The Energy Problem and Lawrence Berkeley National Laboratory

California Air Resources Board

27 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:

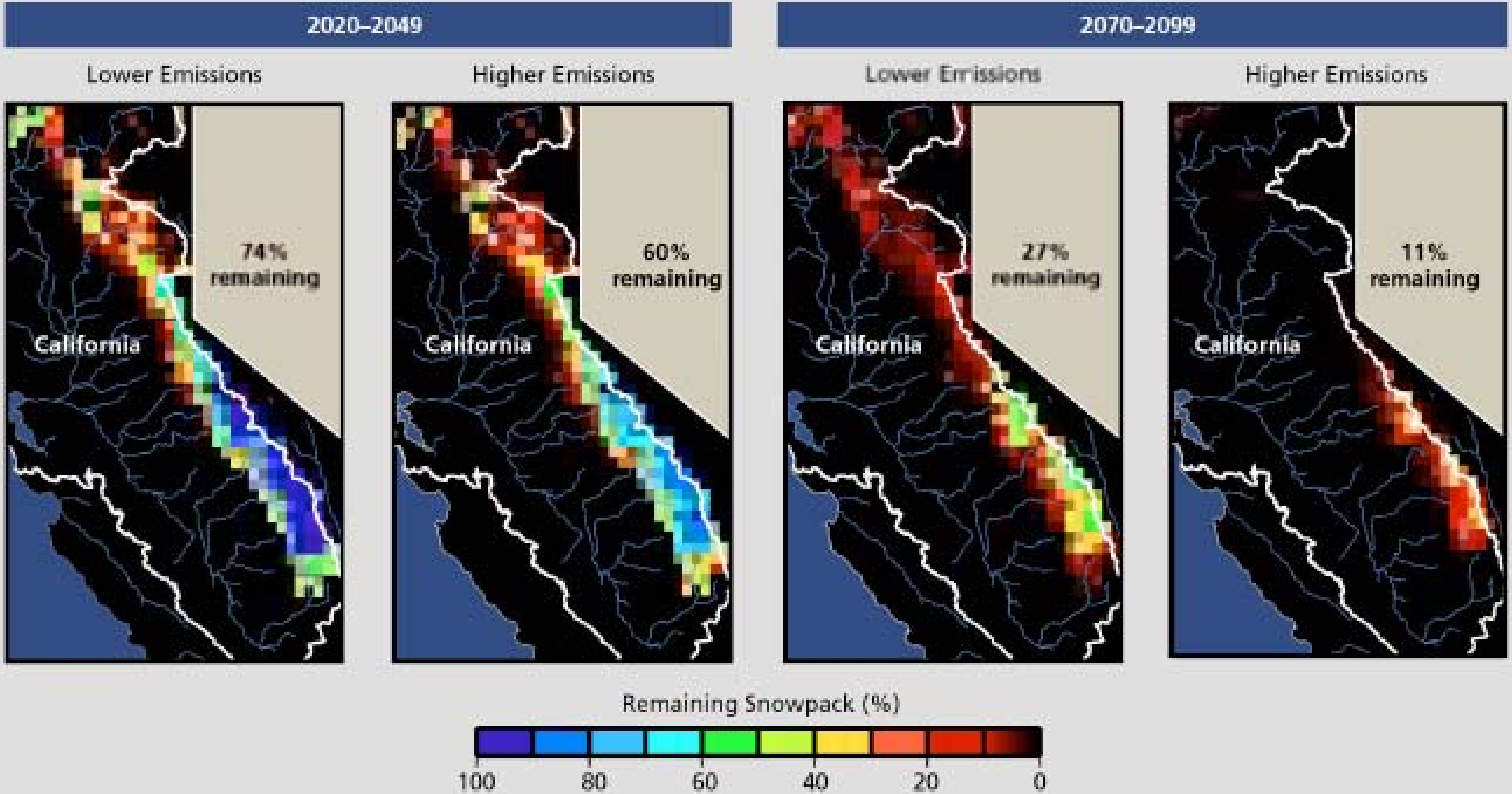
	B1 500ppm	**A1 fi** Current path (BAU)
Heat wave mortality:	**2-3x**	**5-7x**
Alpine/subalpine forests	**50–75%**	**75–90%**
Sierra snowpack	**30–70%**	**73–90%**

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

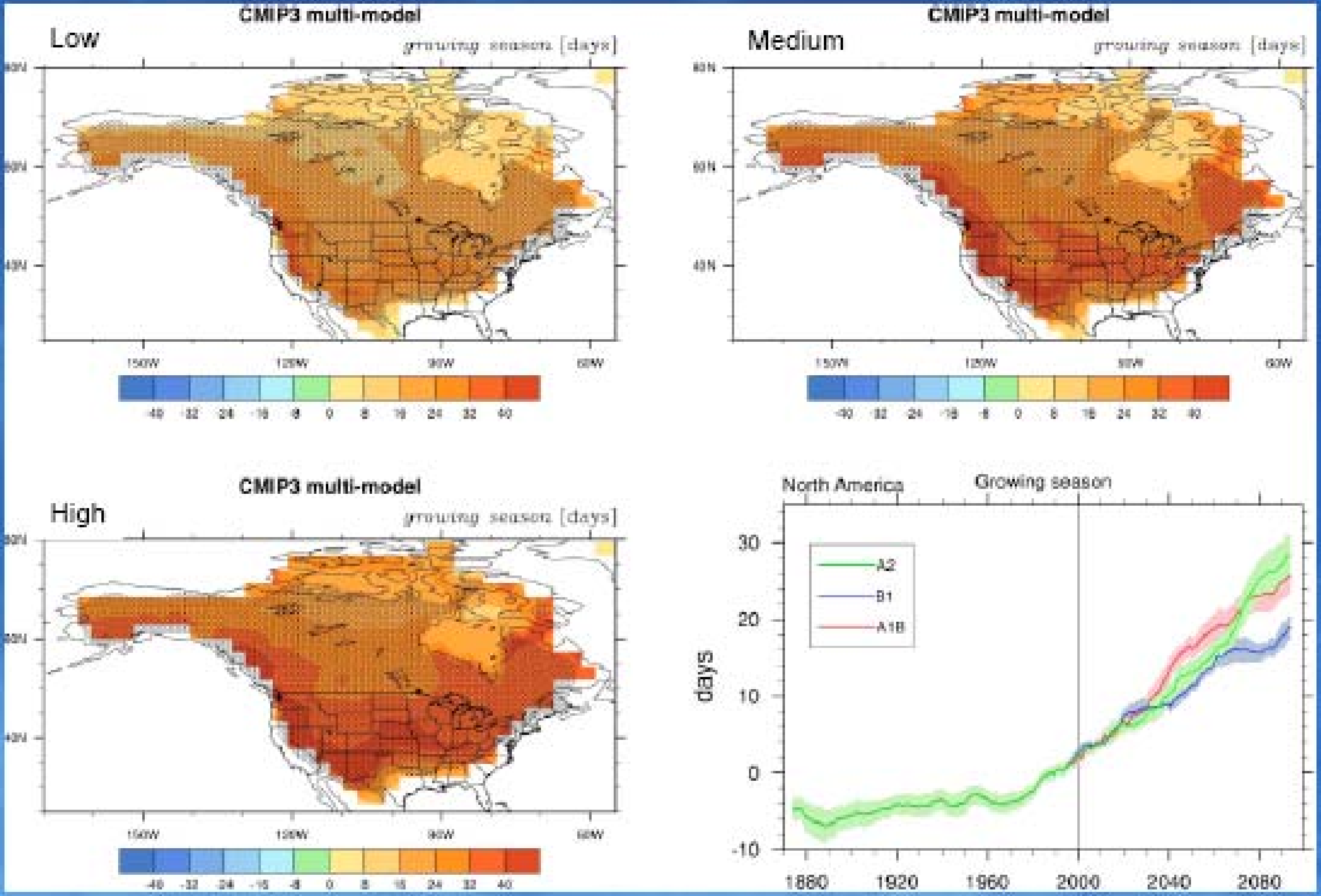
"Approximately 40% of the merchantable pine volume in the province has likely already been killed."

British Columbia, Ministry of Forests and Range, 2006

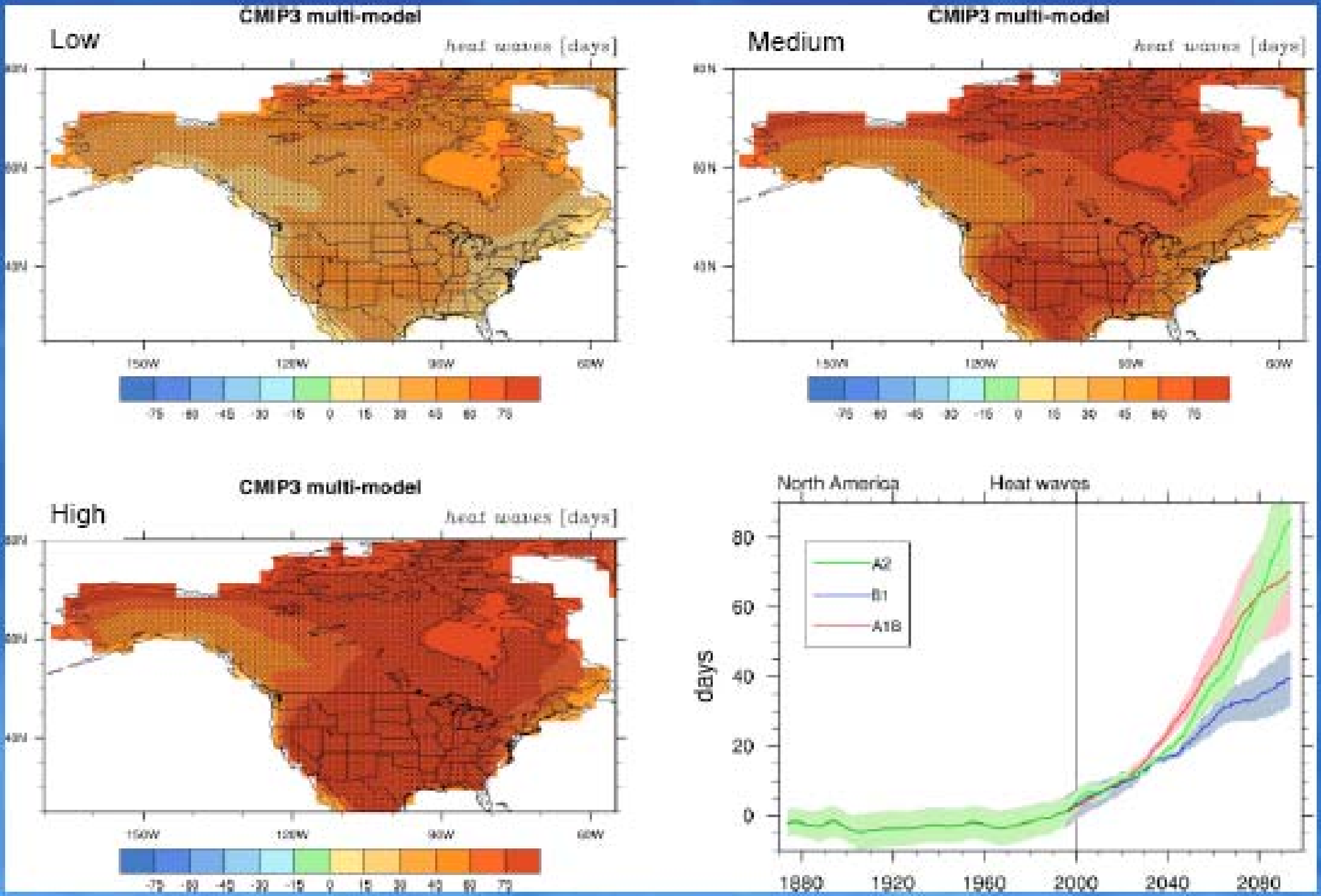
Projections of Sierra snow-pack and implications for water



Silver lining? Longer growing seasons



Downside #1: Longer heat waves



How would atmospheric CO_2 be affected by global warming?

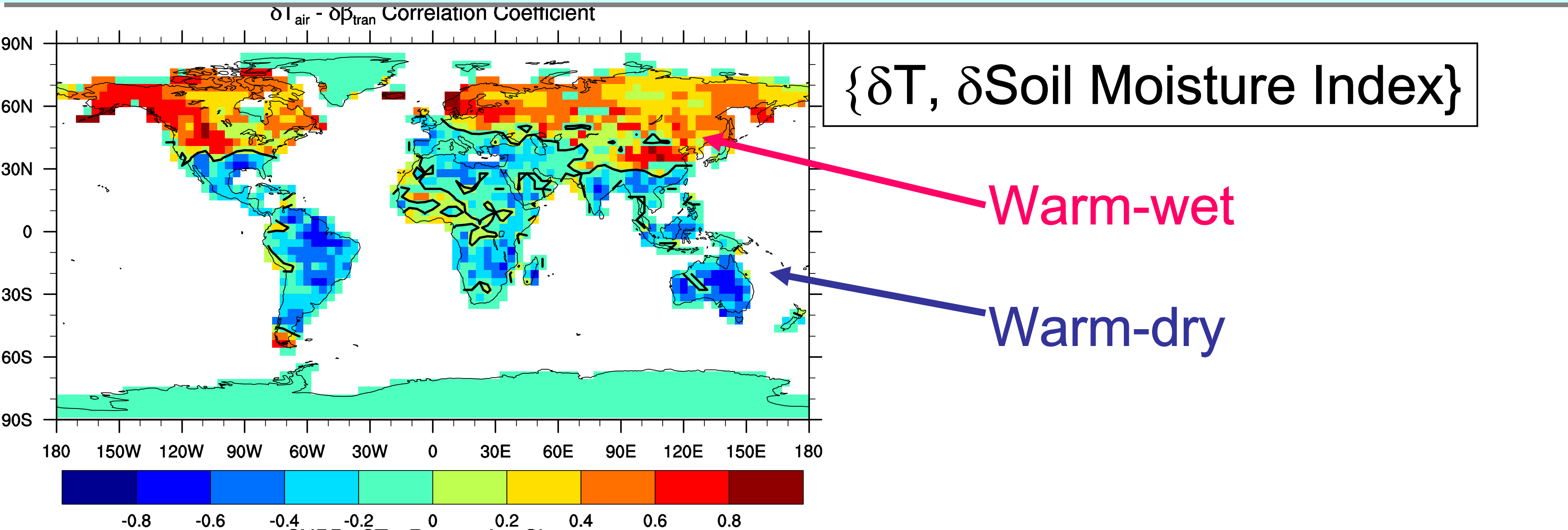
Atm CO_2 would increase because:

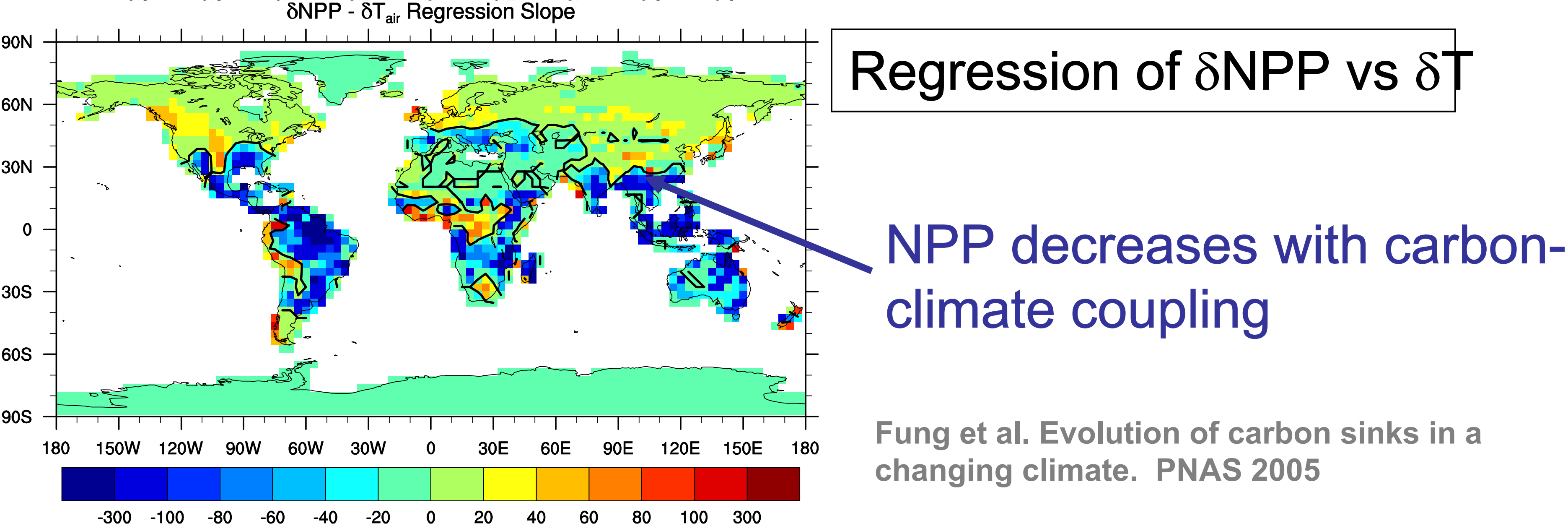
- Warming may enhance decomposition
- Increased ocean stratification → more carbon in mixed layer → reduced air-to-sea flux
- ….

Atm CO_2 would decrease because:

- warming may enhance photosynthesis
- Enhanced marine productivity and export
- …

21st Century Correlations & Regressions: FF= SRES A2 ; δ = Coupled minus Uncoupled





Fung et al. Evolution of carbon sinks in a changing climate. PNAS 2005

A dual strategy is needed to solve the energy problem:

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

Lawrence Berkeley National Laboratory

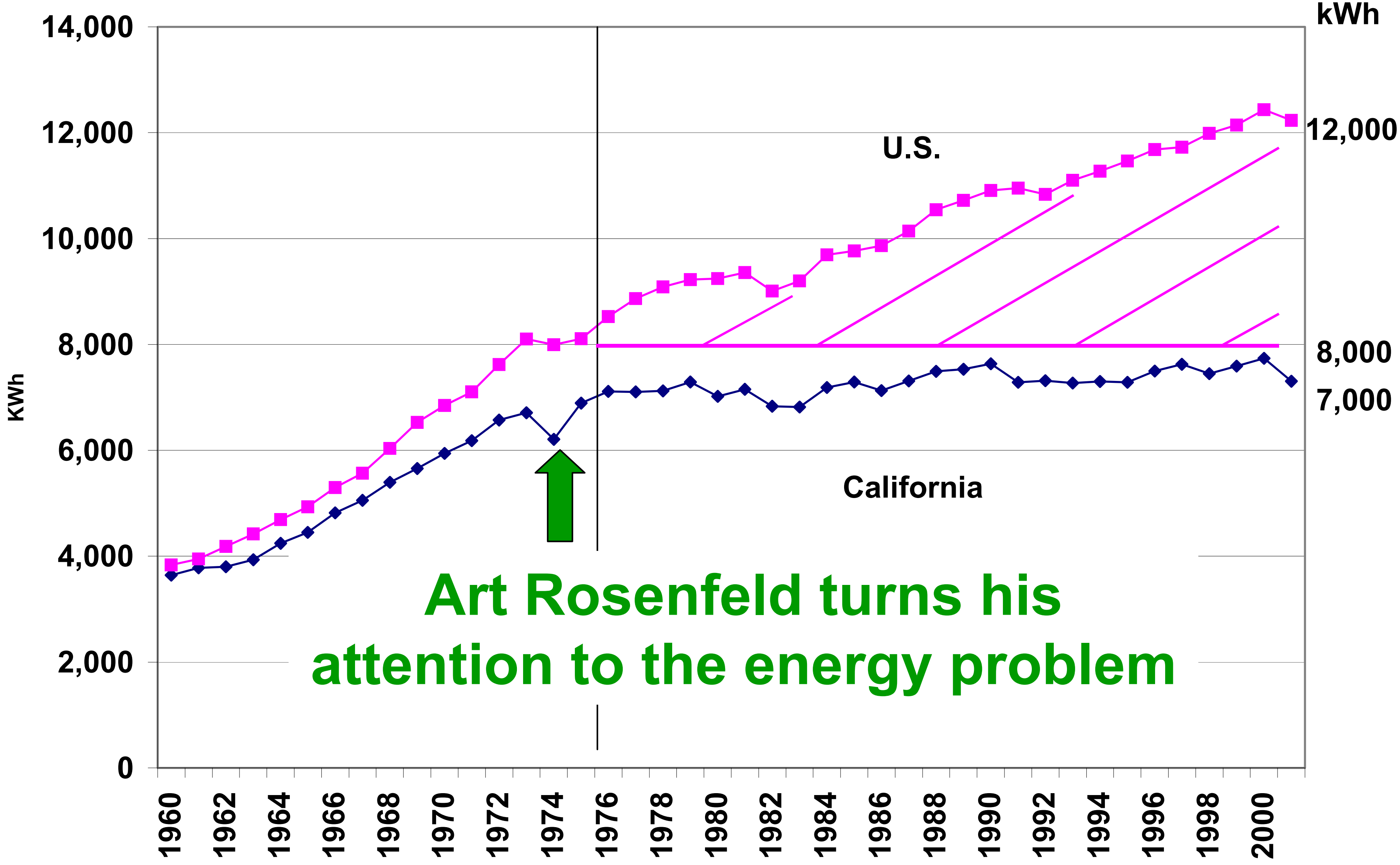
3,800 employees, ~$520 M / year budget

11 employees were awarded the Nobel Prize,
(9 did their Nobel work at the Lab.)
(Over 55 Nobel Laureates either trained or had significant collaborations at LBNL)

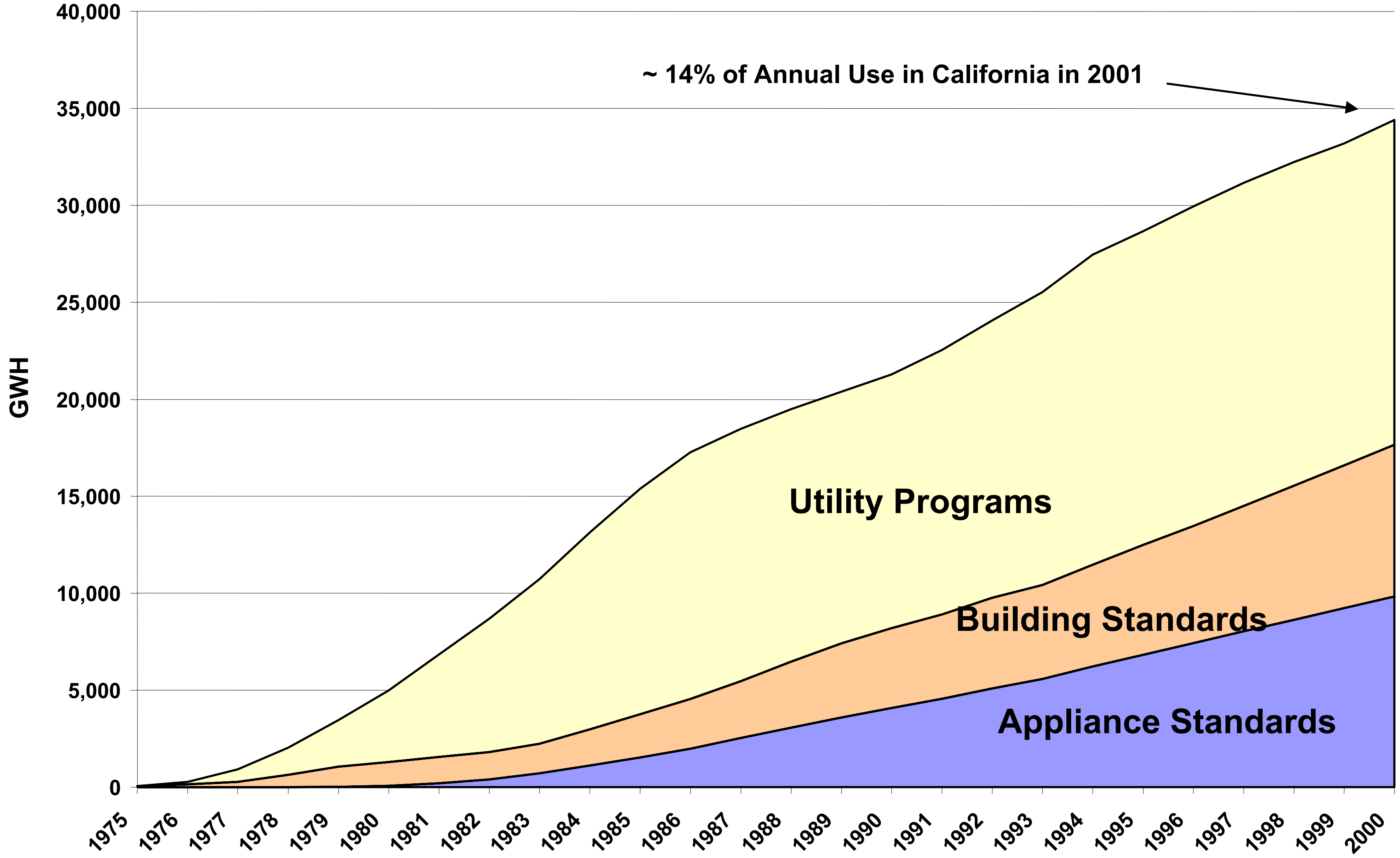
Today:

~ 3% of the members of National Academy of Sciences,
18 in the National Academy of Engineering,
2 in the Institute of Medicine

Electricity use per person (1960 – 2001)

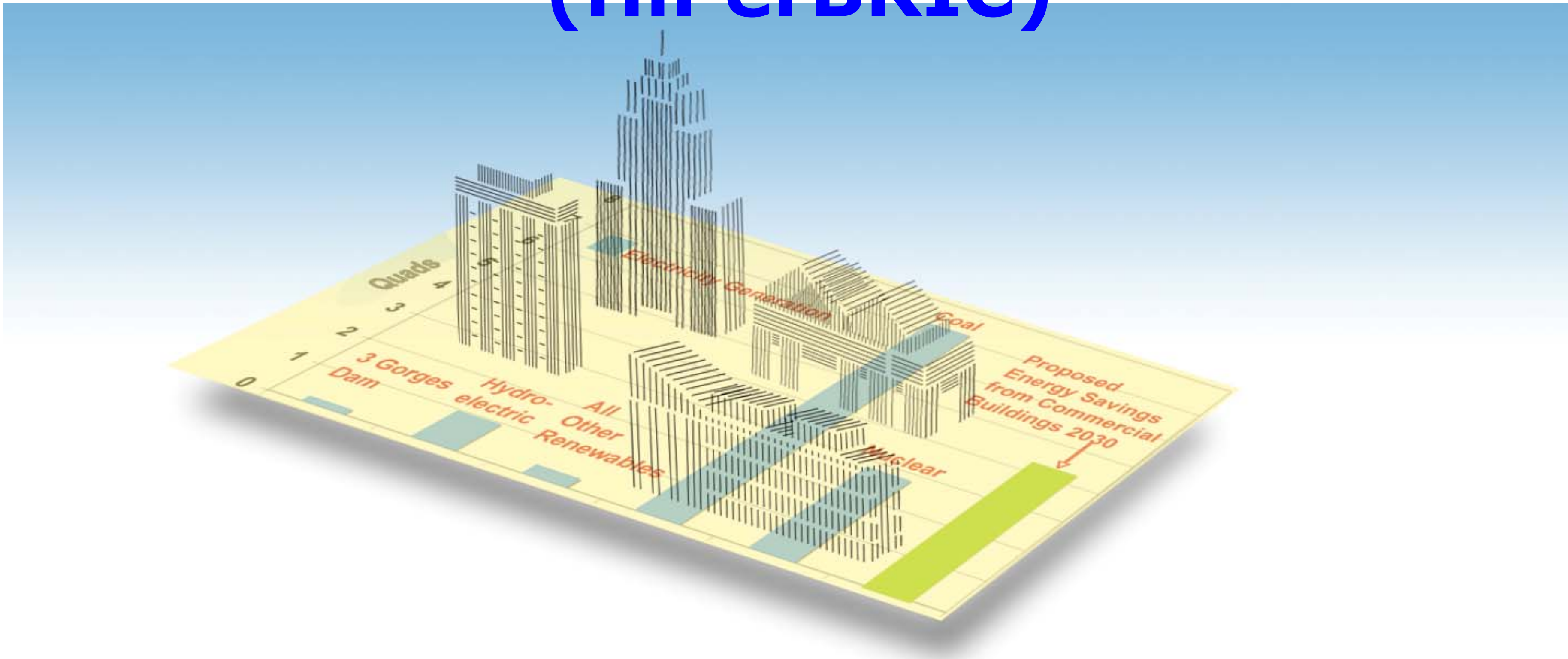


Half of the energy savings in California were made by separating utility profits from selling more energy



Source: Mike Messenger, CEC Staff, April 2003

High Performance Buildings Research & Implementation Center (HiPerBRIC)



United Technologies

Berkeley Lab

"Prius of Buildings: Exploiting the Interfaces between Building Systems"

