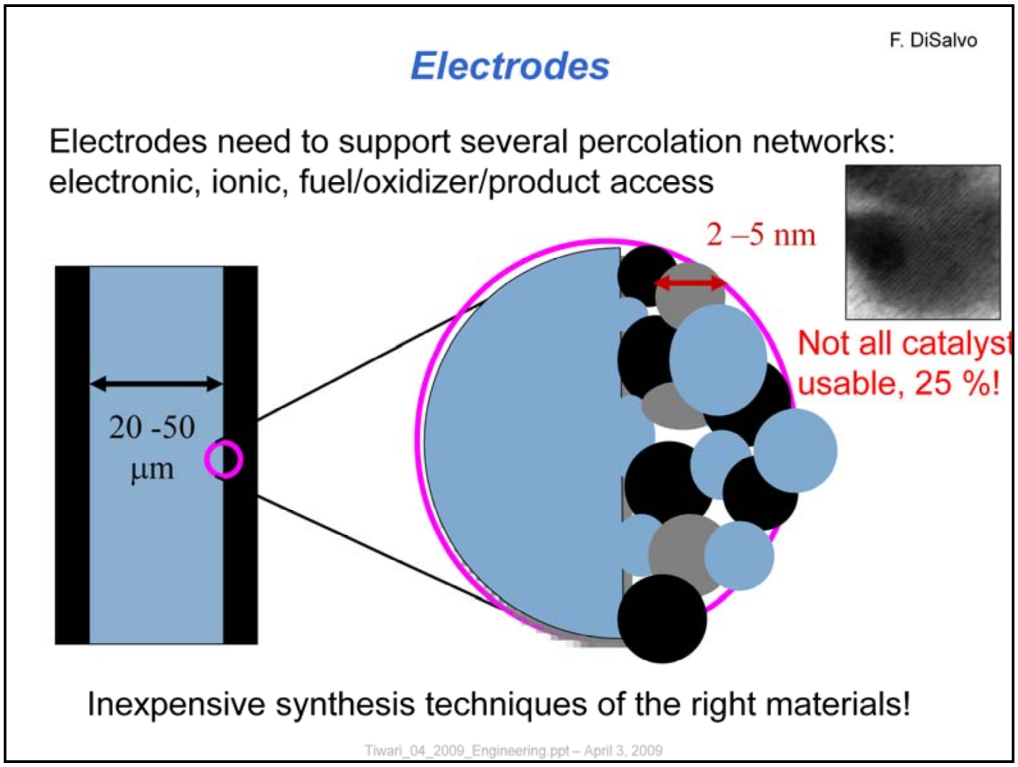
One example

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

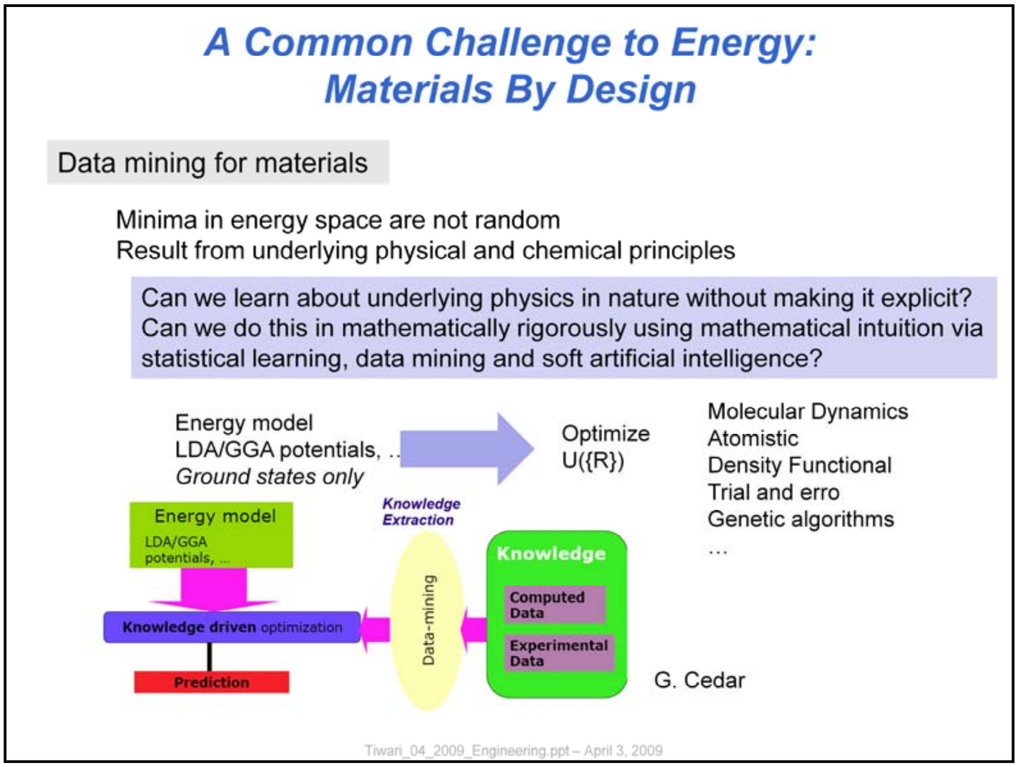
Connection of nano, materials, energy of production, use of materials.



