The world’s energy problem and what we can do about it

2nd International Symposium on Energy and Environment
McDonnell International Scholars Academy
Washington University
8 - 10 December, 2008
The Energy Problem

(1) Global energy and economic security.

(2) Potential for geopolitical conflict in escalating competition for oil and gas.

(3) The risk of adverse Climate Change.
Northern and Southern Hemisphere Earth surface air temperature (1850 to 2006)
Concentration of Greenhouse gases

1750, the beginning of the industrial revolution
Comparison of temperature measurement and climate modeling

Climate change due to natural causes (solar variations, volcanoes, etc.)

Climate change due to natural causes and human generated greenhouse gases
Computer simulations for CO2 increases above pre-industrial revolution levels:

- $2 \times \text{CO}_2: 5 - 8^\circ \text{F}$
- $4 \times \text{CO}_2: 15-25^\circ \text{F}$

Pre-industrial level:
- $\sim 275 \text{ ppm CO}_2$

Today:
- $\sim 420 \text{ CO}_2$ equiv.
  Higher than in the last 1M+ years.
  We are in new territory!
During the lifetime of your youngest grandchildren, 50 - 90% of our Alpine/subalpine forests and 30 - 90% of our Sierra snowpack will vanish due to climate change.

78% of British Columbia pine will have died by 2013.

40% of the pine is now gone.
The chance of Fertile Land becoming Desert
The Mid-West Dust Bowl
(1930 -1936)
Due to drought conditions and poor farm practices.
The permafrost has become less permanent. Thawing microbes will re-cycle carbon in the soil into CO$_2$ and methane.

Zimov et al., 2006. Science. 312:1612-1613
TITANIC: The Sequel
Is there reason for hope?
"The battle to feed all of humanity is over... In the 1970s and 1980s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now."

Prof. Paul Ehrlich, Stanford Biologist
*The Population Bomb* (1968)
The Population Bomb goes to press

The invention of ammonia synthesis by Haber and Bosch made possible artificial fertilizers.

Source: Food and Agriculture Organization (FAO), United Nations
Frequently quoted myths about energy:

1. The wealth of a country is proportional to the energy it uses and its carbon footprint.
Human Development Index (GDP/capita, education level, health care, etc.) vs. Electricity Use

United States

Japan, France, Netherlands, Italy, UK, Germany, Israel, etc.
Electricity use per person (1960 – 2008)

(kWh/person) (2006 to 2008 are forecast data)

From 1973 to 2008, the GDP/capita in California has doubled.

2005 Differences
= 5,300 kWh/yr
= $165/capita
Frequently quoted myths about energy:

1. The wealth of a country is proportional to the energy it uses and its carbon footprint.

2. Energy efficiency and CO$_2$ reductions are not affordable.
Regulation stimulates technology: Refrigerator efficiency standards and performance. The expectation of efficiency standards stimulated industry innovation.

Energy savings is greater than all of US renewable energy. Regulation of consumer electronics and computers can save a similar amount of energy.
A ~80% decrease in the carbon footprint of cost effective commercial and residential buildings is possible with integration of existing technologies.
LEED ratings are based on design performance, not actual performance (EUI = End Use Intensity)

>1 means design goal exceeds performance goal

Mark Frankel, ACEEE (2008)
High Performance Buildings Research & Implementation Center (HiPerBRIC)
2-Integrated Whole Building Approach

Building Design Platform (BDP)
Tool for Architects to Design New Buildings
With Embedded Energy Analysis

Building Operating Platform (BOP)
Sensors, Communication, Controls,
Real-Time Optimization for Cost, Energy Use, CO₂ Footprint

Windows & Lighting
HVAC
Appliances
Natural Ventilation, Indoor Environment
Thermal & Electrical Storage

Building Materials
Onsite Power & Heat
Santorini, Greece

Bermuda

White roofed buildings

Santorini, Greece
Lightly colored roofs and pavements can offset Global Warming

Akbari, Menon and Rosenfeld
Lawrence Berkeley National Lab, California Energy Commission

• Pavements and roofs comprise over 60% of urban surfaces (roofs ~20%, pavements about 40%).

• They calculate that retrofitting urban roofs and pavements in the tropical and temperate regions of the world with solar-reflective materials would offset 44 Billion tonnes of emitted CO₂.

This is equivalent to taking all of the world’s billion cars off the road for 11 years.
Frequently quoted myths about energy:

1. The wealth of a country is proportional to the energy it uses and its carbon footprint.

2. Energy efficiency and CO$_2$ reductions are not affordable.

3. We have all the technology we need to solve the energy problem. It is only a matter of political will.

Political will *is* necessary, but new technology can transform the energy landscape.
International Energy Agency (IEA) forecast

There is abundant fossil energy from coal, methane coal beds, tar sands, shale oil, ... for at least 200 years.

