Physicists and Global Energy Concerns

AAAS Symposium

International Projects and the Future of Physics

15 February, 2008

Some risks of climate change*:

- Water Shortages
- Property losses and population displacement from sea-level rise
- Increased damage from storms, floods, wildfires
- Reduced productivity of farms, forests, & fisheries
- Increased species extinction
- Spread of disease (malaria, cholera, dengue fever, …)

*** See the Stern Review Report: "Part II: The Impacts of Climate Change on Growth and Development"**

Emissions pathways, climate change, and impacts on California

Proceedings of National Academy of Sciences (2004)

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

	B1 500ppm	**A1 fi** Current path (BAU)
Heat wave mortality:	**2-3x**	**5-7x**
Alpine/subalpine forests	**50–75%**	**75–90%**
Sierra snowpack	**30–70%**	**73–90%**

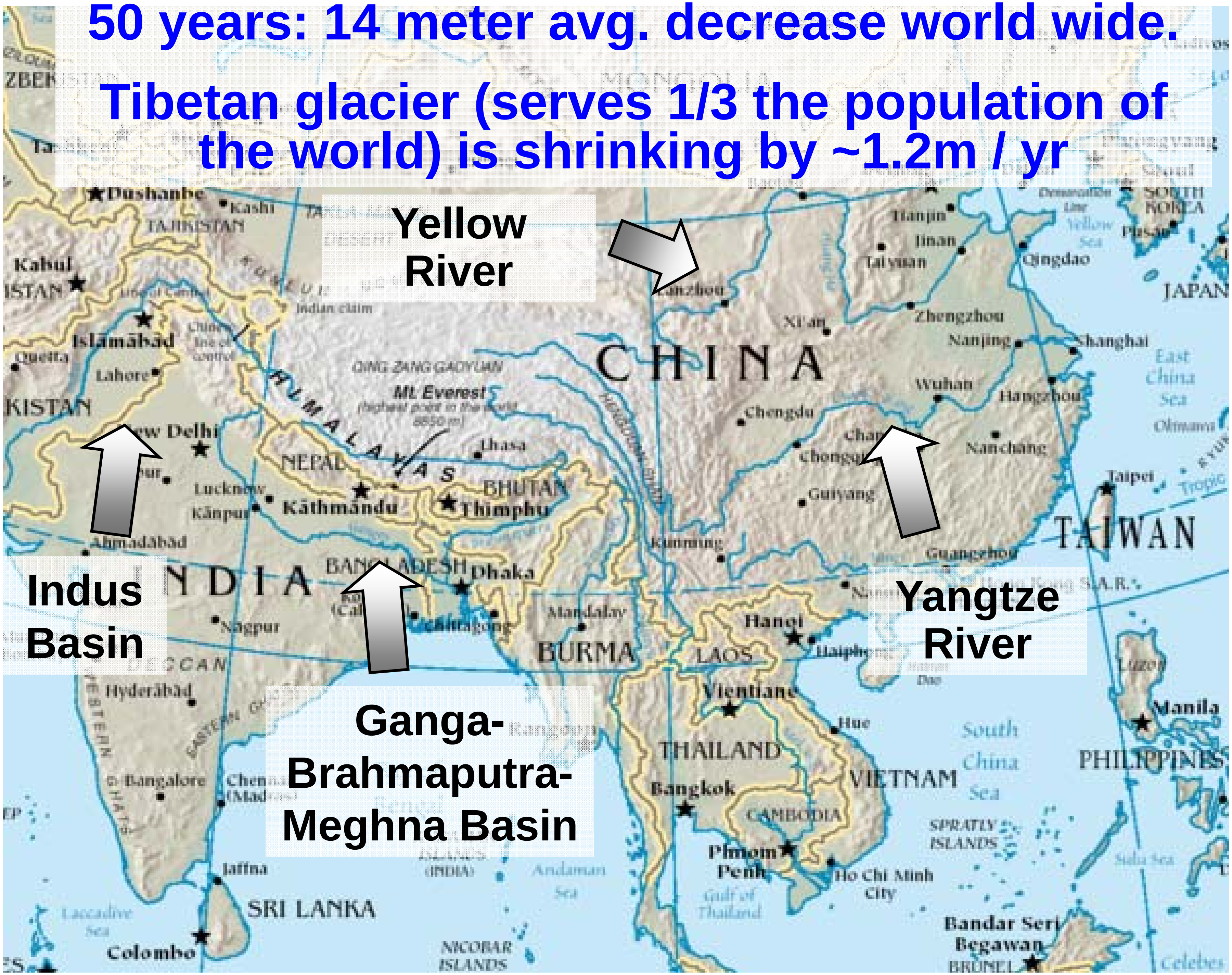
78% of British Columbia pine will have died by 2013.

"Approximately 40% of the merchantable pine volume in the province has likely already been killed."
British Columbia, Ministry of Forests and Range, 2006

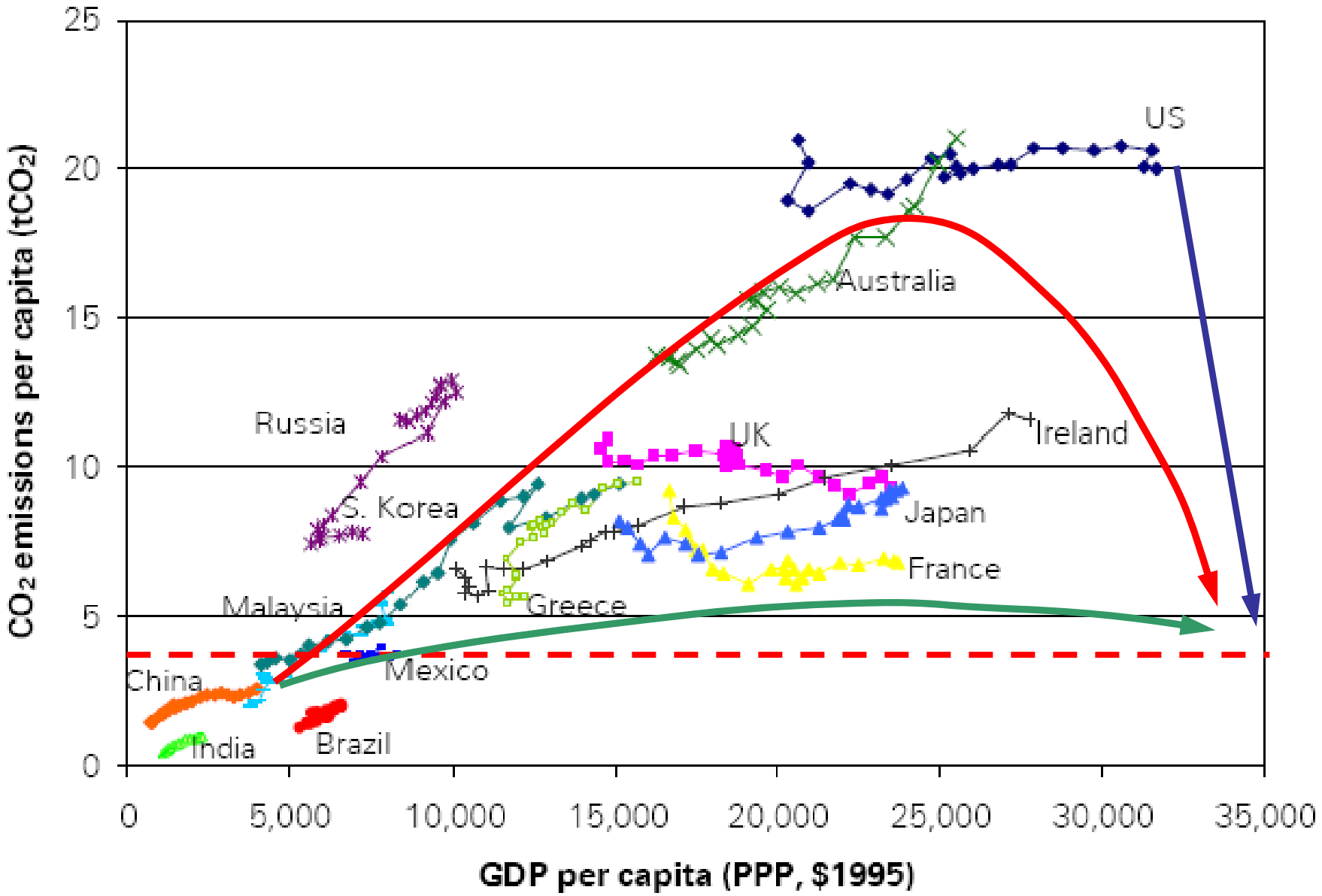
Mount Swanell

50 years: 14 meter avg. decrease world wide.

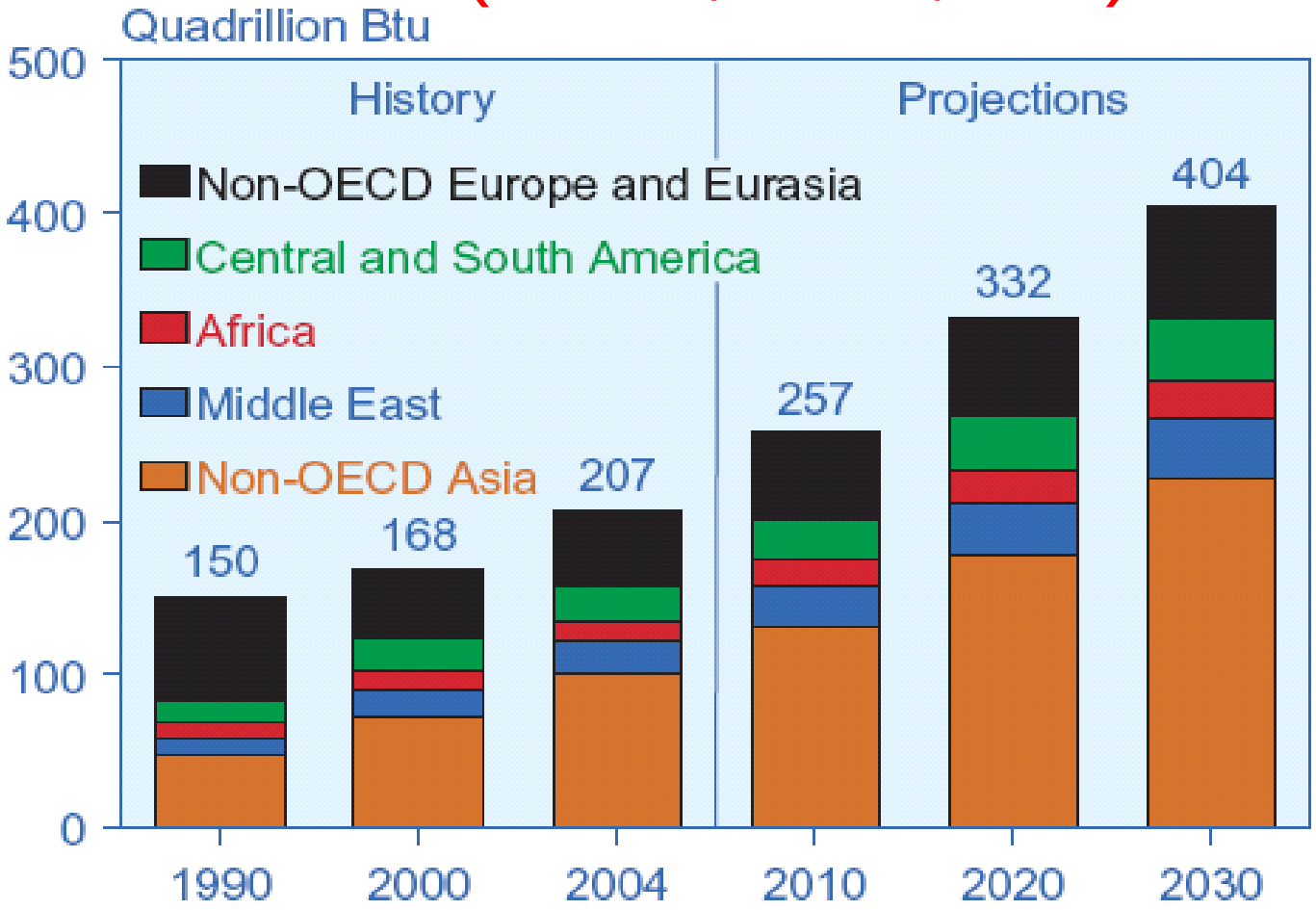
Tibetan glacier (serves 1/3 the population of the world) is shrinking by ~1.2m / yr



CO_2 emissions of selected countries

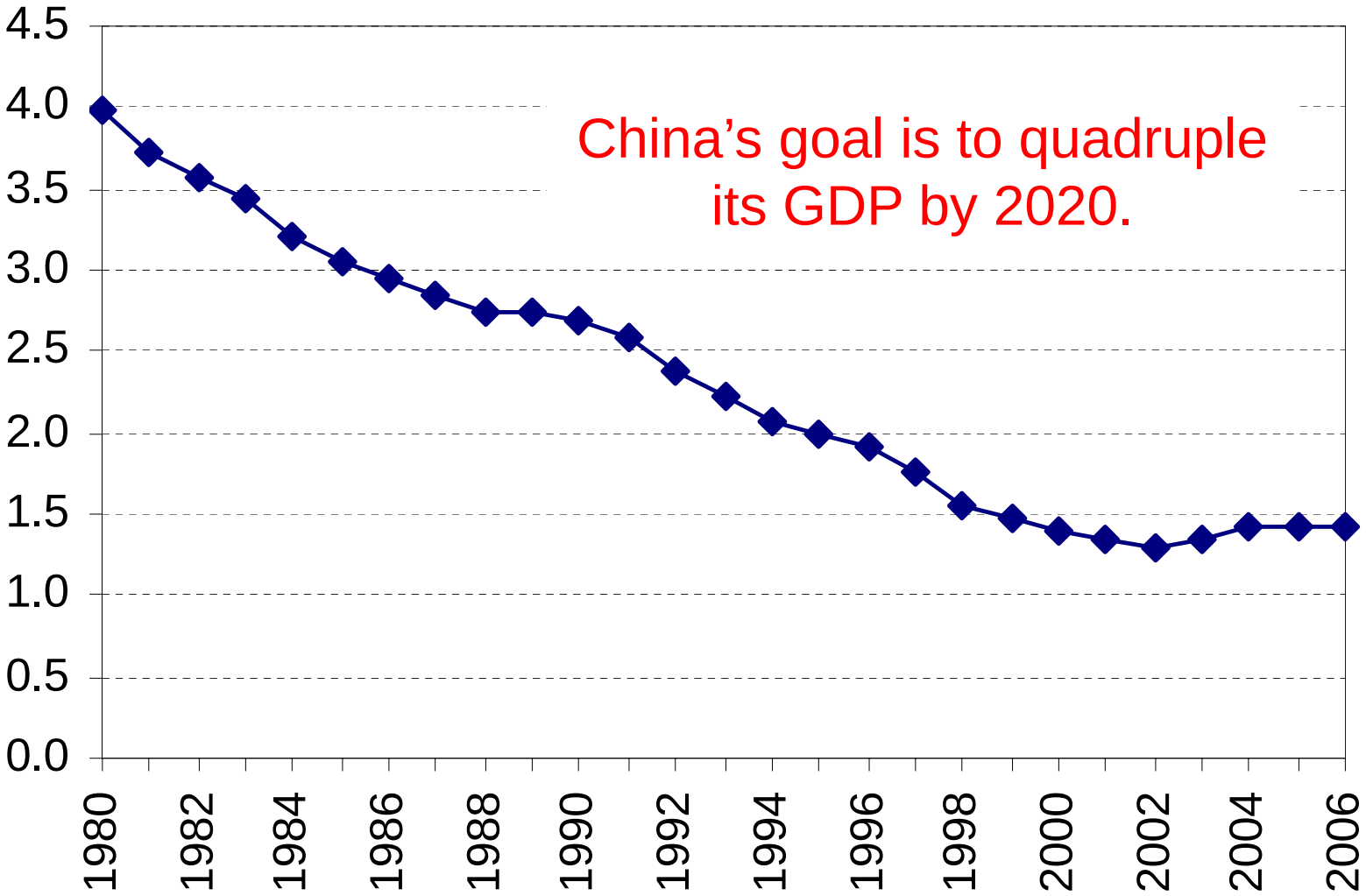


Most of the non-OECD growth will be in Asia (China, India, etc.)



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea. **Projections:** EIA, System for the Analysis of Global Energy Markets (2007).

Energy use / GDP in China



China Energy Group at LBNL

The China Energy Group works collaboratively with groups in China:

- to promote energy efficiency in China,
- to enhance the capabilities of Chinese institutions that promote energy efficiency, and
- to understand the dynamics of energy use in China.

The William and Flora Hewlett Foundation

Hewlett Foundation plans climate change grants

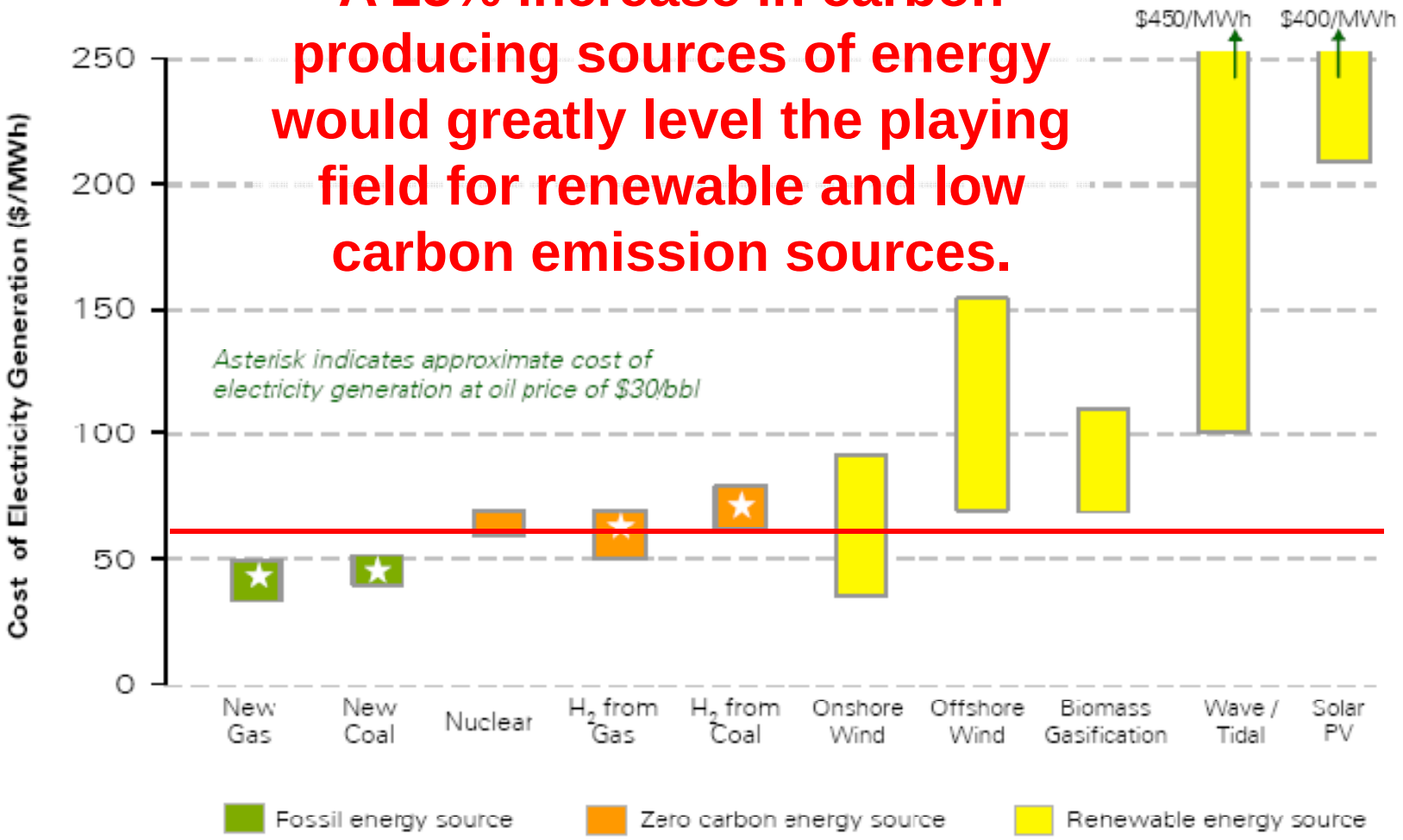
Jan 25, 2008

LONDON (Reuters) - Trustees of a $9 billion endowment fund founded by the late William Hewlett … want to spend tens of millions of dollars a year fighting climate change as part of a bigger fund …. that would increase to $500-$600 million in grant funding a year.

U.S., Europe, India, China and Brazil will be used to improve energy efficiency in city planning and building design, and to advise policymakers.

2005 costs of electricity generation for conventional, renewable and alternative options

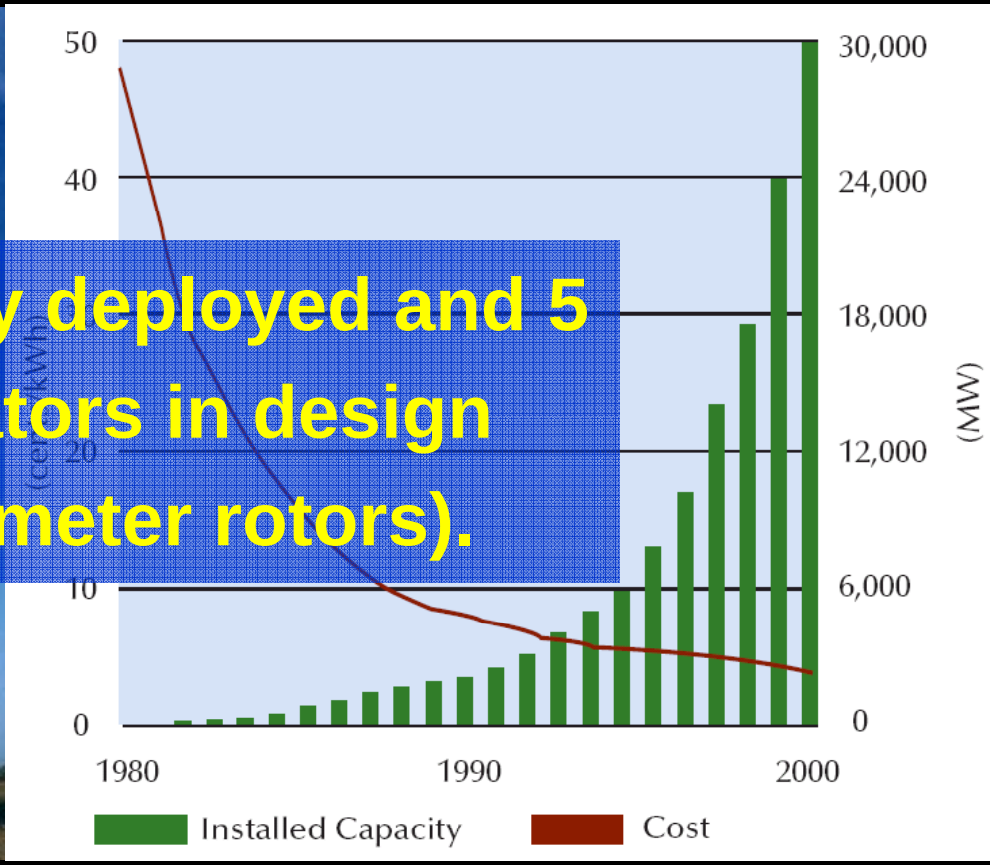
A 25% increase in carbon producing sources of energy would greatly level the playing field for renewable and low carbon emission sources.