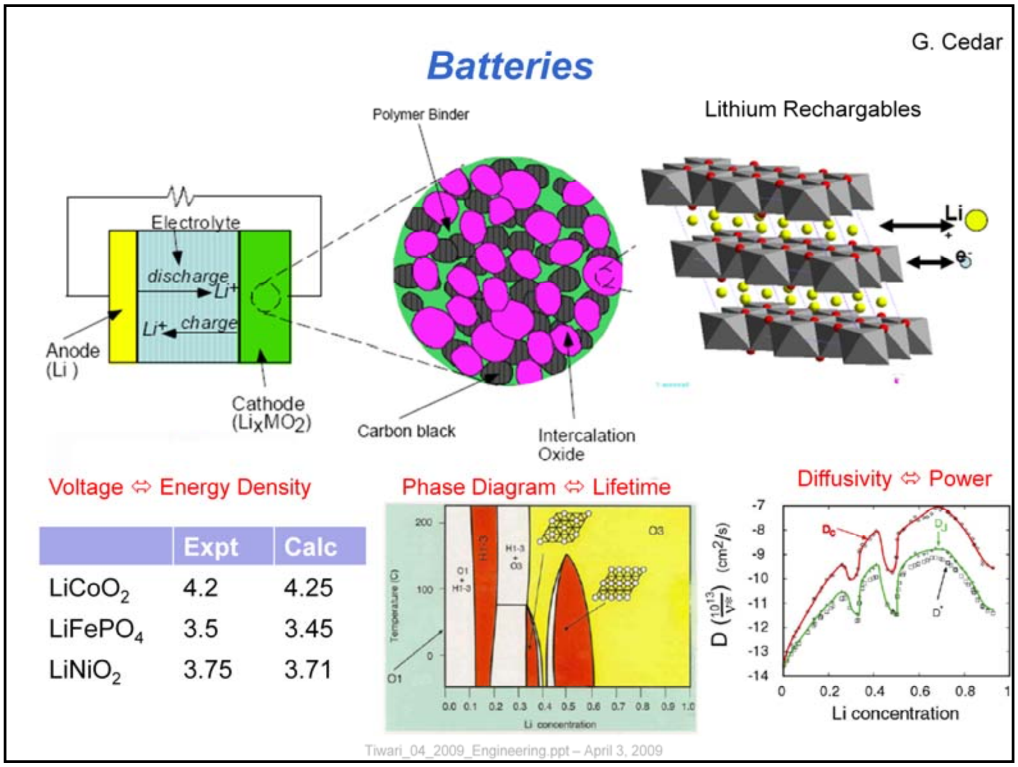
Another example related fuel cells – means of converting chemical to electrical. Materials – movement of ions, catalytic reactions at surfaces, …



