Global Classroom 20 October 2009

ENERGY ENGINEERING & TECHNOLOGY

Dato Ir. Lee Yee Cheong
Special Advisor on Sustainable Energy to InterAcademy Council (IAC) Co-Chairs

Guide Notes to Participants

Discussion will be based on the IAC Energy Study Report “Lighting the Way: Towards a Sustainable Energy Future”

Using the IAC Energy Study Panel Co-Chair Nobel Laureate Dr. Steven Chu’s presentation to the Chinese Academy of Sciences; with sticky notes from me where appropriate.
The Energy Problem and how we might solve it

Chinese Academy of Sciences Graduate School
Sciences and Humanities Forum
11 October, 2007
“Lighting the Way: Toward a Sustainable Energy Future”

Co-chairs: Jose Goldemberg, Brazil
          Steven Chu, USA
Co-Chairs:
  Steven Chu (USA)
  José Goldemberg (Brazil)

Panel Members:
  Shem Arungu Olende (Kenya)
  Mohamed El-Ashry (Egypt)
  Ged Davis (UK)
  Thomas Johansson (Sweden)
  David Keith (Canada)
  Li Jinghai (China)
  Nebosja Nakicenovic (Austria)
  Rajendra Pachauri (India)
  Majid Shafie-Pour (Iran)
  Evald Shpilrain (Russia)
  Robert Socolow (USA)
  Kenji Yamaji (Japan)
  Yan Luguang (China)
# Table of Contents

Executive Summary .............................................................................. 5

Chapter I: Introduction ...................................................................... 21

Chapter II: The Sustainable Energy Challenge ................................. 25

Chapter III: Energy Demand and Efficiency .................................... 43

Chapter IV: Energy Supply ................................................................. 75

IV.1 Fossil Fuels .............................................................................. 76
IV.2 Nuclear Power ........................................................................... 91
IV.3 Non-Biomass Renewables ......................................................... 106
IV.4 Biomass .................................................................................... 119
IV.5 Conclusions ............................................................................. 130

Chapter V: The Role of Government and Contribution of Science and Technology 131

Chapter VI: Conclusions and Recommendations ............................ 153
Chapter I. Introduction

The need for Energy Sustainability:

(1) Environmental concerns: Local pollution, Climate Change, water use.

(2) 2-3 billion people worldwide currently lack access to modern forms of energy.
2.6 billion people use coal, charcoal, firewood, agricultural residues, or dung as their primary cooking fuel. ~ 1.6 billion people worldwide live without electricity.

(3) Reduce the security risks and potential for geopolitical conflict due to escalating competition for energy resources.
O₃ (ozone), Carbon monoxide (CO), Sulfur dioxide (SO₂), Nitrous oxides (NOₓ), Particulate matter, ...

- Respiratory illnesses, cancers, ...
- Premature ageing of buildings, bridges, and other infrastructure
- Damage to agricultural, forests, lakes, wildlife
US became a net importer of oil in 1970

China oil consumption and production 1980 -2005
19 of the 20 warmest years since 1860 have all occurred since 1980.

2005 was the warmest year in the instrumental record and probably the warmest in 1,000 years (tree rings, ice cores).

140 years is nothing by geological time scales!
Temperature over the last 420,000 years

Intergovernmental Panel on Climate Change

We are here

CO$_2$

We are here
Concentration of Greenhouse gases

1750, the beginning of the industrial revolution
Temperature rise due to human emission of greenhouse gases

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

Climate change due to natural causes and human generated greenhouse gases
Emissions pathways, climate change, and impacts on California

Using two climate models that bracket most of carbon emissions scenarios:

<table>
<thead>
<tr>
<th></th>
<th>B1</th>
<th>A1 fi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat wave mortality</td>
<td>2-3x</td>
<td>5-7x</td>
</tr>
<tr>
<td>Alpine/subalpine forests</td>
<td>50–75%</td>
<td>75–90%</td>
</tr>
<tr>
<td>Sierra snowpack</td>
<td>30–70%</td>
<td>73–90%</td>
</tr>
</tbody>
</table>

British Columbia: ~ 78% of the pine forests predicted to be dead within a decade due to pine beetle infestation.
80% of British Columbia pine will have died by 2013. 
~ 40% is now gone.
50 years: 14 meter avg. decrease world wide.