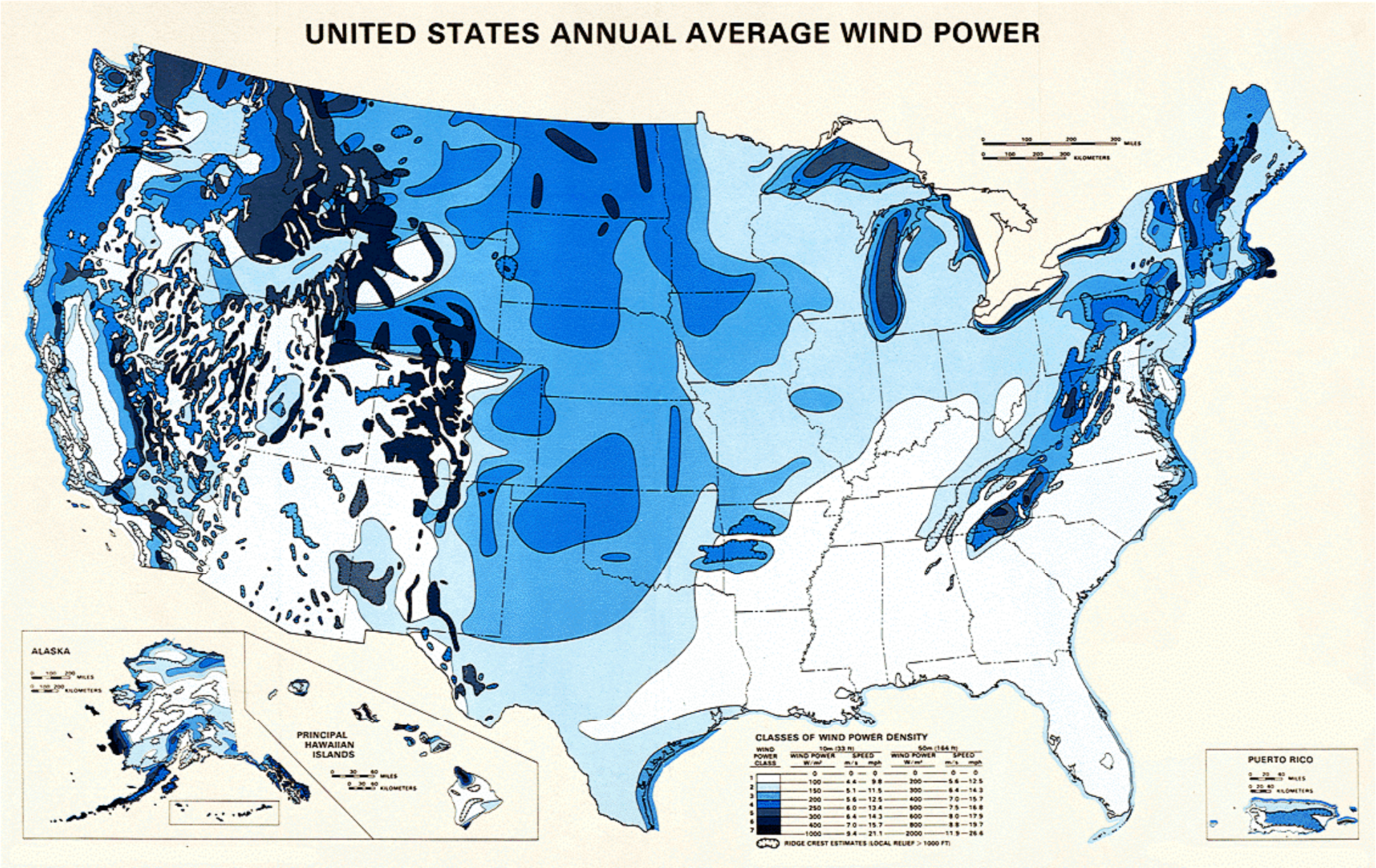
Source: BP Analysis, NCI

Modest but **stable** fiscal incentives were essential to stimulate long term development. Energy transmission/storage is also needed.

3 MW capacity deployed and 5 MW generators in design (126 m diameter rotors).



Wind sites in the US



Advantages of High Voltage DC over AC transmission:

After 500km, HVDC is less expensive!

- Two conductors vs. 3 or 4 for AC.
- Radiative and dielectric losses are much less.
- Capacitance losses
  (Energy used to polarize the capacitance of the cable and surrounding environment)
- Long distance DC grid system will make a more robust grid system.

More Power: Xiangjiaba – Shanghai ± 800 kV UHVDC

Customer: SGCC
Year of commissioning:
2010-2011

Customer's need

- Development of renewable hydro power 2, 000 km from load centre

Technology Solution

- Worlds longest and largest transmission system
- ± 800 kV UHVDC, 6,400 MW

Customer's benefits

- High efficiency - 93 %
- Compact - land use 40 % less than conventional technologies
- Reliable transmission – forced unavailability < 0.5 %

HVDC Interconnections NorNed, Norway-Holland

Customer need

- Optimize electricity production in Northern Europe

Technology Solution

- Build and operate Scandinavian and European system separate
- 580 km/700 MW submarine HVDC cable

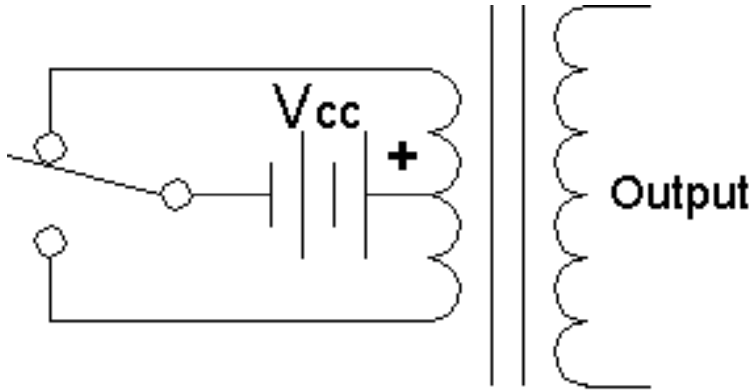
Customer benefit

- Increased security of supply in both markets
- Sharing of balancing power
- Improved power market
- Reduced emissions

The world's longest submarine HV cable

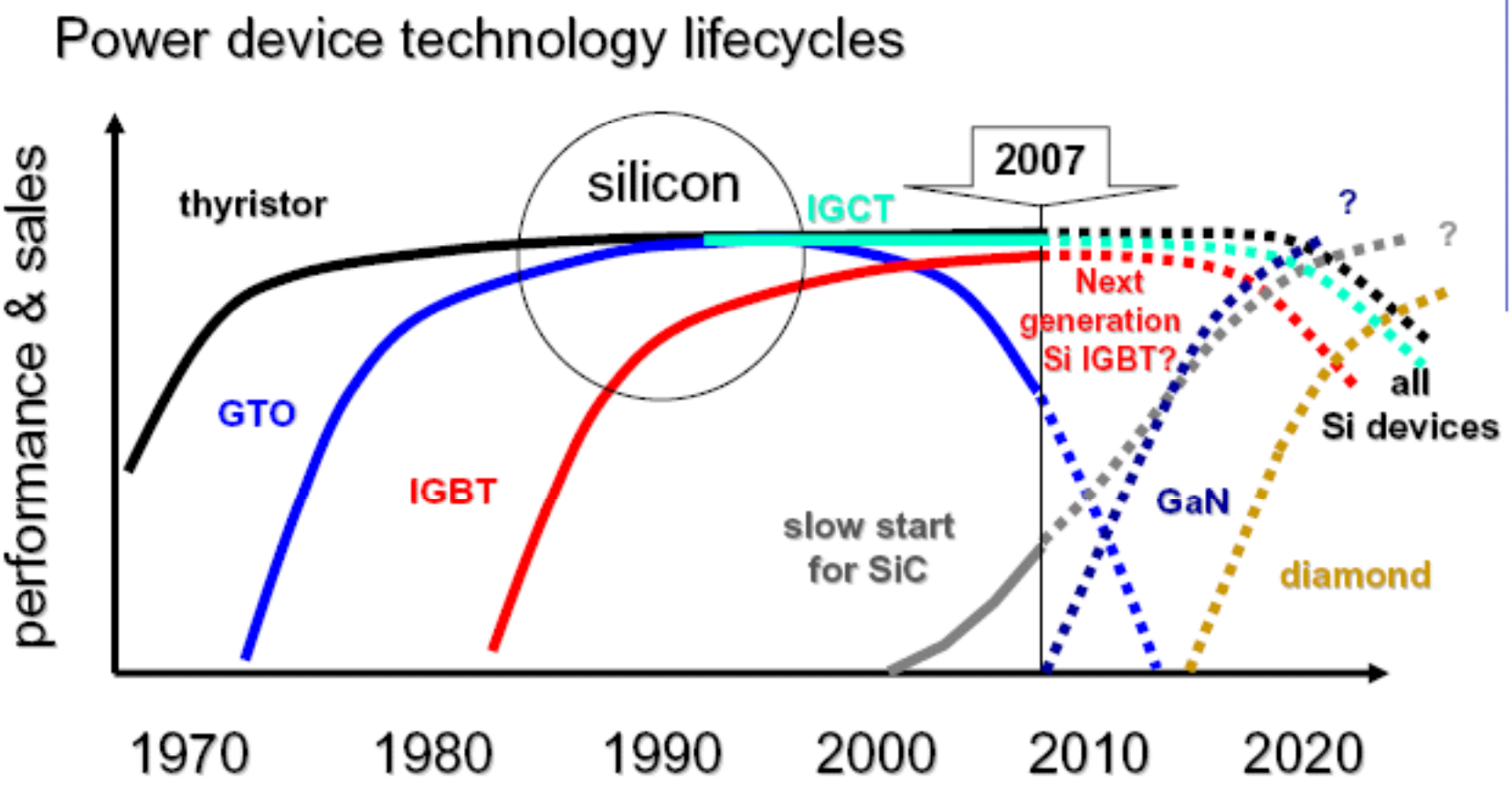
DC to AC inverters

A switch is used to rapidly switch current from a DC source through one end of a transformer.



- **Current controlled devices (thyristors) can be used if transmission is between two points.**
- **Voltages controlled devices (Insulated-gate bipolar transistors – IGBT) are needed for multiple "off ramps" along the right-of-way.**

Trends in power semiconductor technologies



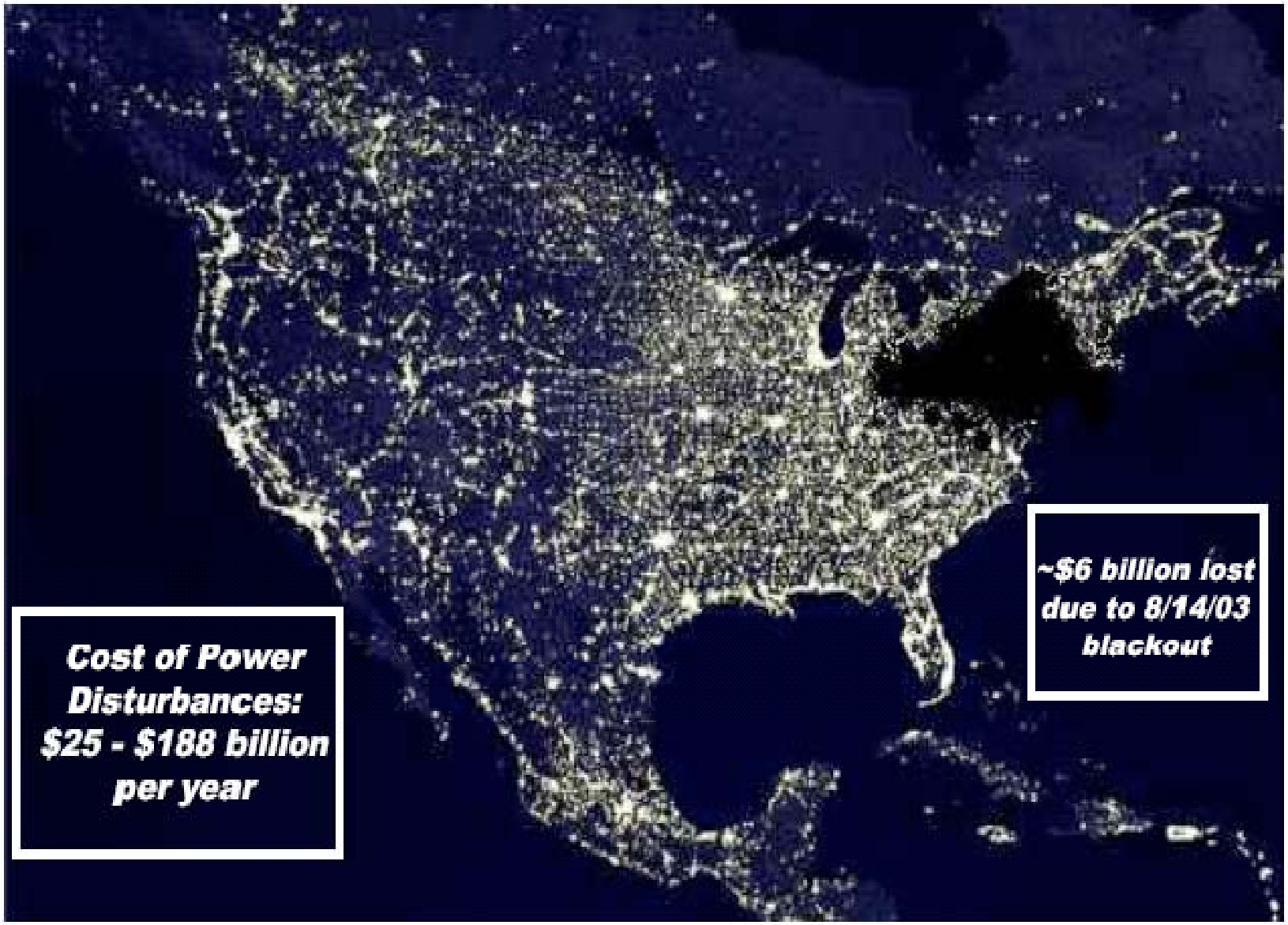
Is there any disruptive power semiconductor technology in the next 5 to 10 years ?

North American power system

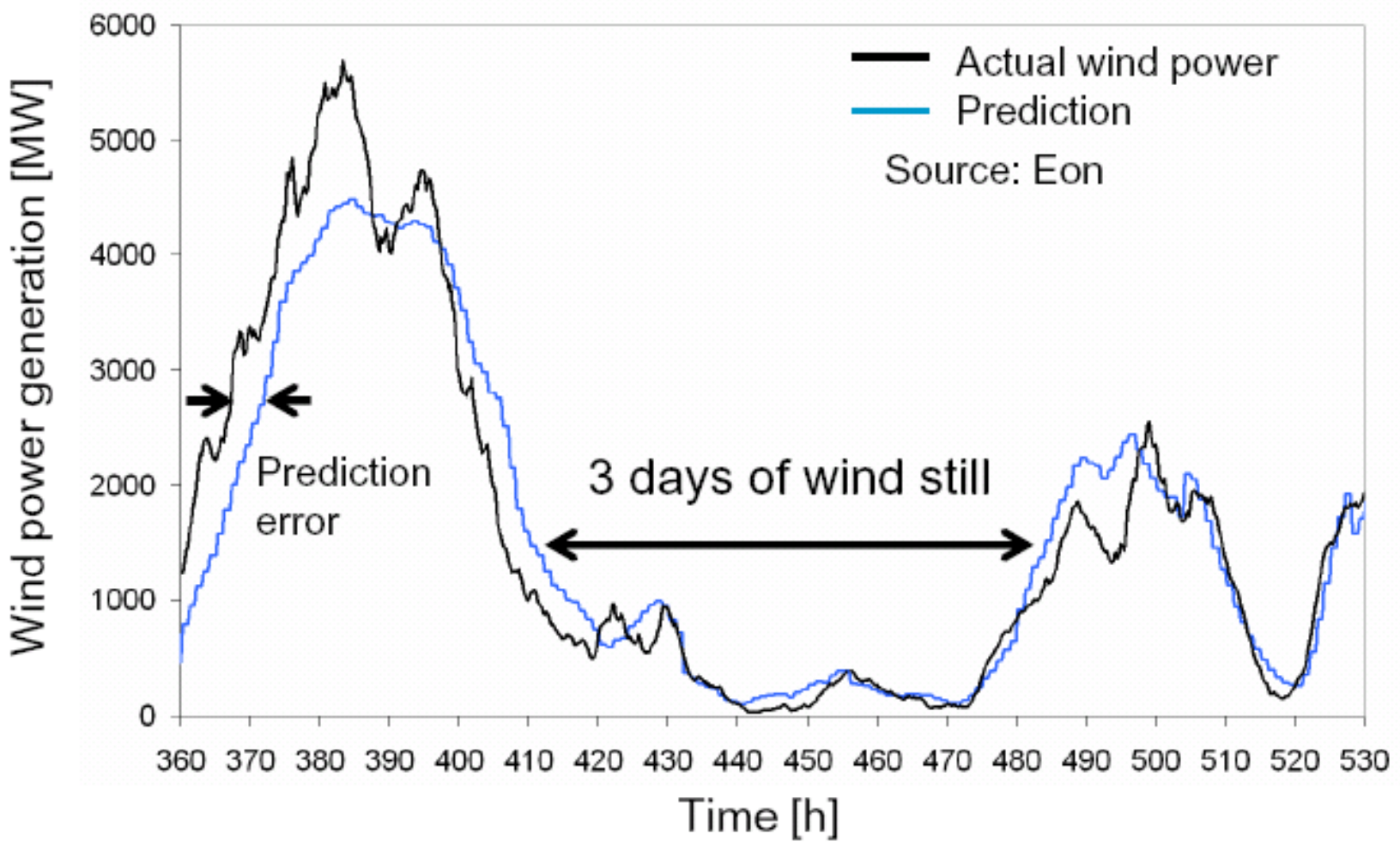
- Transmission network >69 kV, meshed
- Generators, transformers, transmission lines, bulk loads, protection, controls, operators.
- Most of east (or west) of Rockies is connected together and interacting locally and globally.
- Loads and generation change continually; must balance in real time.
- Network size ~ 10,000-100,000 nodes or branches, 100 control centers

The construction of a “smart grid” turns out to be non-trivial!

Blackout - August 14, 2003



Wind power demands accurate weather prediction, energy storage for frequency control and no-wind days.

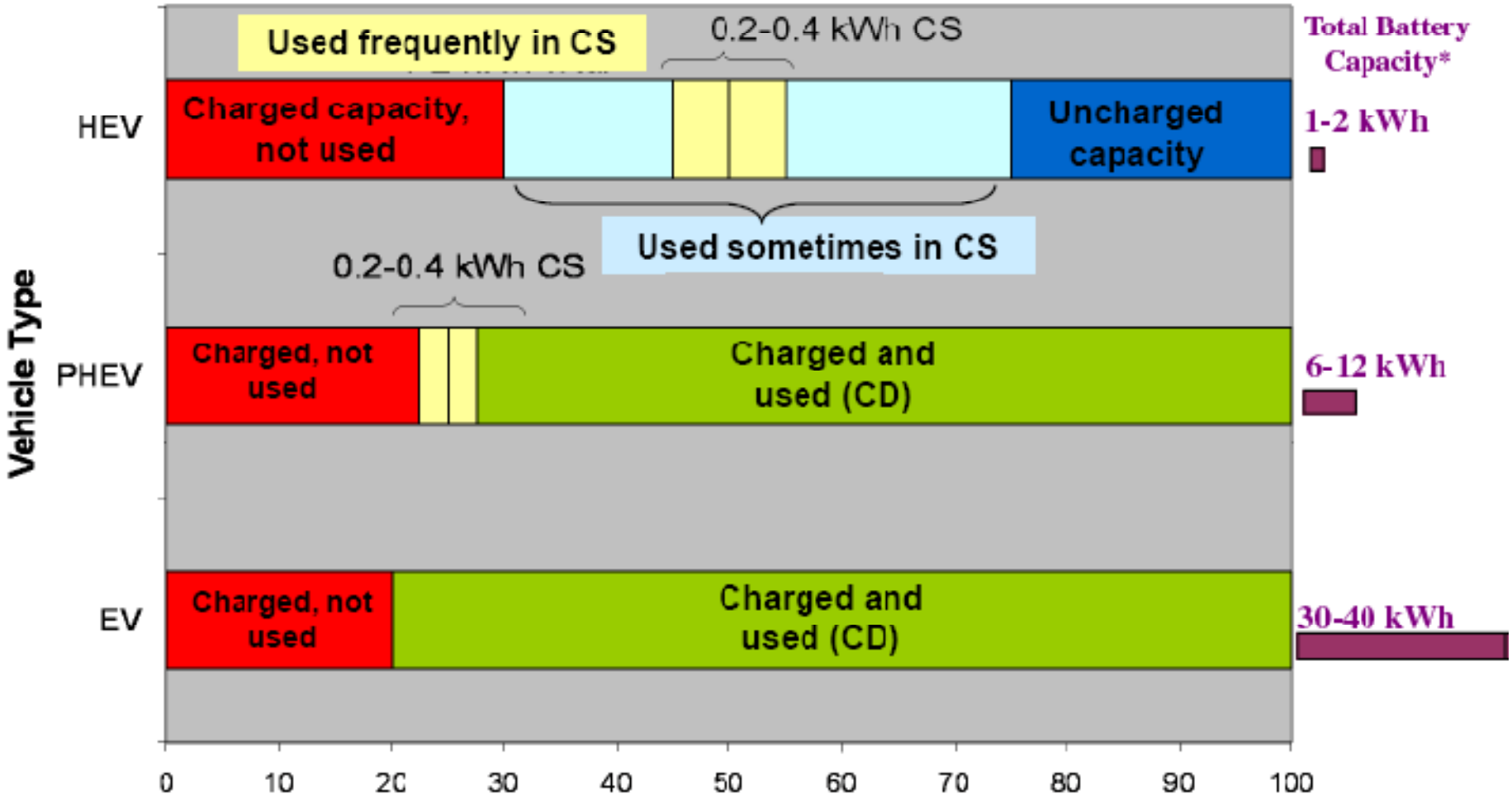


Energy Storage

- Large scale for storage of renewable sources of energy such as wind and solar thermal and photo-voltaic sources.

- Small scale for isolated (off-grid) villages, communities, buildings, homes, automobiles, laptop computers, ….