Connection of nano



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

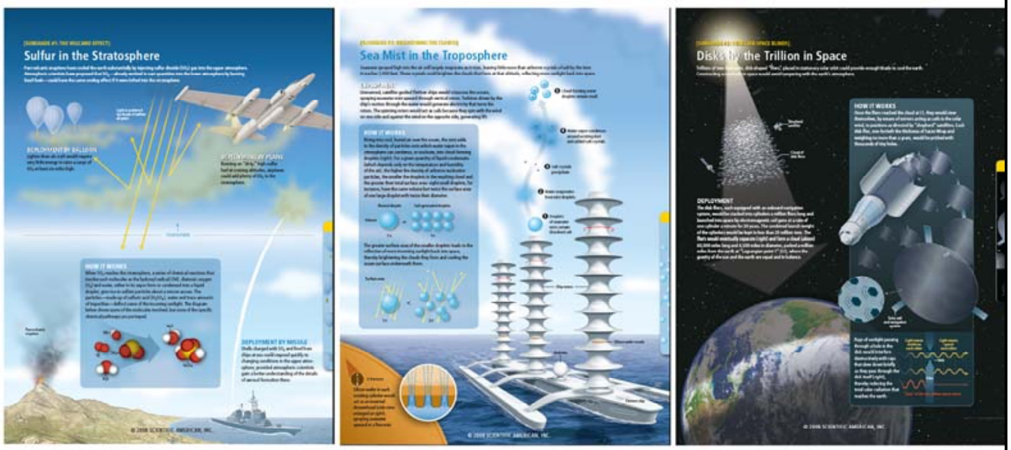
Scientific American, Nov. 2008

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



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

Predictability and wider changes of Temp
Clouds with smaller drops => less rain
Not understood – magnitude of efect
Cheap – could be used as a weapon
Continual maintenance
Carbon still needs to be controlled

Cost - $5 Trillion estimate
Long construction time
Unpredictable weather patterns
Reduced evaporation => less rain
Replacement of fliers
Potential of use as a weapon

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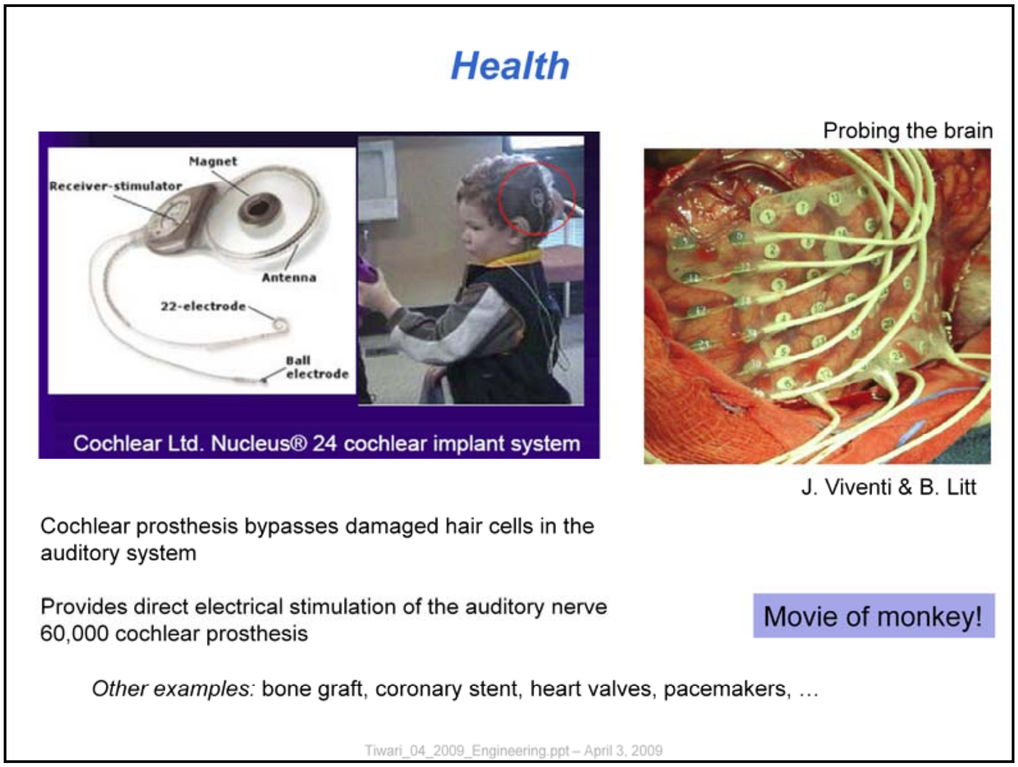
One area where engineering has had just an enormous impact by placing tools in doctor's and people's hands.

