The next revolution in Energy Technology

Energy Summit 2006
Cisco Systems, San Jose
21 July, 2006

InterAcademy Council

About the IAC

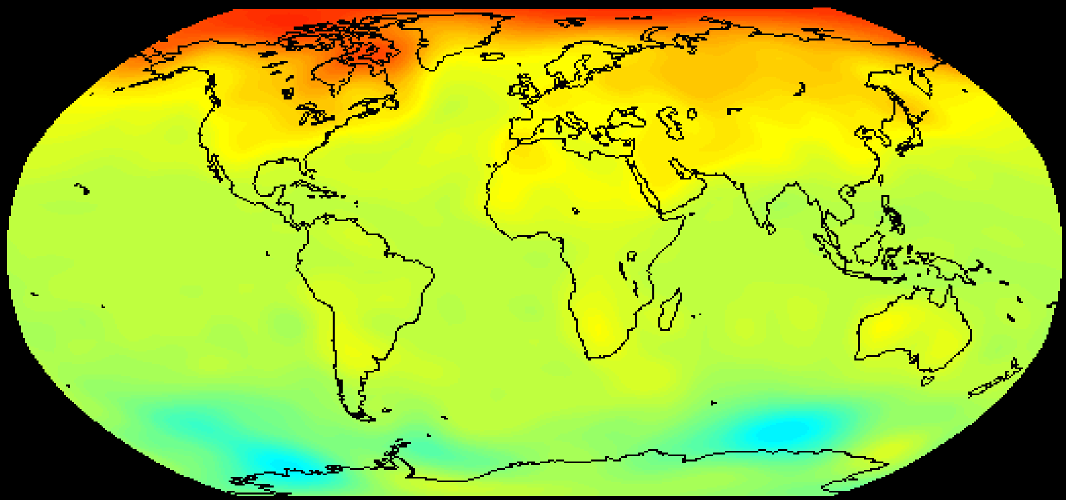
"Transitions to Sustainable Energy"

The world has a clear and major problem, with no global consensus on the way to proceed: how to achieve transitions to an adequately affordable, sustainable clean energy supply"

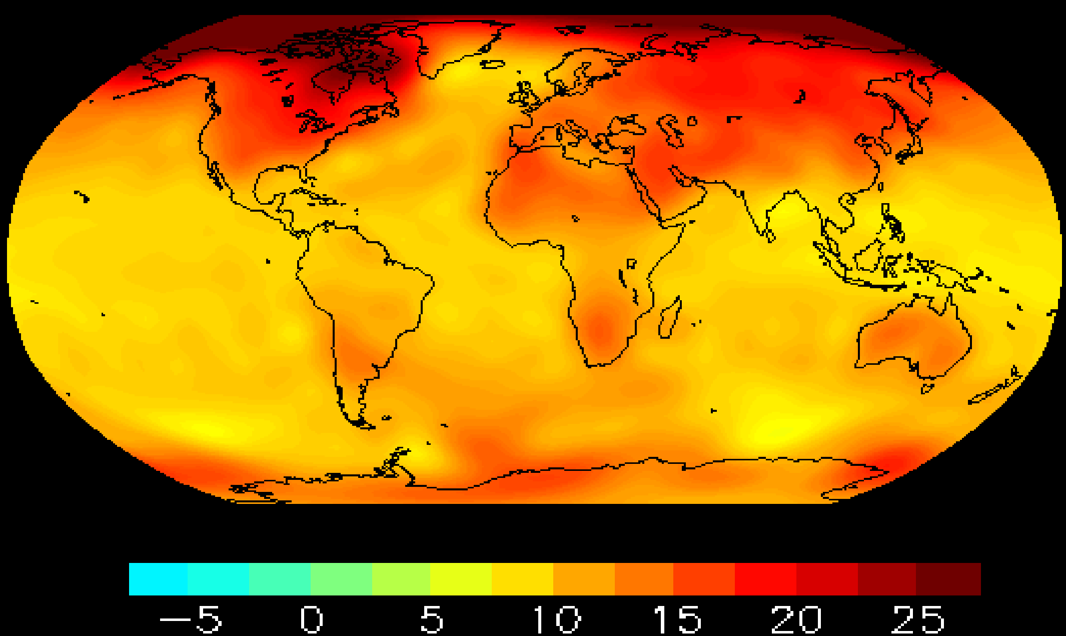
Co-chairs: Jose Goldemberg, Brazil, Secretary of State for the Environment of the State of São Paolo.

Steven Chu, USA

2 x CO_2



4 x CO_2



Computer simulations by the Princeton Geophysical Fluid Dynamics Lab for CO2 increases above pre-industrial revolution levels:

2x CO_2 : 3 – 5° C

4x CO_2 : 6 - 10° C

Pre-industrial:
~275 ppm

Today:
~380 ppm

nature Vol 436|4 August 2005|doi:10.1038/nature03906

LETTERS

Increasing destructiveness of tropical cyclones over the past 30 years

Kerry Emanuel[1]

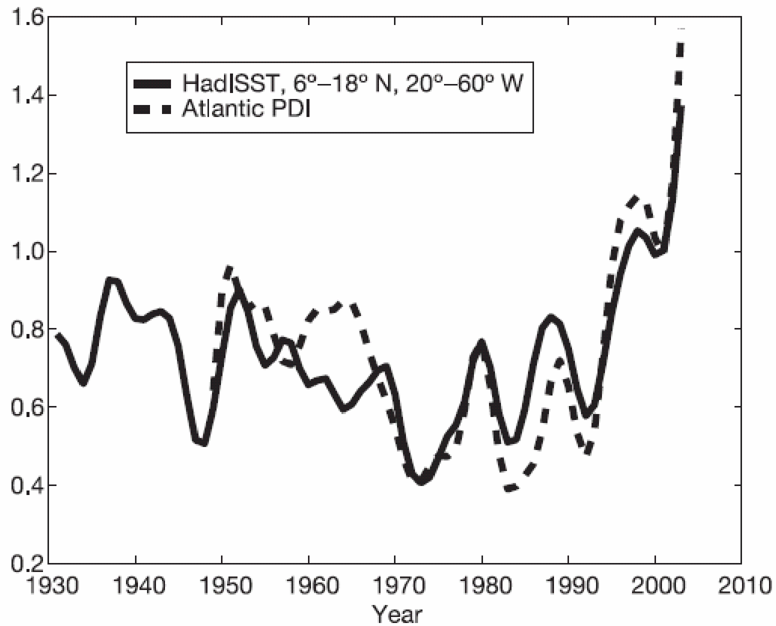


Figure 1 | A measure of the total power dissipated annually by tropical cyclones in the North Atlantic (the power dissipation index, PDI) compared to September sea surface temperature (SST). The PDI has been multiplied by 2.1×10^{-12} and the SST, obtained from the Hadley Centre Sea Ice and SST data set (HadISST)[22], is averaged over a box bounded in latitude by 6° N and 18° N, and in longitude by 20° W and 60° W. Both quantities have been smoothed twice using equation (3), and a constant offset has been added to the temperature data for ease of comparison. Note that total Atlantic hurricane power dissipation has more than doubled in the past 30 yr.