Battery Usage in EVs, HEVs, and PHEVs



Fatal Flaw in Polyethylene Oxide

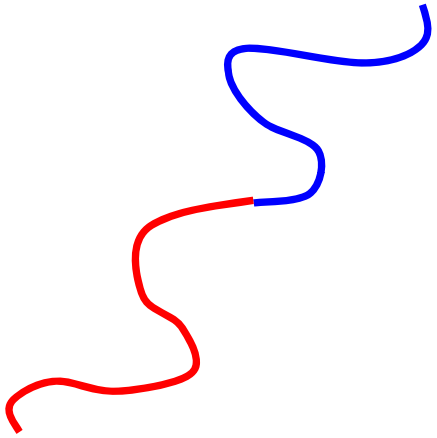
Repeated cycling led to the roughening of the Li surface and eventually to catastrophic dendrite growth.

t=0

intermediate times
high surface area Li

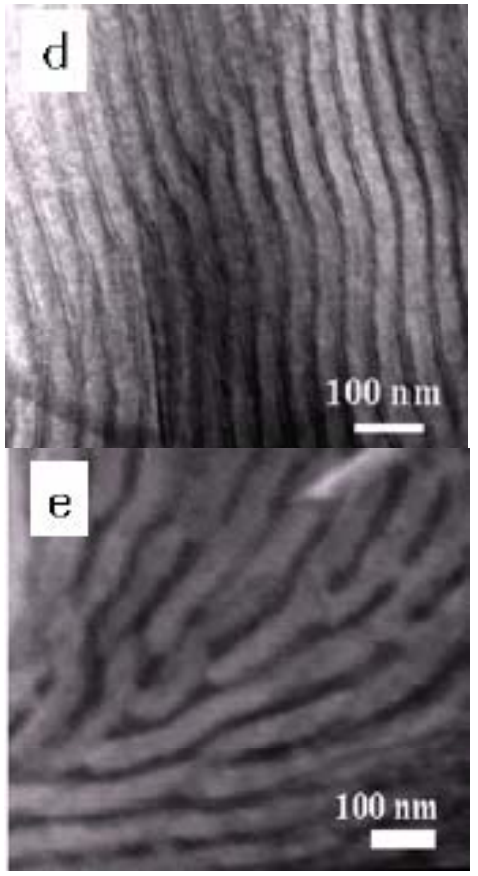
dendrite short

Hybrid solution:* use a co-block polymer that self-organizes into



PEO
(dark bands)

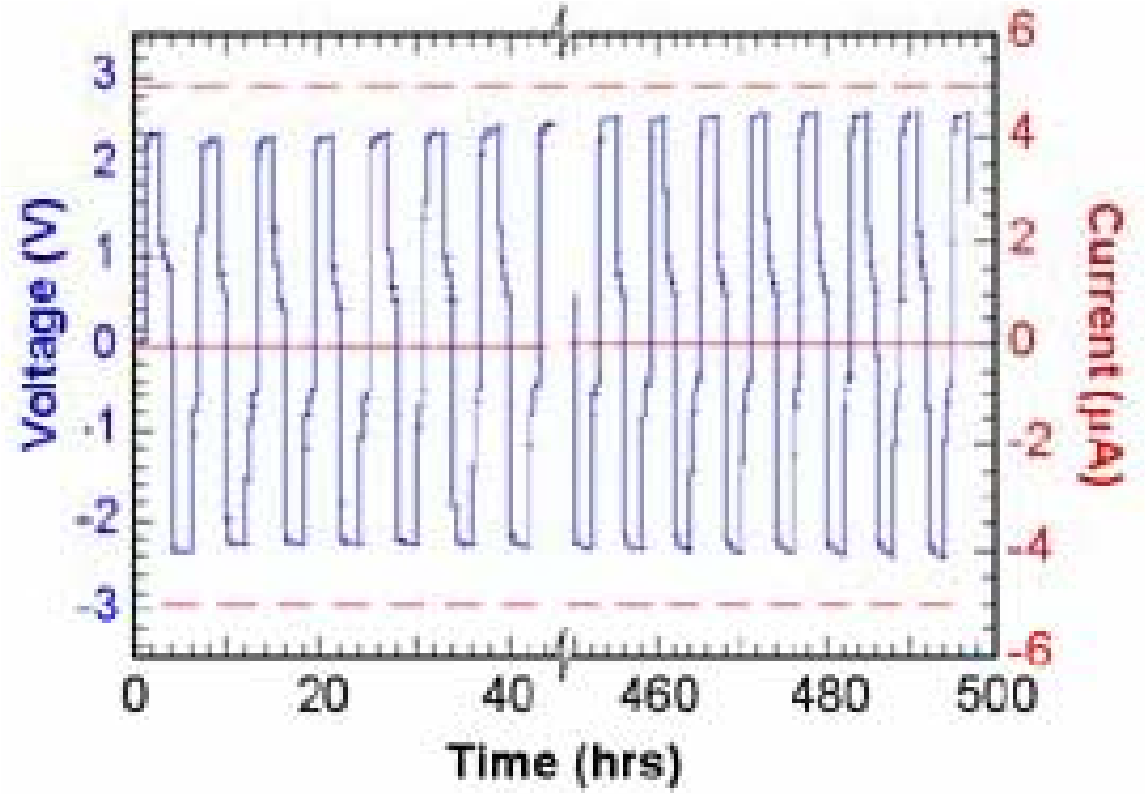
Polystyrene
(light bands)



* Nitash Balsara, Materials Science Division, LBNL;
UC Berkeley professor

A lithium – metal battery material with a dry, block copolymer separator shows promise. (Nitash Balsara)

Latest results of prototype ~ 1000 deep discharge cycles and ***no*** sign of degradation. Energy density initial target: 2x Li-ion



Distributed storage capacity potential

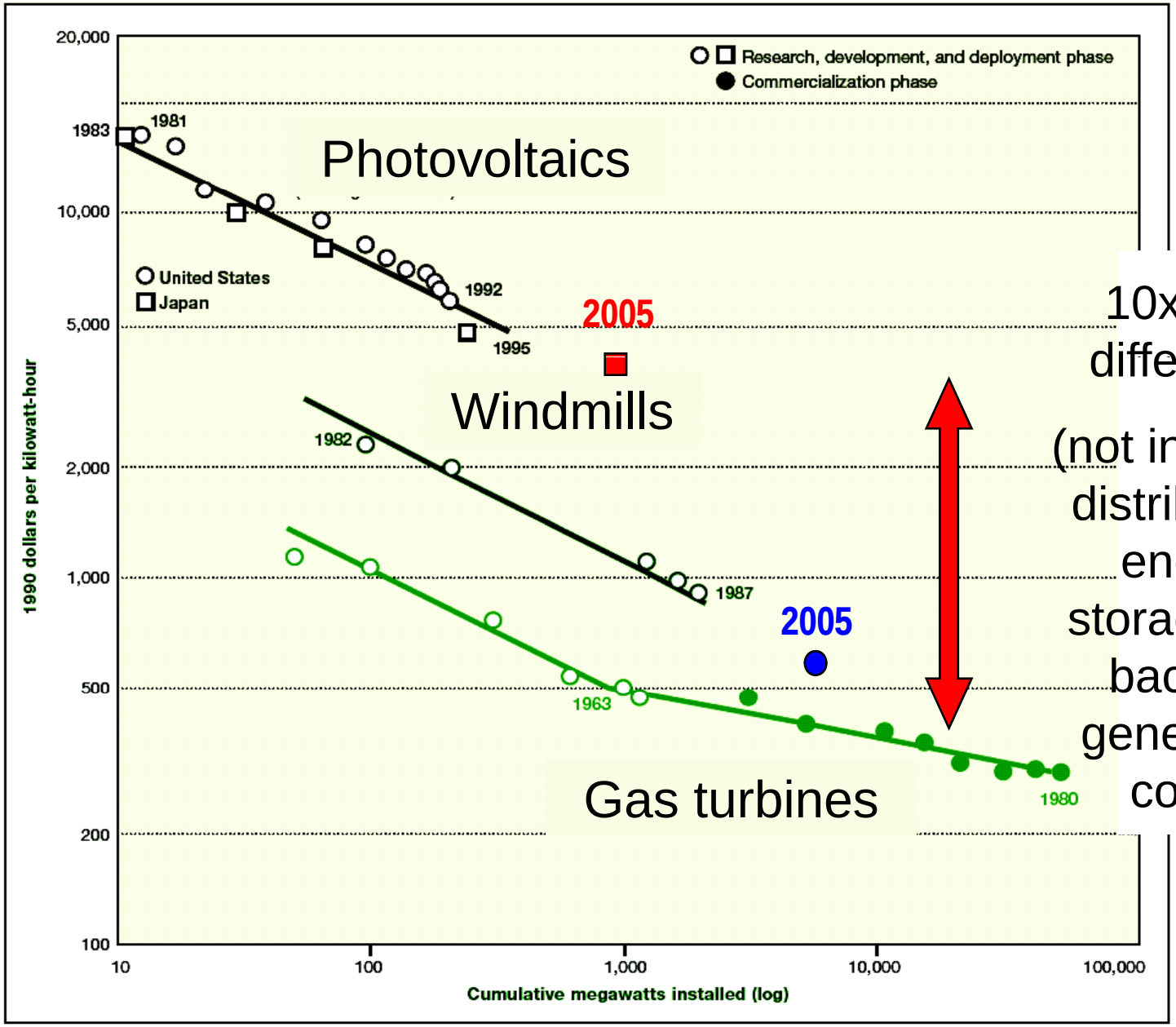
- In North America, there are ~260 million vehicles
  ~ 100 M personal automobiles.

- Assume 50% market penetration and 30 kWh storage per electric vehicle.

- (50 x 10^6 cars)(30kWh) = 1.5 x 10^9 kWh
  = 1.5 TWh
  > 10% of energy used/day

50 M cars can be programmed to buy energy at night (at low cost) and sell back during the afternoon (at high cost).

Cost of electricity generation vs. installed capacity (1990 dollars / installed Megawatt hour)



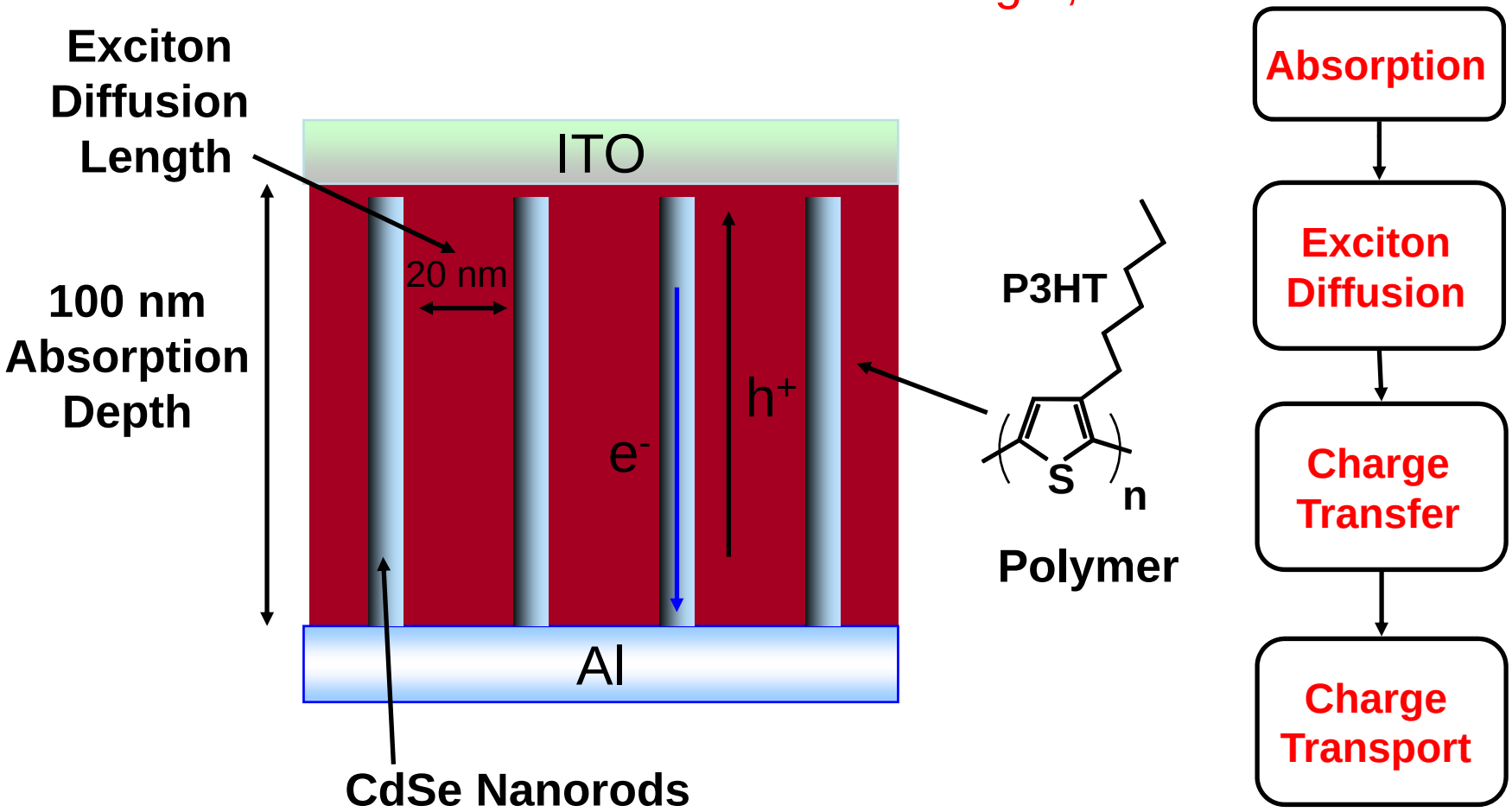
10x cost difference

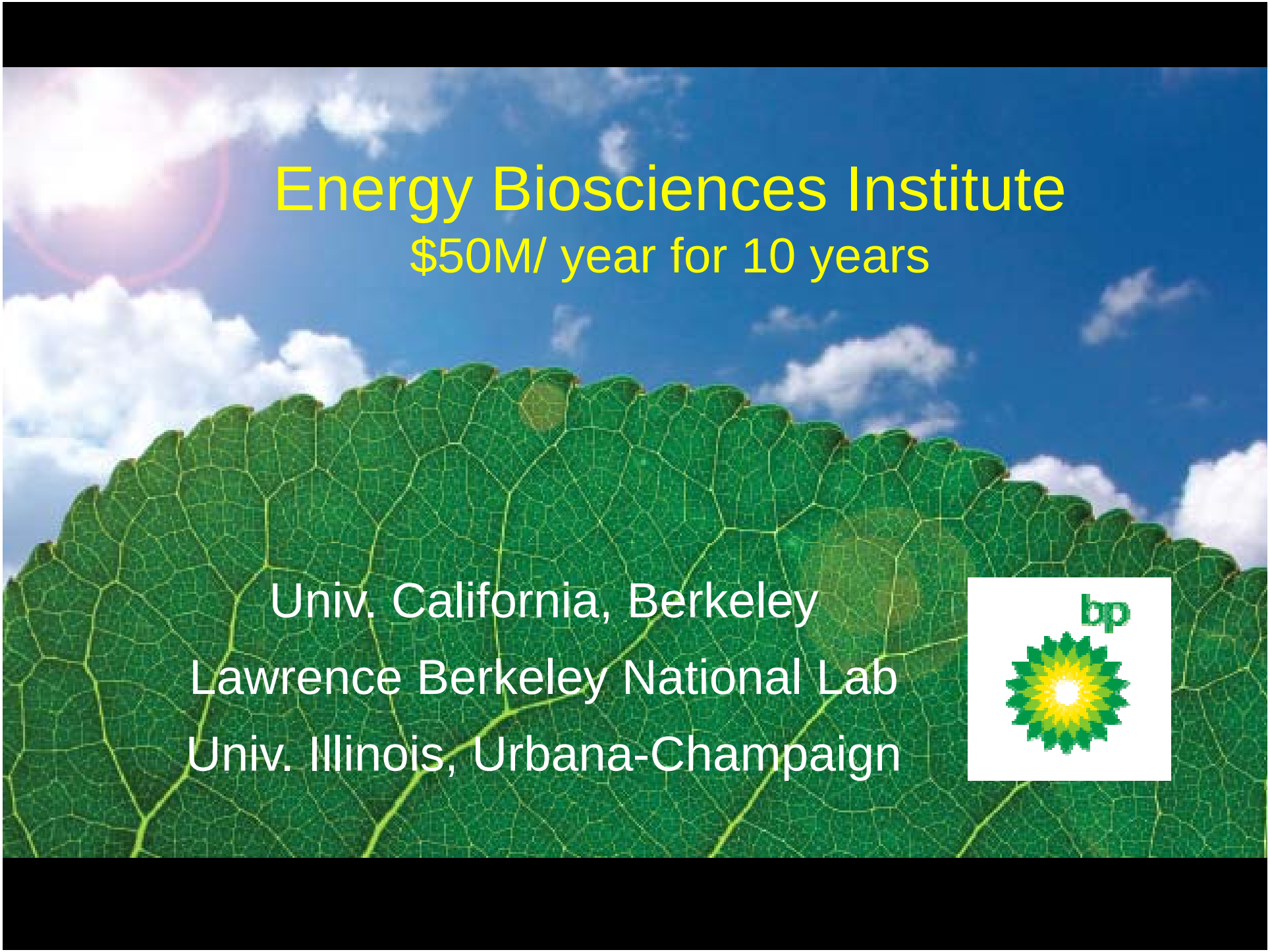
(not including distribution, energy storage and back-up generation costs)

Distributed junction nano-solar cells *

(Separation of electrons and hole creation and transport.)

* A. Heeger, et. al.




Energy Biosciences Institute
$50M/ year for 10 years
Univ. California, Berkeley
Lawrence Berkeley National Lab
Univ. Illinois, Urbana-Champaign
bp

Berkeley Lab
LAWRENCE BERKELEY NATIONAL LABORATORY

Office of Science
U.S. DEPARTMENT OF ENERGY

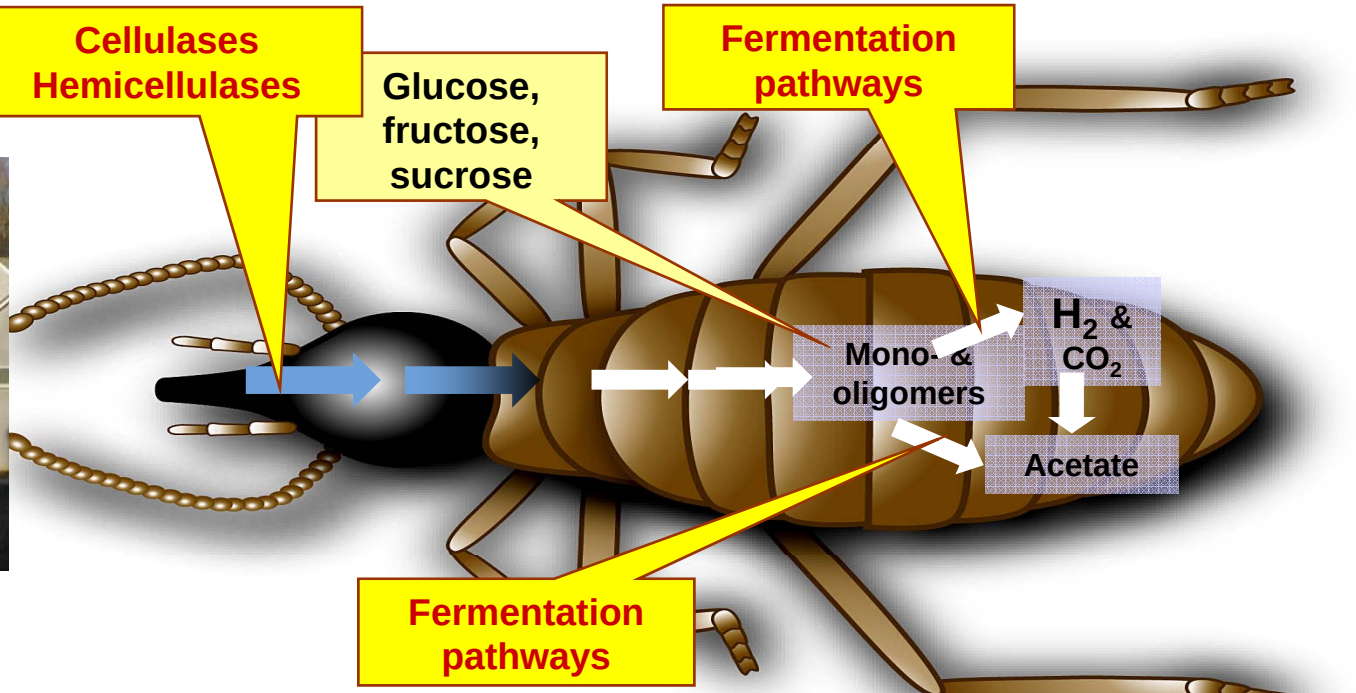
Joint Bio-Energy Institute (JBEI)

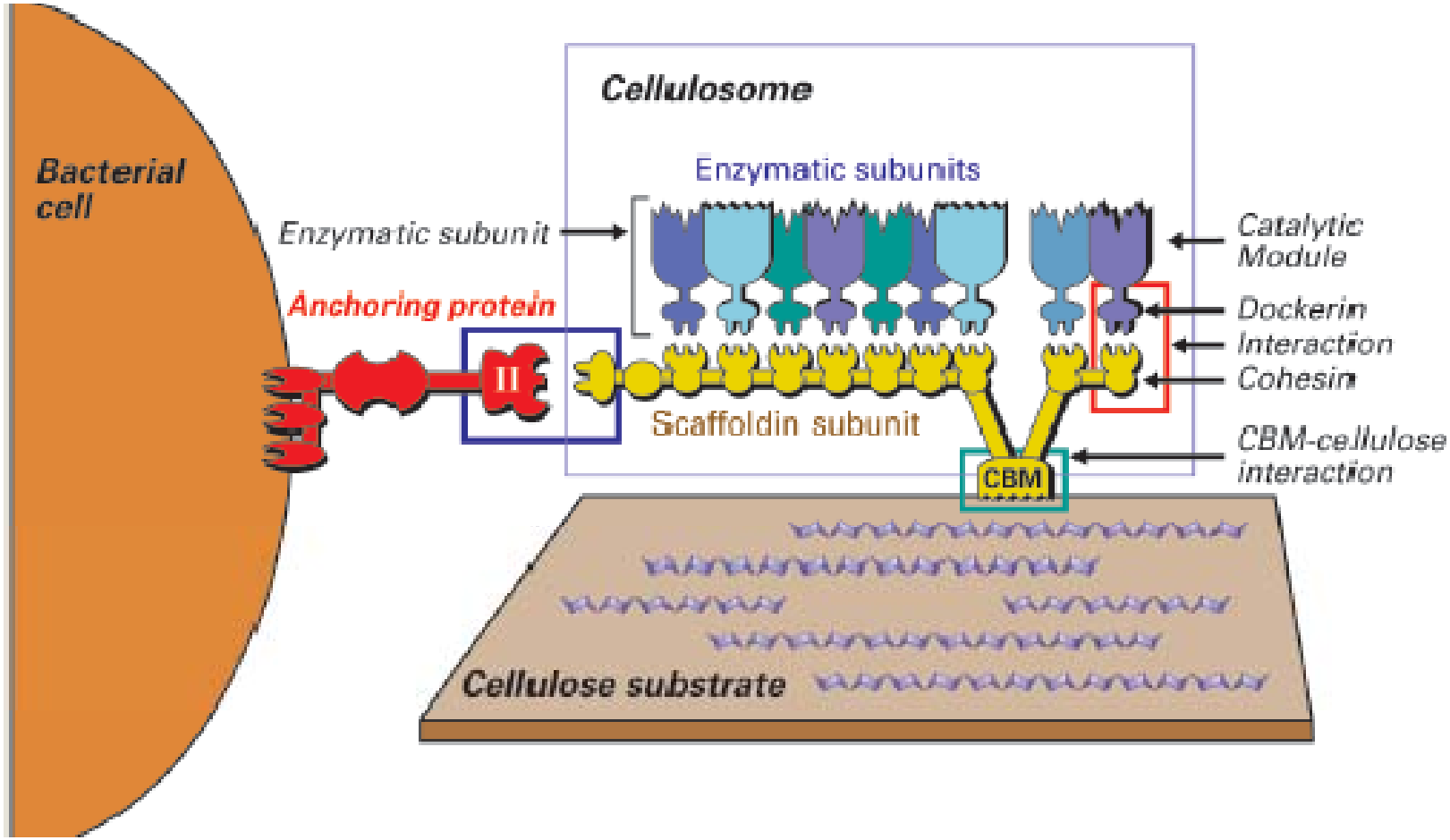
LBNL, Sandia, LLNL, UC Berkeley,

Stanford, UC Davis

$25M / year for 5 years

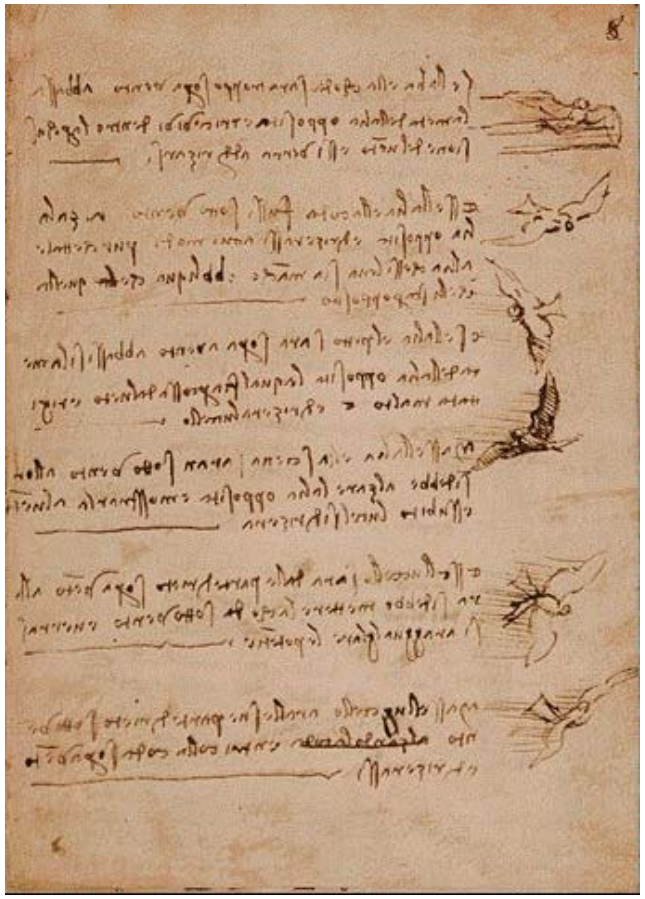
Termites have many specialized microbes that efficiently digest lignocellulosic material