Buildings Design & Energy Analysis

HVAC

Natural Ventilation, Indoor Environment

Windows & Lighting

Networks, Communications

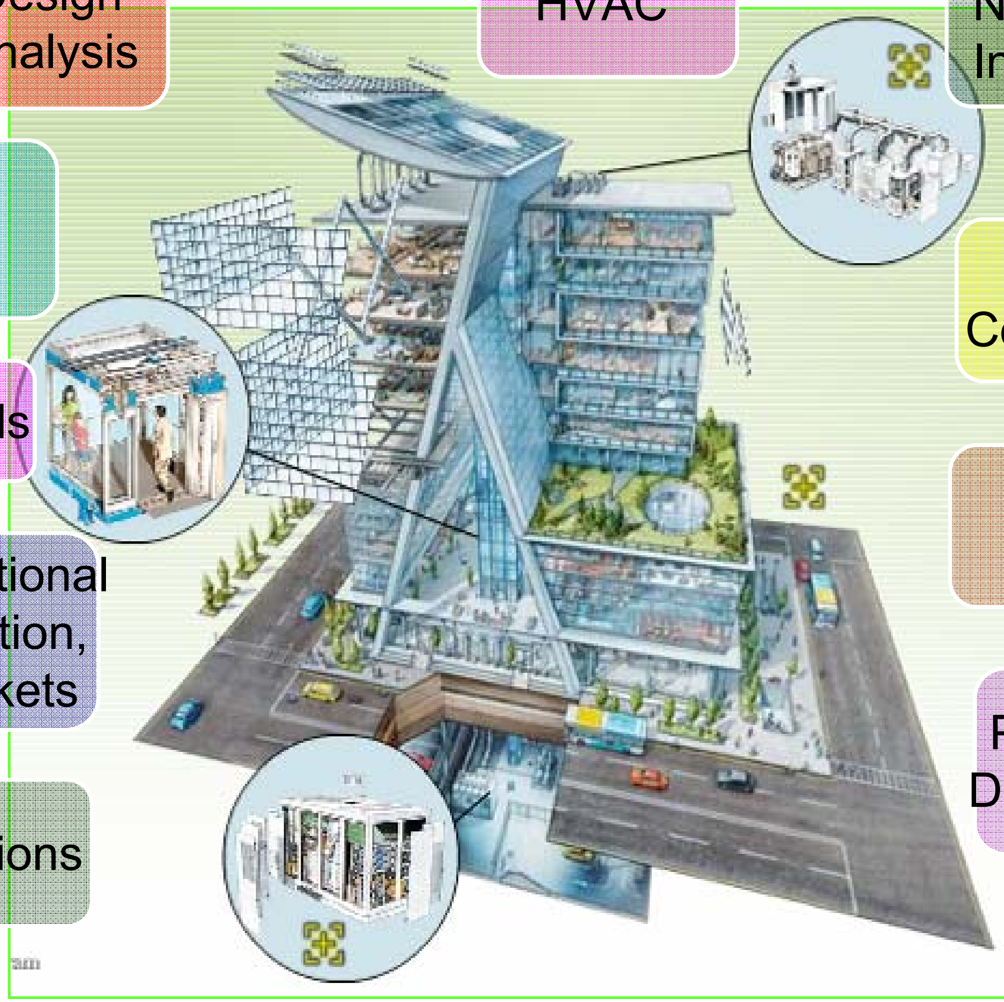
Building Materials

Sensors, Controls

Domestic/International Policies, Regulation, Standards, Markets

Power Delivery & Demand Response

Demonstrations



Integration & Building Operating Platform

Potential supply-side solutions to the Energy Problem by 2050

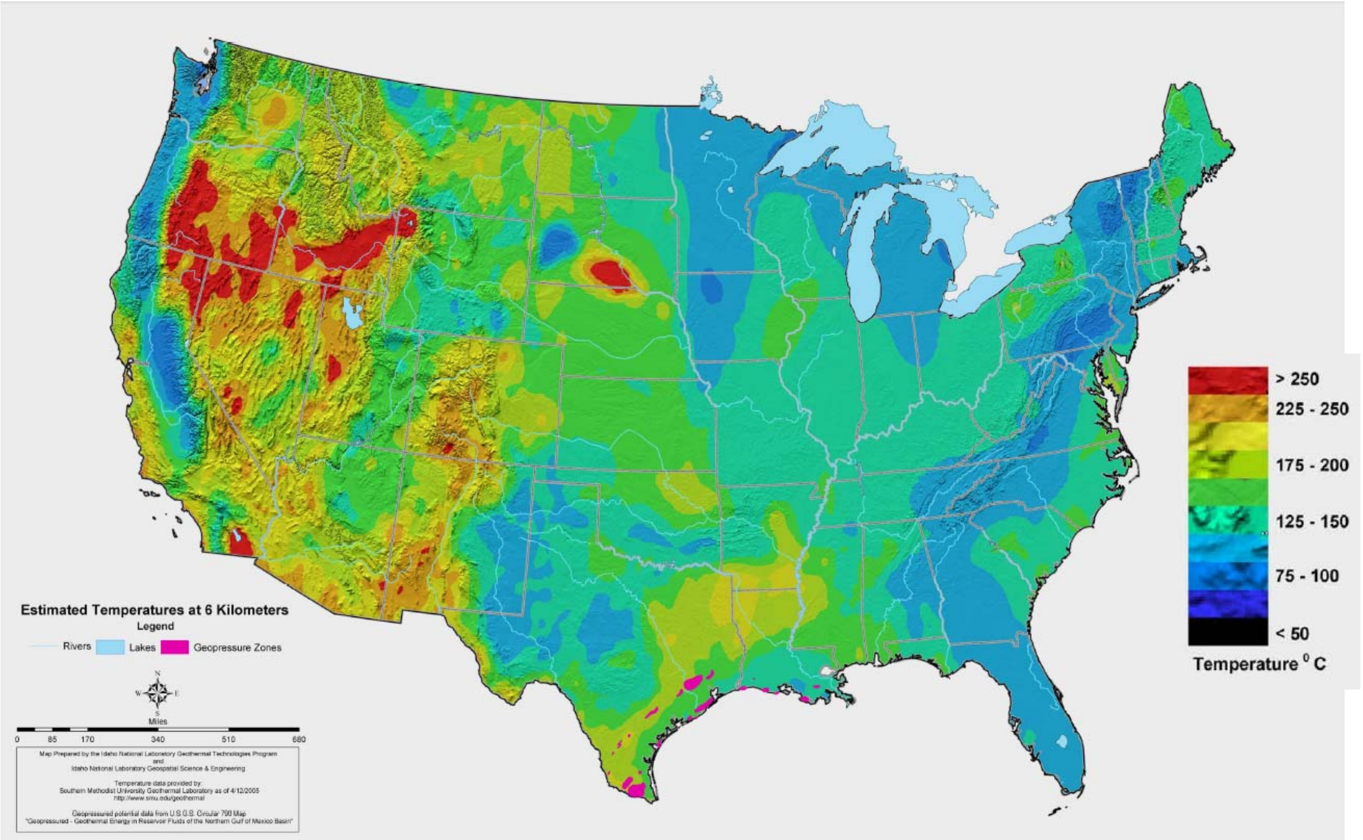
- Oil, Unconventional Oil
- Coal
- Gas
- Fission
- Geothermal

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

U.S. Geothermal Resources are Huge

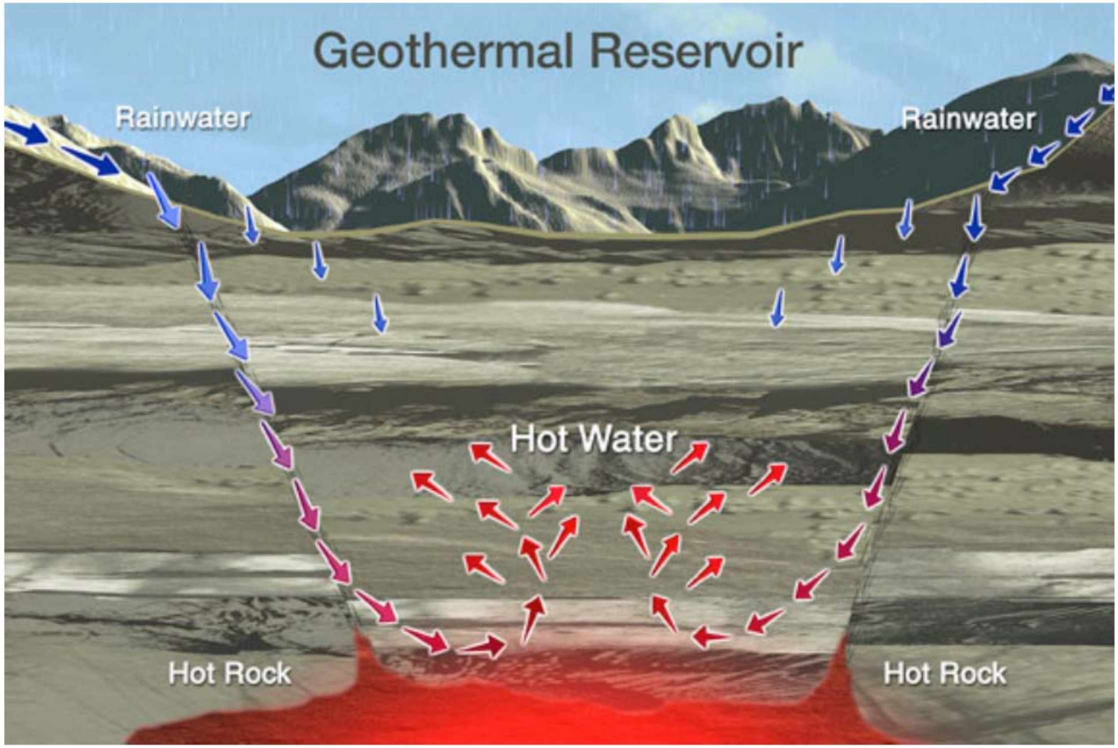


Heat at 6 km depth:

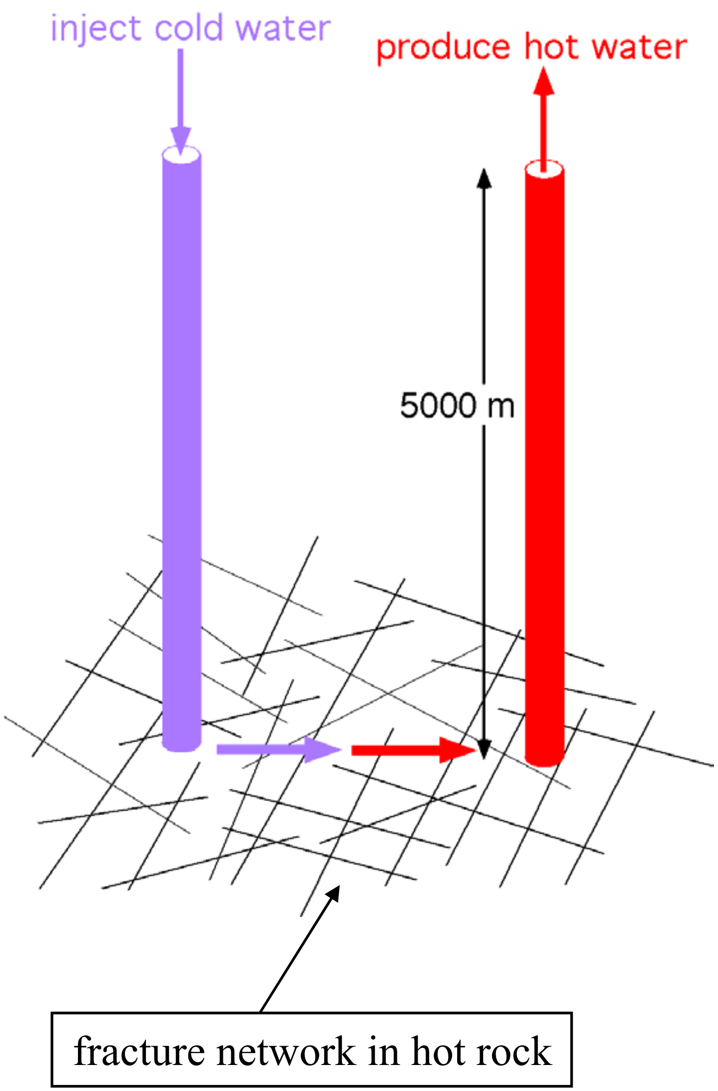
- **T > 200 ˚C: 296,000 EJ*; T > 125 ˚C: 2,410,000 EJ**
- **Total US energy consumption: ≈ 100 EJ**
- **Total U.S. geothermal energy use is ~0.3 %**

Why is Geothermal Energy Contribution so Small?

- Geothermal energy extraction is currently limited to natural hydrothermal systems.
- There is a vast store of geothermal heat that is difficult to recover (hot rocks lacking fluid and permeability).



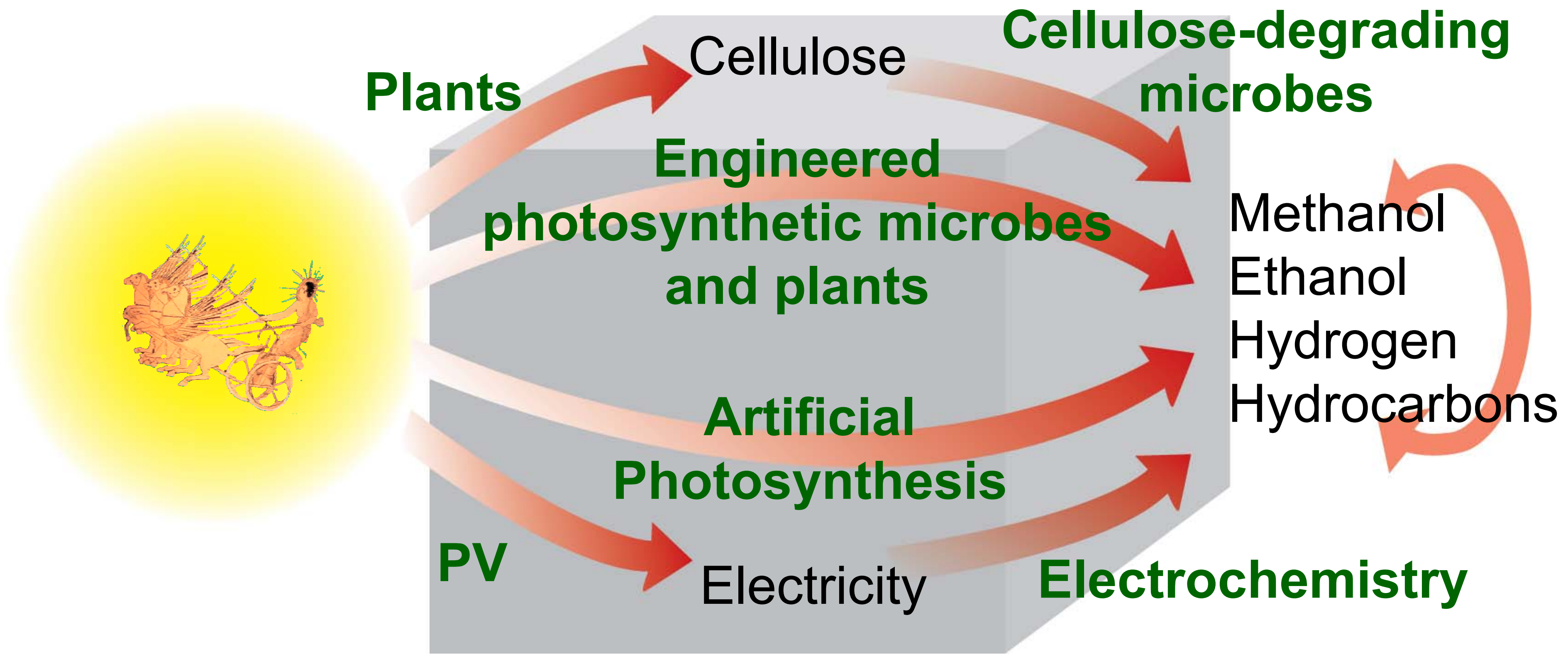
Enhanced Geothermal Systems (EGS)