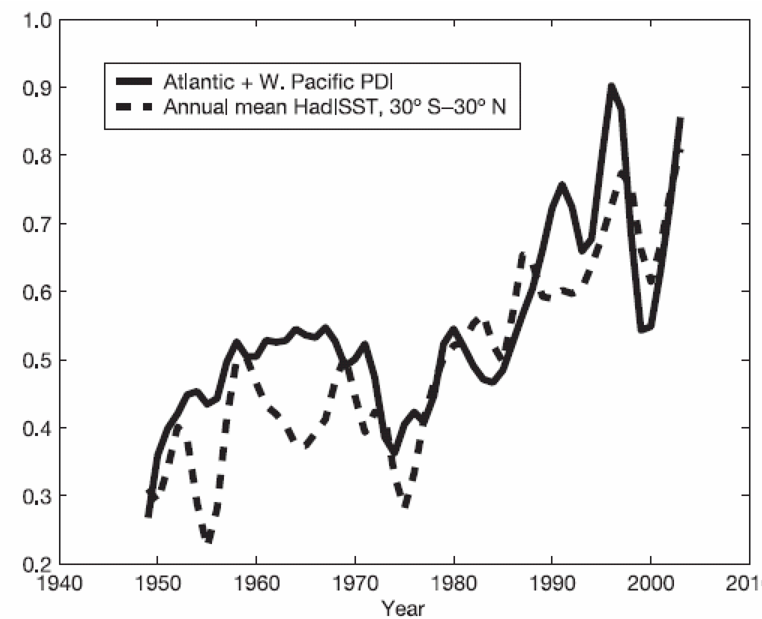
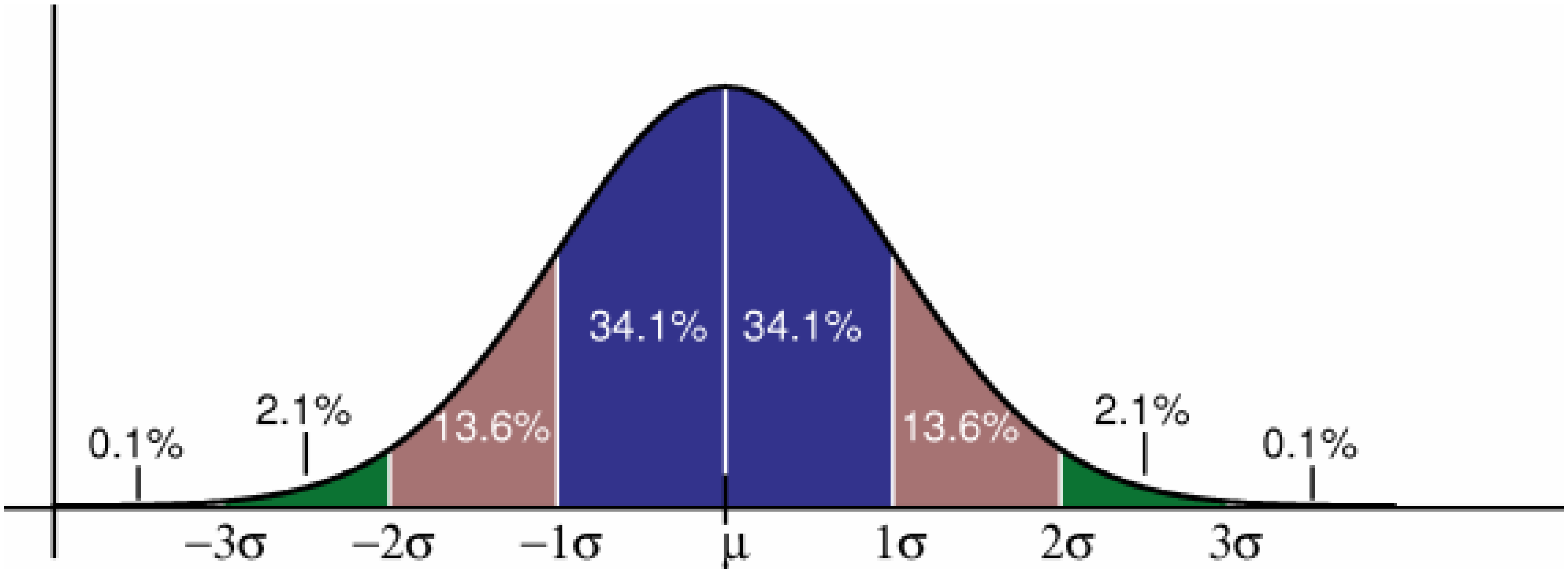


Figure 3 | Annually accumulated PDI for the western North Pacific and North Atlantic, compared to annually averaged SST. The PDI has been multiplied by a factor of 5.8×10^{-13} and the HadISST (with a constant offset) is averaged between 30° S and 30° N. Both quantities have been smoothed twice using equation (3). This combined PDI has nearly doubled over the past 30 yr.

For a Gaussian distribution:



1 σ = 68 % confidence level

2 σ = 95.4% confidence level

3 σ = 99.7% confidence level

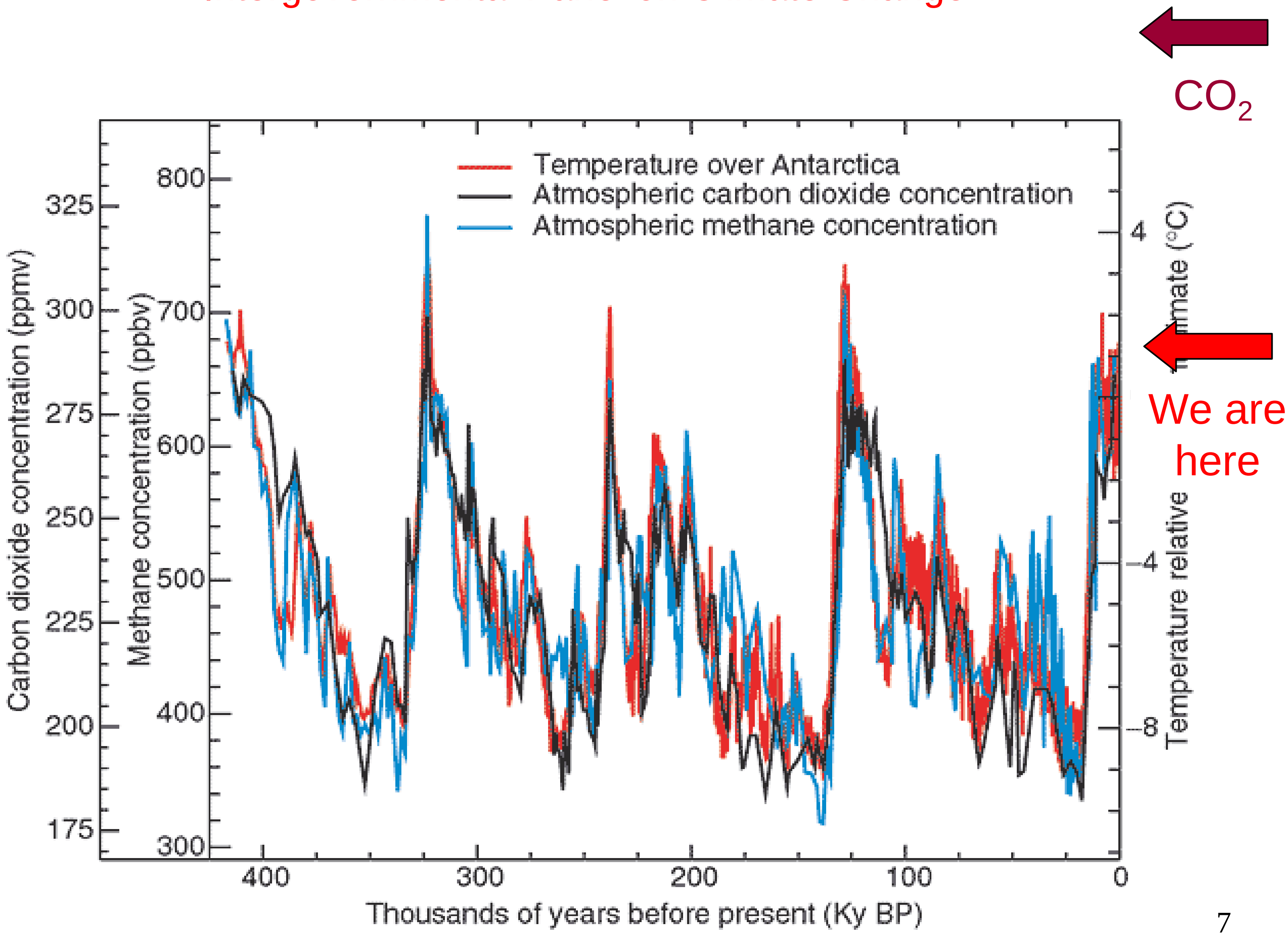
Unstable Glaciers

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

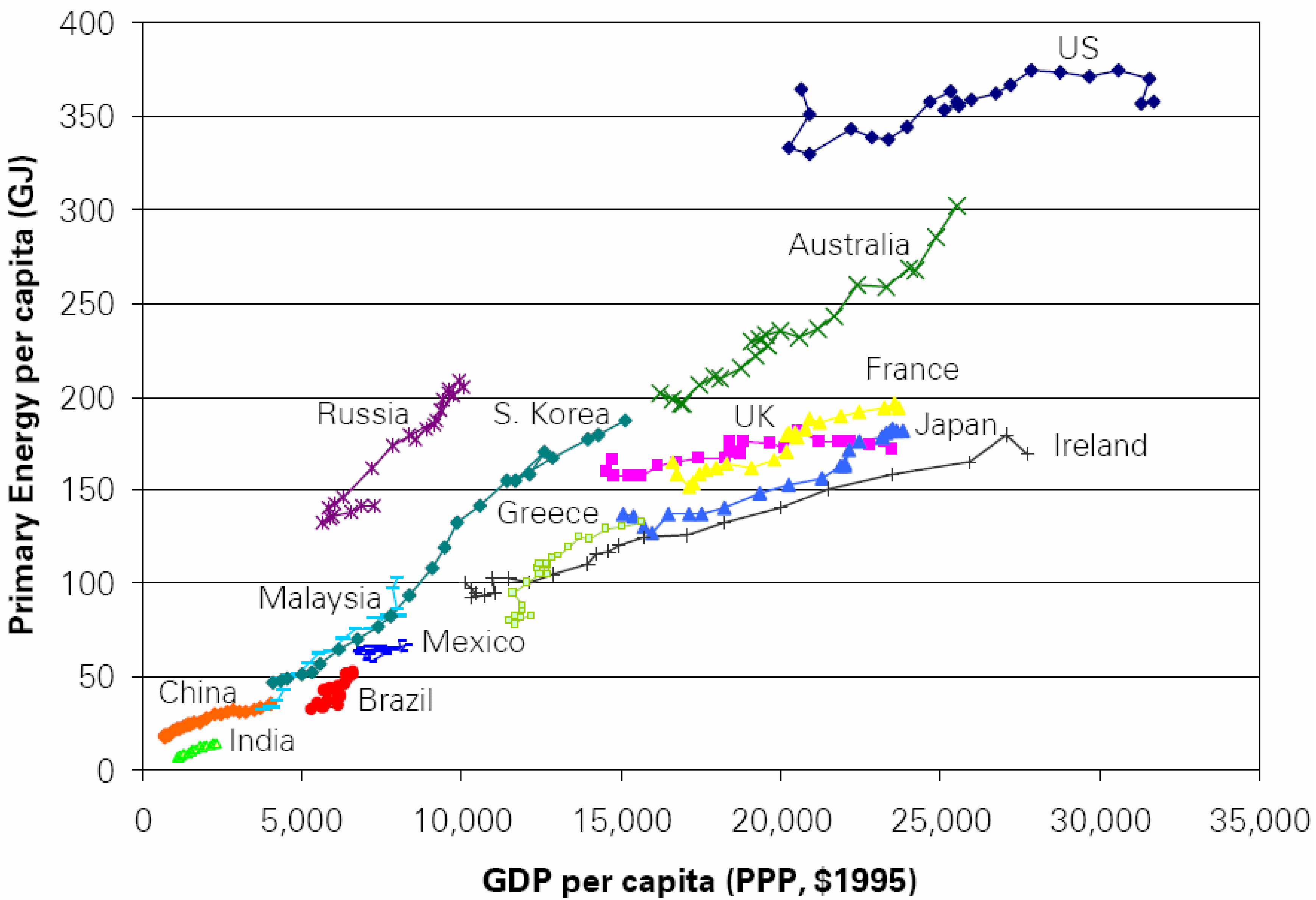
Source: Roger Braithwaite

Temperature over the last 420,000 years