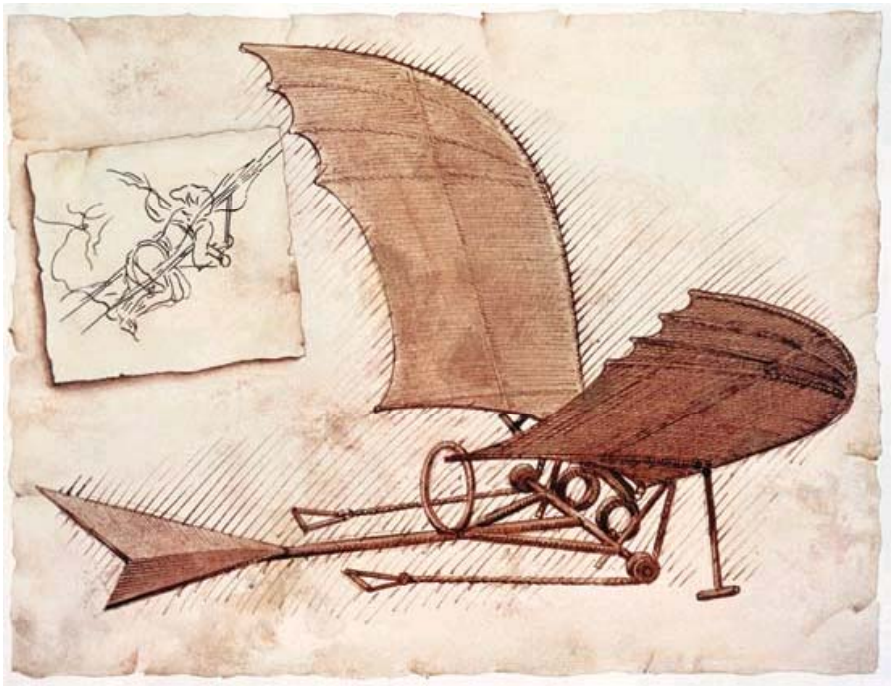


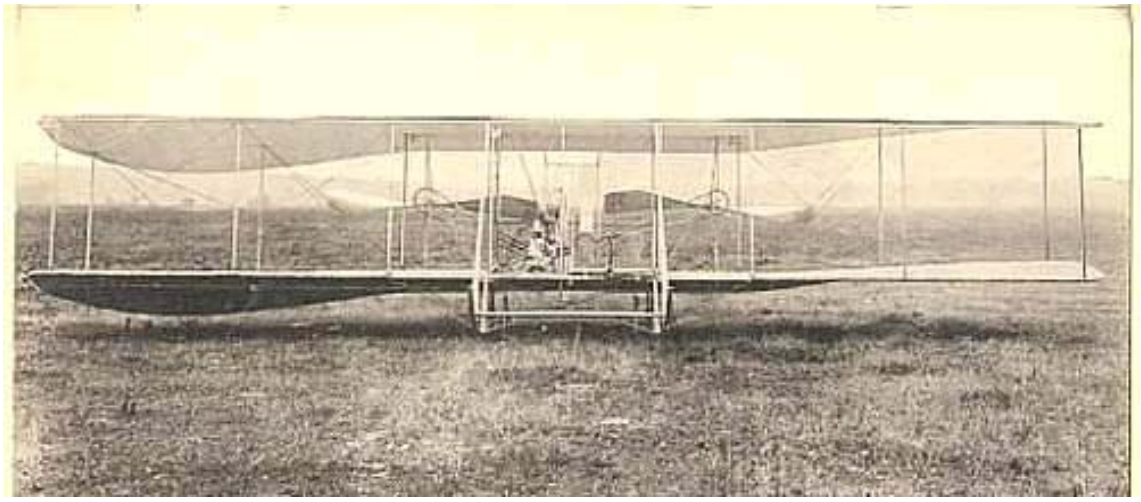


Cellulosomes can be designed with complementary enzymes to form a single multi-enzyme complex. Cellulose hydrolysis rates were shown to be 2.7- to 4.7-fold higher compared with purified enzyme preparations.

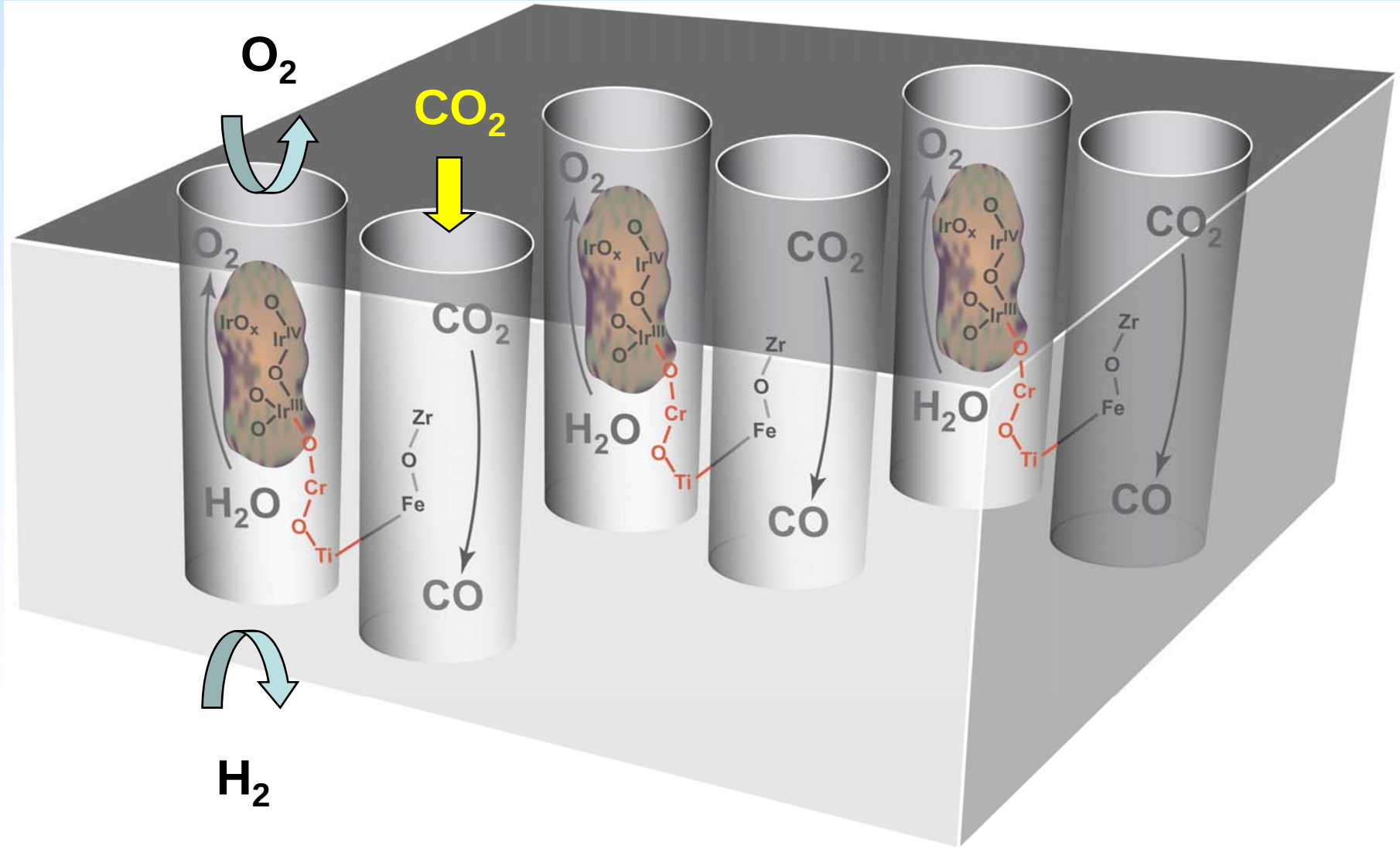
Man first learned to fly by imitating nature







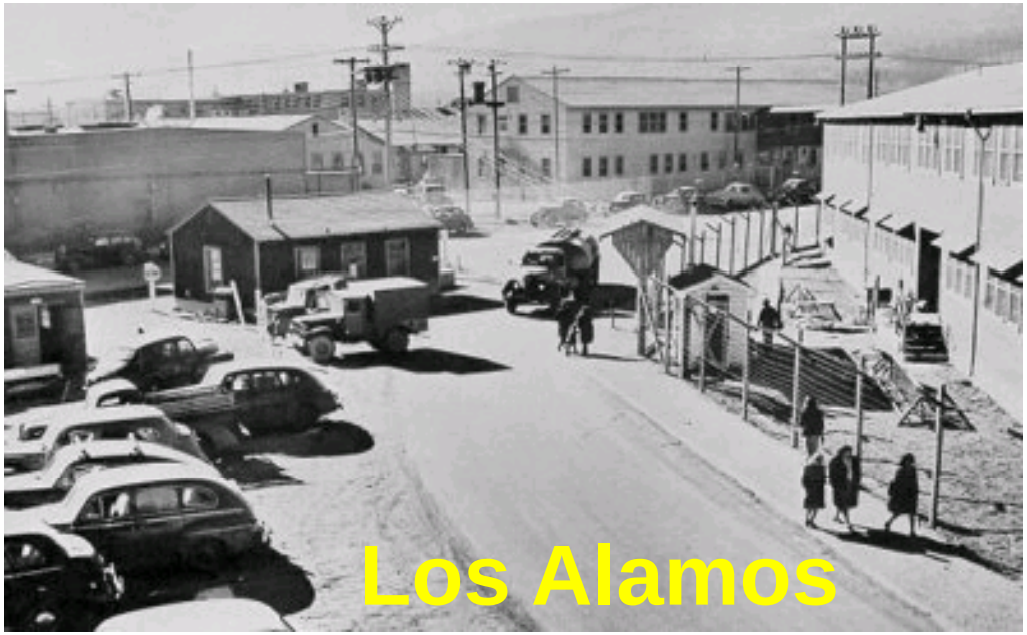
Is it possible to engineer an artificial photo-synthetic system?



E.O. Lawrence introduced the idea of "team science"

Ernest Lawrence, Robert Serber, Luis Alverez, Edwin McMillian, Robert Oppenheimer, Robert R. Wilson, …(Glenn Seaborg not shown)

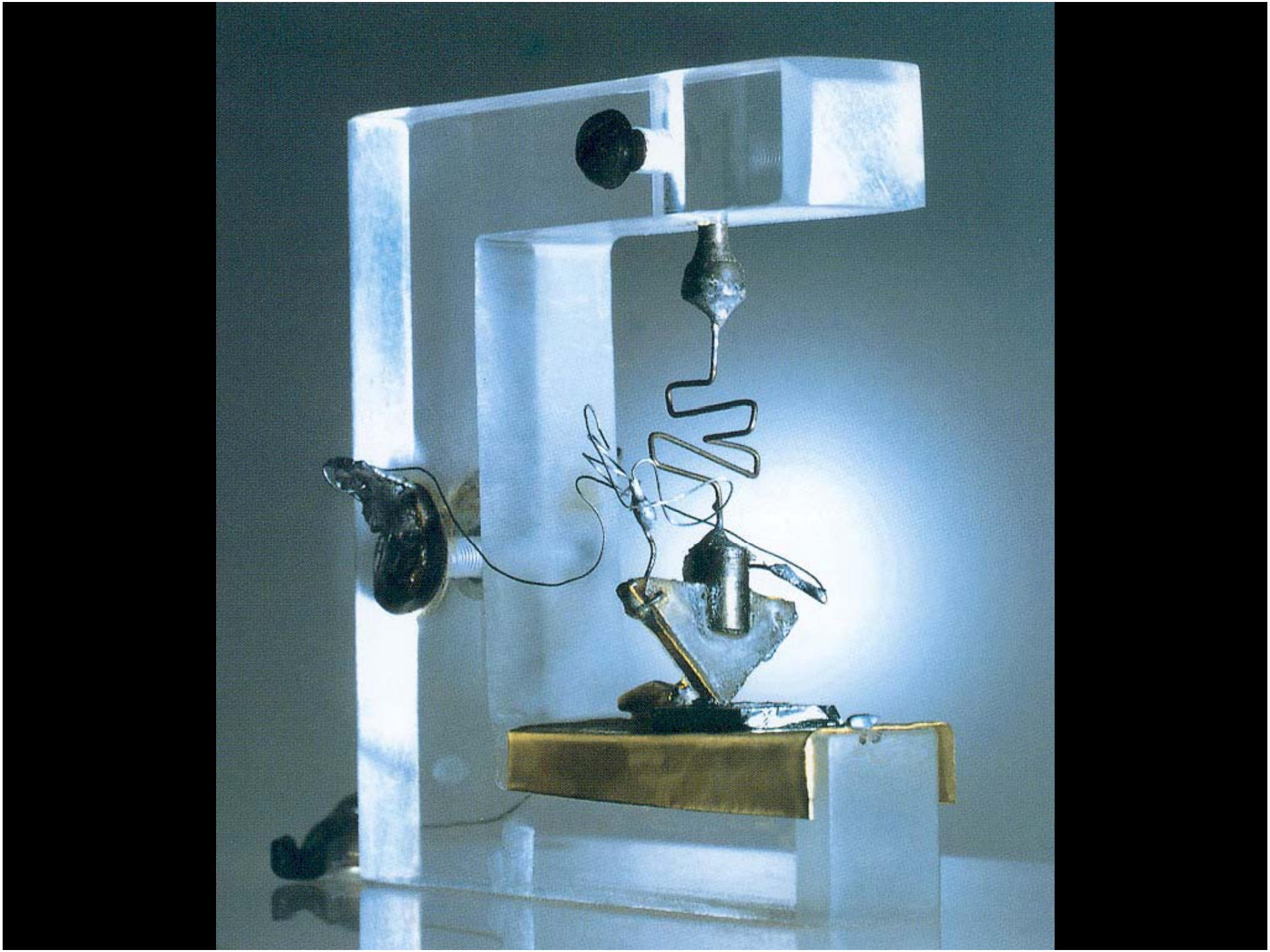
Most university research is based on a professor-led research group. In times of national need, a more coordinated effort is required.

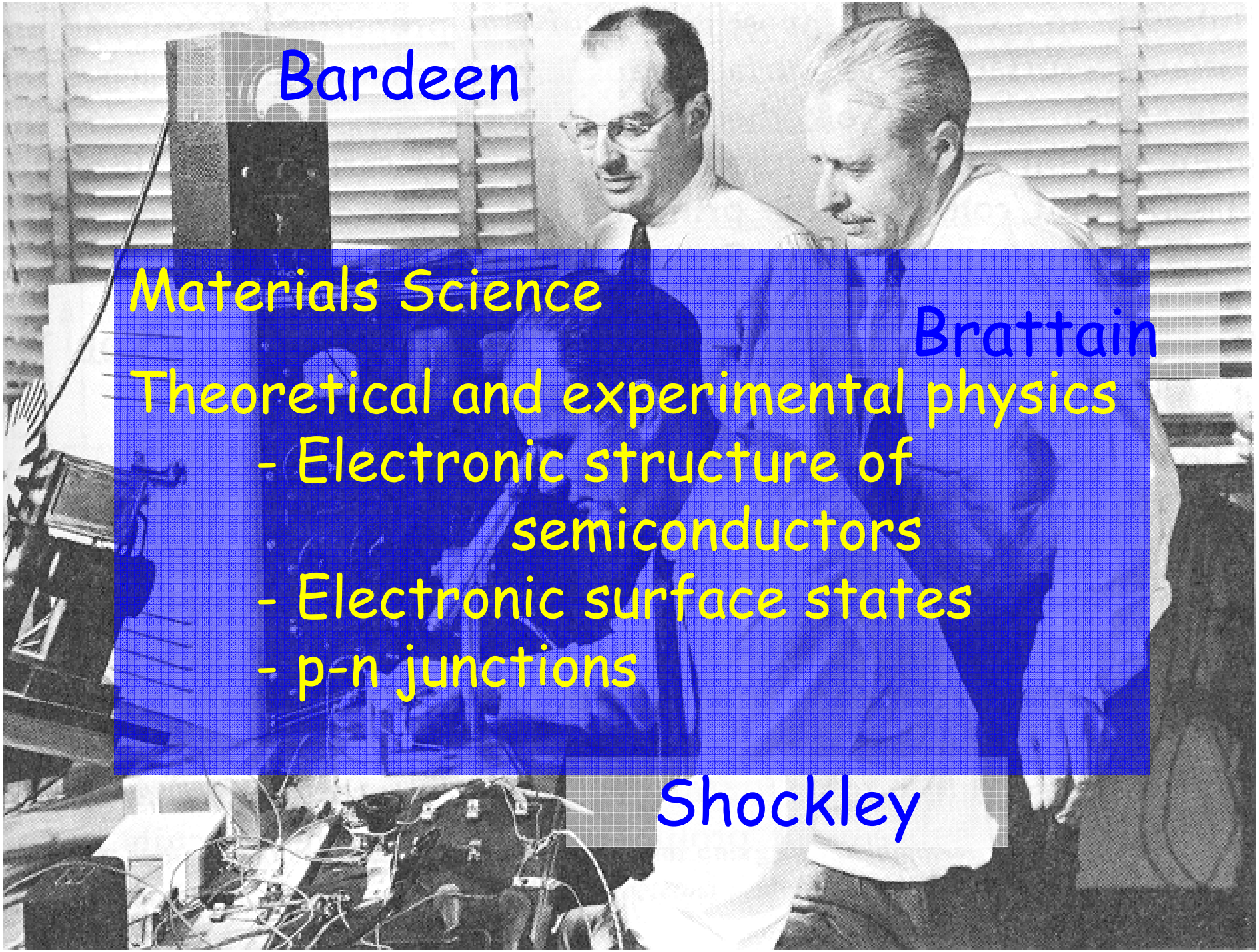


Transformative solutions requires a concentration of talent and a coordinated commitment of an appropriate scale in size, time, and disciplines.

Bell Laboratories (Murray Hill, NJ)

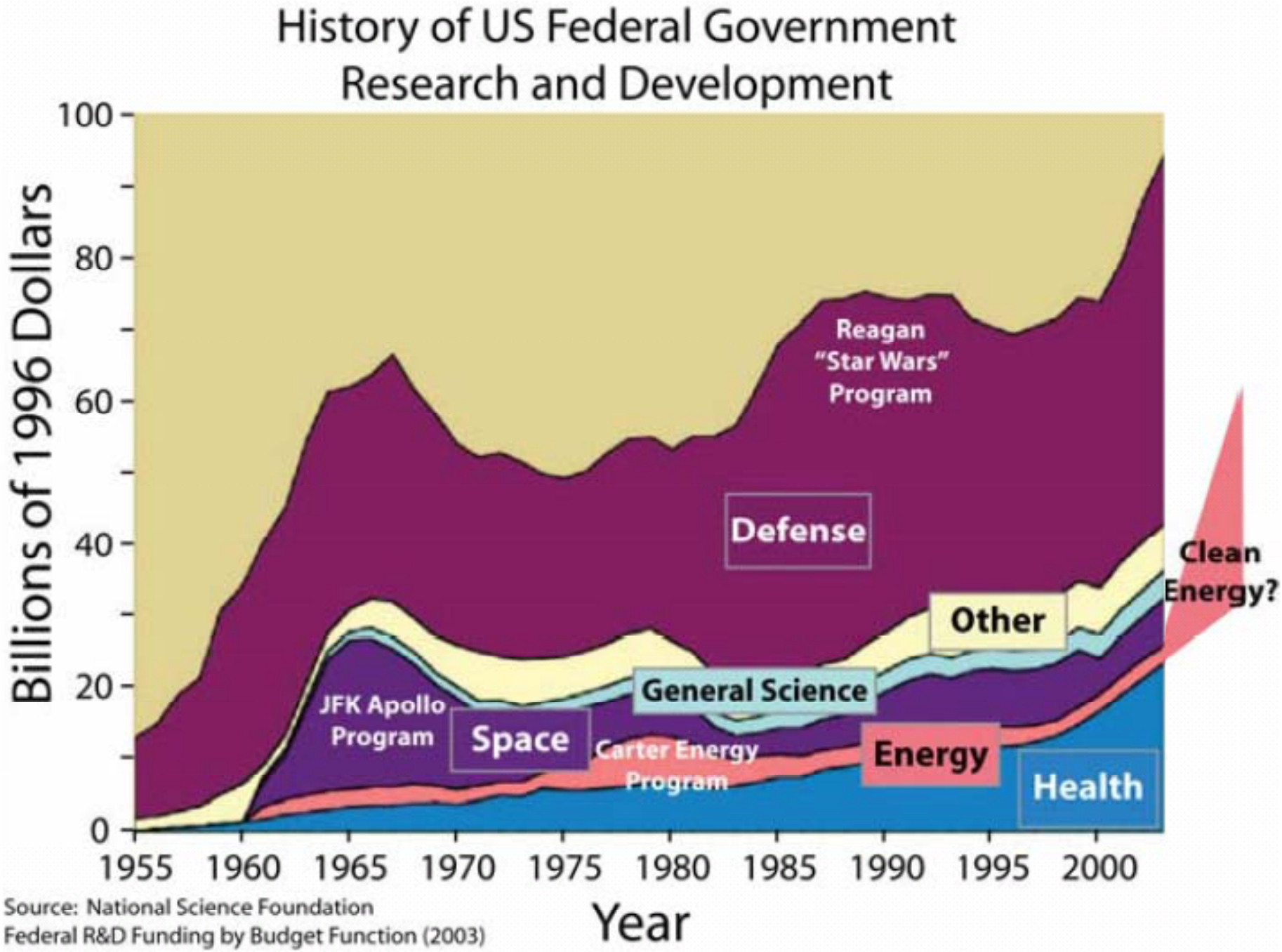
15 scientists who worked at AT&T Bell laboratories received Nobel Prizes.




Bardeen
Materials Science
Brattain
Theoretical and experimental physics
- Electronic structure of semiconductors
- Electronic surface states
- p-n junctions
Shockley

Common denominators of the best run research laboratories during their “golden eras”

- Individual genius was nurtured, especially in their early careers; individuals were encouraged to quickly form teams to rapidly exploit ideas.
- The scientific direction was guided by collective wisdom and “managed” by top scientists with intimate, expert knowledge.
- Bold approaches were encouraged; some failure was expected, but there was an emphasis on recognizing failure quickly, and moving on to other opportunities.


History of US Federal Government
Research and Development
Billions of 1996 Dollars
100
80
60
40
20
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year
Reagan
"Star Wars"
Program
Defense
Other
Clean
Energy?
General Science
JFK Apollo
Program
Space
Carter Energy
Program
Energy
Health
Source: National Science Foundation
Federal R&D Funding by Budget Function (2003)

Earthrise from Apollo 8 (December 24, 1968)

LBNL's "Helios Project" is for the preservation of this spaceship.

“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

InterAcademy Council

About the IAC |

Mobilizing the World's Best Science to Advise Decision-makers.