Tibetan glacier (serves 1/3 the population of the world) is shrinking by ~1.2m / yr
Positive feedback: melting *reflective* ice and snow is replaced by *absorbing* dark oceans.

The data from different instruments:

- Multi-channel microwave radiometer (Nimbus 7 satellite)
- Microwave imagers attached to the Defense Meteorological Satellite Programs.
More recent Arctic melting data

SUMMER SEA ICE
This summer saw a record-breaking loss of Arctic sea ice. Experts attribute the changes to the interaction of wind, weather, ice drift, ocean currents and greenhouse gases.

SUMMER SEA ICE EXTENT*

*Sea ice extent is the area of ocean covered by at least 15 percent ice.

PERENNIAL SEA ICE
Ocean within this boundary had been covered with ice year-round since satellite records began in 1979. This summer was the first time that part of the perennial sea ice was open water.
Greenland Ice Sheet: 70m thinning in 5 years

Record melt of 2002 was exceeded in 2005

Surging glaciers + melting
Unstable Glaciers

Surface melt on Greenland ice sheet descending into moulin, a vertical shaft carrying the water to base of ice sheet.

Source: Roger Braithwaite
Predicted surface temperature (Celsius) trend averaged over the years 2000 - 2050

(Drew Shindell, Gavin Schmidt, NASA)
A human needs to ingest 2,500 kilocalories a day to sustain life. 350 GJ / per capita / year is the equivalent of having 100 energy “servants”. The average person in China has ~10 servants / person.
Human Development Index vs. Energy consumption

World Average: HDI = 0.741; World average per Capita Electricity Consumption = 2430 kWh/person.year
Emissions Trajectories for atmospheric CO$_2$ concentration ceilings

Source: Fourth Assessment of the Intergovernmental Panel on Climate Change; Summary for Policy Makers, February 2007.
Energy efficiency and conservation is and will remains the lowest hanging fruit for the next several decades
Electricity Consumption/person in the US and California

[Graph showing electricity consumption for the US and California from 1960 to 2000, with data points indicating a steady increase over time.]
Refrigerator efficiency standards and performance. When efficiency standards could not be fought politically, innovation began.
US Electricity Use of Refrigerators and Freezers compared to sources of electricity

- **Nuclear**
- **Conventional Hydro**
- **Existing Renewables**
- **3 Gorges Dam**
- **50 Million 2 kW PV Systems**

---

**Billion kWh per year**

- **150 M Refrigerators/Freezers**
  - at 1974 efficiency
  - at 2001 efficiency

---

**Saved Used**

- **Used**
Half of the energy savings in California were made by separating utility profits from selling more energy.

Source: Mike Messenger, Calif. Energy Commission Staff, April 2003
Efficiency in the industrial sector

- Iron and steel
- Cement
- Aluminum
- Chemicals
- Petroleum refining
- Pulp and paper

Energy-intensive industries account for more than half of the sector’s energy consumption in most countries.
Chapter IV: Energy Supply

III.1 Fossil Fuels
III.2 Nuclear Power
III.3 Non-Biomass Renewables
III.4 Biomass
III.5 Conclusions
The Efficiency of Coal Burning Plants

Japan (~40%)

U.S.

China

India (~30%)
A combined cycle power plant combines employs two or more thermodynamic cycles.

Final use of low-temperature heat is used for space and water heating. (Co-generation)
The Efficiency of Coal Burning Plants

- 50% may be possible with Supercritical Steam boilers, but new, temperature resistant metals are needed.