67% of the world supply of coal:

<table>
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<tr>
<th>Country</th>
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<tr>
<td>US</td>
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<td>Russia</td>
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<td>China</td>
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<td>India</td>
<td>10%</td>
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Long term geological storage in saline aquifers will be tested by the DOE in a variety of sites.
CO$_2$ sequestration is not off-the-shelf ready. More RD&D on capture and sequestration is needed ASAP.

1. To survive NIMBY law suits, testing, monitoring in different geological sites is needed.

2. The verdict is not in: IGCC vs. CO$_2$ capture “after stack” vs. oxy-burn? Supercritical takes us from 42% to 48% efficiency. Better metal alloys or metal-ceramic composites are needed for better performance.

3. IGCC, oxy-burn are new technologies. ~10-15 years before significant deployment can start. In the mean time we are building conventional plants. We desperately need a commercially viable “after-stack” technology.
Modest but **stable** fiscal incentives were essential to stimulate long term development. Energy transmission and storage is also needed.

6 MW generator (126 m diameter rotors).
Wind sites in the US

Our current electrical transmission and distribution system is a set of lines built to serve local customers. It can not accommodate large capacity variable energy sources or long distance transmission of energy.
Energy Storage is an unsolved problem

• Large scale for storage of renewable sources of energy such as wind and solar sources. (Pumped hydro-storage and compressed air are currently our best options)

• Small scale storage is needed for plug-in automobiles, micro-grids,
Existing photovoltaic technologies will not be competitive with fossil fuel generation for ~20 - 25 years.

We need transformative solutions to solve the climate problem.

Cost of Gas generated electricity is ~ 5x less
A transformative technology

• An essential component transcontinental telephone line was the vacuum tube.

• Vacuum tubes generated a lot of heat and burned out.

• AT&T Bell Laboratories invested heavily in improving vacuum tubes. They also embarked on a research program to develop a solid state replacement to the vacuum tube.
Why liquid fuels?

- Diesel fuel, heating oil
- Biodiesel
- Gasoline
- LNG
- Propane (liquid)
- Ethanol
- Coal
- Methanol
- Corn
- Forest residues
- Wood
- Propane (gas 1 bar)
- Liquid H2
- STP H2
- NiMH, lithium

Stored energy per volume (MJ/l):
- Diesel fuel: ~ 50,000 kJ/kg
- Li-ion batteries: ~ 0.15 kW/kg

Stored energy per weight (MJ/kg):
- High energy/volume or weight, “transportable”
A lithium – metal battery material with a dry, block copolymer separator shows promise. (Nitash Balsara)

Latest results of prototype ~ 1500 deep discharge cycles and no sign of degradation.
Energy density will be ~300 kW.kg, 2x current Li-ion
Energy Biosciences Institute
$50M/ year for 10 years

Univ. California, Berkeley
Lawrence Berkeley National Lab
Univ. Illinois, Urbana-Champaign
Sunlight to energy via Bio-mass

Develop energy plants that can use marginal agricultural land, need less nutrients, water, and are easier to breakdown into simple sugars.

Improved conversion of cellulose into fuel. New organisms for biomass conversion.
Deconstruction Division: Ionic liquid (Emim acetate) treatment of switchgrass

Before Pretreatment

Swollen cell wall after 10 minutes of Pretreatment

After 3 hours of IL pre-treatment

After addition of water
Termites have many specialized microbes that efficiently digest lignocellulosic material

- Cellulases
- Hemicellulases
- Fermentation pathways

Glucose, fructose, sucrose

Fermentation pathways

Mono- & oligomers
H₂ & CO₂

Termitesidæ: 
Neotermes corrigi 
Gut of worker
Production of artemisinin in bacteria

Jay Keasling

Director of Physical Biosciences Division
The synthetic biology technology used to produce a new anti-malarial drug (artemisinin) has been used to turn bacteria and yeast into producing a gasoline, diesel and jet fuels.
The first important step:

Sunlight + 2H₂O → O₂ + 4H⁺ + 4e⁻
There is reason for hope, but ...

• We need a 2\textsuperscript{nd} Industrial Revolution and Green Revolution based on a \textit{sustainable} use of Earth’s resources.

• We need to move away from a society that values consumption.

"Earth provides enough to satisfy every man's need, but not every man's greed."