"Lighting the Way: Toward a Sustainable Energy Future"

Released October 22, 2007

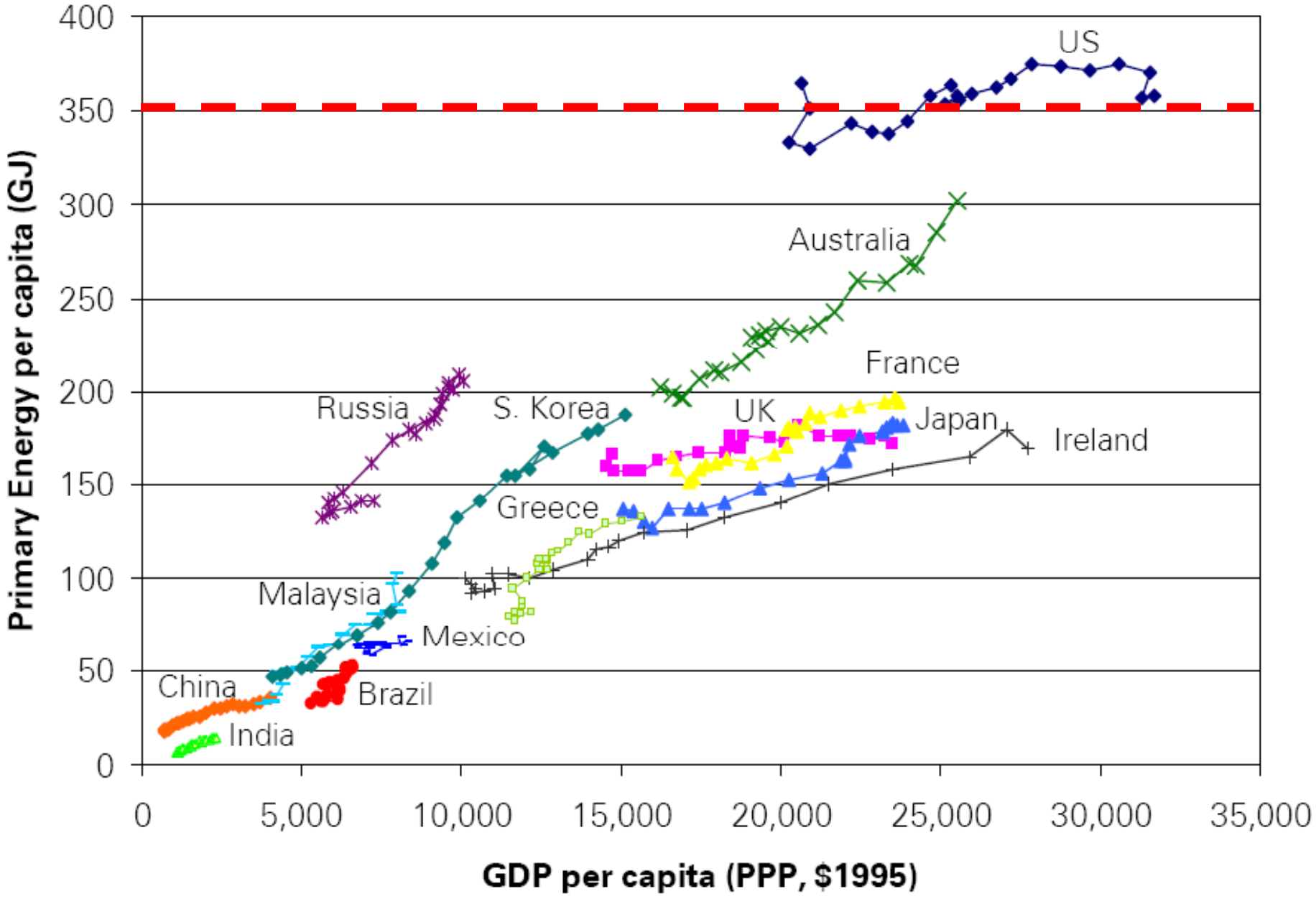
Co-chairs: Jose Goldemberg, Brazil
Steven Chu, USA

Norman Borlaug, 1970 Nobel Peace Prize

(for development of disease-resistant, high yield wheat)

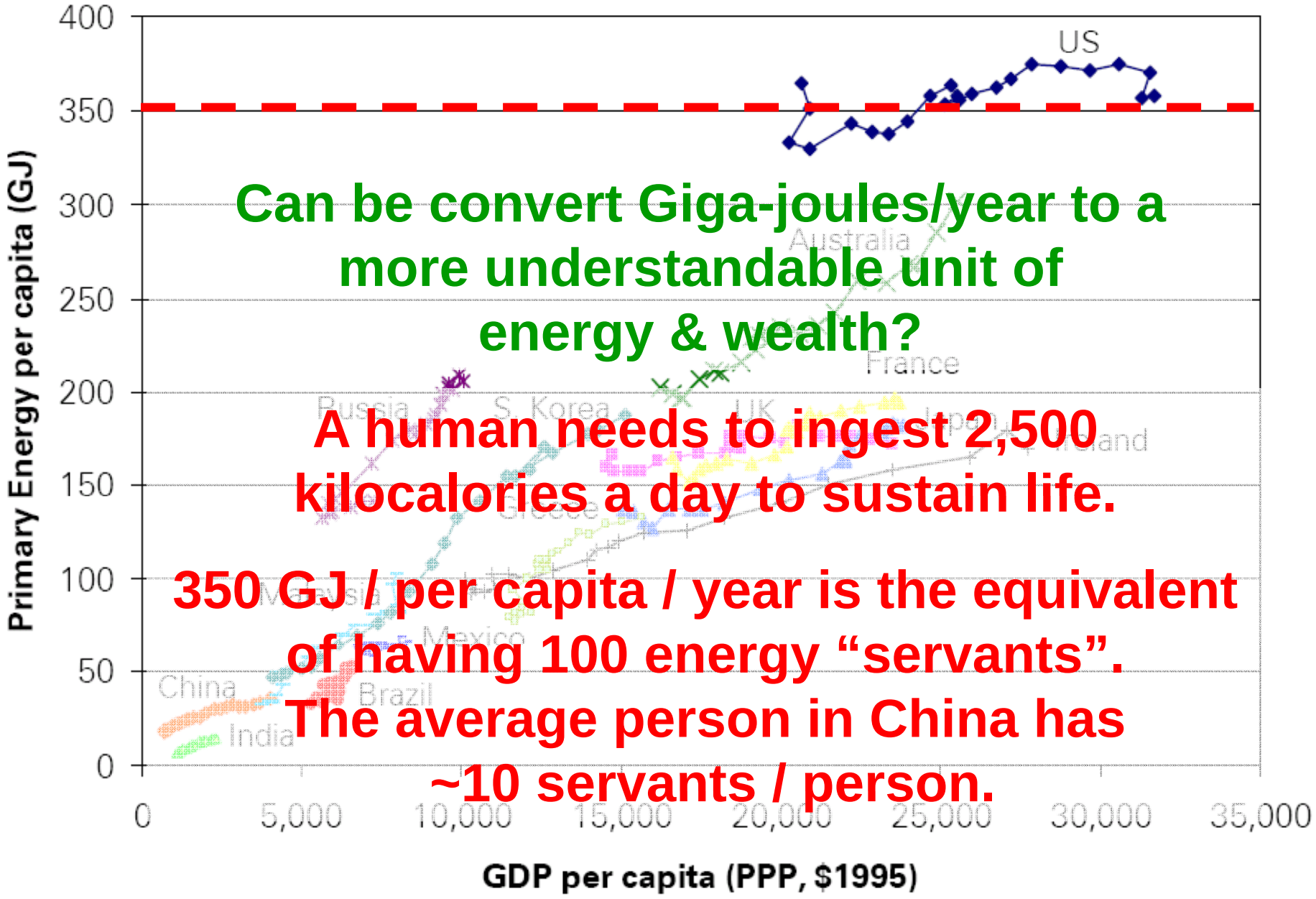
"Some of the environmental lobbyists of the Western nations are the salt of the earth, but many of them are elitists. They've never experienced the physical sensation of hunger … If they lived just one month amid the misery of the developing world, as I have for fifty years, they'd be crying out for tractors and fertilizer and irrigation canals and be outraged that fashionable elitists back home were trying to deny them these things".

Energy demand vs. GDP per capita



Source: UN and DOE EIA

Energy demand vs. GDP per capita



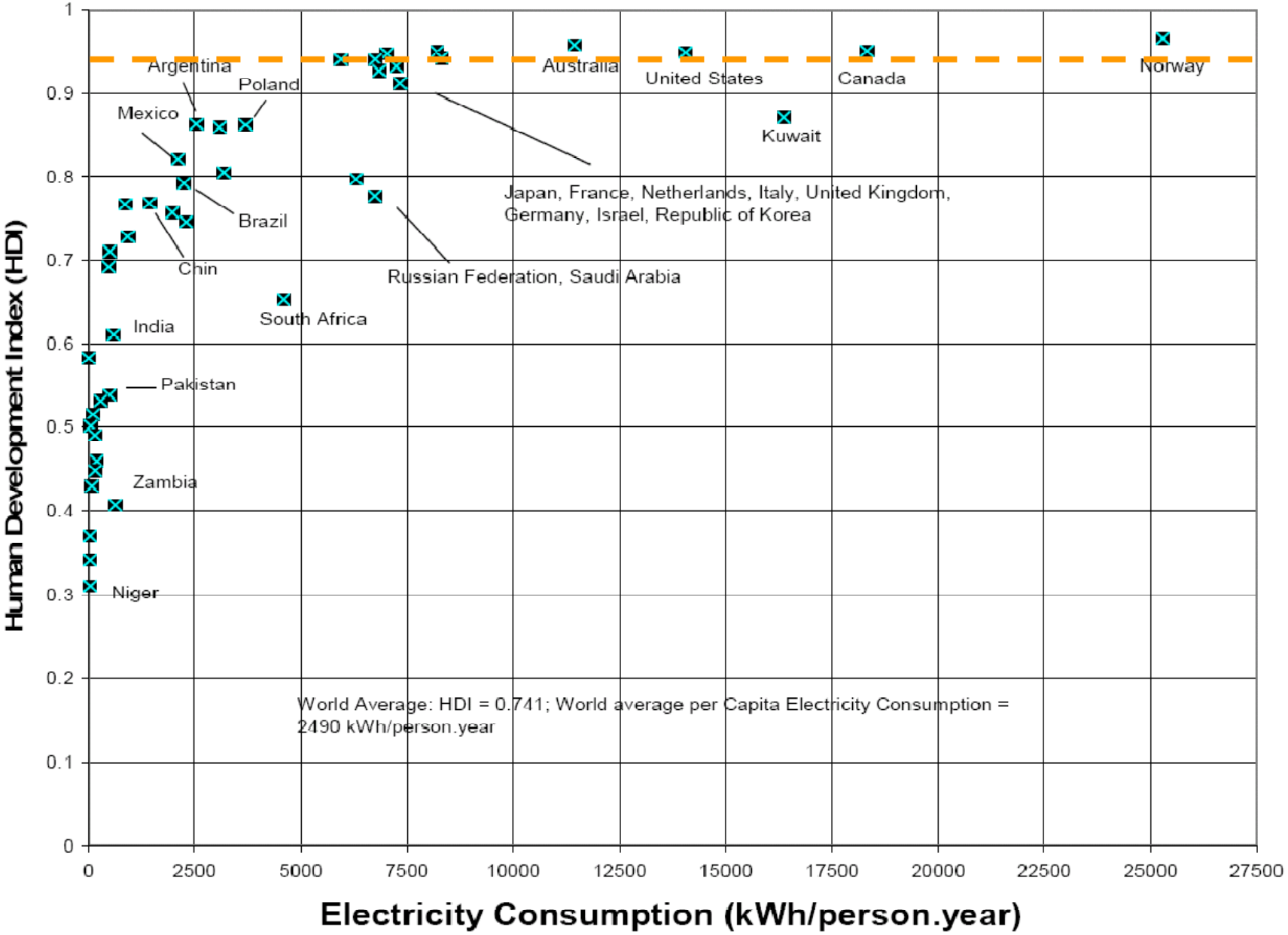
Can be convert Giga-joules/year to a more understandable unit of energy & wealth?

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.

Source: UN and DOE EIA

Human Development Index vs. Energy consumption



Advantages of High Voltage DC over AC transmission: (cost less if > 500 miles)

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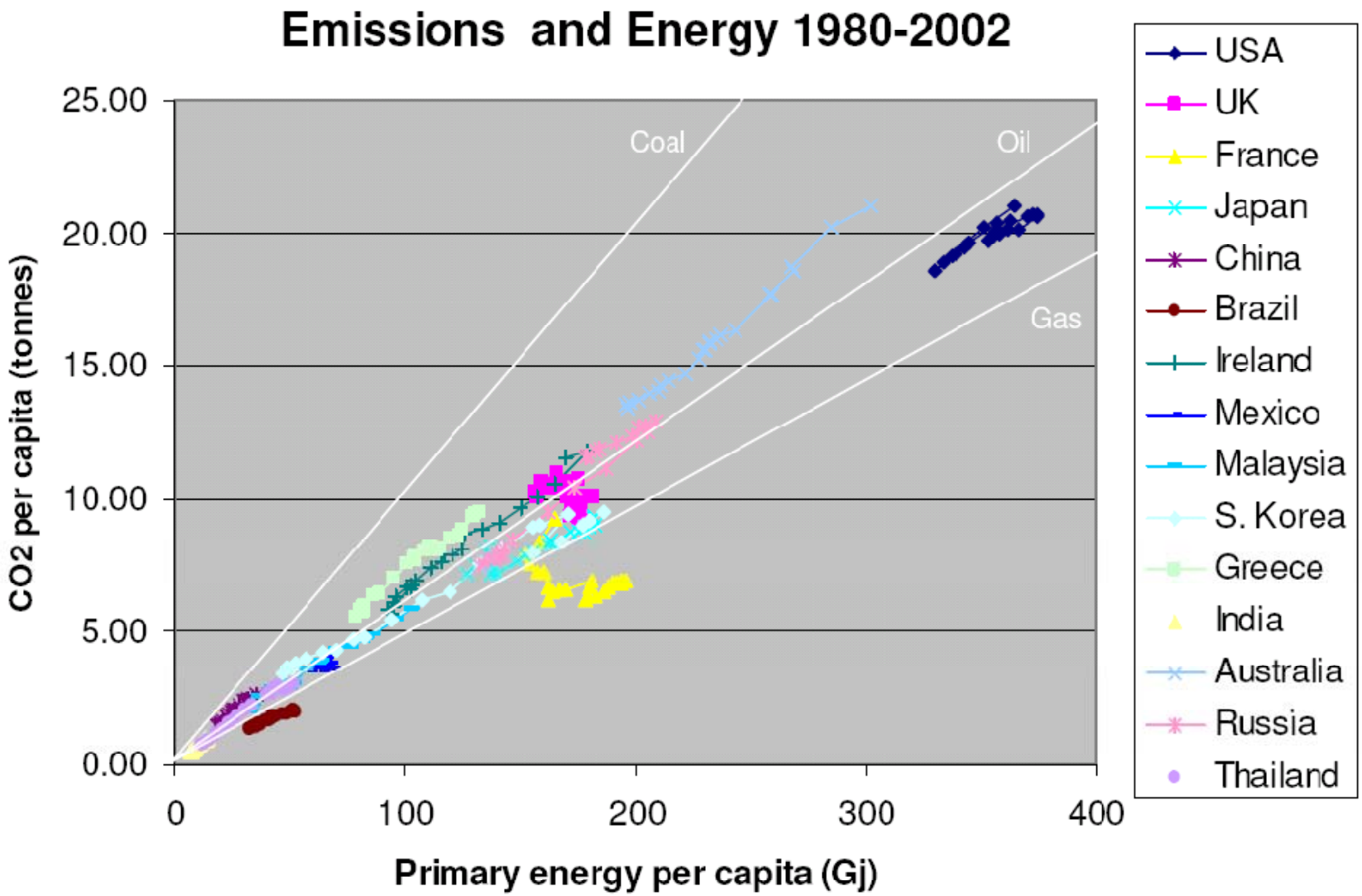
- Radiative and dielectric losses are much less.
- Capacitance losses
  (Energy used to polarize the capacitance of the cable and surrounding environment)
- Long distance DC grid system will make a more robust grid system.

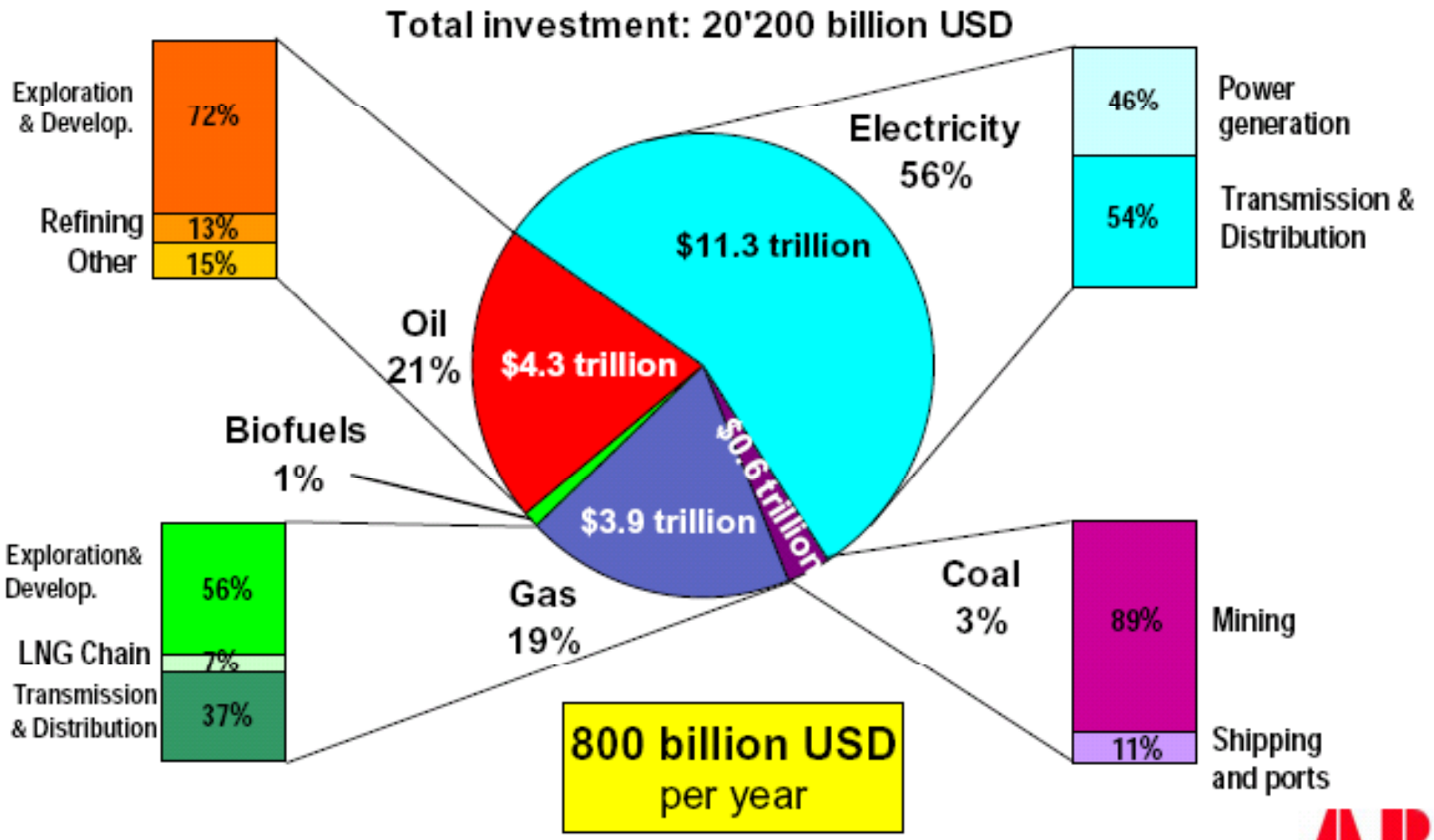
CO_2 emissions depends on the energy source



"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)

World Energy Investment 2005 - 2030

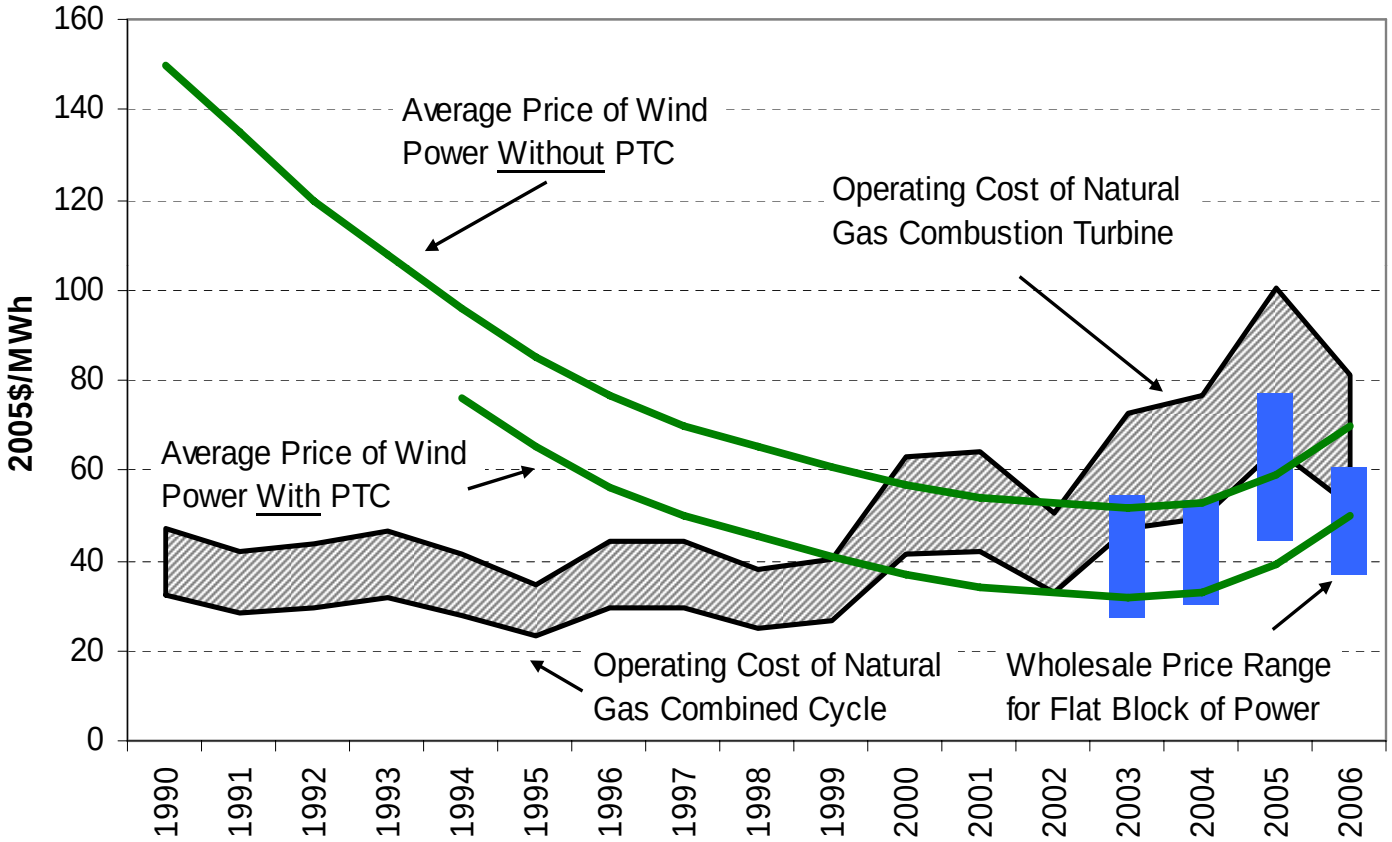


Source: International Energy Agency - World Energy Outlook 2006

Many Drivers, Including Improved

Wind power with PTC competitive in many locations in the US, but needs policy support (typically RPS) in others

Whether wind is competitive in long-term absent policy support depends on cost of fossil fuels



Feedstock grasses (*Miscanthus)* is a largely unimproved crop.