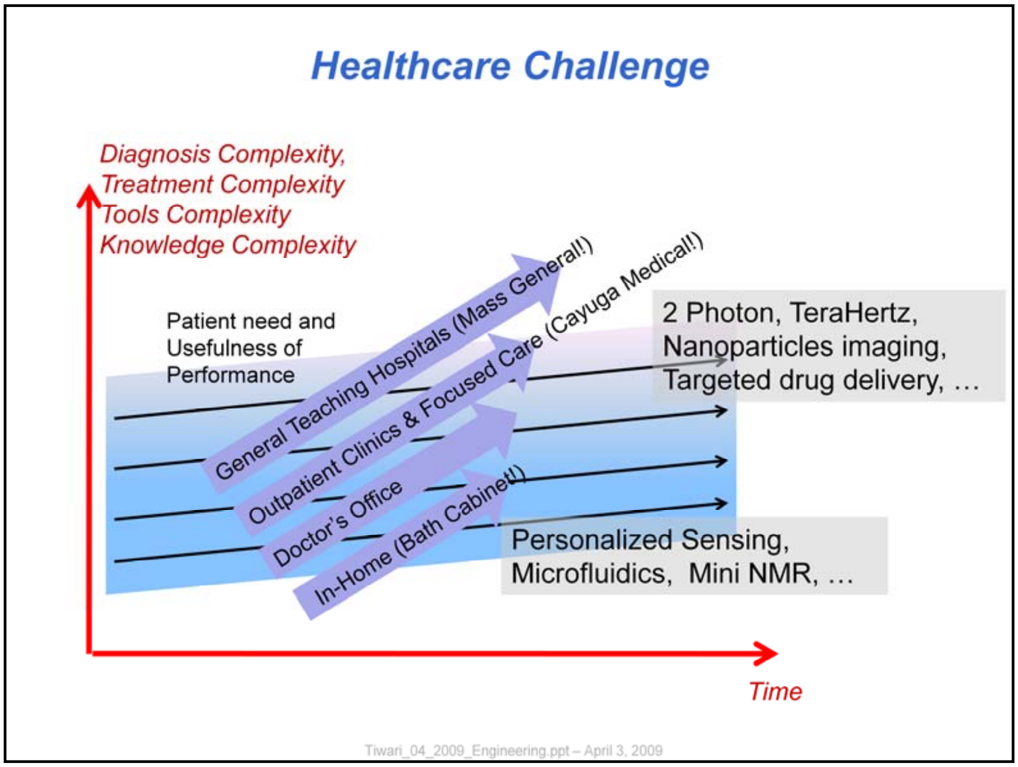


Examples of some where life has been changed just entirely.

…

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.



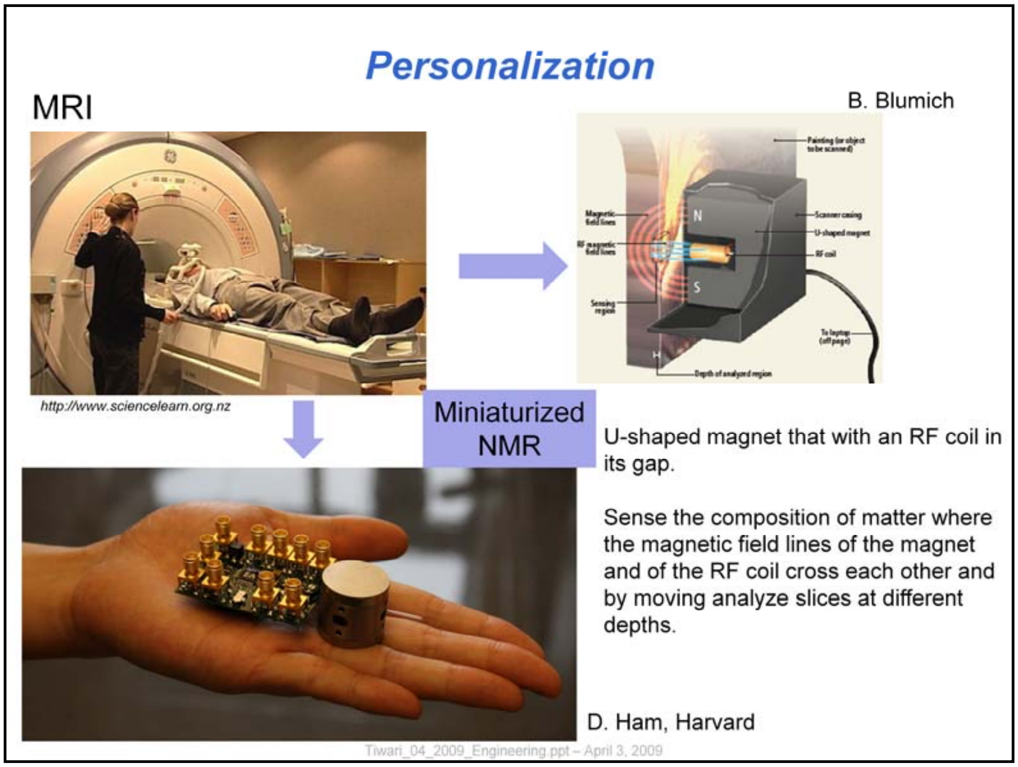
Importance of how health care and costs arise and how engineering can help.