EGS is currently not economically viable. The chief obstacles are:

- dissolution and precipitation of rock minerals, that may cause anything from short-circuiting flows to formation plugging
- large power requirements for keeping water circulating
- water losses from the circulation system
- inadequate reservoir size - heat transfer limitations
- high cost of deep boreholes (≈ 5 km)

Helios: Lawrence Berkeley Laboratory and UC Berkeley

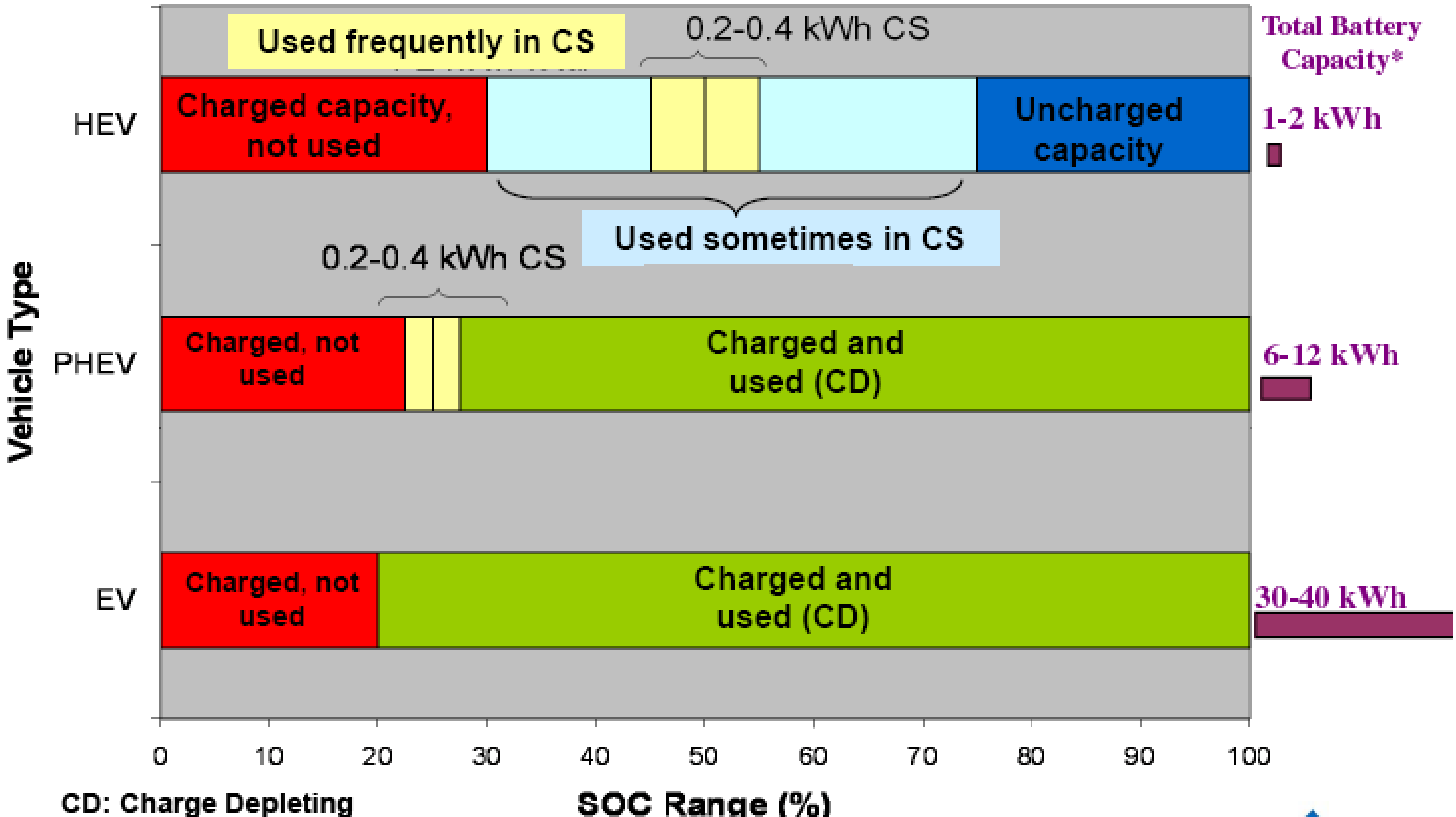


Energy Storage

- 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



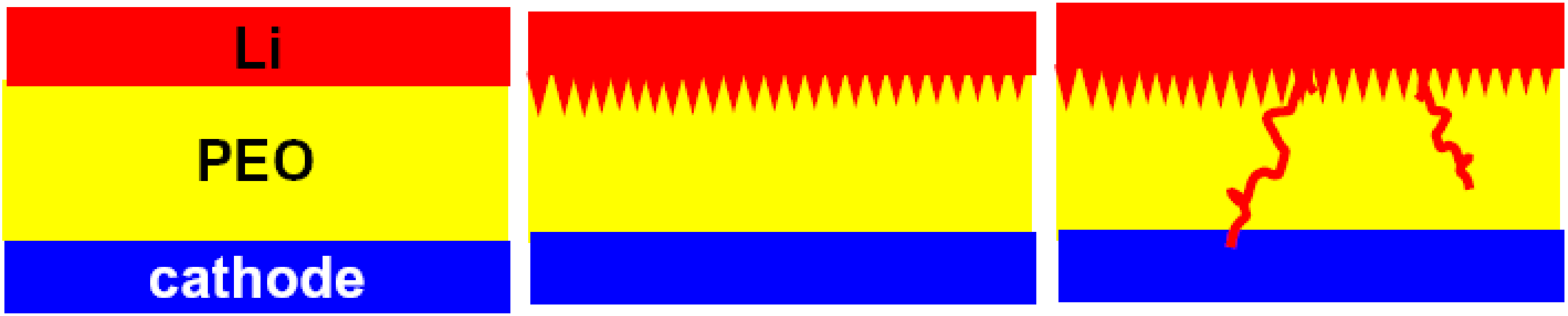
CD: Charge Depleting

CS: Charge Sustaining

*Battery capacity for a midsize car

Fatal Flaw in Polyethylene Oxide

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

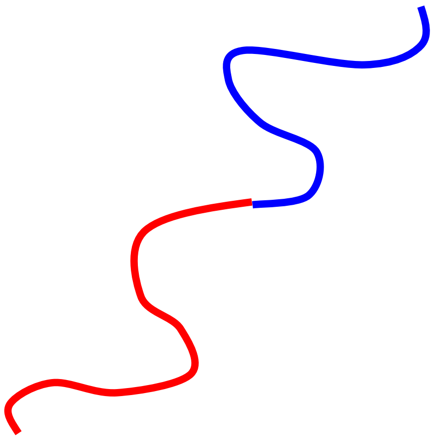


t=0

intermediate times
high surface area Li

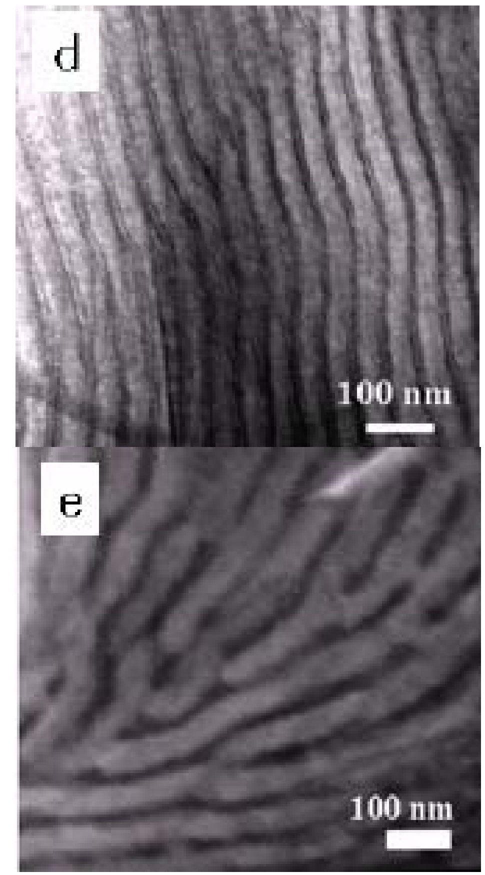
dendrite short

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



PEO
(dark bands)

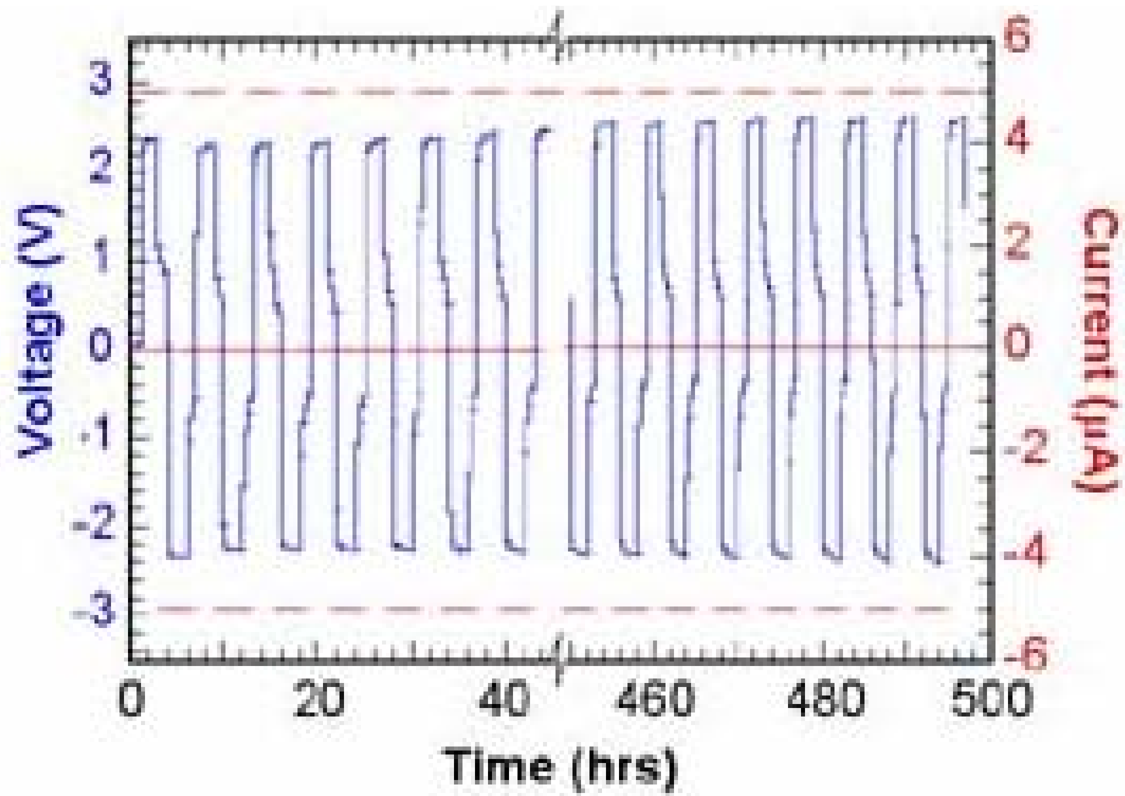
Polystyrene
(light bands)



* 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.

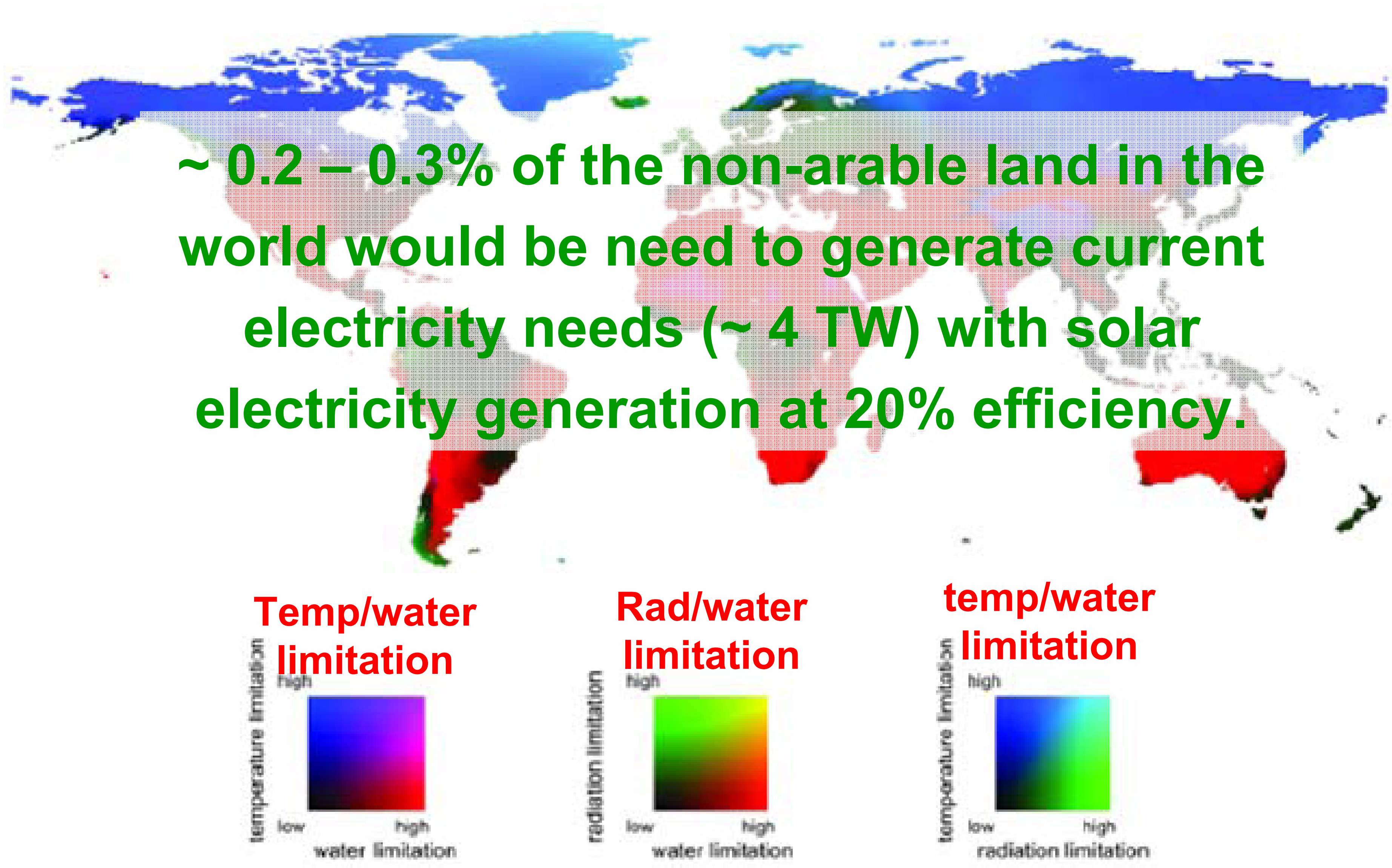
- Assume 50% market penetration and 30 kWh storage per electric vehicle.