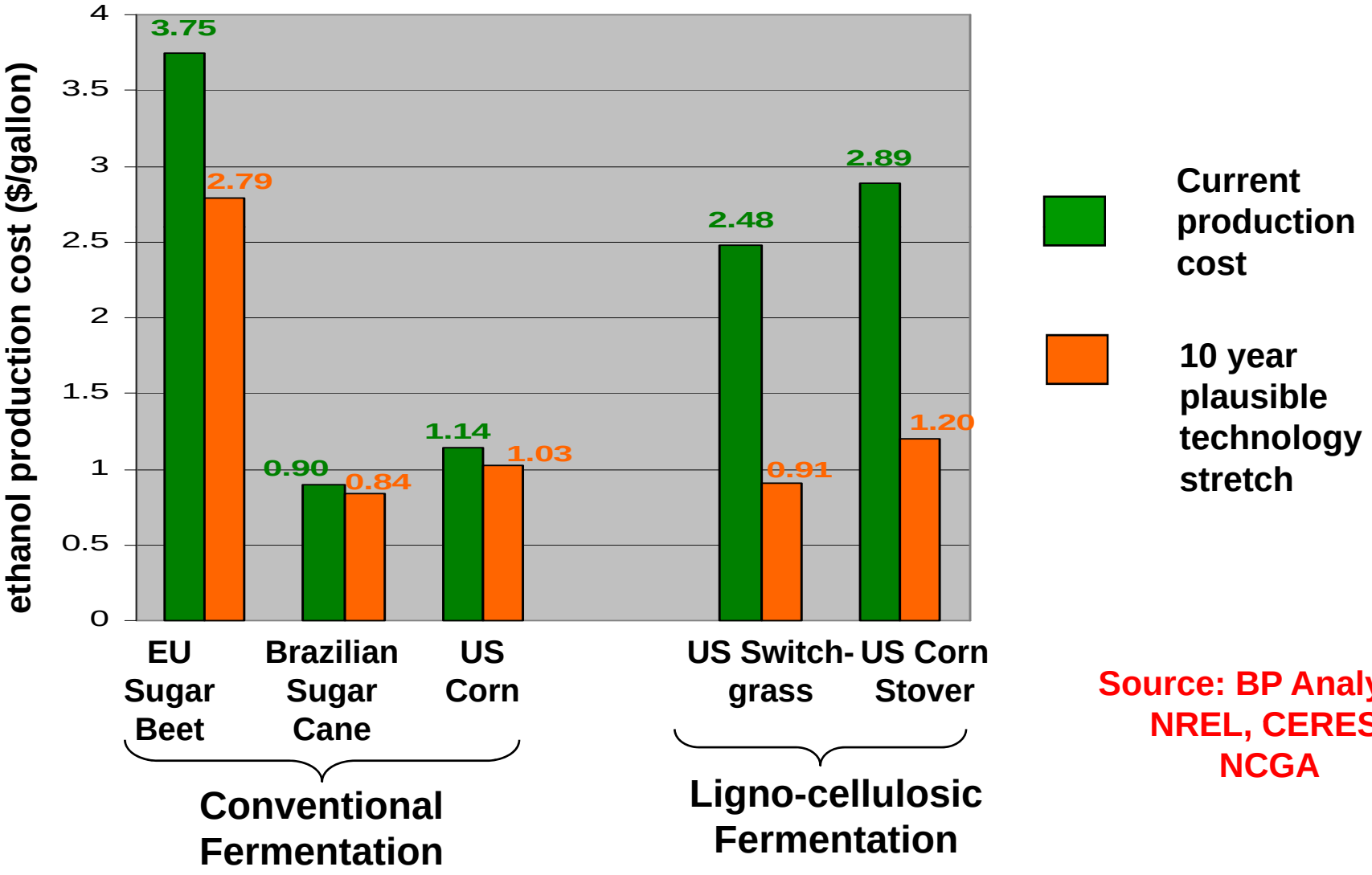
Non-fertilized, non-irrigated test field at U. Illinois yielded

15x more ethanol / acre than corn.

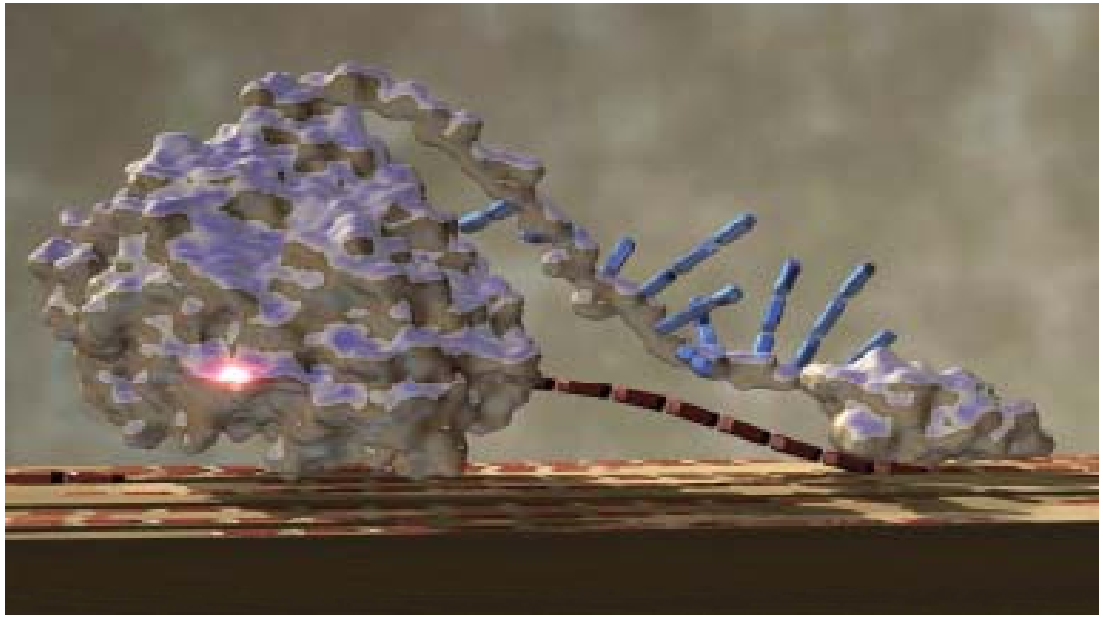
50 M acres of energy crops plus agricultural wastes (wheat straw, corn stover, wood residues, urban waste, animal manure, etc.) can produce ***half*** to ***all*** of current US consumption of gasoline.

Current and projected production costs of ethanol

Courtesy Steve Koonin, BP Chief Scientist

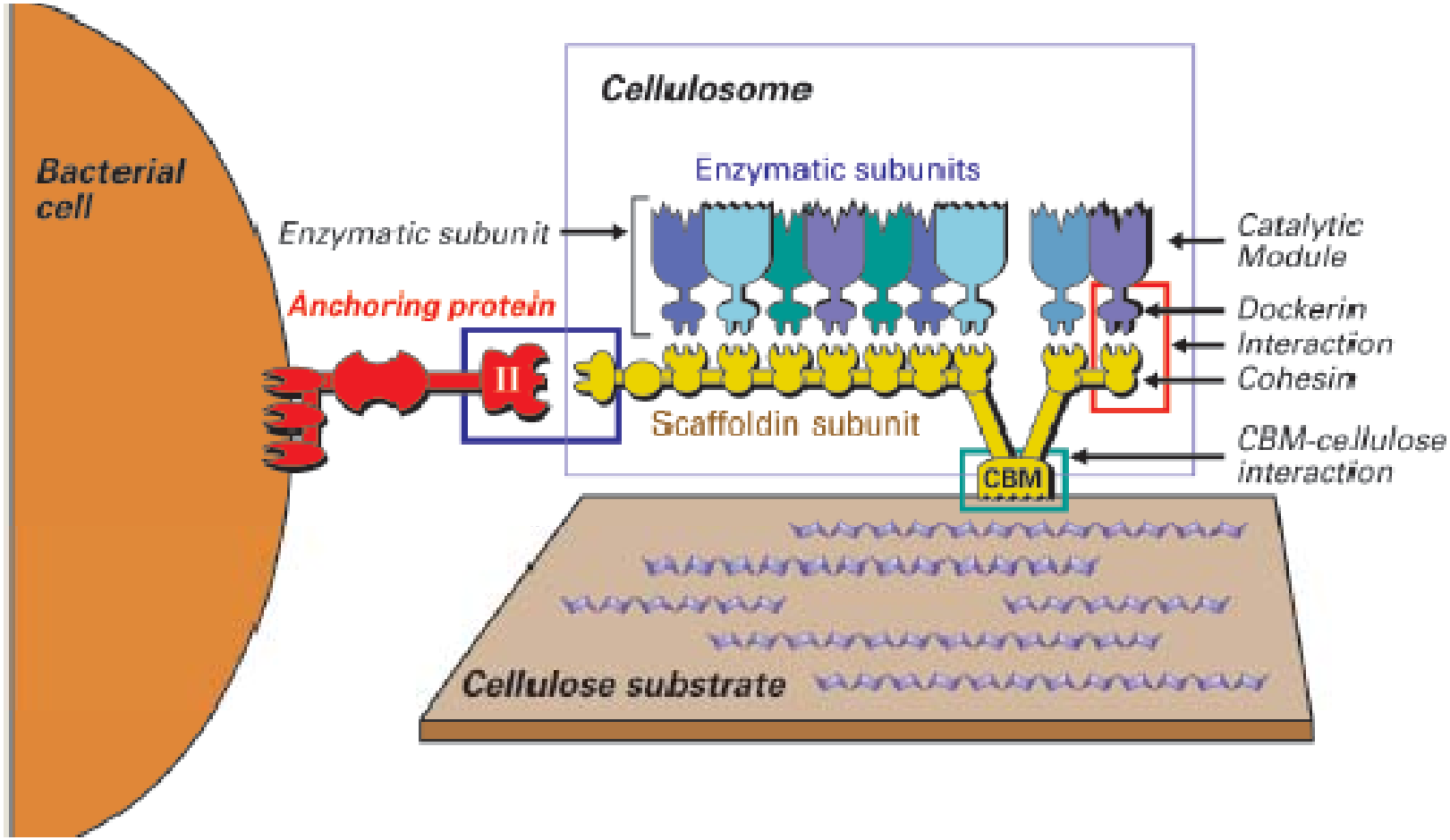


Source: BP Analysis, NREL, CERES, NCGA



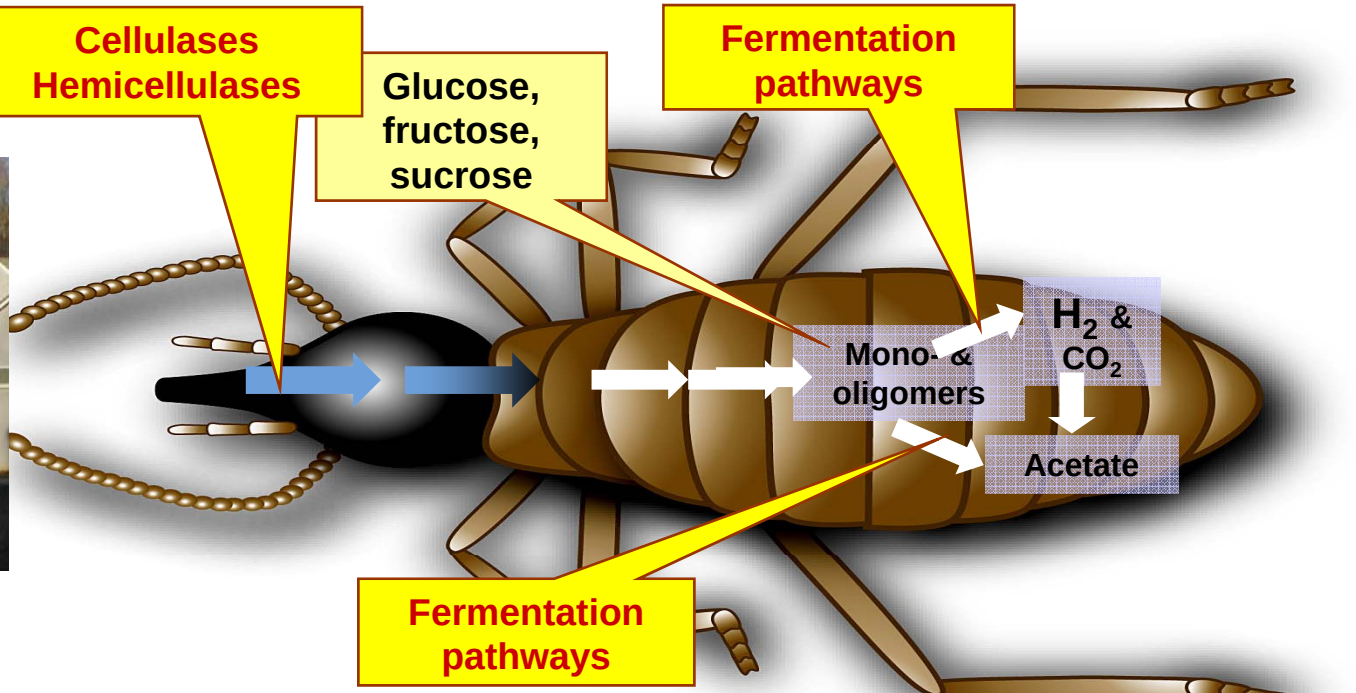
Departmant of Energy, working with Genencor and Novozymes, achieved a 20 -30 fold reduction in enzyme costs. A cocktail of three different enzymes were found to work more efficiently in converting cellulose into simple sugars.

Further cost reductions are required: Current costs are over 20¢ /gal.

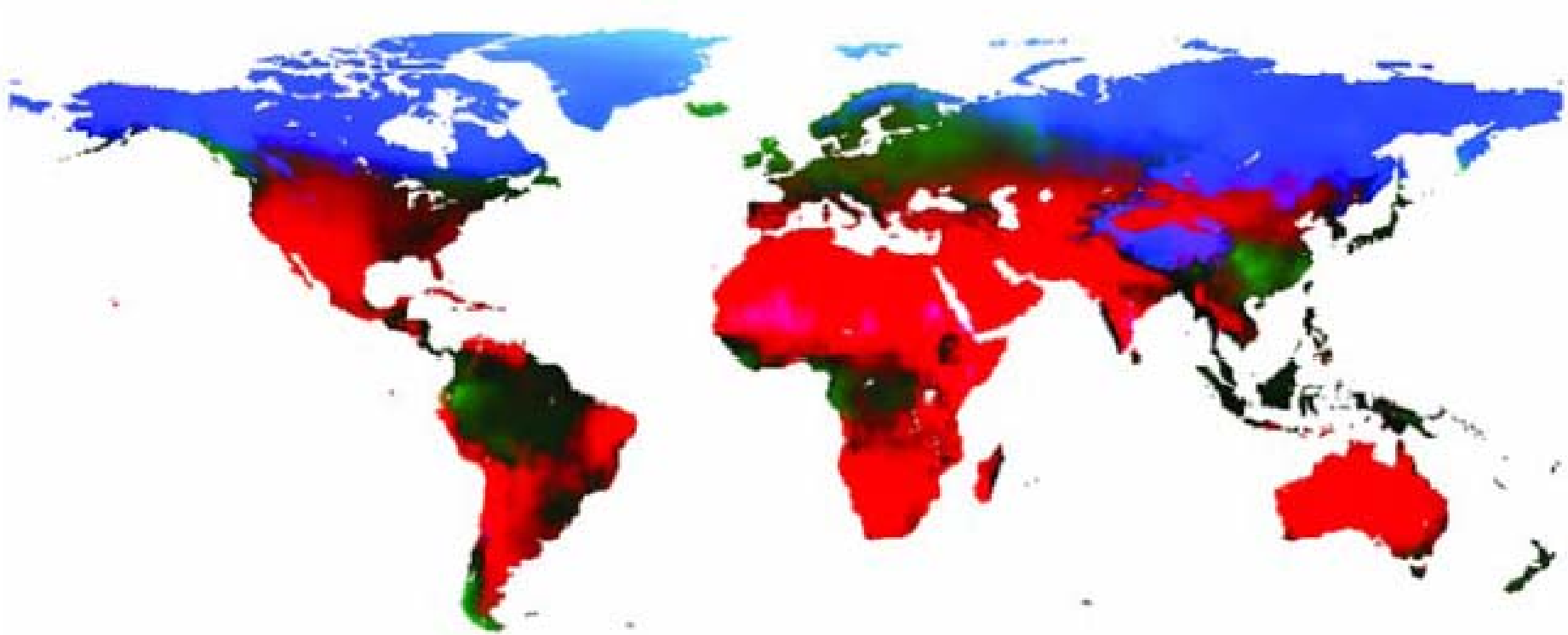


Cellulosomes can be designed with complementary enzymes to form a single multi-enzyme complex. Cellulose hydrolysis rates were shown to be 2.7- to 4.7-fold higher compared with purified enzyme preparations.

Termites have many specialized microbes that efficiently digest lignocellulosic material



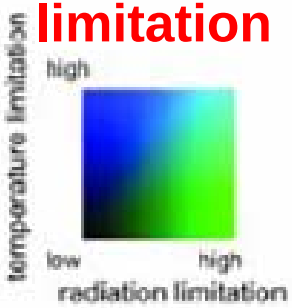
Limiting factors for plant productivity



Temp/water limitation

Rad/water limitation

temp/water limitation

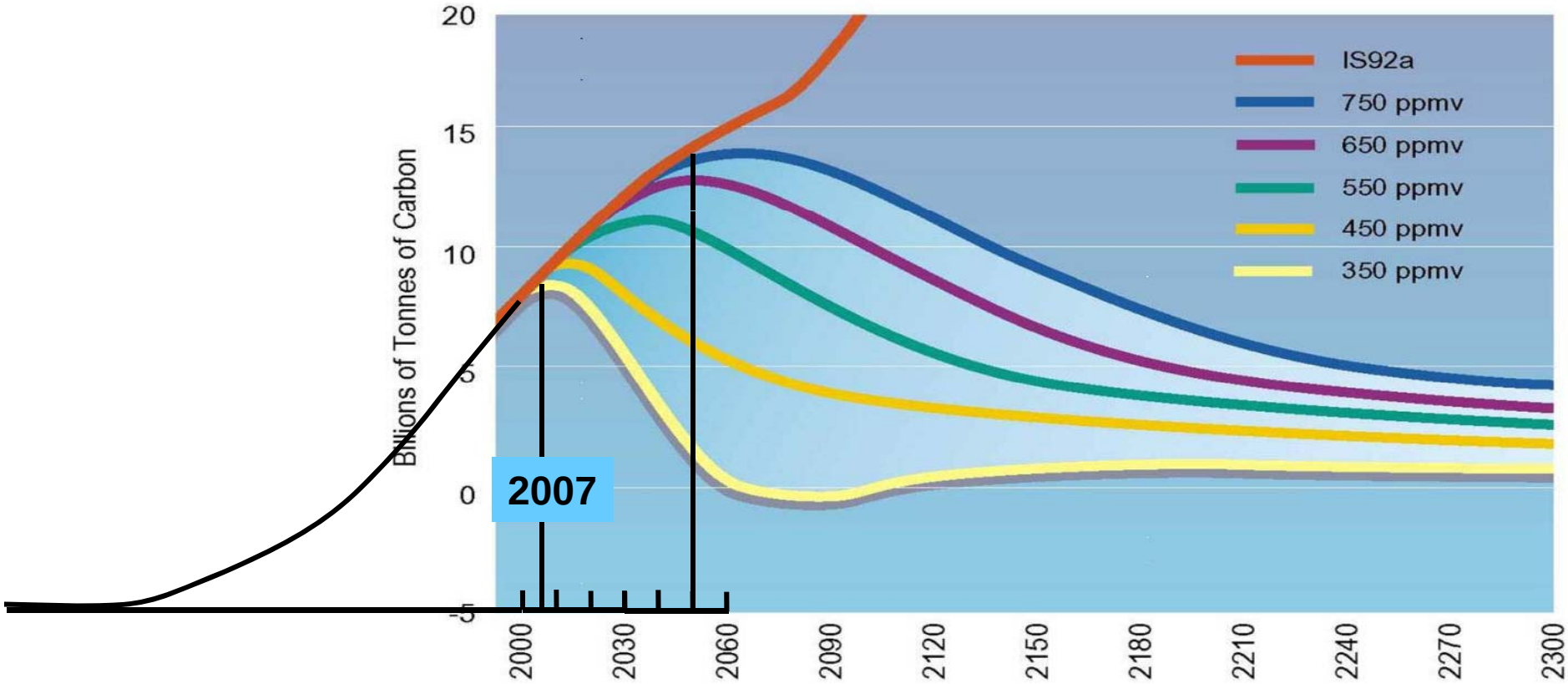


Baldocchi et al. 2004 SCOPE 62

China Energy Group

Mark Levine
David Fridley
Jonathan Sinton
Jiang Lin
Nan Zhou
Joe Huang
Lynn Price
Joanna Lewis
Tyler Dillavou
Rachel Stern

Emissions Trajectories for atmospheric CO_2 concentration ceilings



Source: Fourth Assessment of the Intergovernmental Panel on Climate Change; Summary for Policy Makers, February 2007.

DOE workshop
on
Mathematical Research Challenges
in
Optimization of Complex Systems

Robert J. Thomas **Cornell University**

Phillip N. Overholt **US DOE**

December 7, 2006

The creation of a “smart electrical grid” is non-trivial

- System and Control Theory for Power Systems, Edited by J.H. Chow, R.J. Thomas and P.V. Kokotovic. IMA Volumes in Mathematics and its Applications. **Springer-Verlag**, Vol. 64., 1994

- Applied Mathematics For Restructured Electric Power Systems: Optimization, Control, and Computational Intelligence, Edited by Joe H. Chow , Felix F. Wu , James A. Momoh, **Kluwer Academic Publishers**, 2003

A dual strategy is needed:

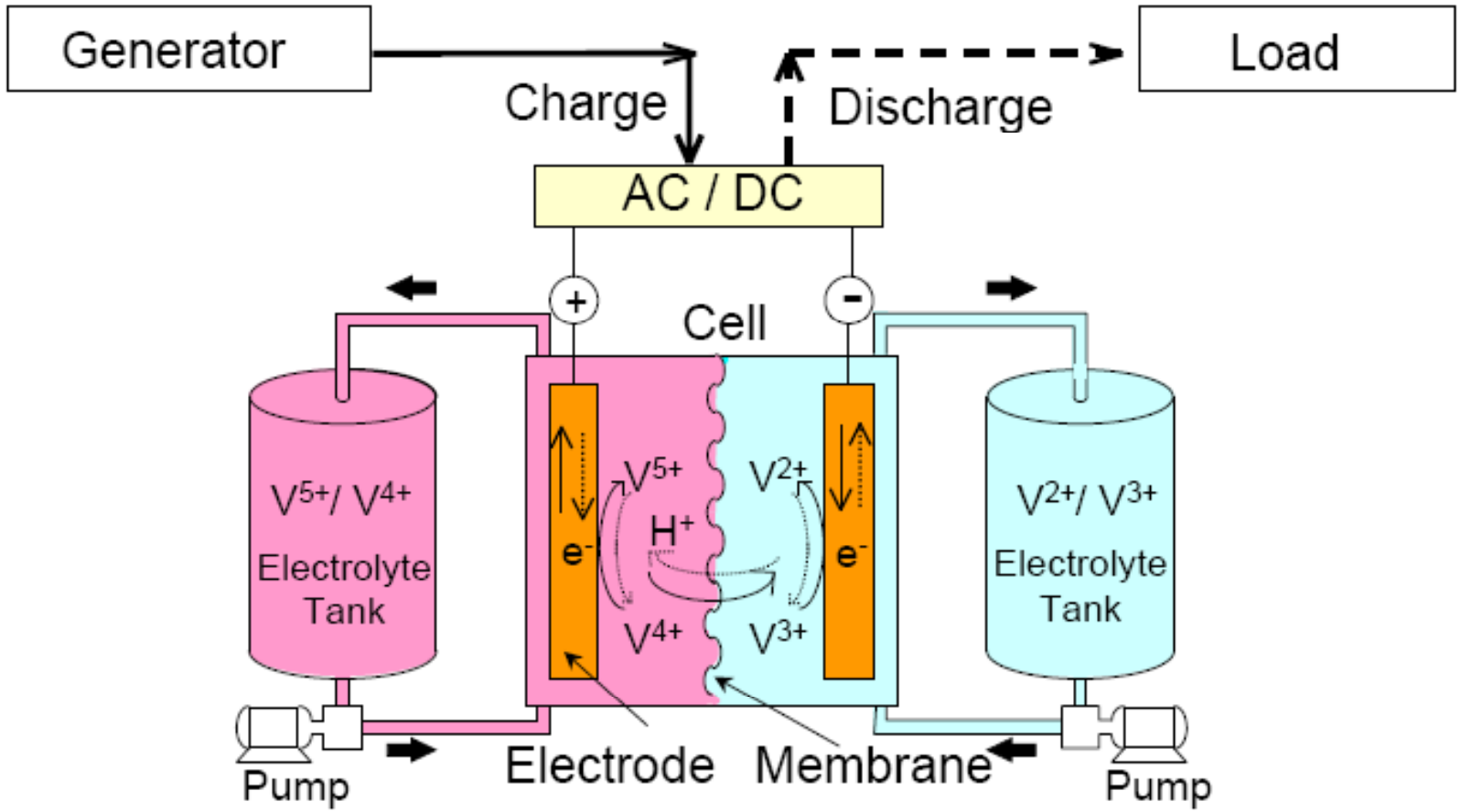
1) Maximize energy efficiency and decrease energy use. *This part of the solution will remain the lowest hanging fruit for the next few decades.*

2) Develop new sources of clean energy

What characterizes power systems problems ?