Intergovernmental Panel on Climate Change

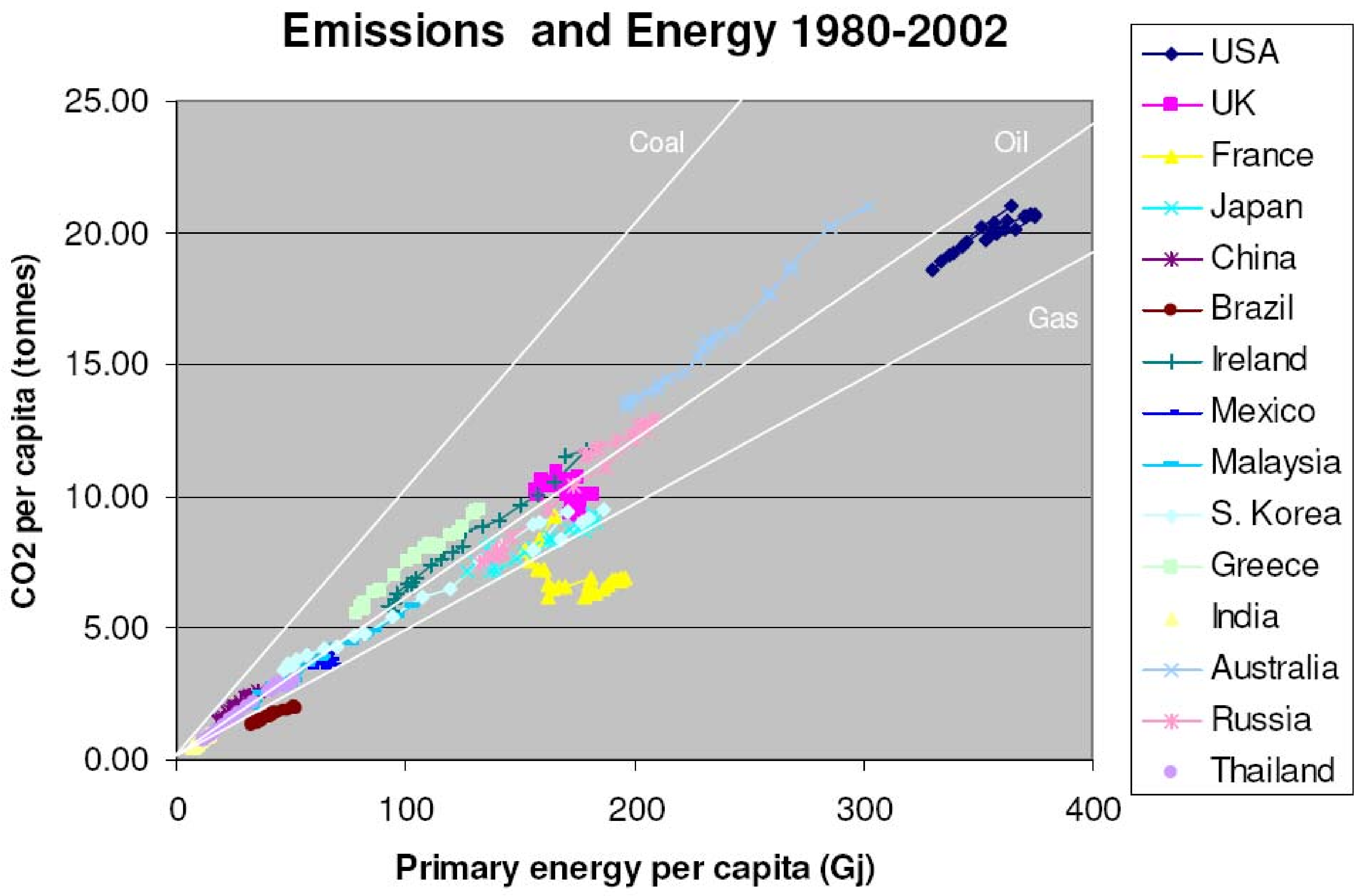


Energy demand vs. GDP per capita



Source: UN and DOE EIA

CO_2 emissions depends on the energy source



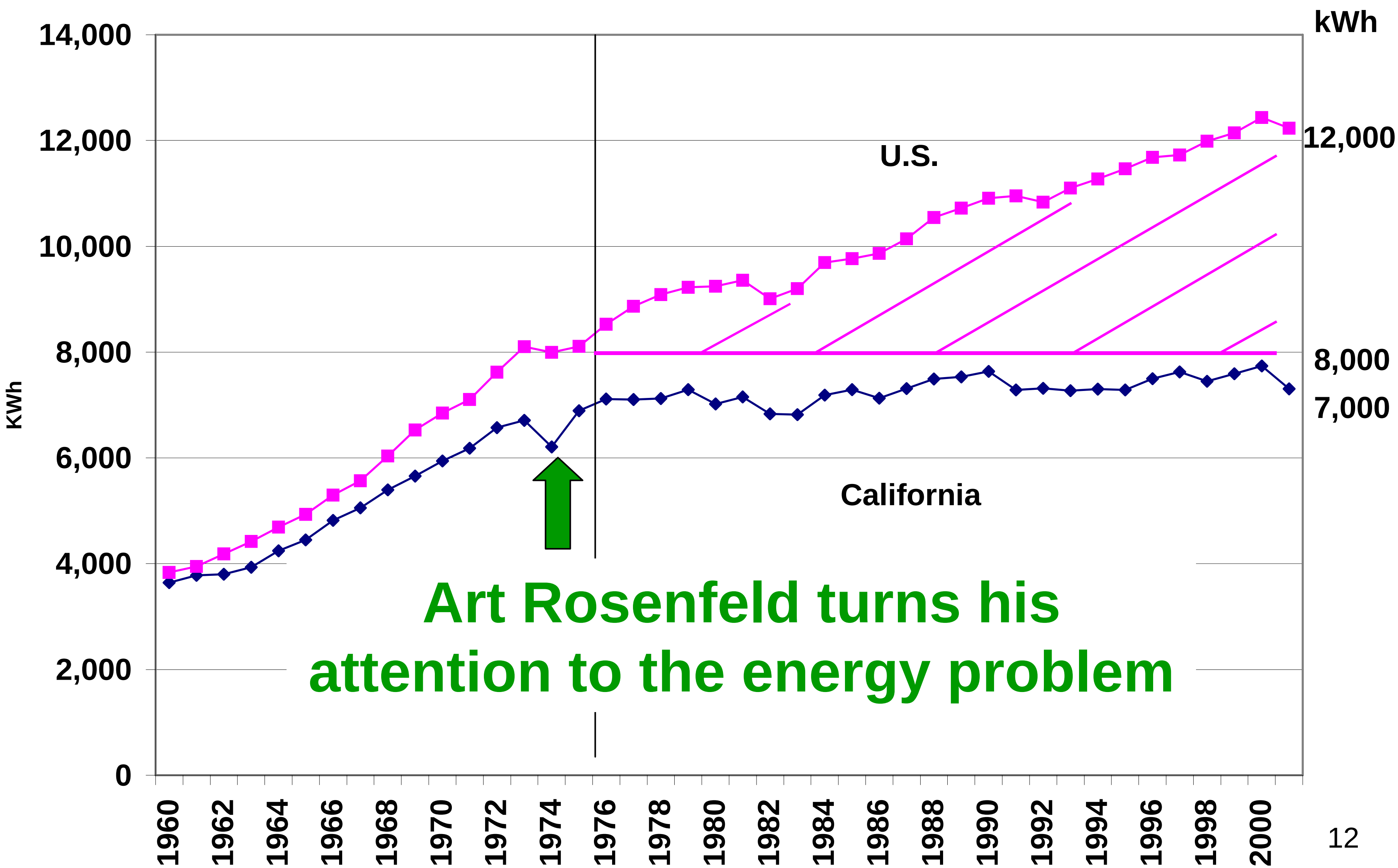
A dual strategy is needed to solve the energy problem:

1) Conservation: maximize energy efficiency and minimize energy use, while insuring economic prosperity

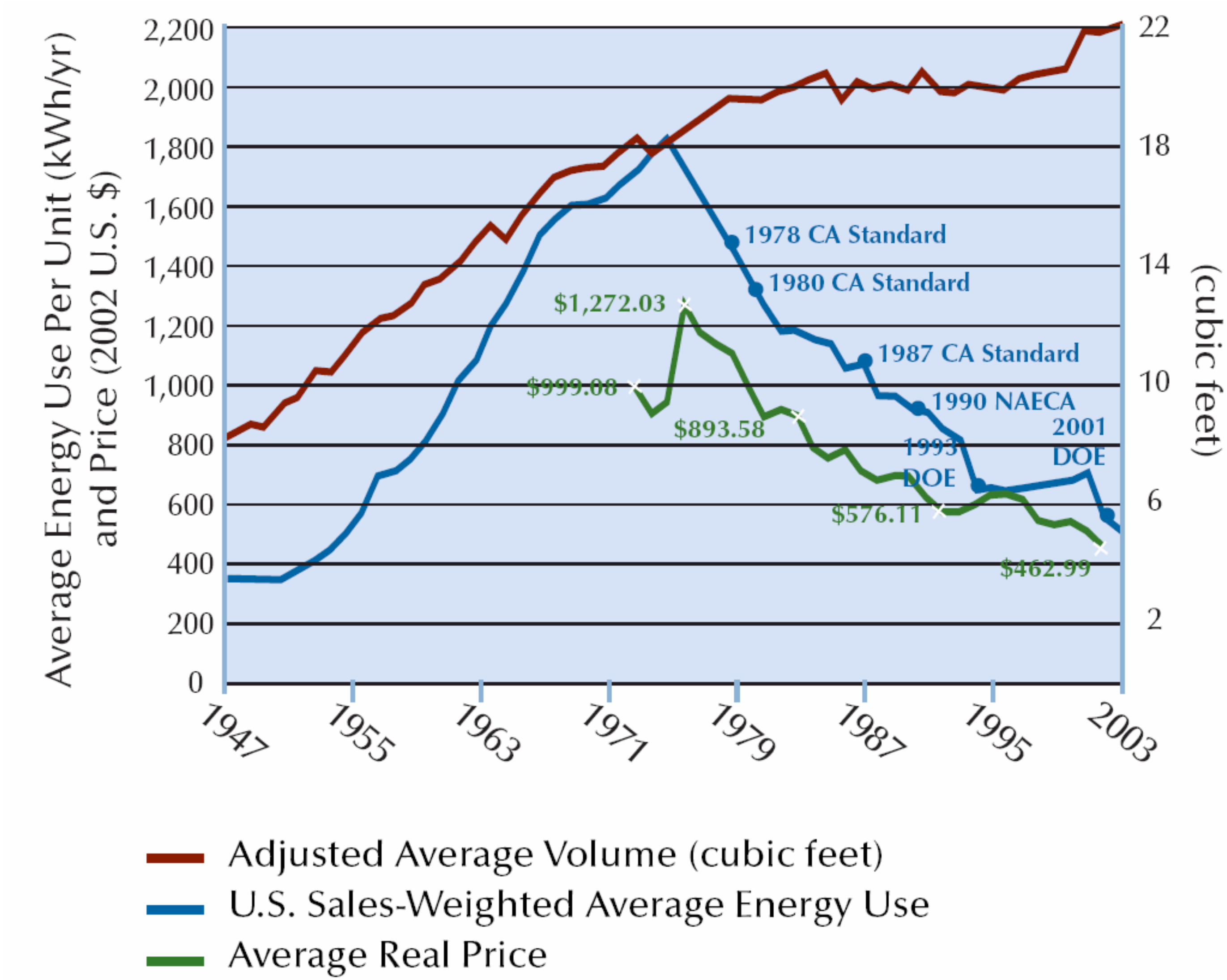
2) Develop new sources of clean energy

The Demand side of the Energy Solution

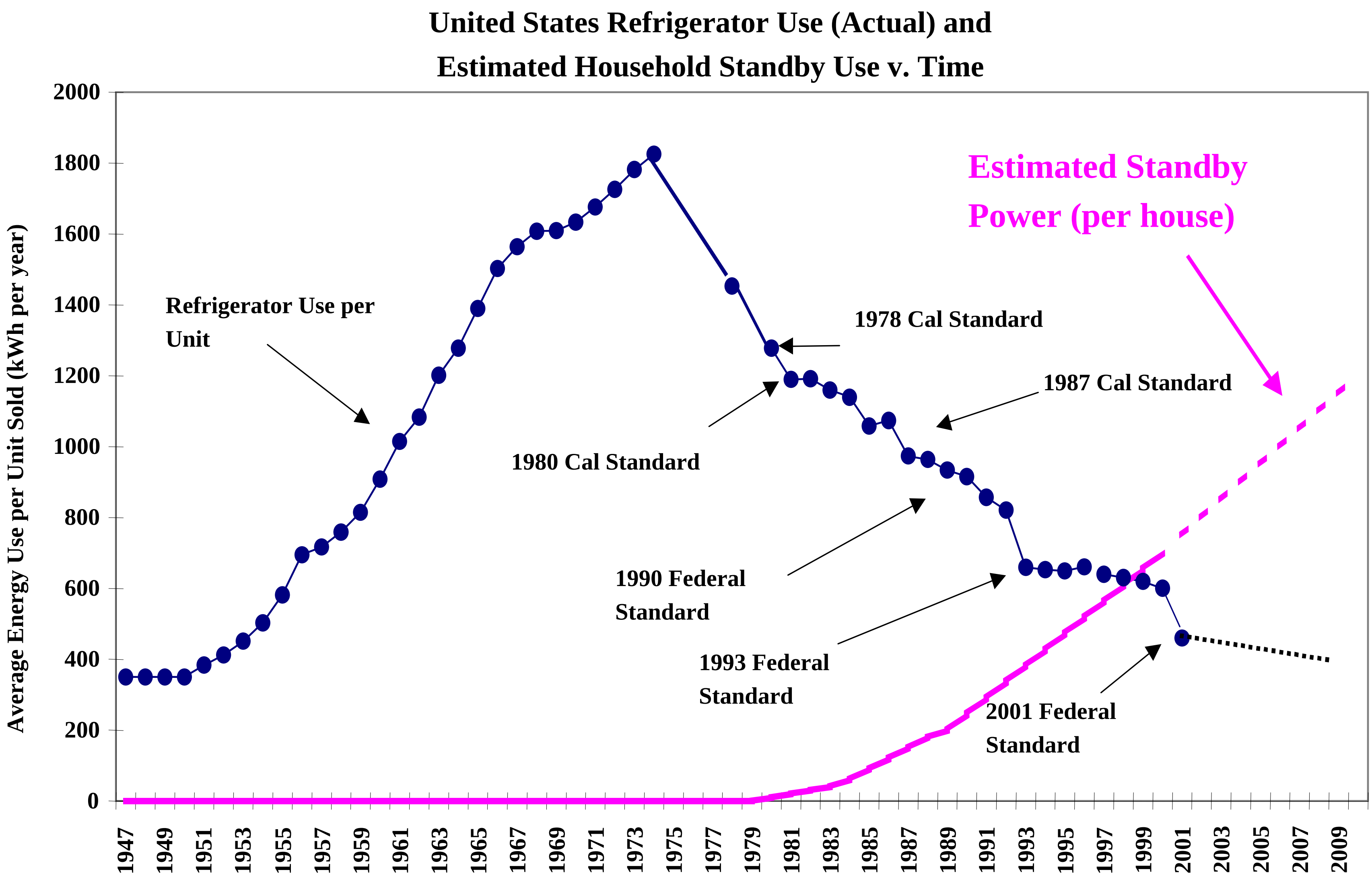