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, …



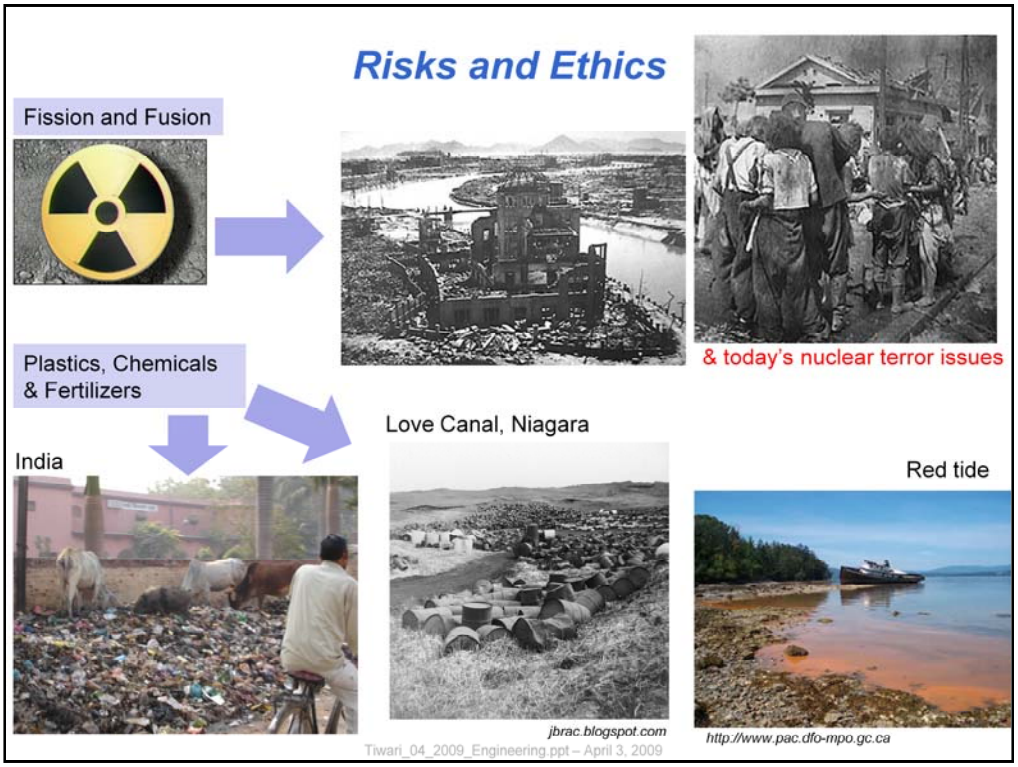
An example from imaging.

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

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

Miniaturization.

Summary Commentary



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.