- Complexity - Nonlinear PDE's, ODE's, algebraic and mixed integer constraints, human behavior, economic externalities
- Scale - Time and Space, e.g., large numbers of variables, wide areas over which measurements are made and communicated, decisions from microseconds to hours.

Principle of Vanadium Redox Flow Battery



$$\oplus \quad V^{4+} \rightleftharpoons V^{5+} + e^-$$

$$\ominus \quad V^{3+} + e^- \rightleftharpoons V^{2+}$$

Energy supply

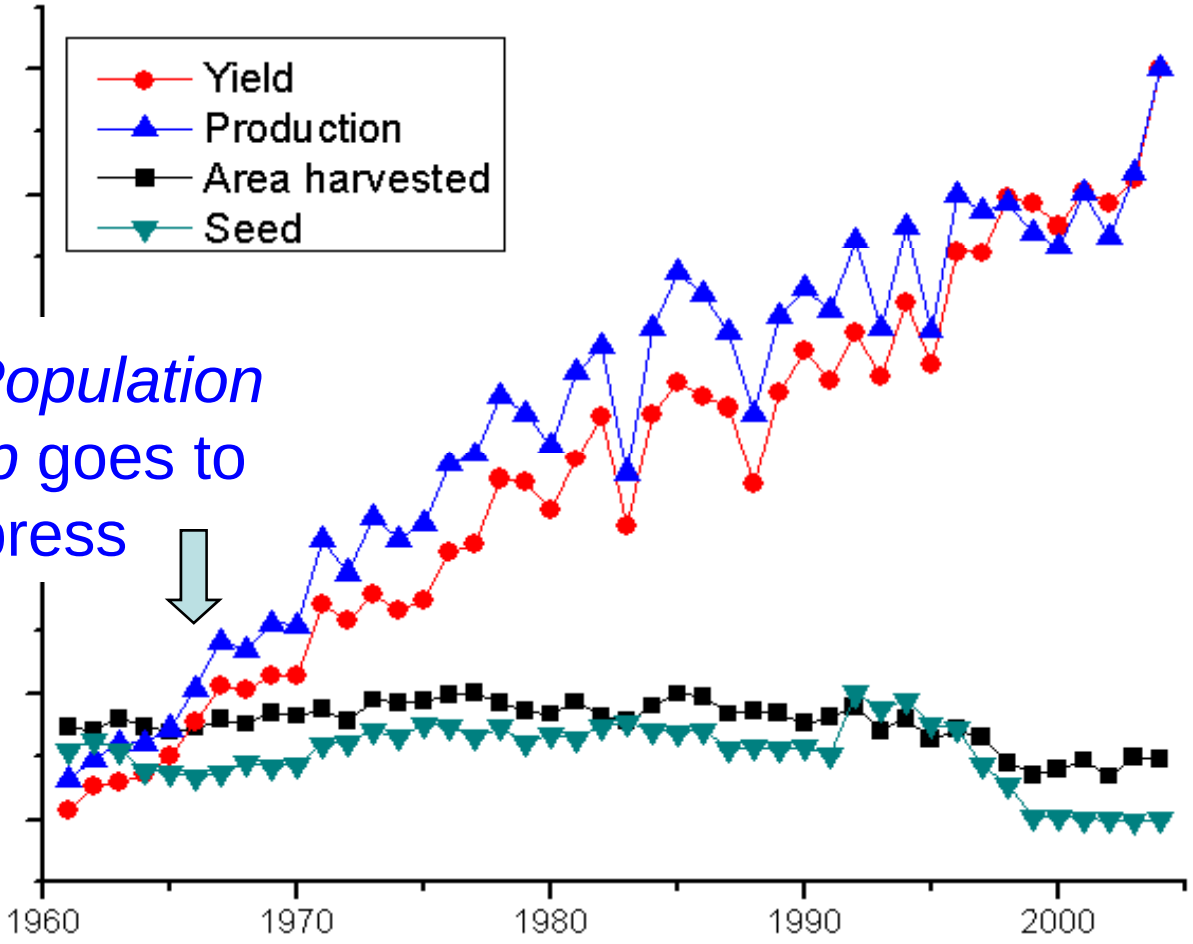
- Oil, Unconventional Oil
- Coal
- Gas
- Fission
- Geothermal

Base-load electricity generation

- Wind
- Solar photovoltaic and Solar thermal
- Bio-mass

Energy storage *and* efficient electricity transmission is needed before transient sources >30% of baseload

World Production of Grain (1961 – 2004)



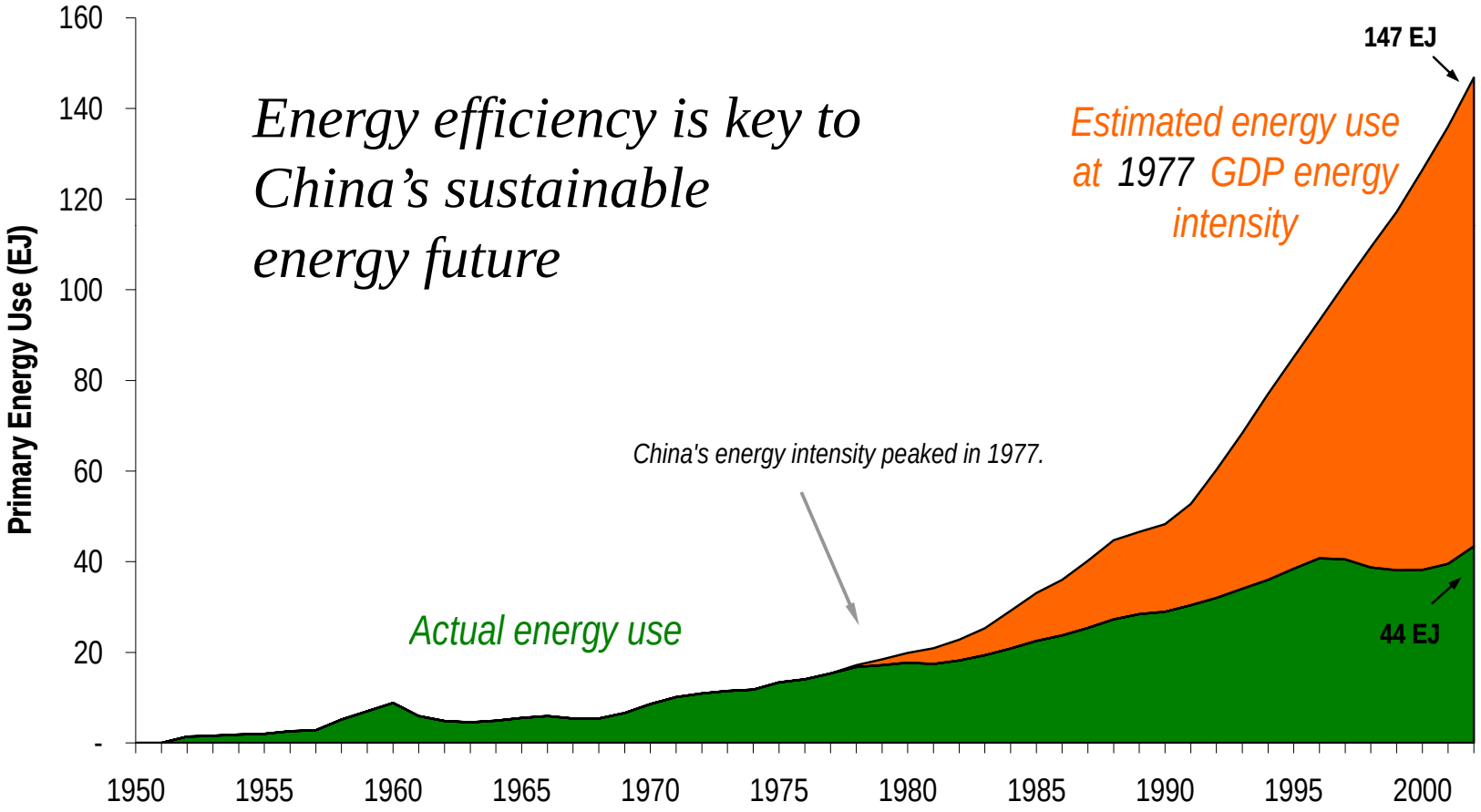
The Population Bomb goes to press

1960:
Population = 3 B

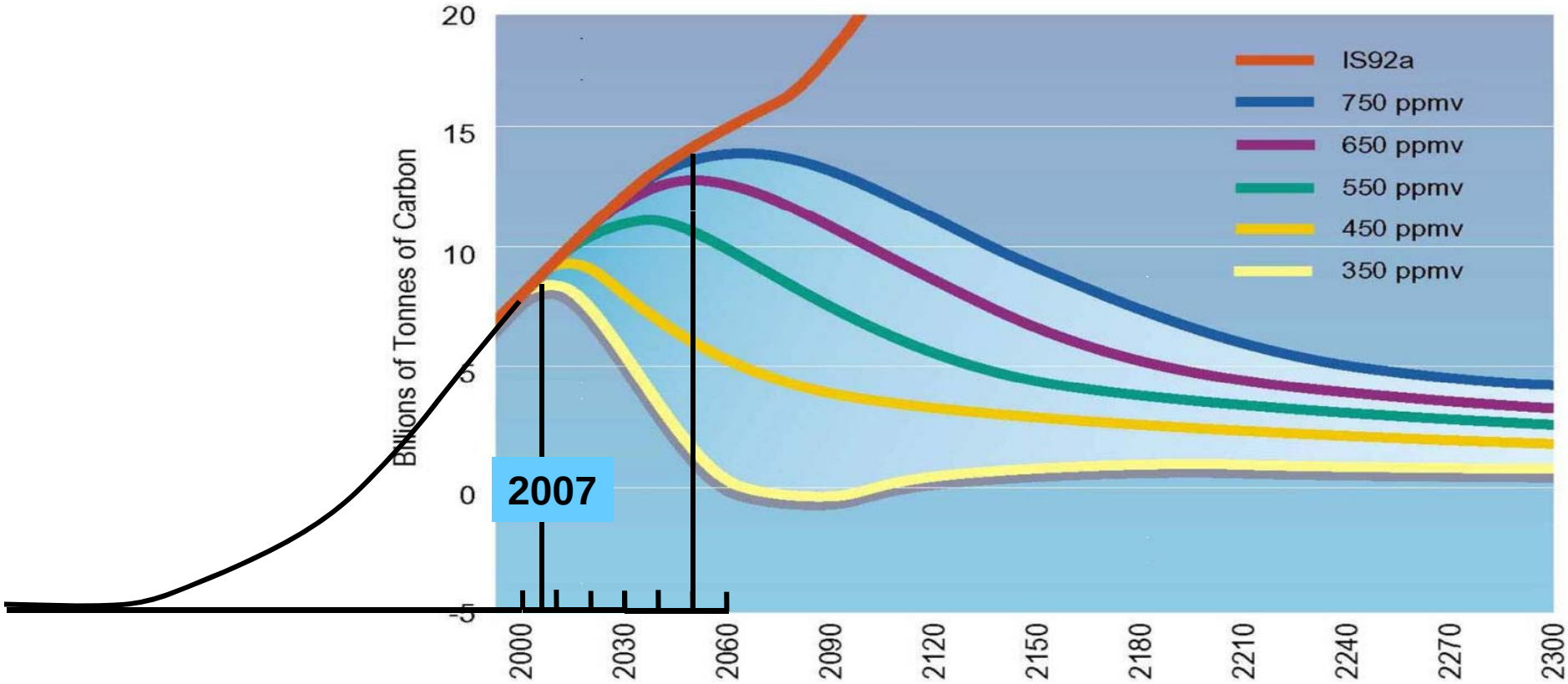
2005:
Population = 6.5 B

Source: Food and Agriculture Organization (FAO), United Nations

Why the Focus on China?

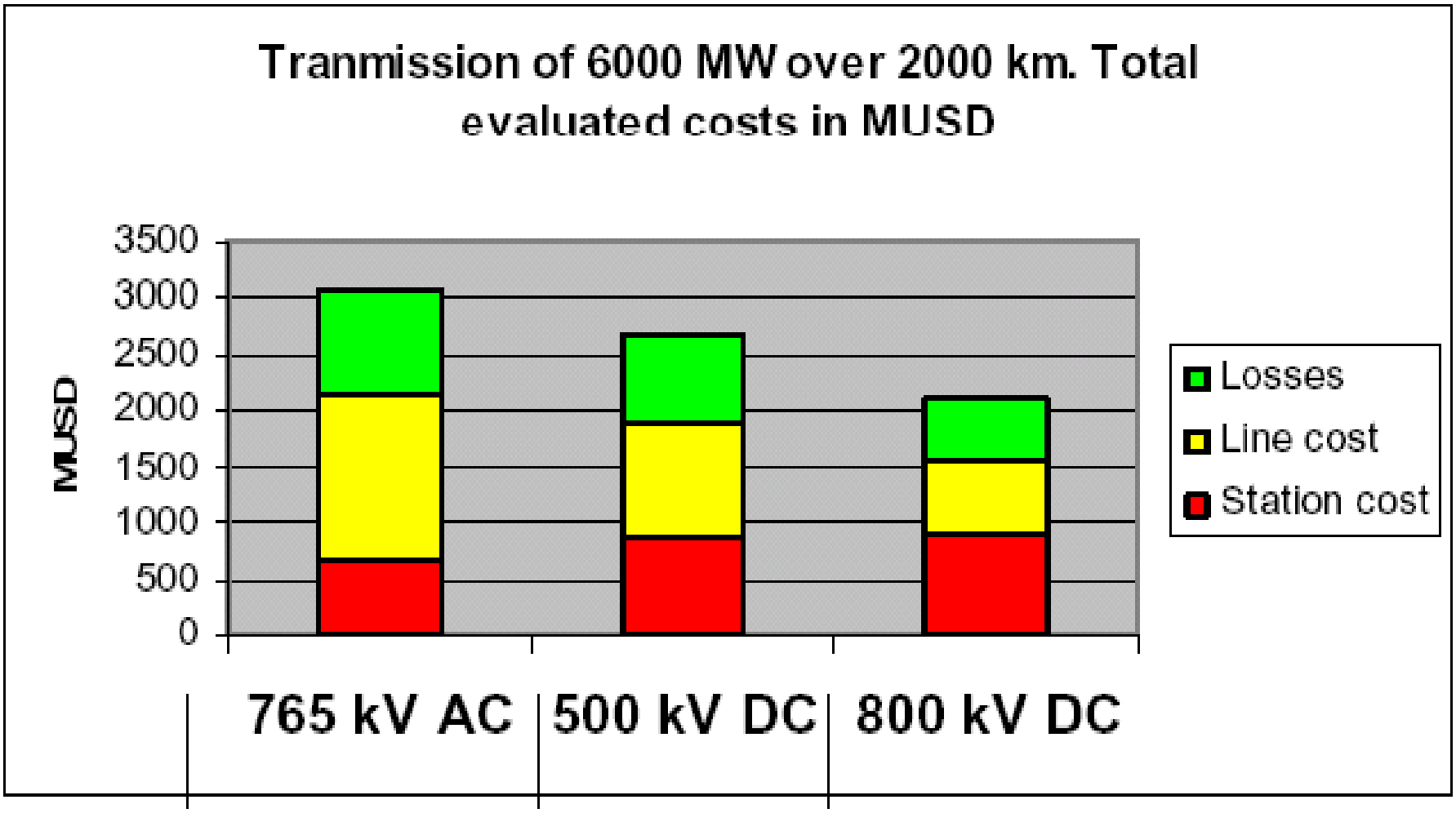


Emissions Trajectories for atmospheric CO_2 concentration ceilings



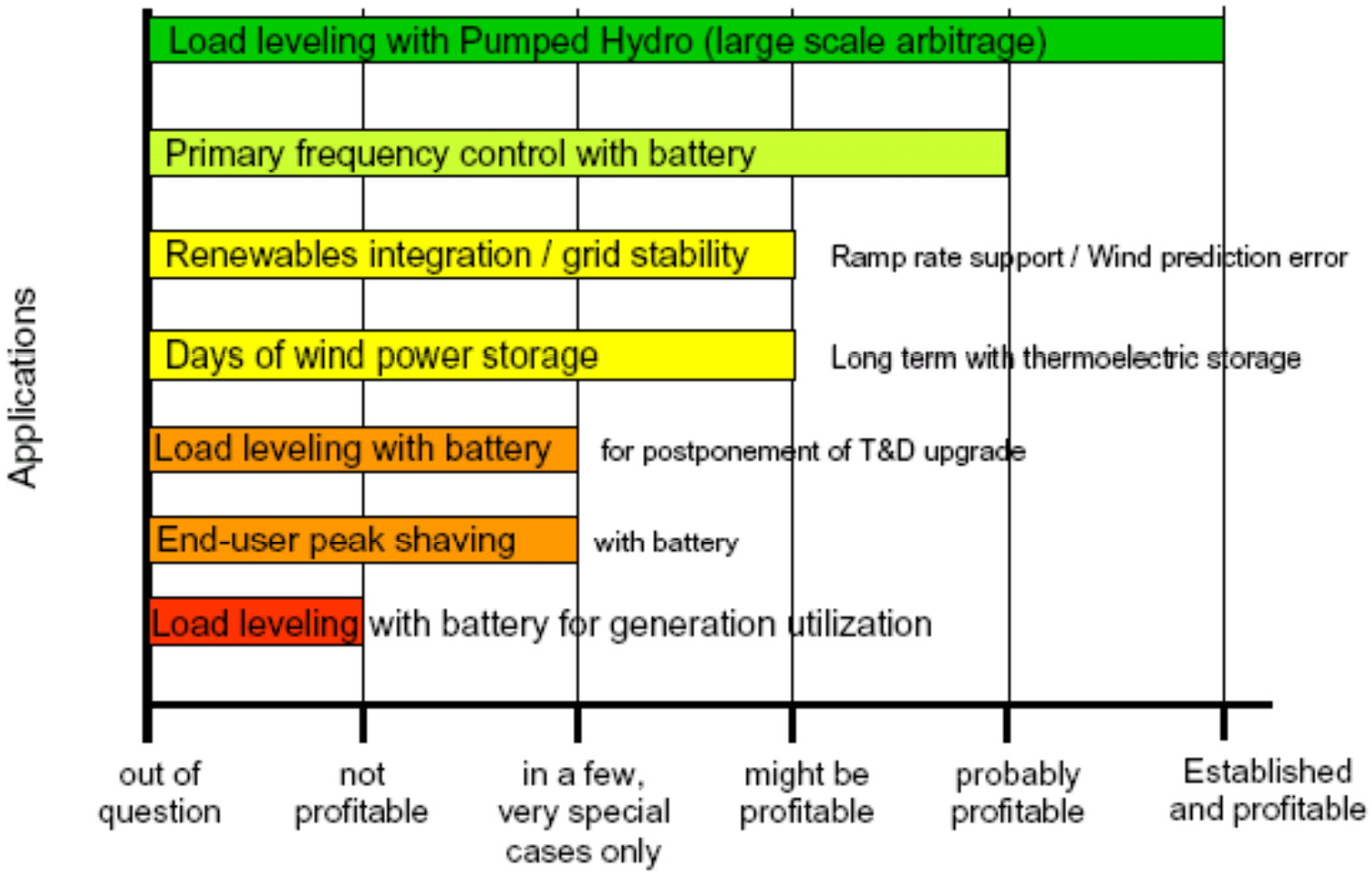
Source: Fourth Assessment of the Intergovernmental Panel on Climate Change; Summary for Policy Makers, February 2007.