- $(50 \times 10^6$ cars$)(30$kWh$) = 1.5 \times 10^9$ 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).

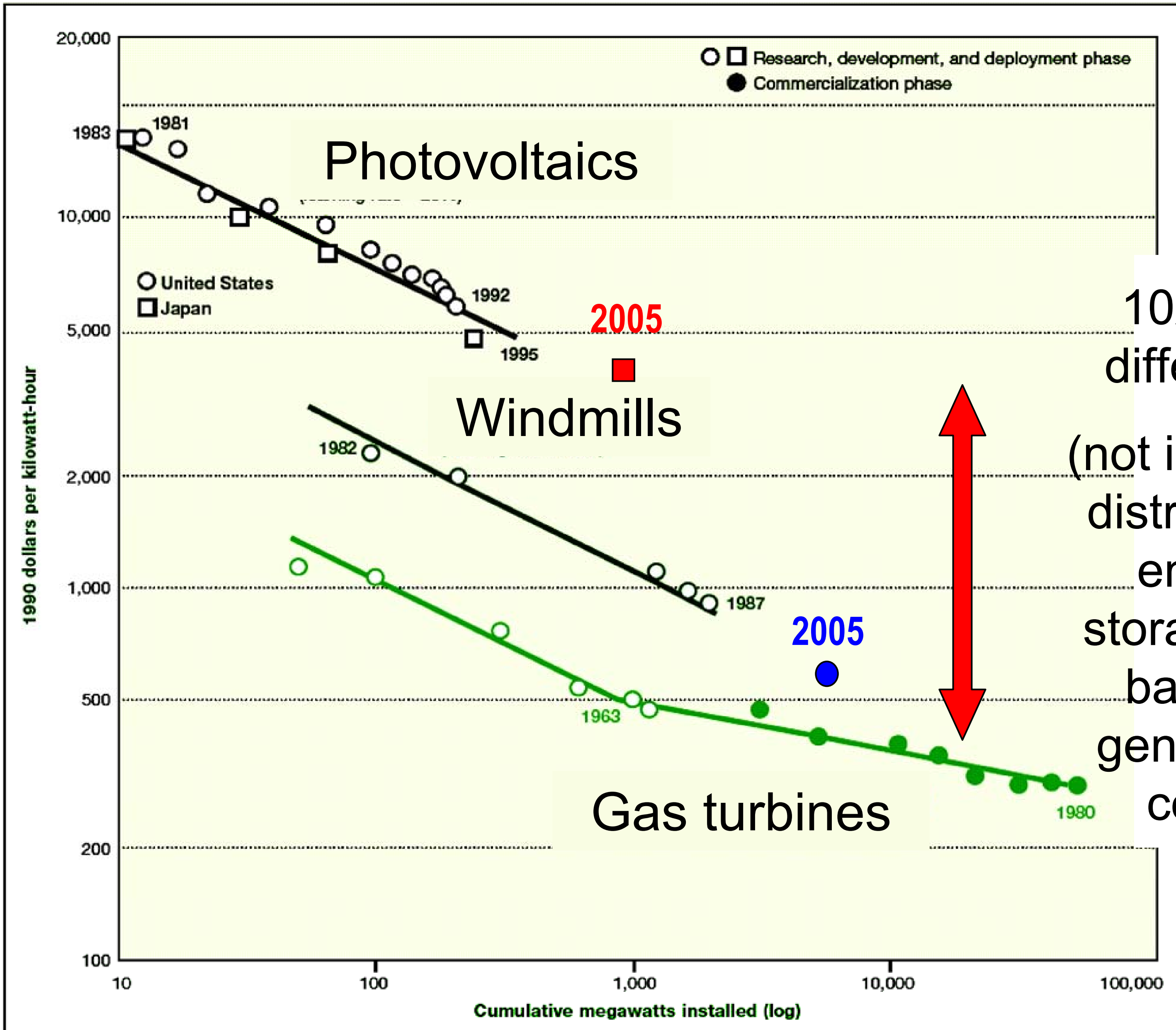
Limiting factors for plant productivity

~ 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.



Baldocchi et al. 2004 SCOPE 62

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

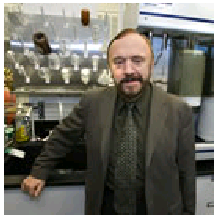


10x cost difference

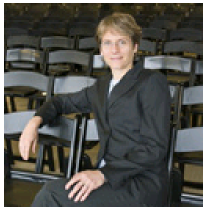
(not including distribution, energy storage and back-up generation costs)

The Molecular Foundry

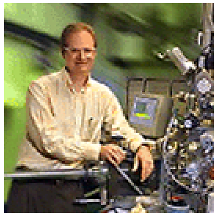
MOLECULAR FOUNDRY FACILITY DIRECTORS



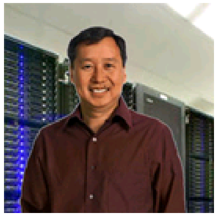
Organic and Macromolecular Synthesis Facility
Jean M.J. Fréchet



Biological Nanostructures Facility
Carolyn R. Bertozzi

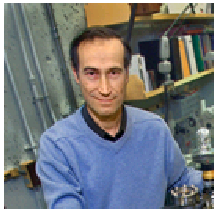


Inorganic Nanostructures Facility
A. Paul Alivisatos



Theory of Nanostructured Materials
Steven G. Louie

Nanofabrication Facility
Jeffrey Bokor



Imaging and Manipulation of Nanostructures Facility
Miquel Salmeron
Research Interests

Reel-to-reel mass production of solar cells using nano-technology?

Energy Biosciences Institute

$50M/ year for 10 years

Univ. California, Berkeley

Lawrence Berkeley National Lab

Univ. Illinois, Urbana-Champaign

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

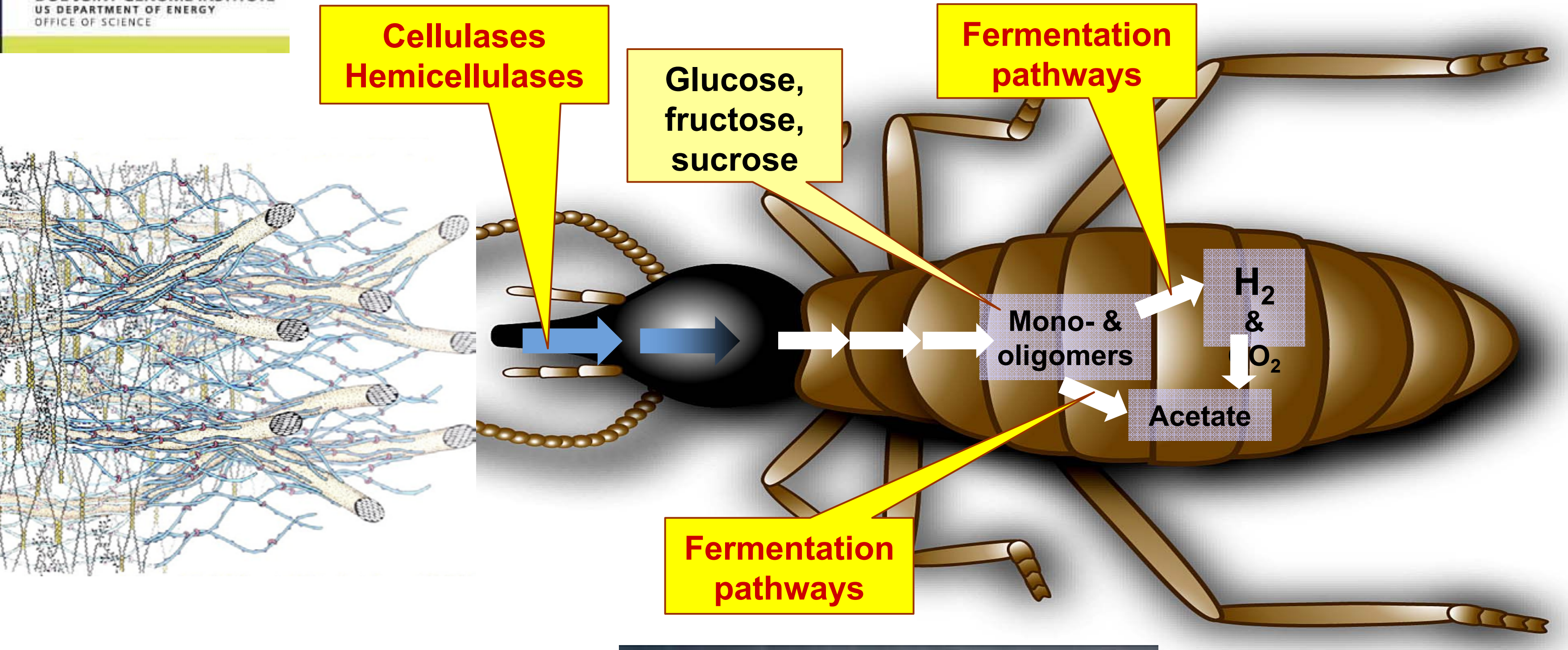
Feedstock grasses (*Miscanthus)* is a largely unimproved crop.

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

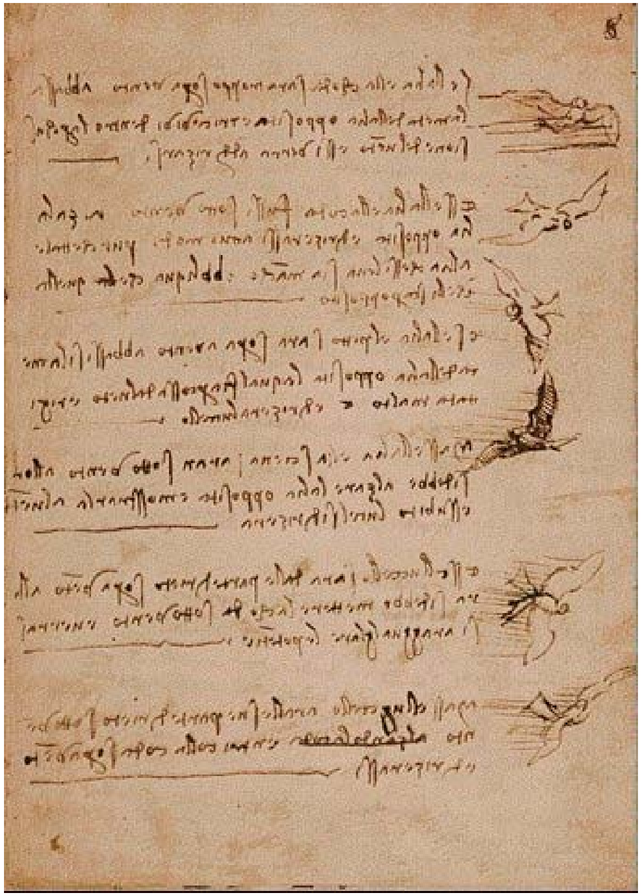
15x more ethanol / acre than corn.

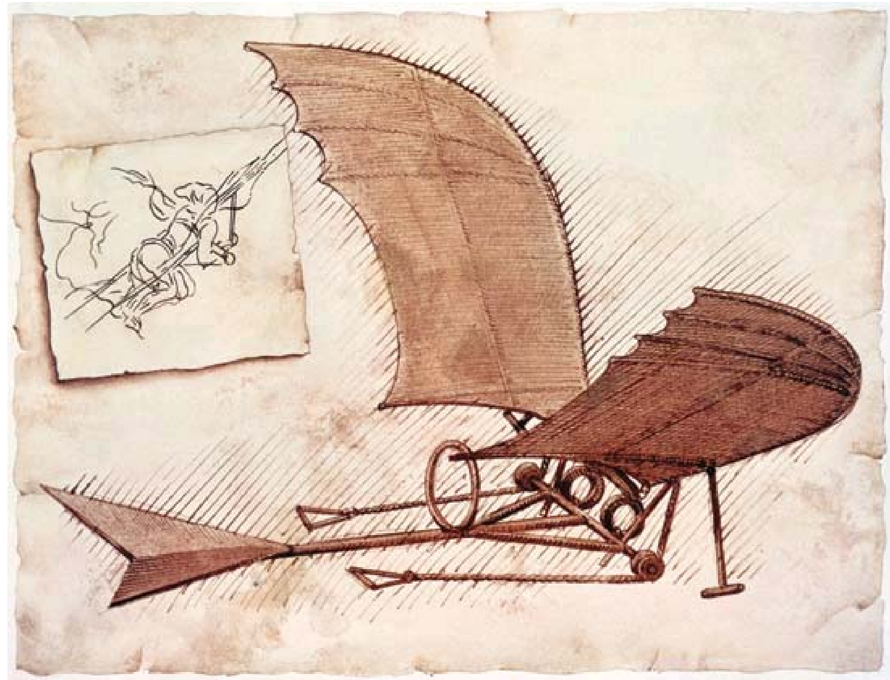
50 M acres of energy crops plus agricultural wastes (wheat straw, corn stover, wood residues, urban waste, animal manure, etc.) can produce ***half*** to ***all*** of current US consumption of gasoline.