\textbf{Mahatma Gandhi}
Earthrise from Apollo 8 (December 24, 1968)
Global average temperature

Departures in temperature in °C (from the 1961-1990 average)

the past 1000 years (Northern Hemisphere)
Temperature over the last 420,000 years

Intergovernmental Panel on Climate Change

We are here

CO₂
Batteries for Advanced Transportation Applications (BATT)

- **Specific Energy (Wh/kg)**
  - Lead-Acid
  - Ni-MH
  - Li-ion

- **Specific Power (W/kg)**
  - IC Engine
  - Fuel Cells

- **Range**
  - EV goal
  - PHEV goal

- **Acceleration**
  - HEV goal
  - Capacitors

Source: Product data sheets

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Block Co-Polymer (PEO-Polystyrene)

**Balsara et al…**
SERC (Solar Energy Research Center): Nano-technology research aimed at efficient solar cells that can be produced in reel-to-reel process.
Davisson, Bell Laboratory’s first Nobel Laureate, was hired to do research on vacuum tubes.

Bardeen, Brattain and Shockley were part of a decade long effort to find a vacuum tube replacement.

What will replace the great industrial or war-time labs in our energy crisis?
Historical Perspective

- Lead Acid
- Ni-Cd
- Ni-MH
- Li-Ion

Year

1850 1900 1950 2000
Fatal Flaw in Polyethylene Oxide

Repeated cycling led to the roughening of the Li surface and eventually to catastrophic dendrite growth.

\[ t=0 \quad \text{intermediate times} \quad \text{high surface area Li} \quad \text{dendrite short} \]
Hybrid solution:* use a co-block polymer that self-organizes into

PEO (dark bands)

Polystyrene (light bands)

* Nitash Balsara, Materials Science Division, LBNL; UC Berkeley professor
A lithium–metal battery material with a block copolymer electrolyte shows promise. (Nitash Balsara)

Latest results of prototype ~ 1000 deep discharge cycles and no sign of degradation. Energy density ~ 2x Li-ion
Experience with New York Times HQ
Just a start

“one of a kind” new building without system integration

- Construction complete, occupied June 2007
- Automated shading and daylight dimming installed and working
- Extensive monitoring planned
- Challenge: Adoption by others…

Experimental Validation

Photo from the 8th floor of the NY Times after commissioning of shading and lighting controls.

Dimmable; Addressable; Affordable

Modeling Daylight Distribution
Can we design a modern-day equivalent of Lincoln Labs or Los Alamos, focused on mission driven research, but also connected to the industrial world? Can we created an energy equivalent of AT&T Bell Laboratories, which remain at the pinnacle of its field for ~75 years.
Davisson (NL-1937) comes to Bell Labs in 1917 to work on vacuum tube for military communications.

In 1927, he and his assistant, Lester Germer, bombard a crystal of nickel with a beam of electrons.

The electrons diffract, so they must have wave-like properties.

William Shockley joins in 1936 to work with Davisson on vacuum tubes, but soon moves to a newly formed solid-state research group.
Theory of glass and magnetic materials

The Maser - Laser

Discovered 3° Blackbody Radiation Remnant of the Big Bang while developing ultra-low noise microwave receivers for satellite communications

Phil Anderson

Laser Spectroscopy

Robert Wilson

Arno Penzias

Art Schawlow

Charles Townes

Jim Gordon
Nobel Prize Members at Bell Labs hired in 1977-78

Douglas Osheroff

Me (at 32)

Dan Tsui

Horst Stormer

Bob Laughlin
Projections of Sierra snow-pack and implications for water

- **2020–2049**
  - Lower Emissions: 74% remaining
  - Higher Emissions: 60% remaining

- **2070–2099**
  - Lower Emissions: 27% remaining
  - Higher Emissions: 11% remaining

*Remaining Snowpack (%)*
Sydney Brenner (NL-2004) Advisor to Sidney Altman (NL-1989), Andrew Fire (NL-2006), on the early days of the LMB:

“Nobody was a professional. We were all talented amateurs.”

“We attracted the best, and our job was to create people better than ourselves and other senior people. The best, most daring, are the youngest …”

The LMB and Bell Labs almost never hired senior scientists, preferring instead to home-grow their own.
People stimulate each other. The managers should be top practicing scientists.

Bell Laboratories had structures to promote communication:

- Internal memos were widely circulated.
- Managers connected their department members with other lab members.
- Murray Hill and Holmdel were isolated in the suburbs. Virtually everybody ate at the cafeteria. Lunch time was a major center of scientific exchanges.
- Journal clubs and tea time were times of animated (and sometimes very blunt) discussions.
Sydney Brenner:

“Everybody worked in the lab. Flies, rats, physicists, chemists all going in the same direction.

We attracted an extremely talented group of post docs. Turf was not divided and they could do what they wanted to do.

All directions come from science. We did not build machines and wait for people to come. Central important problems is what unifies people from different disciplines.”