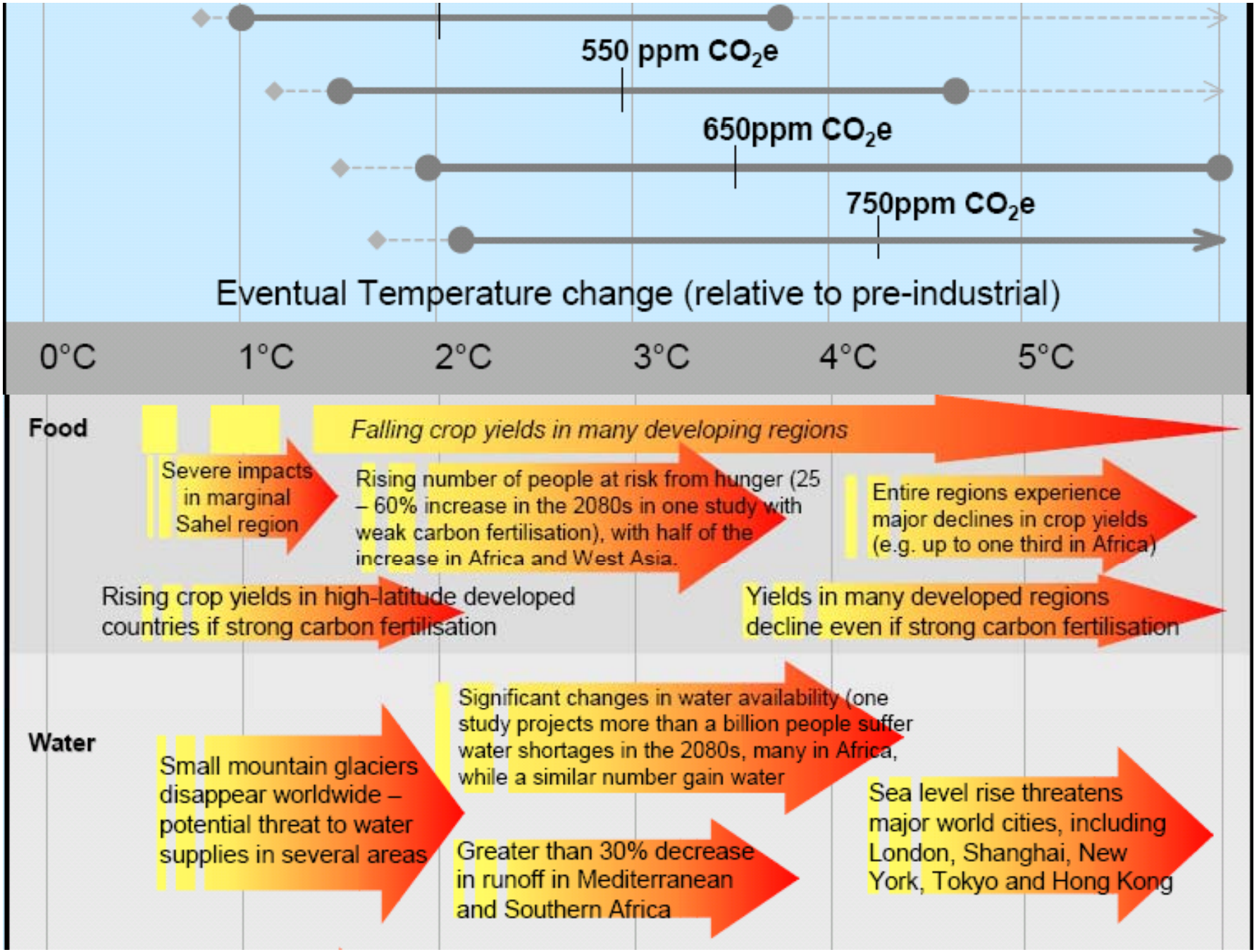
Breakdown of transmission costs

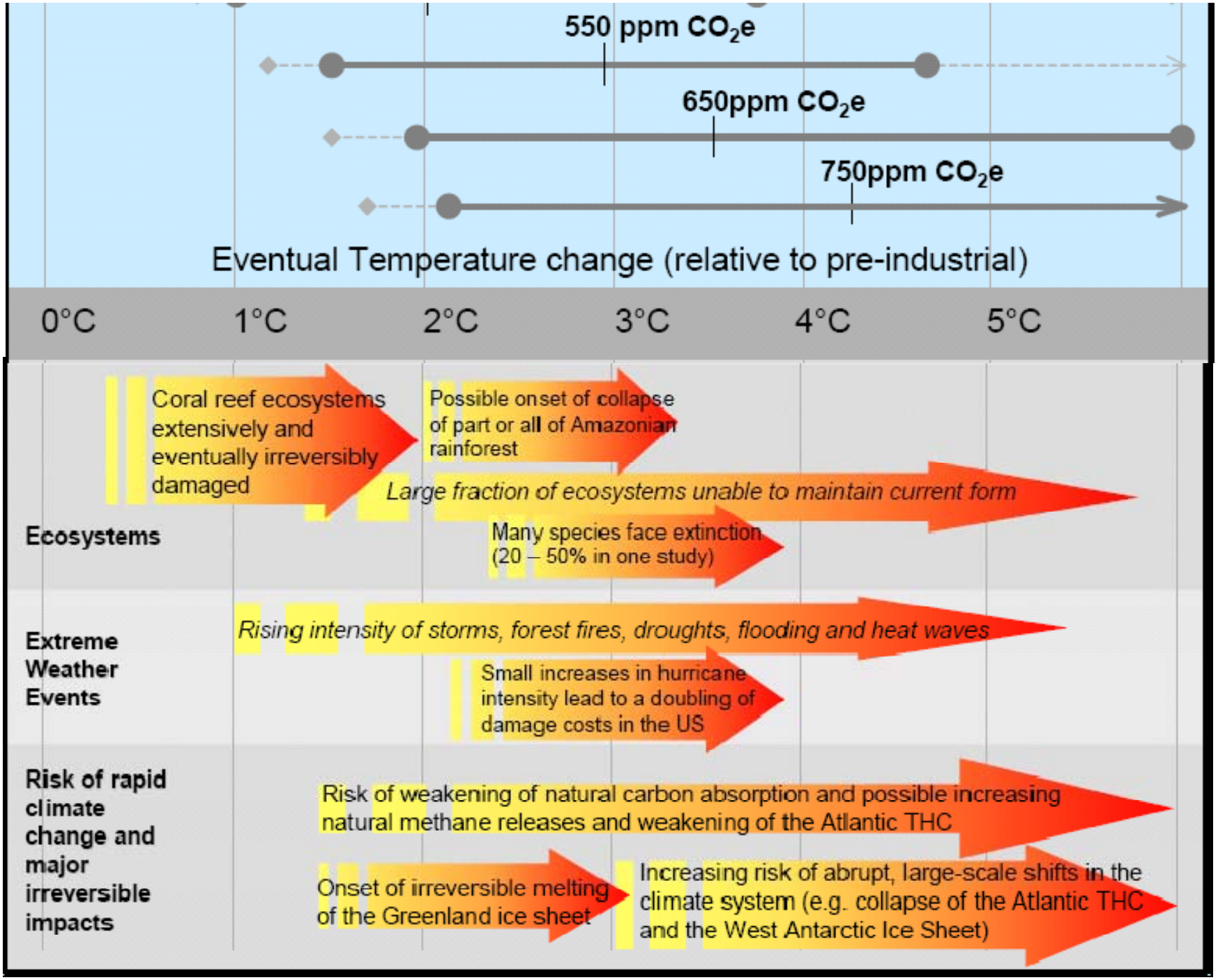


Source: ABB

Valuation of Bulk Energy Storage Applications




550 ppm CO_2e
650ppm CO_2e
750ppm CO_2e
Eventual Temperature change (relative to pre-industrial)
0°C
1°C
2°C
3°C
4°C
5°C
Food
Falling crop yields in many developing regions
Severe impacts in marginal Sahel region
Rising number of people at risk from hunger (25 – 60% increase in the 2080s in one study with weak carbon fertilisation), with half of the increase in Africa and West Asia.
Entire regions experience major declines in crop yields (e.g. up to one third in Africa)
Rising crop yields in high-latitude developed countries if strong carbon fertilisation
Yields in many developed regions decline even if strong carbon fertilisation
Water
Small mountain glaciers disappear worldwide – potential threat to water supplies in several areas
Significant changes in water availability (one study projects more than a billion people suffer water shortages in the 2080s, many in Africa, while a similar number gain water
Greater than 30% decrease in runoff in Mediterranean and Southern Africa
Sea level rise threatens major world cities, including London, Shanghai, New York, Tokyo and Hong Kong


550 ppm CO_2e
650ppm CO_2e
750ppm CO_2e
Eventual Temperature change (relative to pre-industrial)
0°C
1°C
2°C
3°C
4°C
5°C
Coral reef ecosystems extensively and eventually irreversibly damaged
Possible onset of collapse of part or all of Amazonian rainforest
Large fraction of ecosystems unable to maintain current form
Many species face extinction (20 – 50% in one study)
Ecosystems
Rising intensity of storms, forest fires, droughts, flooding and heat waves
Small increases in hurricane intensity lead to a doubling of damage costs in the US
Extreme Weather Events
Risk of weakening of natural carbon absorption and possible increasing natural methane releases and weakening of the Atlantic THC
Onset of irreversible melting of the Greenland ice sheet
Increasing risk of abrupt, large-scale shifts in the climate system (e.g. collapse of the Atlantic THC and the West Antarctic Ice Sheet)
Risk of rapid climate change and major irreversible impacts

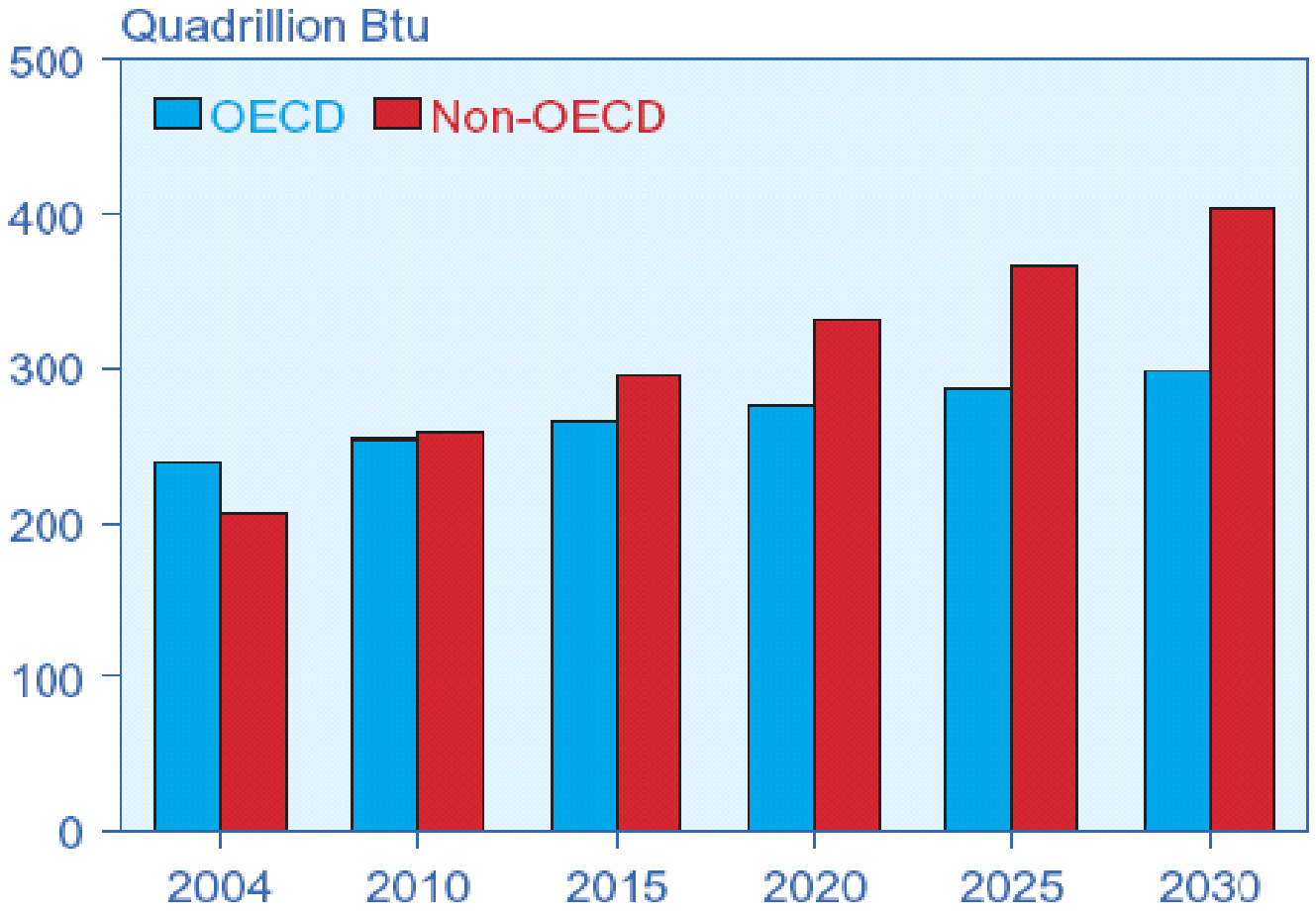
The Energy Problem

(1) Potential for geopolitical conflict due to escalating competition for energy resources and energy security.

(2) ~ 2 billion people worldwide currently lack access to modern forms of energy.

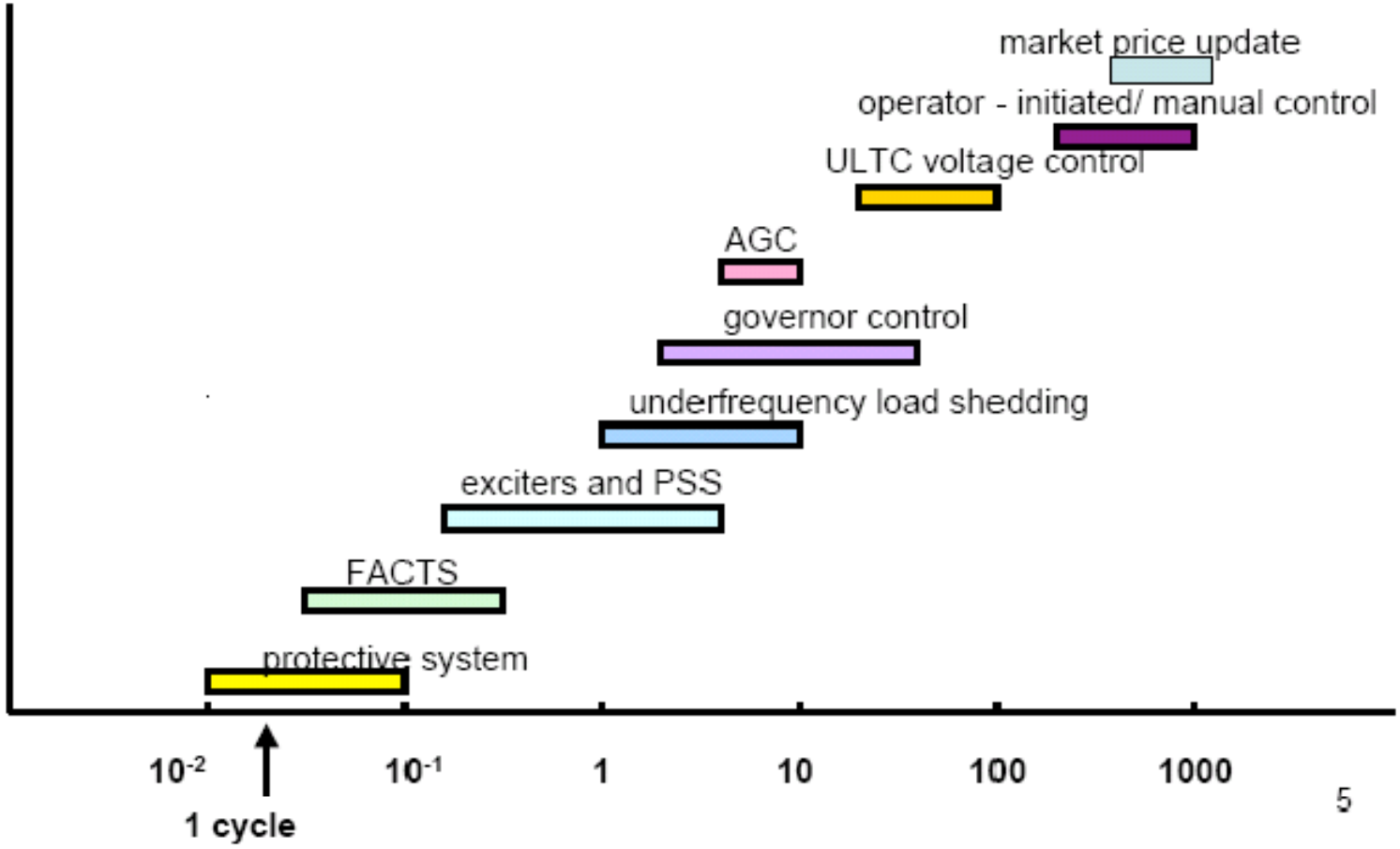
(3) Environmental pollution and climate change risks.

Developing (non-QECD) countries are passing OECD countries in energy use



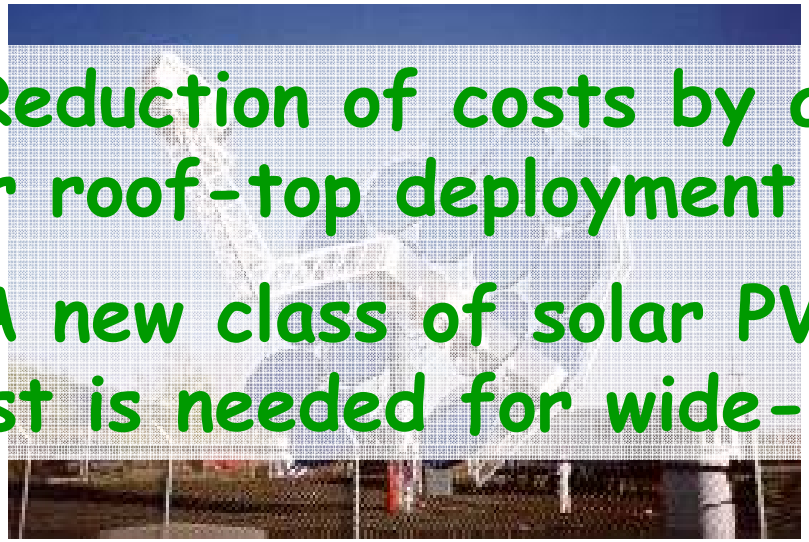
Sources: **2004:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea. **Projections:** EIA, System for the Analysis of Global Energy Markets (2007).

Time-scale hierarchy

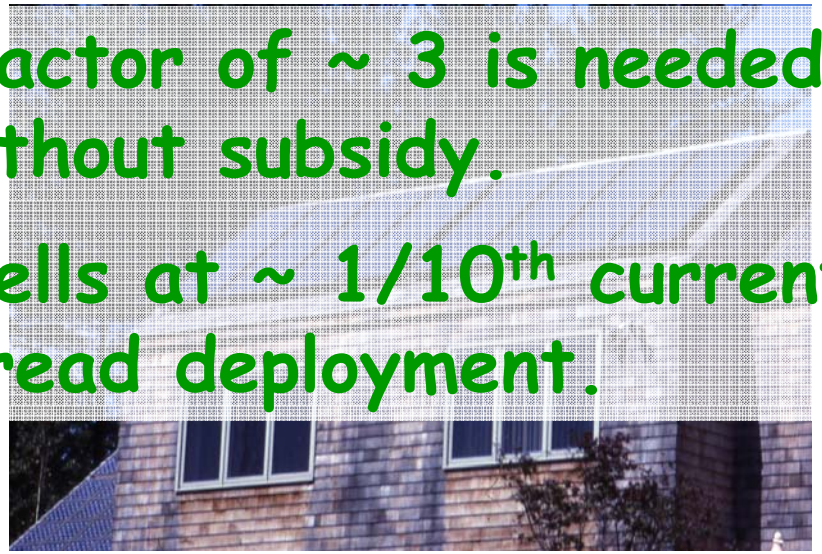


- Economic decisions (energy arbitrage)
- Human error, energy skimming?

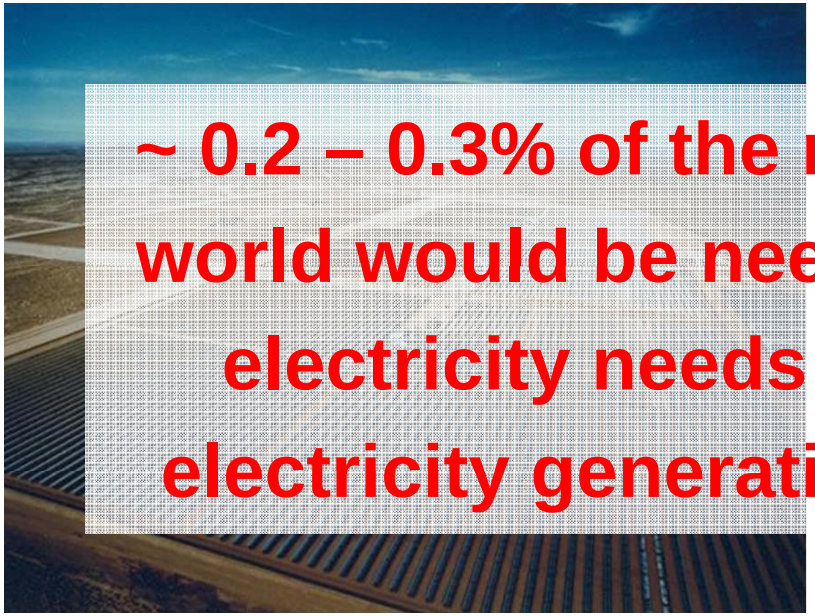
Solar thermal

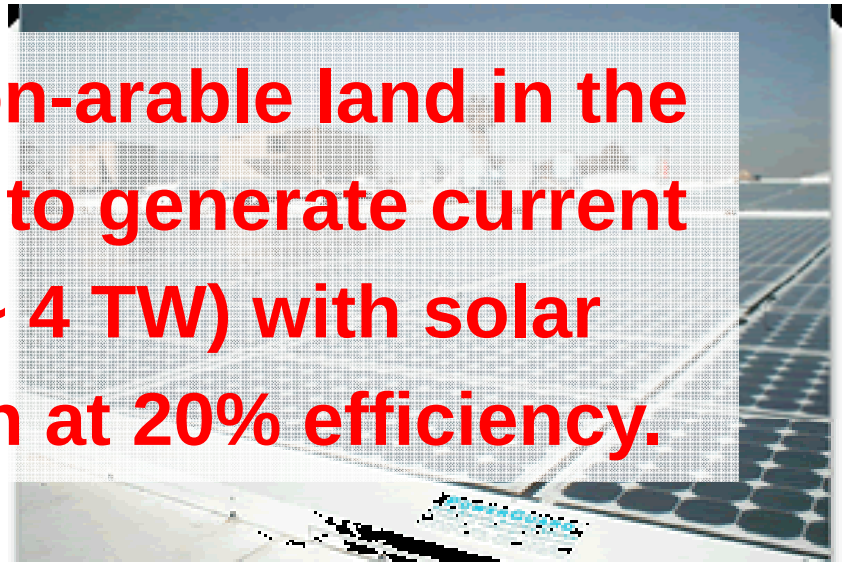


Solar photovoltaic



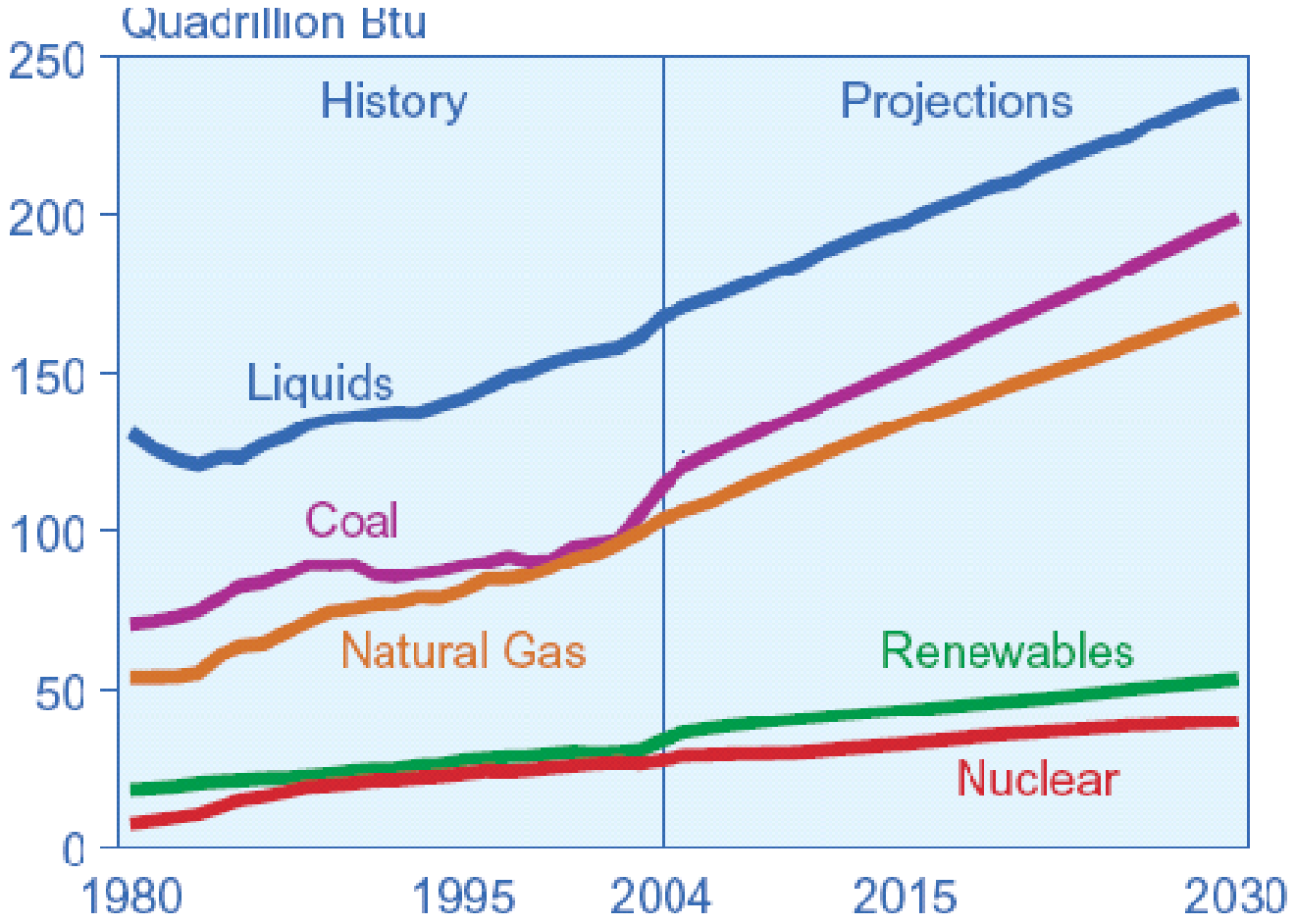
- Reduction of costs by a factor of ~ 3 is needed for roof-top deployment without subsidy.
- A new class of solar PV cells at ~ 1/10th current cost is needed for wide-spread deployment.





~ 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.

Energy Use by Fuel Type (1980 – 2030)



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea. **Projections:** EIA, System for the Analysis of Global Energy Markets (2007).

Helios: Lawrence Berkeley Laboratory and UC Berkeley