The Rosenfeld Effect



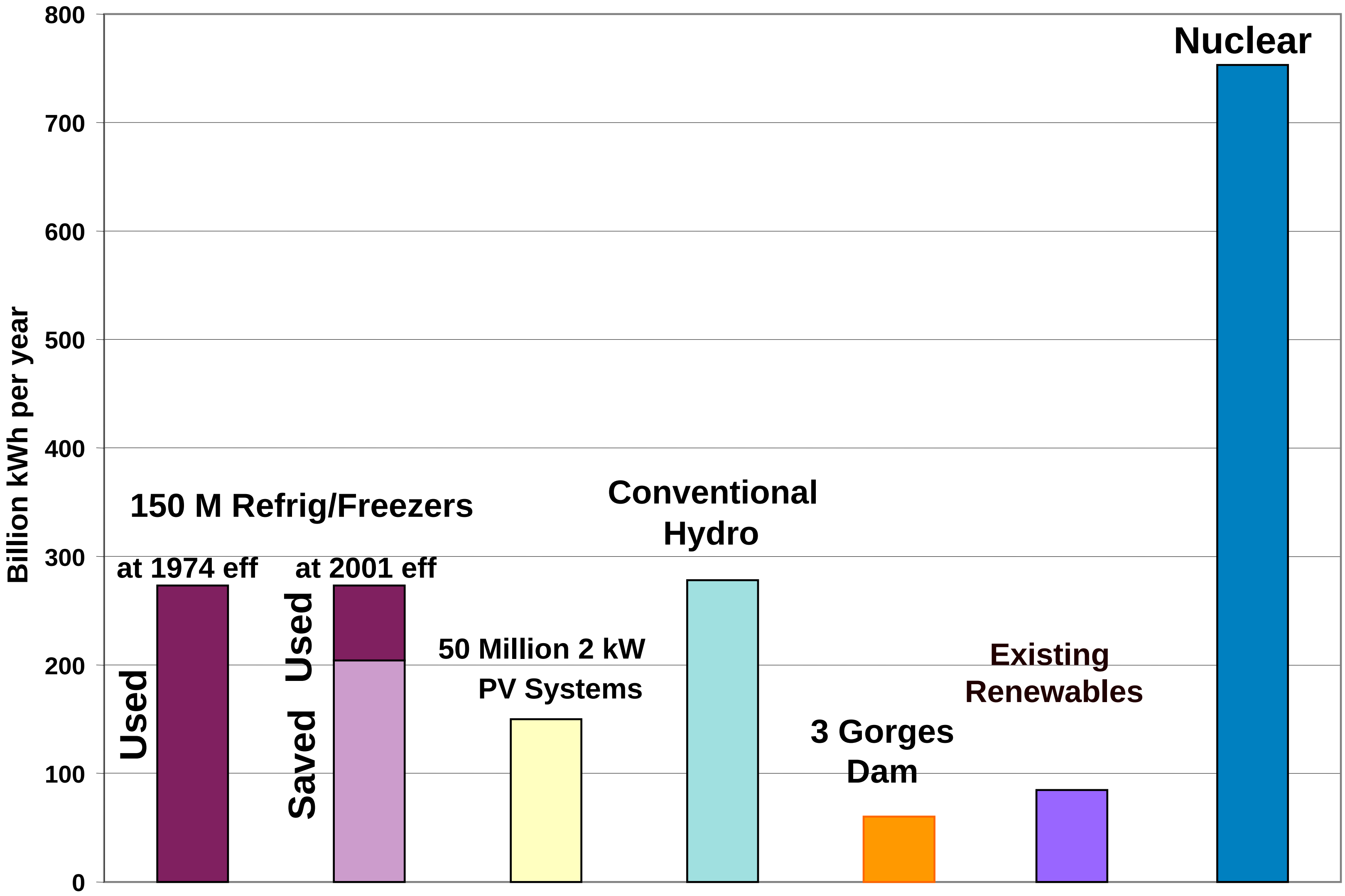
Regulation stimulates technology: Refrigerator efficiency standards and performance. The *expectation* of efficiency standards also stimulated industry innovation