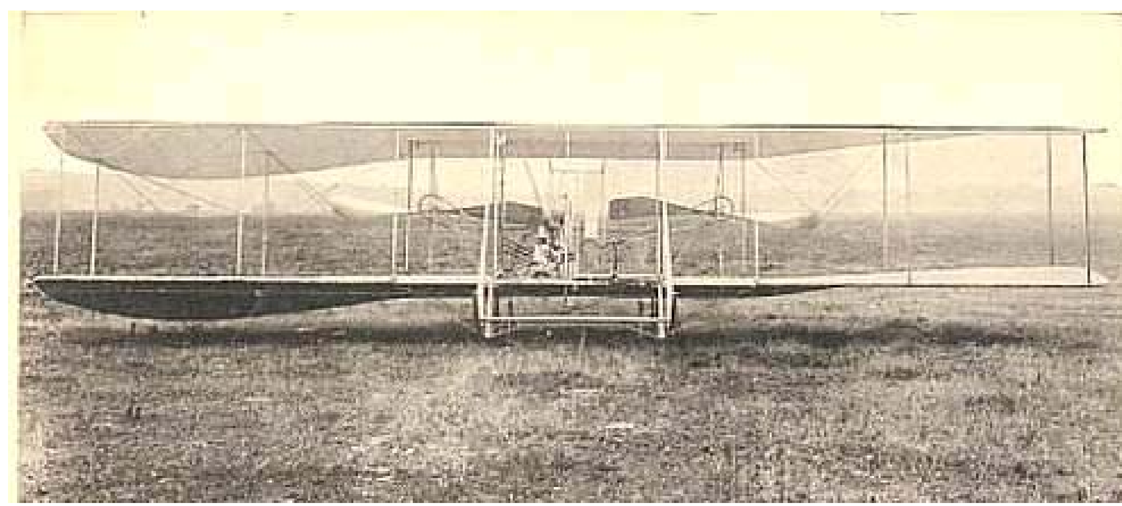
Termites have many specialized enzymes for efficiently digesting lignocellulosic material



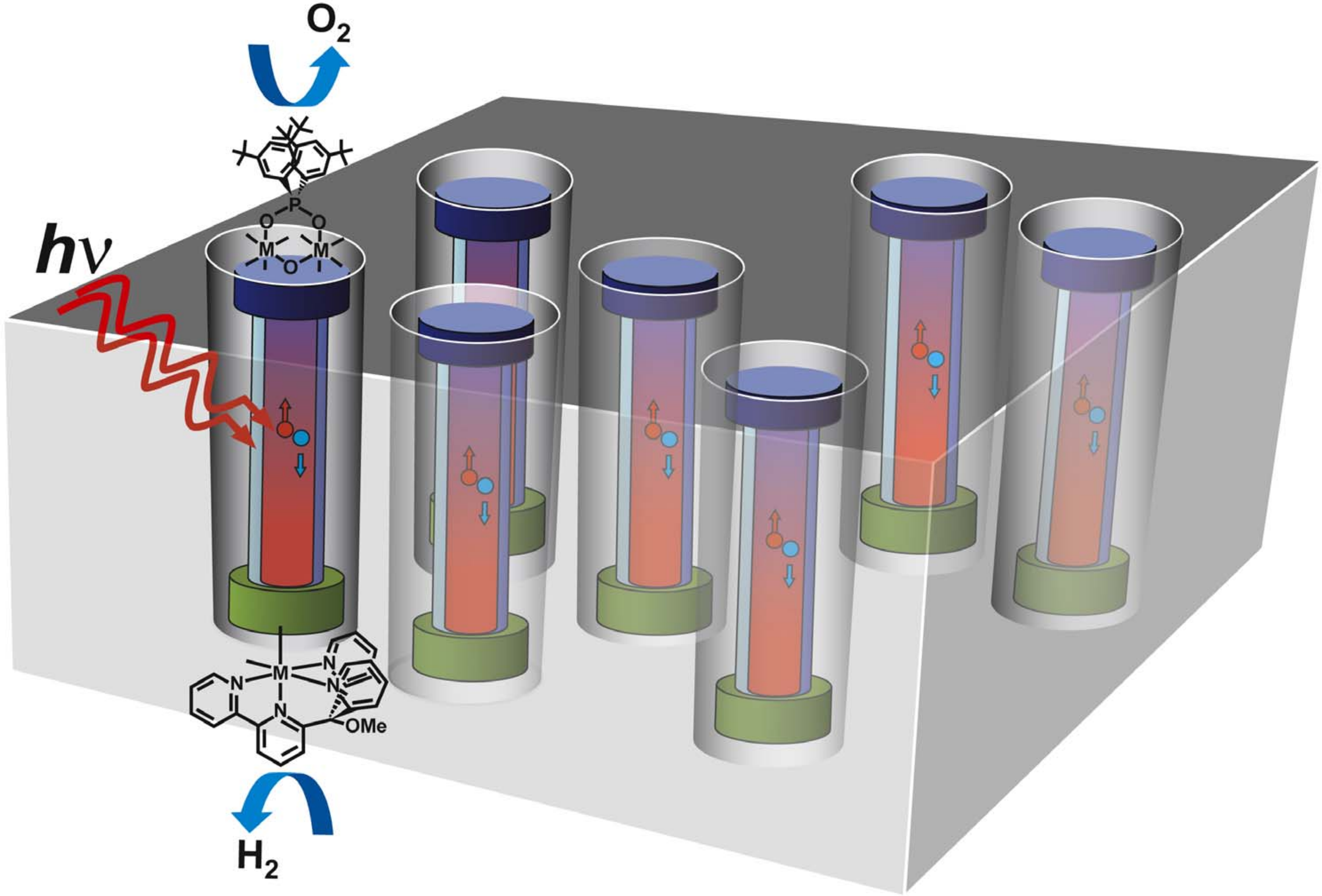
Man first learned to fly by imitating nature



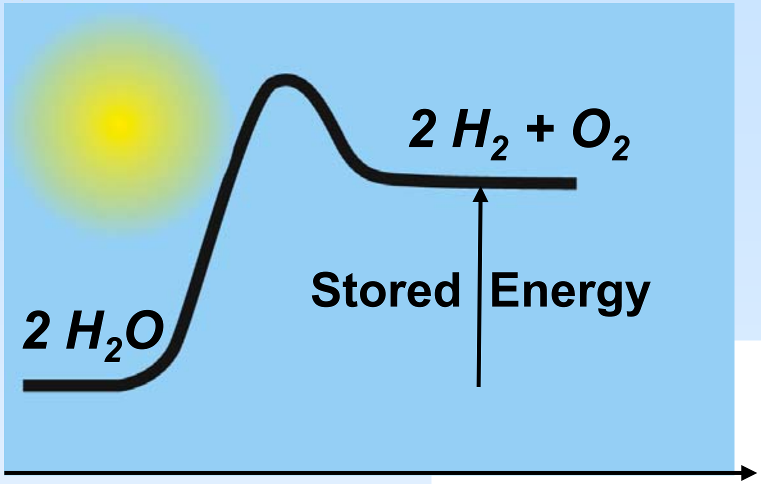




Can we make an artificial photosynthesis system?