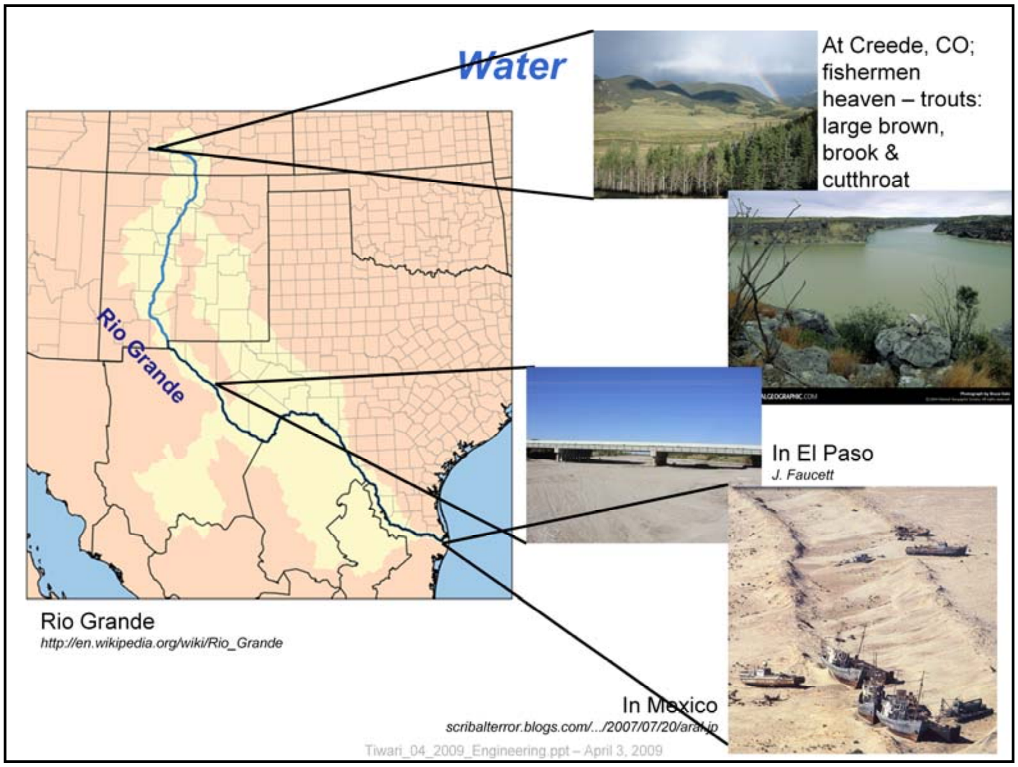
Today's nuclear issues.

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.

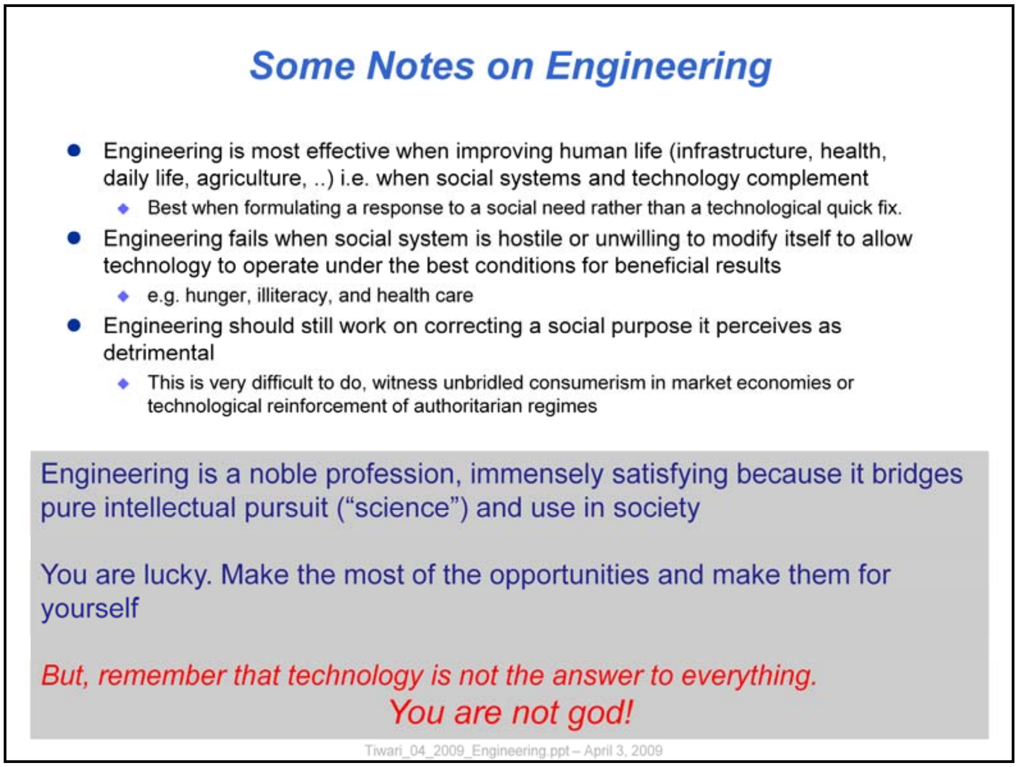
Rio Grande, …

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.



…

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.