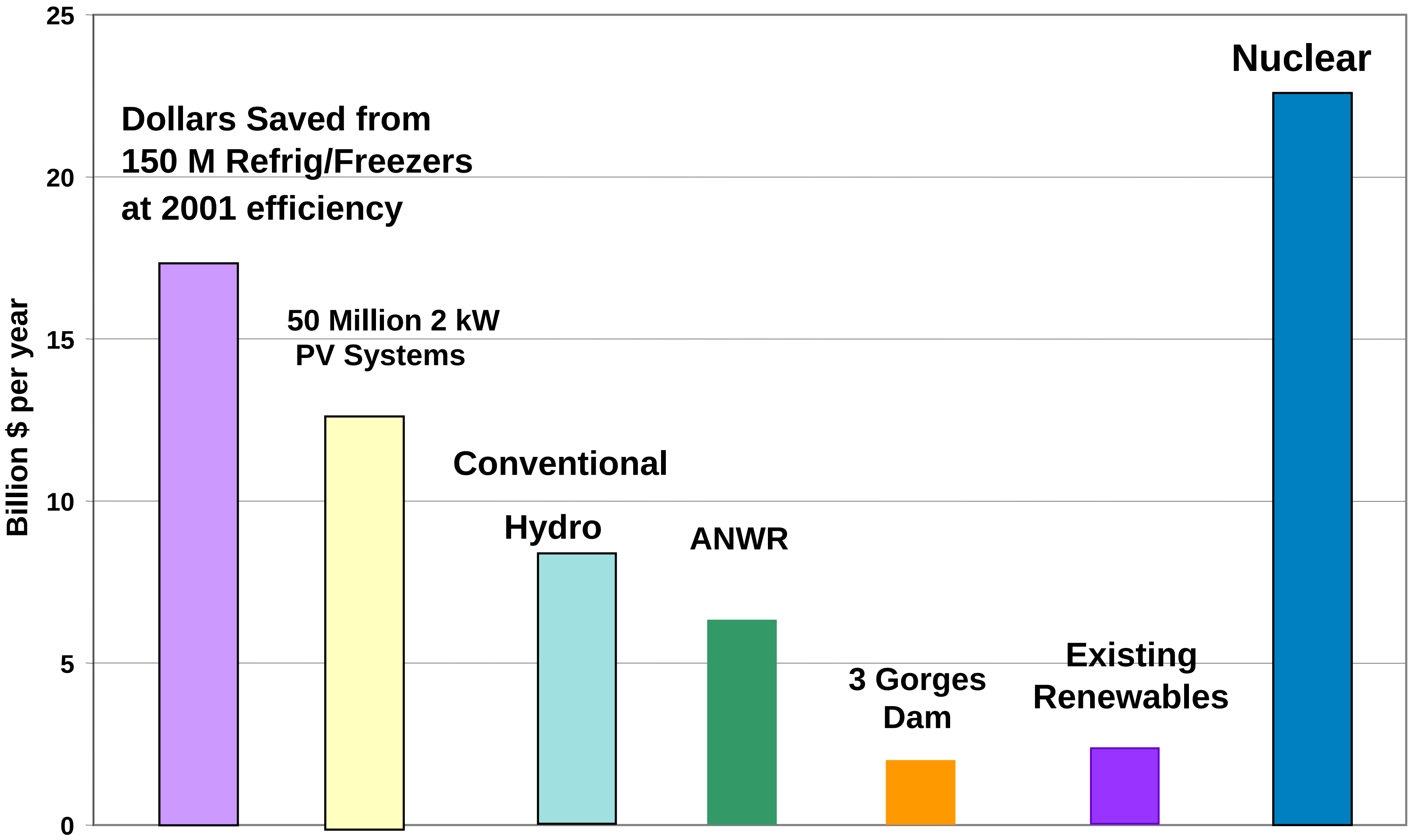
“Vampire” drains on energy



US Electricity Use of Refrigerators and Freezers compared to sources of electricity



The Value of Energy Saved and Produced. (assuming cost of generation = $.03/kWh and cost of use = $.085/kWh)

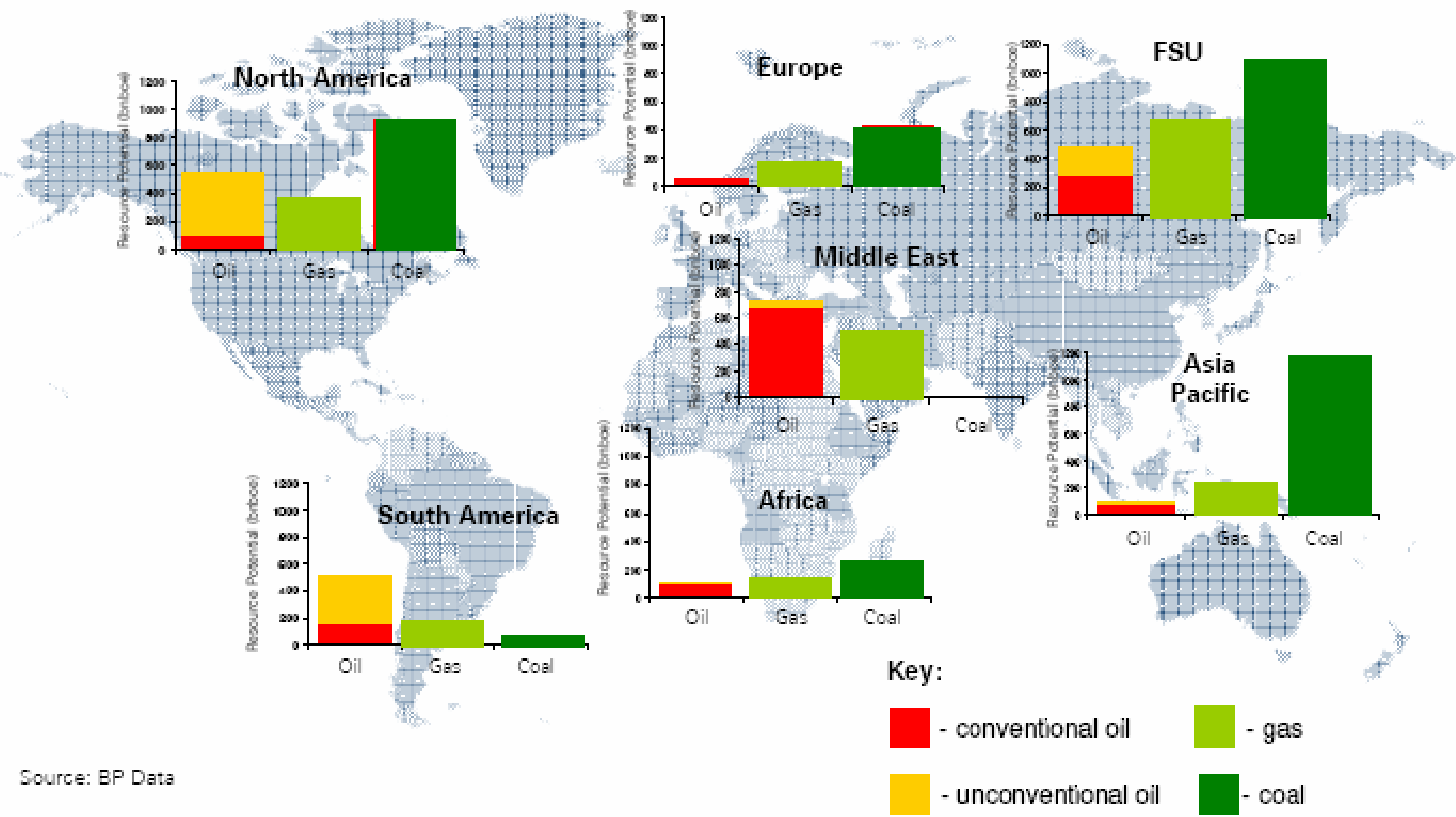


Potential supply-side solutions to the Energy Problem

- Coal, tar sands, shale oil, …
- Fusion
- Fission
- Wind
- Solar photocells
- Bio-mass

significant hydrocarbon resource potential

Oil, Gas and Coal Resources by Region (bnboe)



Source: BP Data

Potential supply-side solutions to the Energy Problem

- Coal, tar sands, shale oil, …
- Fusion
- Fission
- Wind
- Solar photocells
- Bio-mass