- The same technology can allow oxygen-burn boilers and at-the-stack retro-fit capable CO₂ capture.

- Natural gas is 60% efficient. (80% with co-generation)

- IGCC can also use turbine technology (~60%), but capital costs are becoming prohibitive.
International Energy Agency (IEA) forecast

Carbon emission in the next 30 years will add 3x more CO$_2$ emission than the previous history of all humanity!

There is abundant fossil energy from coal, methane coal beds, tar sands, shale oil, ... for at least 200 - 400 years.

67% of the world supply of coal:
- US: 27%
- Russia: 17%
- China: 13%
- India: 10%

Coal is the default option of the US, China, and India.
Chapter IV. The Role of Government

A combination of incentives, fiscal policies, and regulations will be needed to guide industry and personal choices.

Free markets, when left alone will fail if there is a “commons problem”:

- Water and air pollution
- International fishing
- Climate change
Regulation stimulates industrial innovation

Efficiency began before standards!

A Low Energy High Rise: the New San Francisco Federal Building

- Natural ventilation in tower – no mechanical cooling or ventilation in open-plan perimeter office space
- Exposed structural concrete for thermal inertia
- Extensive use of natural lighting
- Designed with state-of-the-art computer simulation tools
Automobile Fuel Economy Standards

Miles per gallon vs. Year (2002-2016)

- US
- EU
- Japan
- China
- Australia
- Canada
- California
Chapter IV. Contribution of Science and Technology.
3 MW capacity wind generators deployed
5 MW generators in design
(126 m diameter rotors).

Assuming conservation of mass for incompressible flow and conservation of momentum,

Maximum kinetic energy delivered to a wind turbine

\[ = \frac{16}{27} \left(\frac{1}{2}\right)mv^2 \]

\(~ 0.59 \text{ of kinetic energy}~

The biggest turbines capture
\(~ \frac{5}{6} \text{ of this amount.}~\)
Helios: Lawrence Berkeley Laboratory and UC Berkeley’s attack on the energy problem

- Plants
- Cellulose
- Cellulose-degrading microbes
- Engineered photosynthetic microbes and plants
- Artificial Photosynthesis
- Electricity
- PV
- Electrochemistry
- Methanol
- Ethanol
- Hydrogen
- Hydrocarbons
- Wind, waves, nuclear
Limiting factors for plant productivity

Baldocchi et al. 2004 SCOPE 62
Solar thermal

- Reduction of costs by a factor of ~3 is needed for roof-top deployment without subsidy.
- A new class of solar PV cells at ~1/10th current cost is needed for wide-spread deployment.

~0.2 – 0.3% of the non-arable land in the world would be need to generate current electricity needs (~4 TW) with solar electricity generation at 20% efficiency.
Cost of electricity generation (1990 dollars/kilowatt hour)
Limiting sizes for distributed junction nano-solar cells
(Creation of electrons and holes by one nano-structure; charge transport to electrodes with another.)
Sunlight to energy via Bio-mass

- Sunlight
- $\text{CO}_2$, $\text{H}_2\text{O}$, Nutrients

Biomass

- More efficient use of water, sunlight, nutrients.
- Drought and pest resistant

Chemical energy

- Improved conversion of cellulose into fuel.
- New organisms for biomass conversion.
World Production of Grain (1961 – 2004)

1960: Population = 3 B
2005: Population = 6.5 B

Source: Food and Agriculture Organization (FAO), United Nations
Feedstock grasses (*Miscanthus*) is a largely unimproved crop. Non-fertilized, non-irrigated test field at U. Illinois can yield 10x more ethanol / acre than corn.