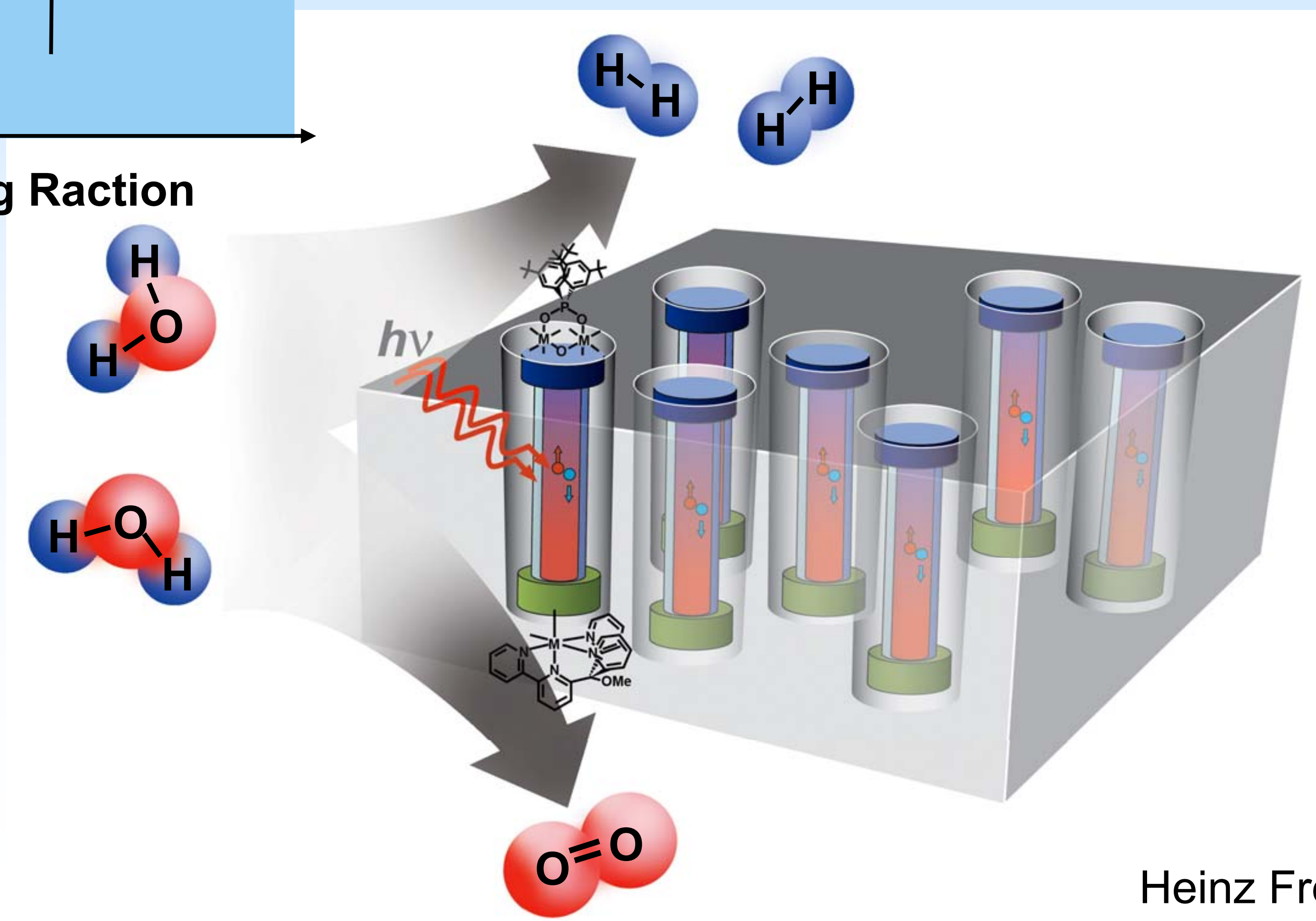


Water Splitting by Sunlight



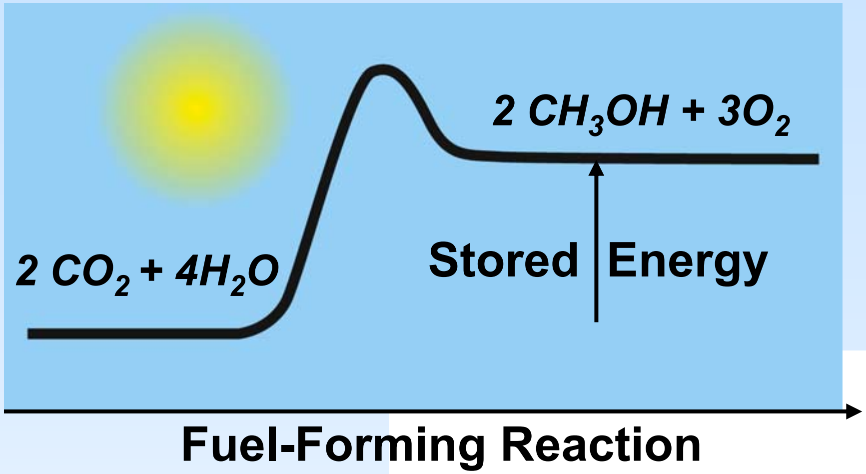
Water Splitting Raction

$$2\,H_2O \longrightarrow 2\,H_2 + O_2$$

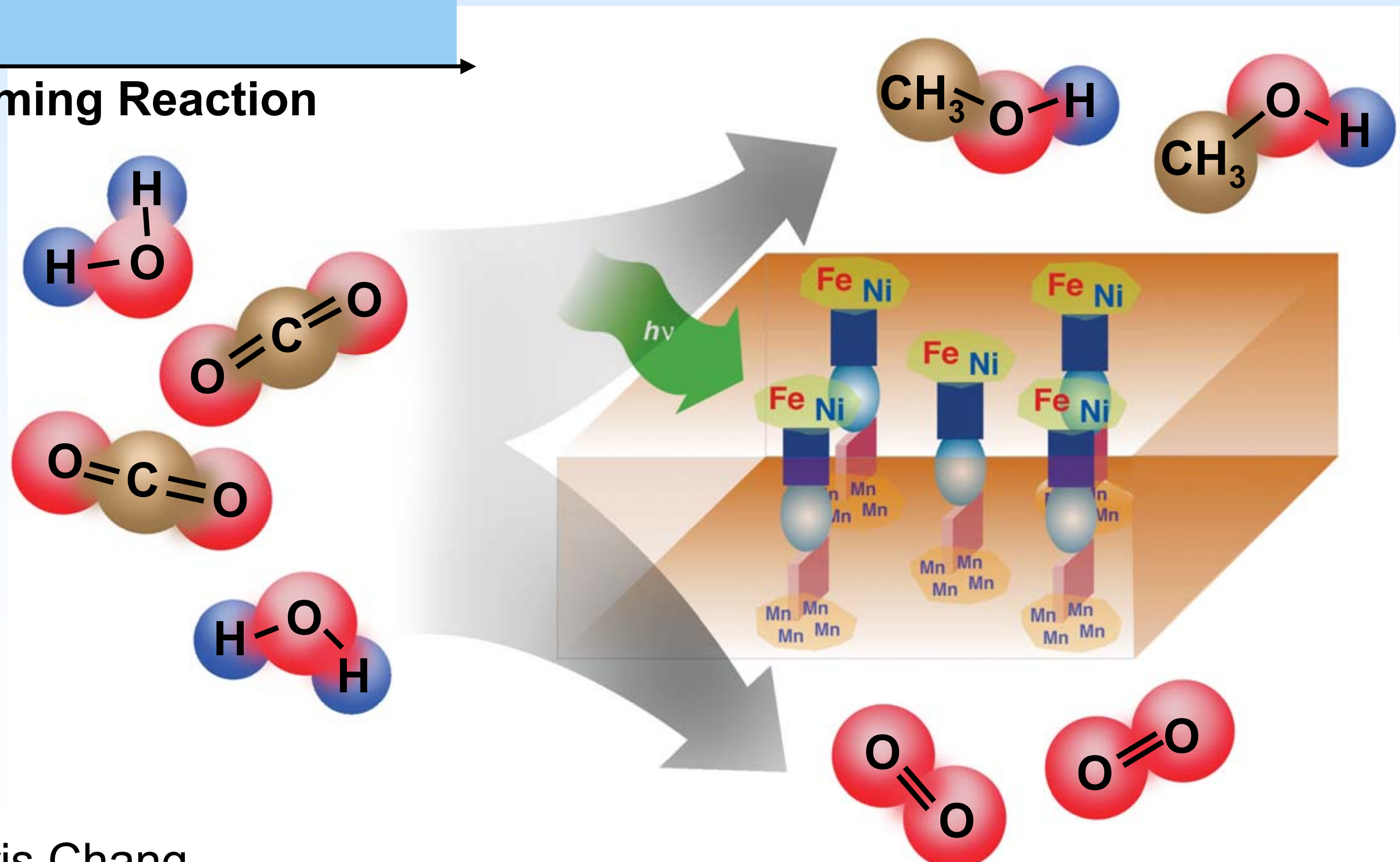


Heinz Frei

Carbon Dioxide to Liquid Fuel by Sunlight



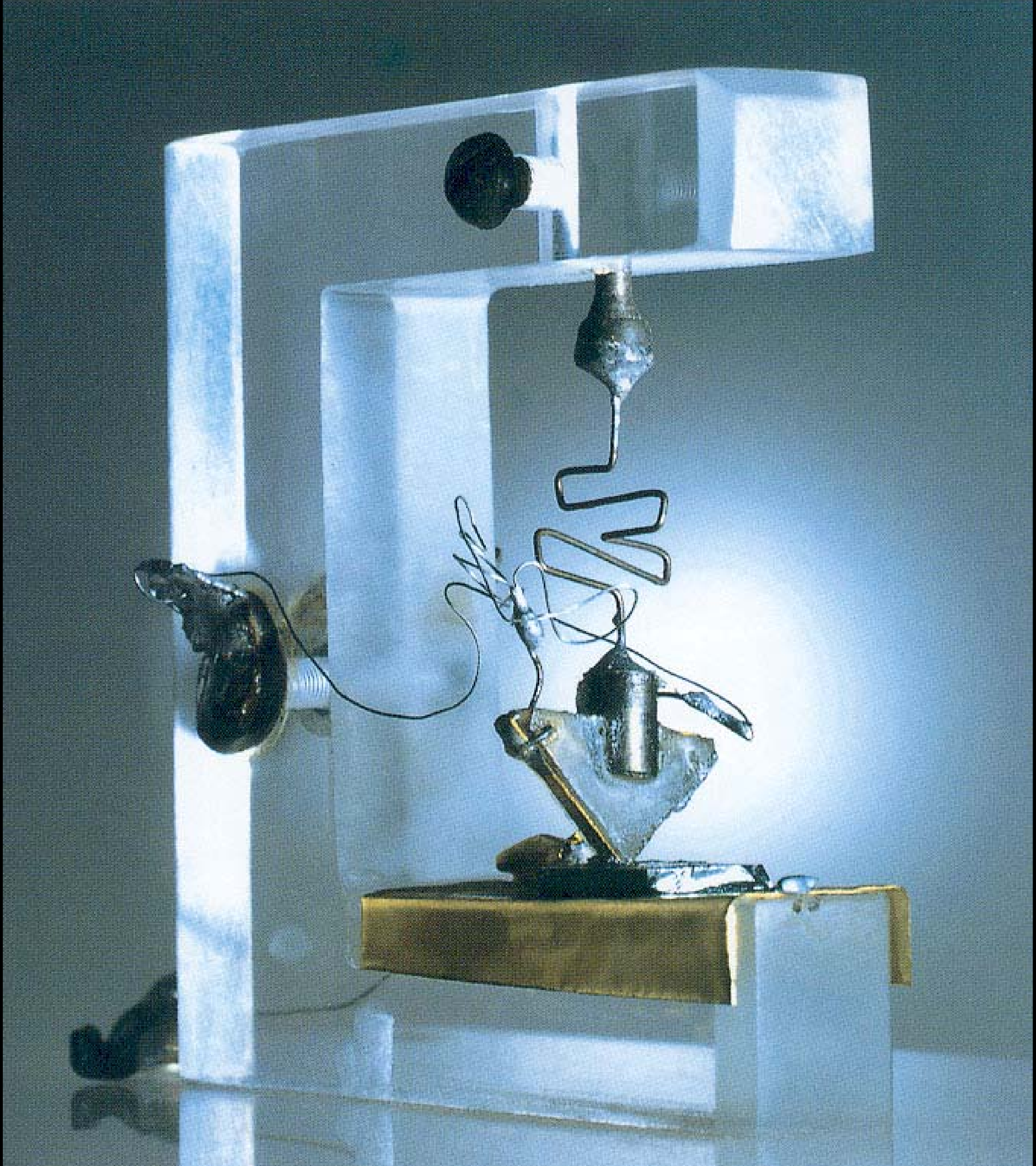
$$2\ CO_2 + 4\ H_2O \longrightarrow 2\ CH_3OH + 3\ O_2$$

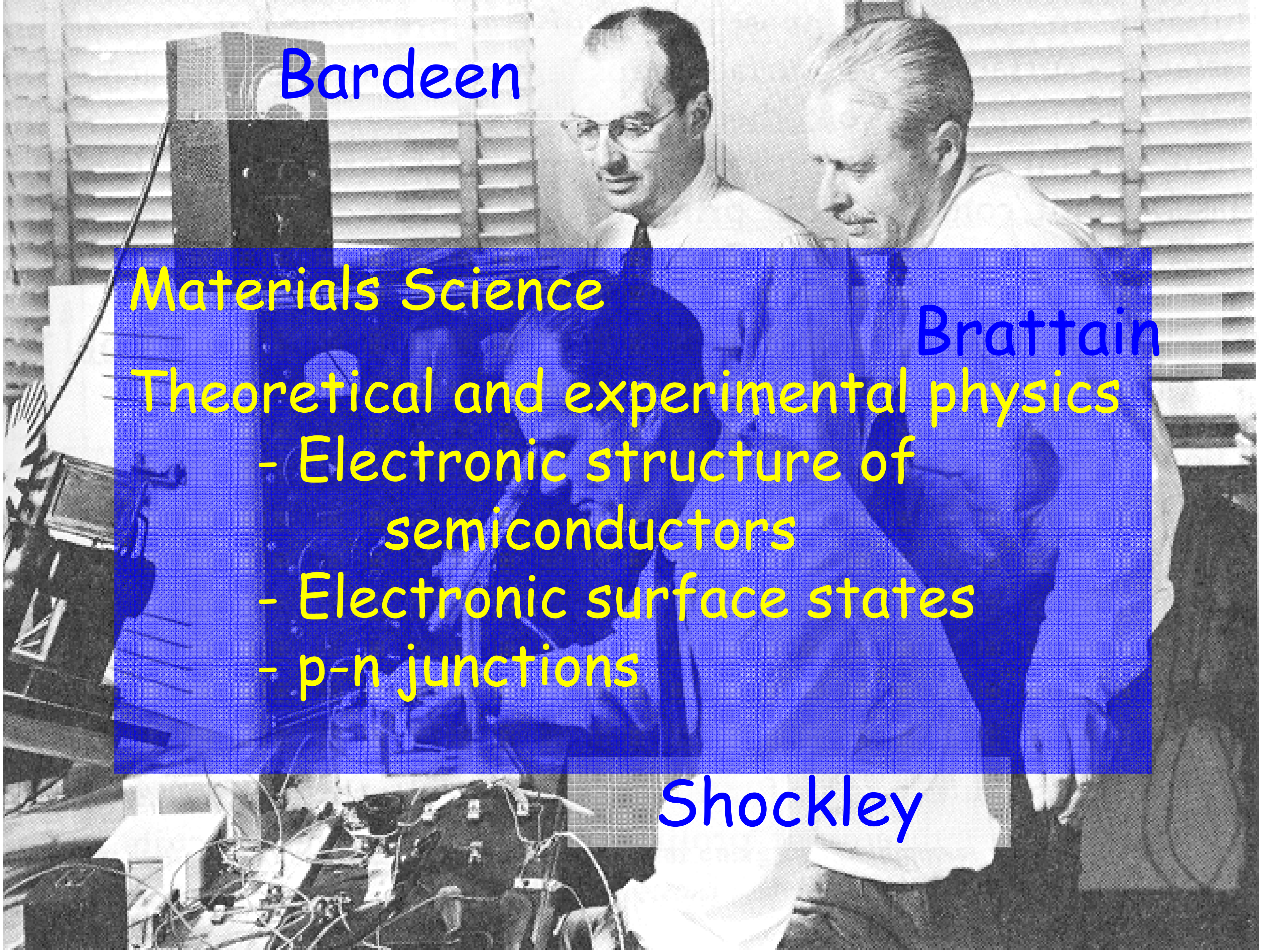


Chris Chang

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

Ernest Lawrence, Robert Serber, Luis Alverez, Edwin McMillan, Robert Oppenheimer, Robert Wilson (Glenn Seaborg not present)




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.

"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

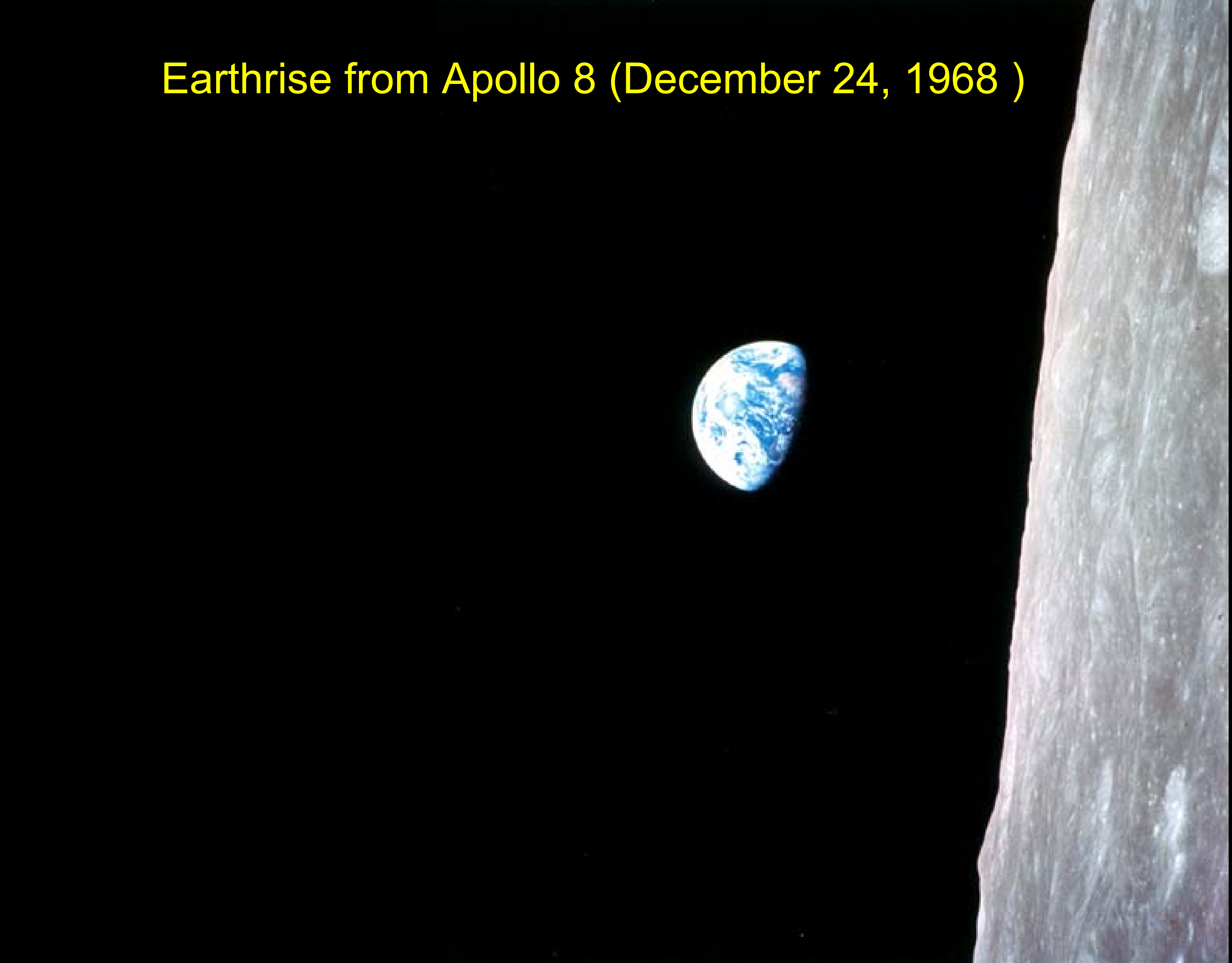
About the IAC |

"Lighting the Way: Toward a Sustainable Energy Future"

Released October 22, 2007

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

Earthrise from Apollo 8 (December 24, 1968)

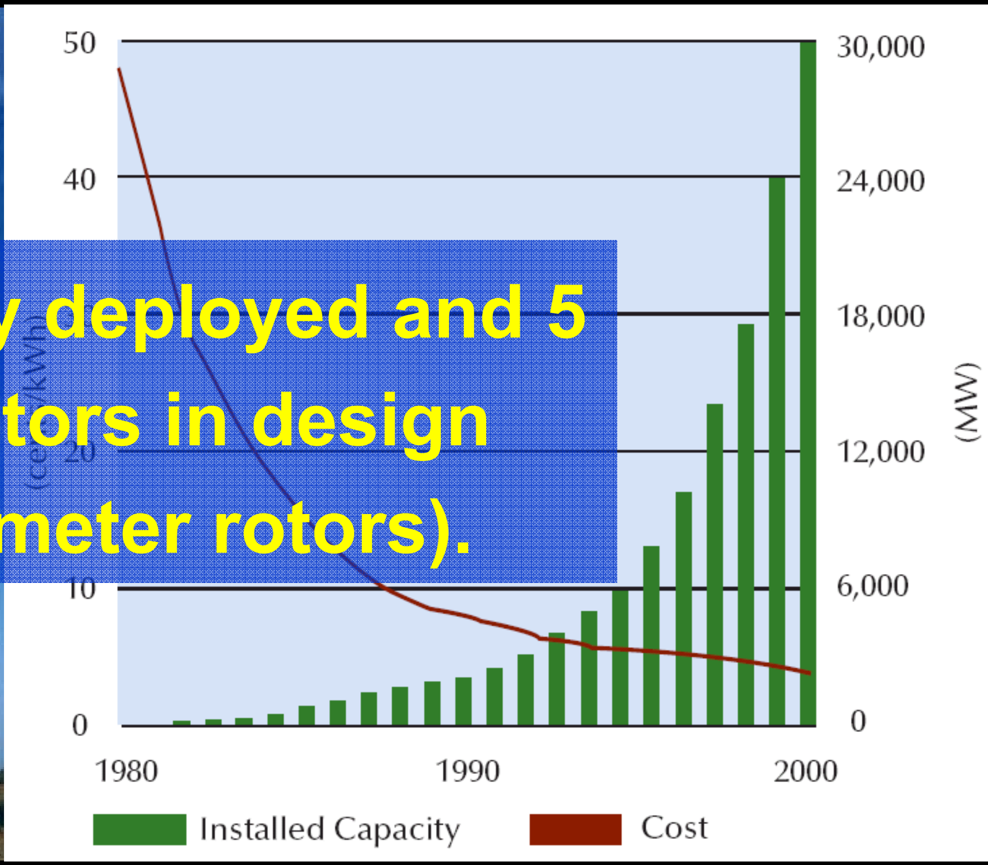


How about using CO_2 as Heat Transmission Fluid?

property	CO_2	water
chemistry	**poor solvent for rock minerals**	powerful solvent for rock minerals: lots of potential for dissolution and precipitation
fluid circulation in wellbores	**highly compressible and larger expansivity** **==> more buoyancy, lower parasitic power consumption**	low compressibility, modest expansivity ==> less buoyancy
ease of flow in reservoir	**lower viscosity**, lower density	higher viscosity, **higher density**
heat transmission	smaller specific heat	**larger specific heat**
fluid losses	**earn credits for storing greenhouse gases**	costly

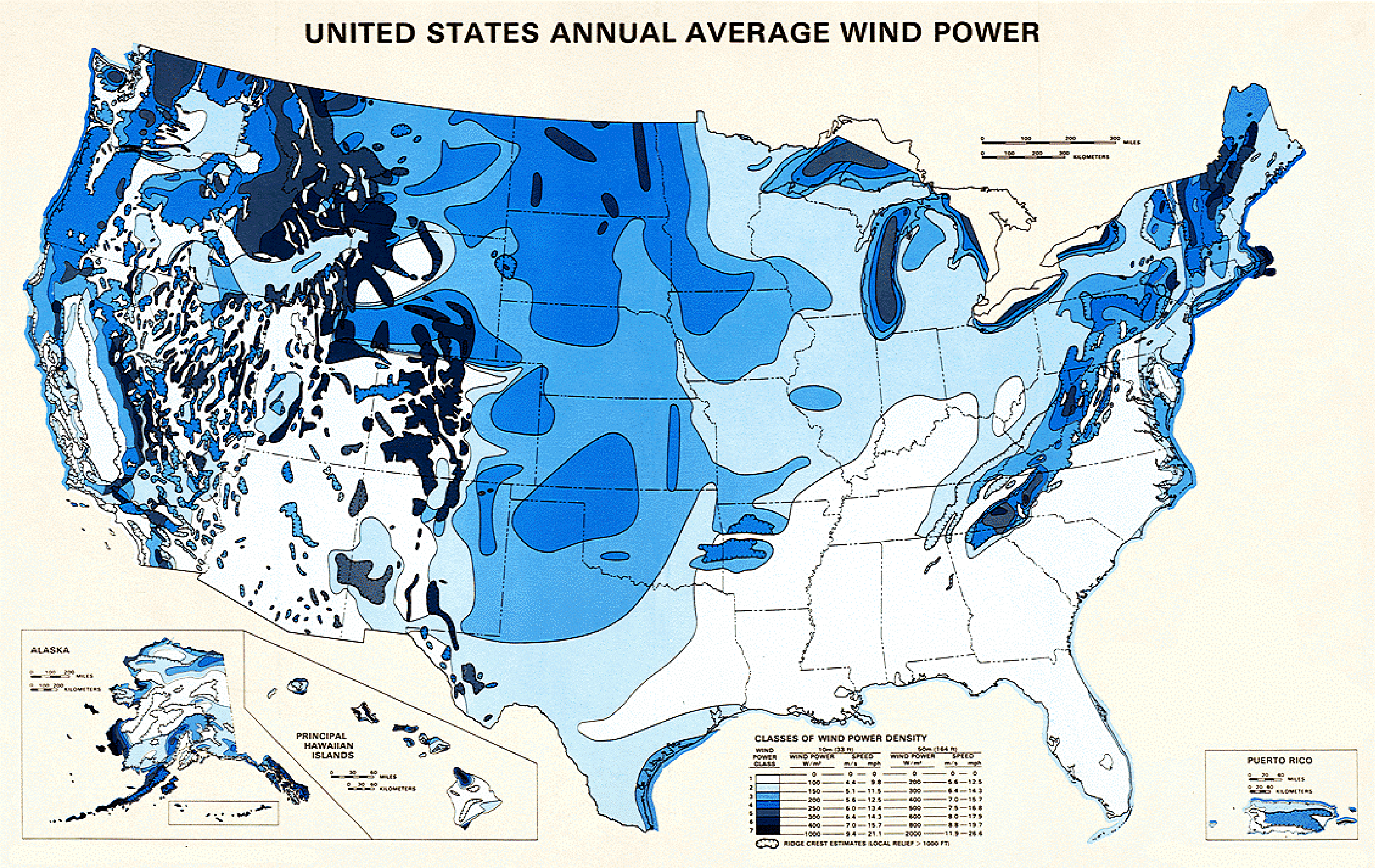
Favorable properties are shown **bold-faced**.

Modest but **stable** fiscal incentives were essential to stimulate long term development of power generation from wind



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:

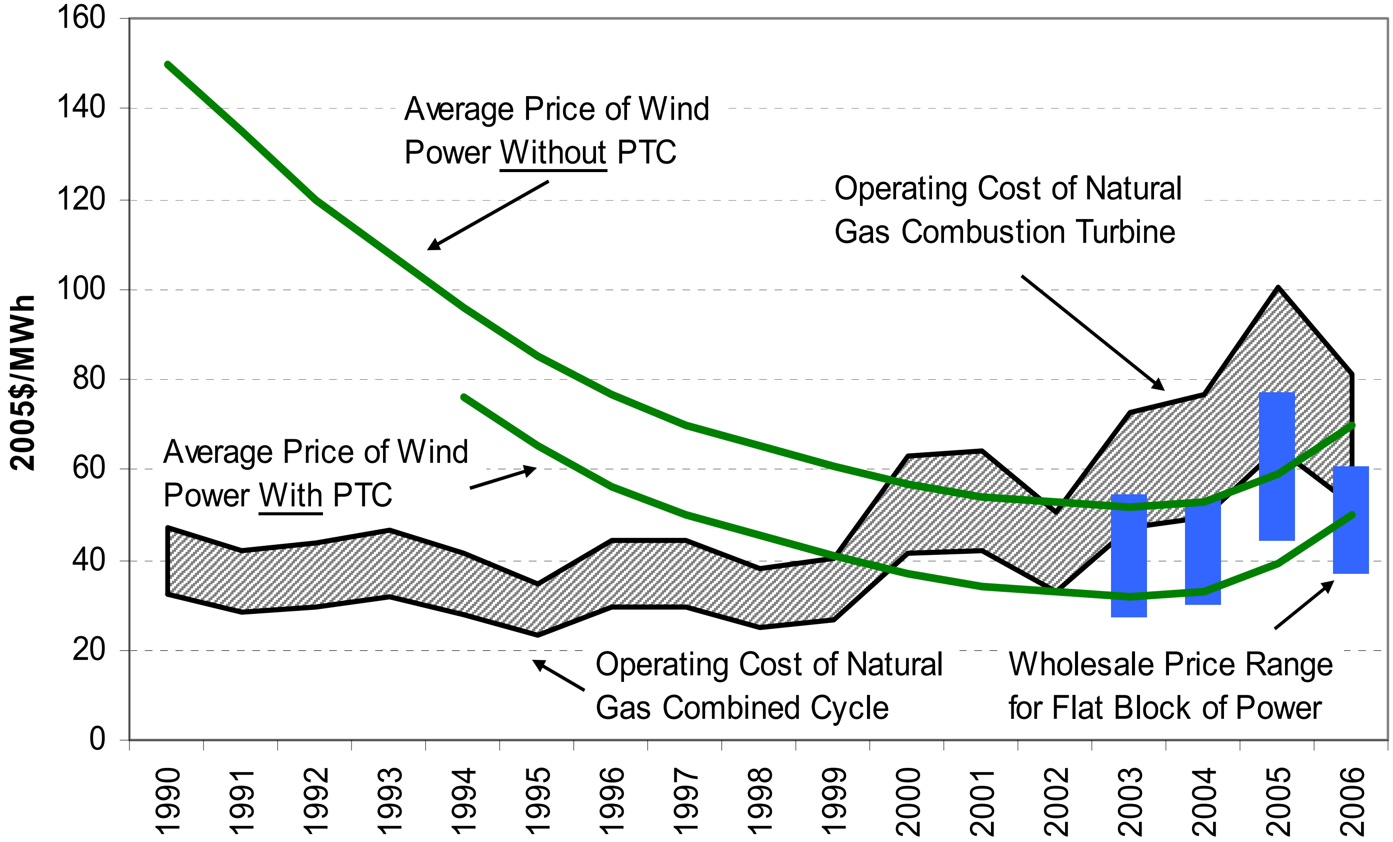
After 500km, HVDC is less expensive!

- 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.

Many Drivers, Including Improved Economics and Policy Support

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

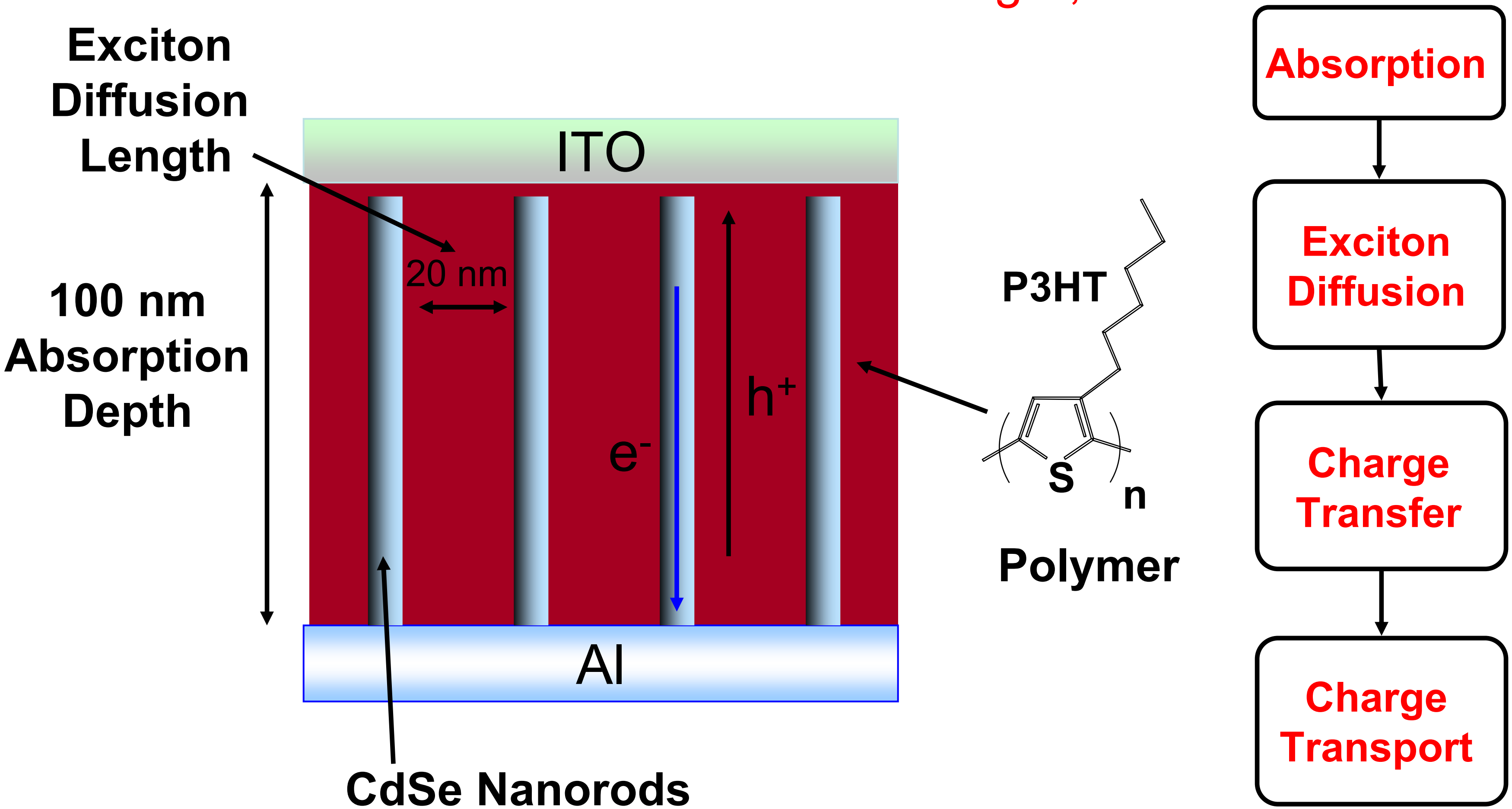
Whether wind is competitive in long-term absent policy support depends on cost of fossil fuels

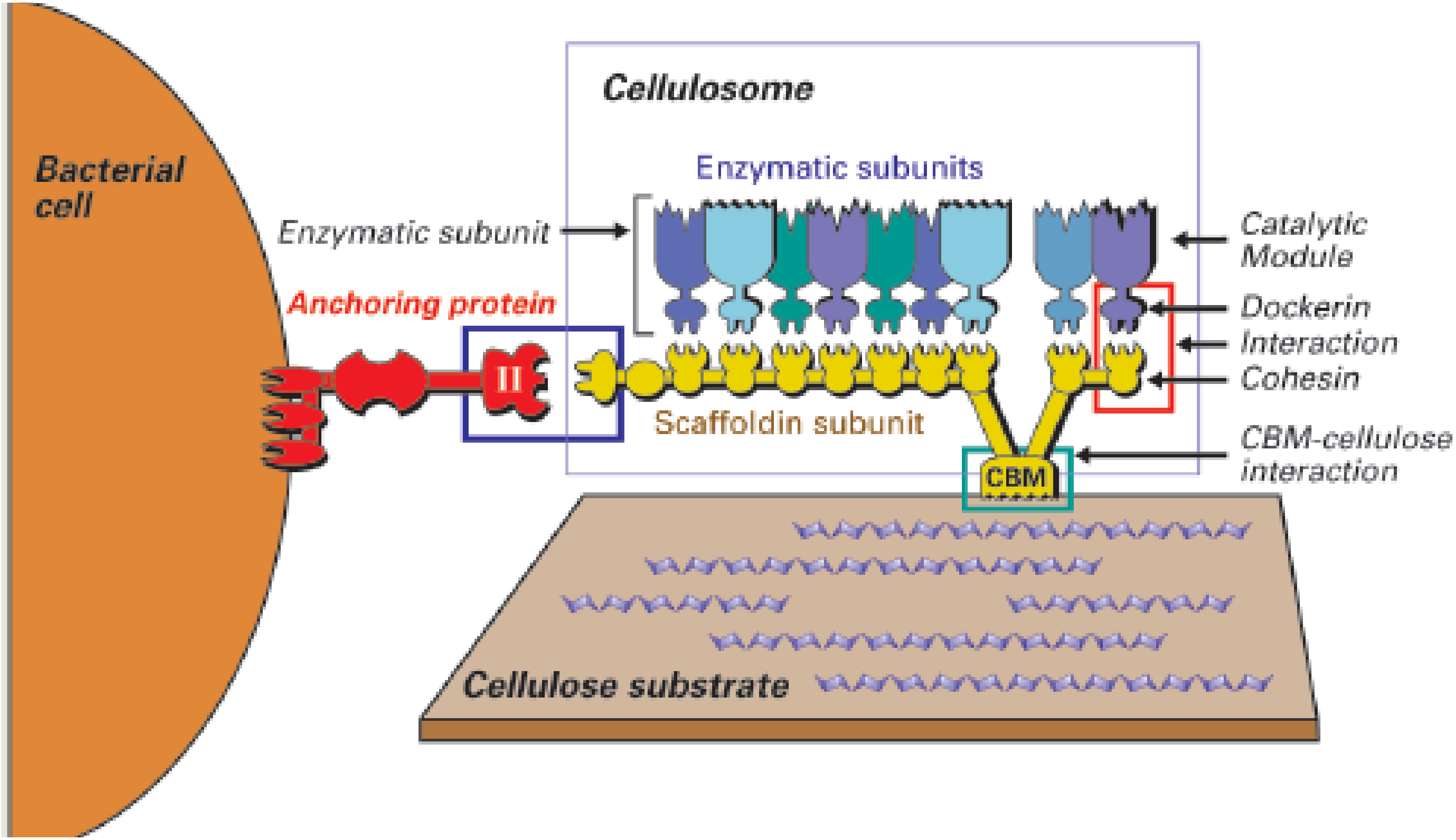


Distributed junction nano-solar cells *

(Separation of electrons and hole creation and transport.)

* A. Heeger, et. al.





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.