50 M acres of energy crops plus agricultural wastes (wheat straw, corn stover, wood residues, etc.) can produce *half* to *all* of current US consumption of gasoline.
Advantages of perennial plants such as grasses:

- No tillage for ~ 10 years after first planting
- Long-lived roots establish symbiotic interactions with bacteria to acquire nitrogen and mineral nutrients.
- Some perennials withdraw a substantial fraction of mineral nutrients from above-ground portions of the plant before harvest.
- Perennials have lower fertilizer runoff than annuals. (Switchgrass has ~ 1/8 nitrogen runoff and 1/100 the soil erosion of corn.)
Current and projected production costs of ethanol

Courtesy Steve Koonin, BP Chief Scientist

- EU Sugar Beet: 3.75
- Brazilian Sugar Cane: 2.79
- US Corn: 2.89
- US Switchgrass: 2.48
- US Corn Stover: 1.20
- EU Sugar Beet: 3.75
- Brazilian Sugar Cane: 2.79
- US Corn: 2.89
- US Switchgrass: 2.48
- US Corn Stover: 1.20

Source: BP Analysis, NREL, CERES, NCGA
The effect of lignin on enzyme recovery of sugars in miscanthus

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>40-60% Percent Dry Weight</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>20-40%</td>
</tr>
<tr>
<td>Lignin</td>
<td>10-25%</td>
</tr>
</tbody>
</table>
Energy Biosciences Institute
$50M/ year for 10 years

Joint Bio-Energy Institute (JBEI)
LBNL, Sandia, LLNL, UC Berkeley, Stanford, UC Davis
$25M / year for at least 5 years

Univ. California, Berkeley
Lawrence Berkeley National Lab
Univ. Illinois, Urbana-Champaign
Termites have many specialized microbes that efficiently digest lignocellulosic material.
Man first learned to fly by imitating nature
Is it possible to engineer an artificial photosynthetic system that is powered by either sunlight or electricity?
Chapter V: Conclusions and Recommendations

1. Meeting the basic energy needs of the poorest people on this planet is a moral and social imperative that must be pursued in concert with sustainability objectives.

2. Concerted efforts must be made to improve energy efficiency and reduce the carbon intensity of the world economy.

3. Technologies for capturing and sequestering carbon from fossil fuels can play a central role in the cost-effective management of global carbon dioxide emissions.
4. To reduce future geopolitical conflict and economic vulnerability associated with oil and natural gas, conservation and alternative sources must be developed.

5. Nuclear power (currently ~16% of world electricity generation) can play a significant role.

6. Renewable energy offers immense opportunities.

   • Price on carbon ($100 - $150/avoided ton of carbon, $27–$41 per ton of carbon dioxide equivalent.)

   • Subsidies should be targeted to promising but not-yet-commercial technologies and decline gradually over time.

   • Renewable portfolio standards and “reverse auctions” (renewable energy developers bid for a share of public funds on the basis of the minimum subsidy they require).
7. Invest in research and development on more transformational technologies.

8. Assess and mitigate any negative environmental impacts associated with the large-scale deployment of renewable energy technologies.

9. Develop better energy storage technologies, new energy carriers, and improved transmission infrastructure (DC).

10. The science and technology community—together with the general public—must be effectively engaged.
There are solutions to the energy/climate change problem:

“We believe that aggressive support of energy science and technology, coupled with incentives that accelerate the concurrent development and deployment of innovative solutions, can transform the entire landscape of energy demand and supply …

What the world does in the coming decade will have enormous consequences that will last for centuries; it is imperative that we begin without further delay.”
“On December 10, 1950, William Faulkner, the Nobel Laureate in Literature, spoke at the Nobel Banquet in Stockholm,

... I believe that man will not merely endure: he will prevail. He is immortal, not because he alone among creatures has an inexhaustible voice, but because he has a soul, a spirit capable of compassion and sacrifice and endurance.’

With these virtues, the world can and will prevail over this great energy challenge.”

Steven Chu (USA) and José Goldemberg (Brazil)
Co-Chair’s Preface
“Lighting the Way: Toward a Sustainable Energy Future”
“Lighting the Way: Toward a Sustainable Energy Future”

Public release: October 12, 2007

Co-chairs: Jose Goldemberg, Brazil
Steven Chu, USA