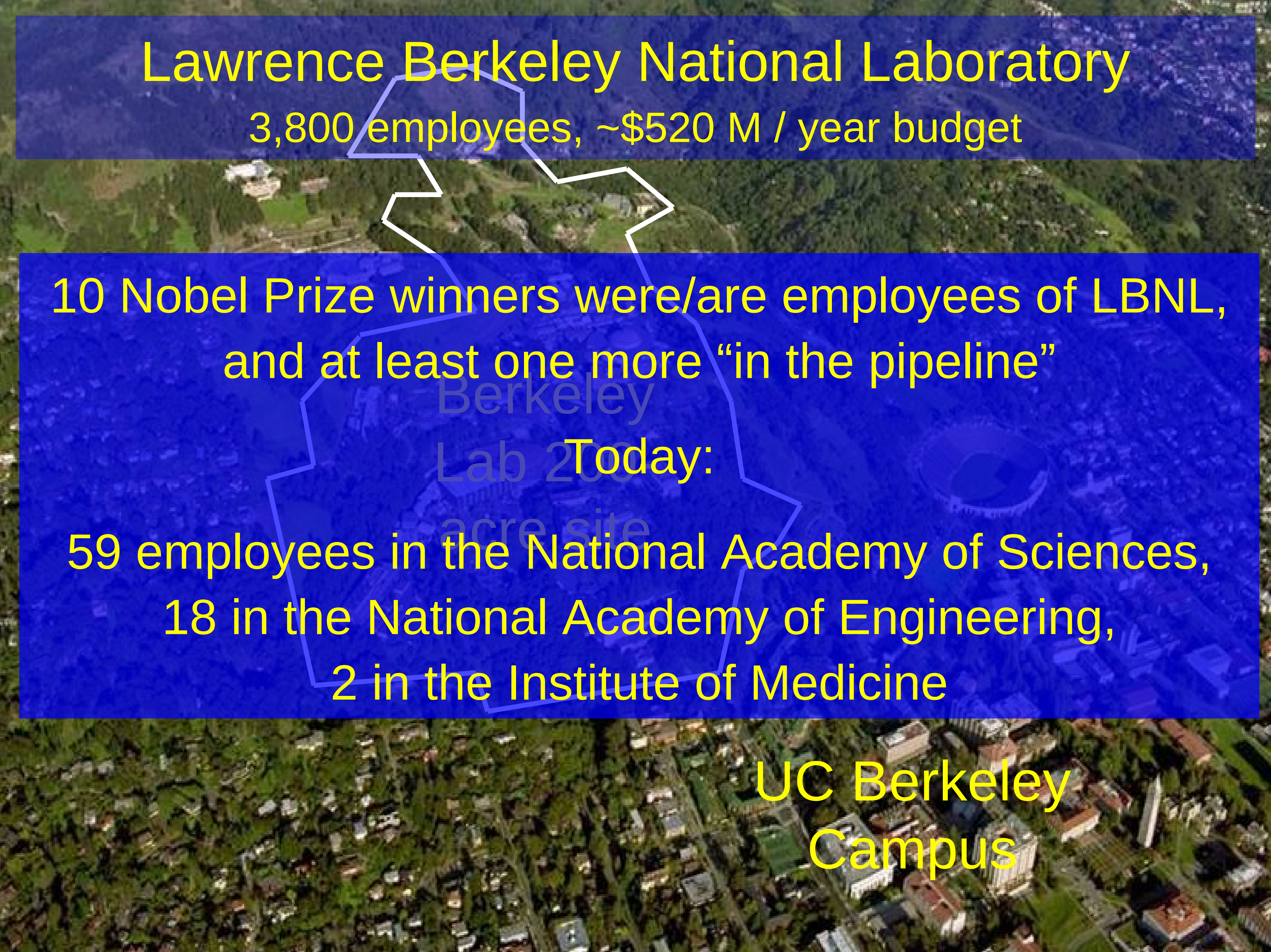
Lawrence Berkeley National Laboratory

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

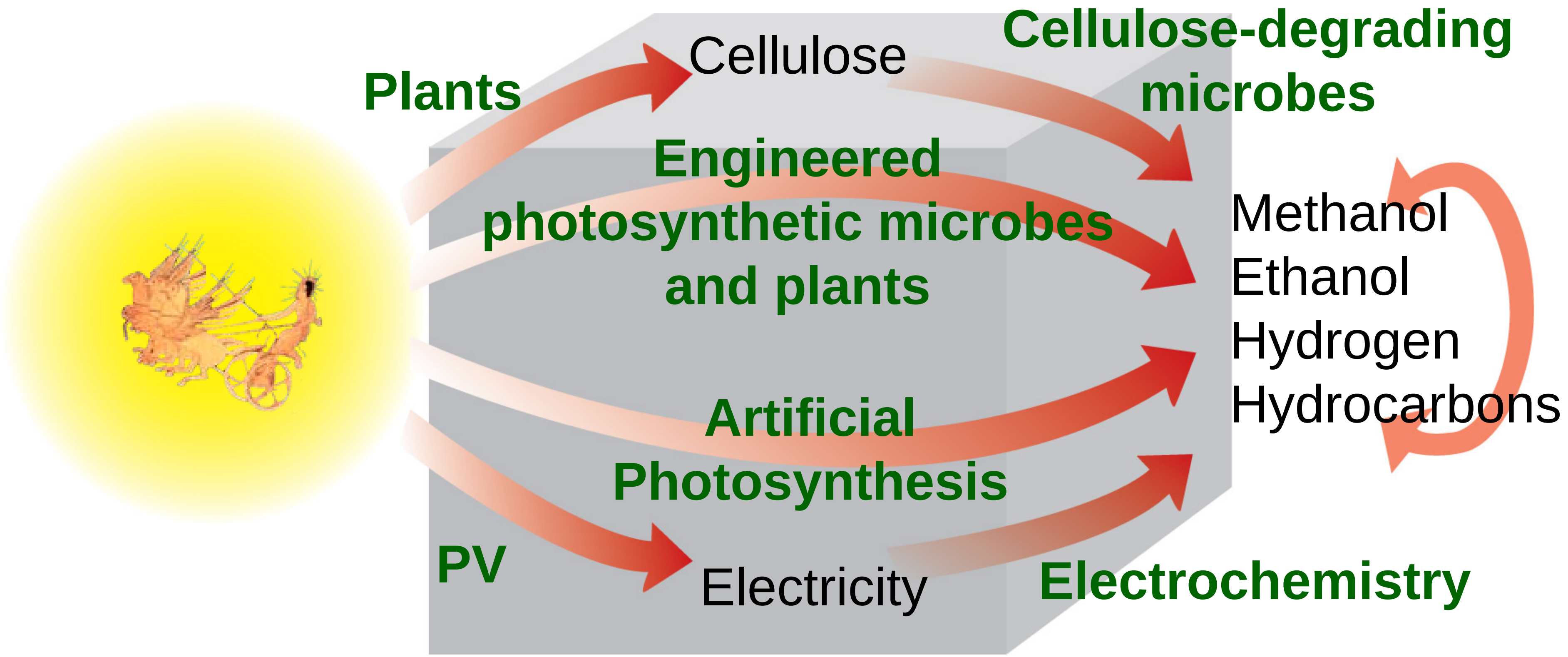
10 Nobel Prize winners were/are employees of LBNL, and at least one more "in the pipeline"

Today:

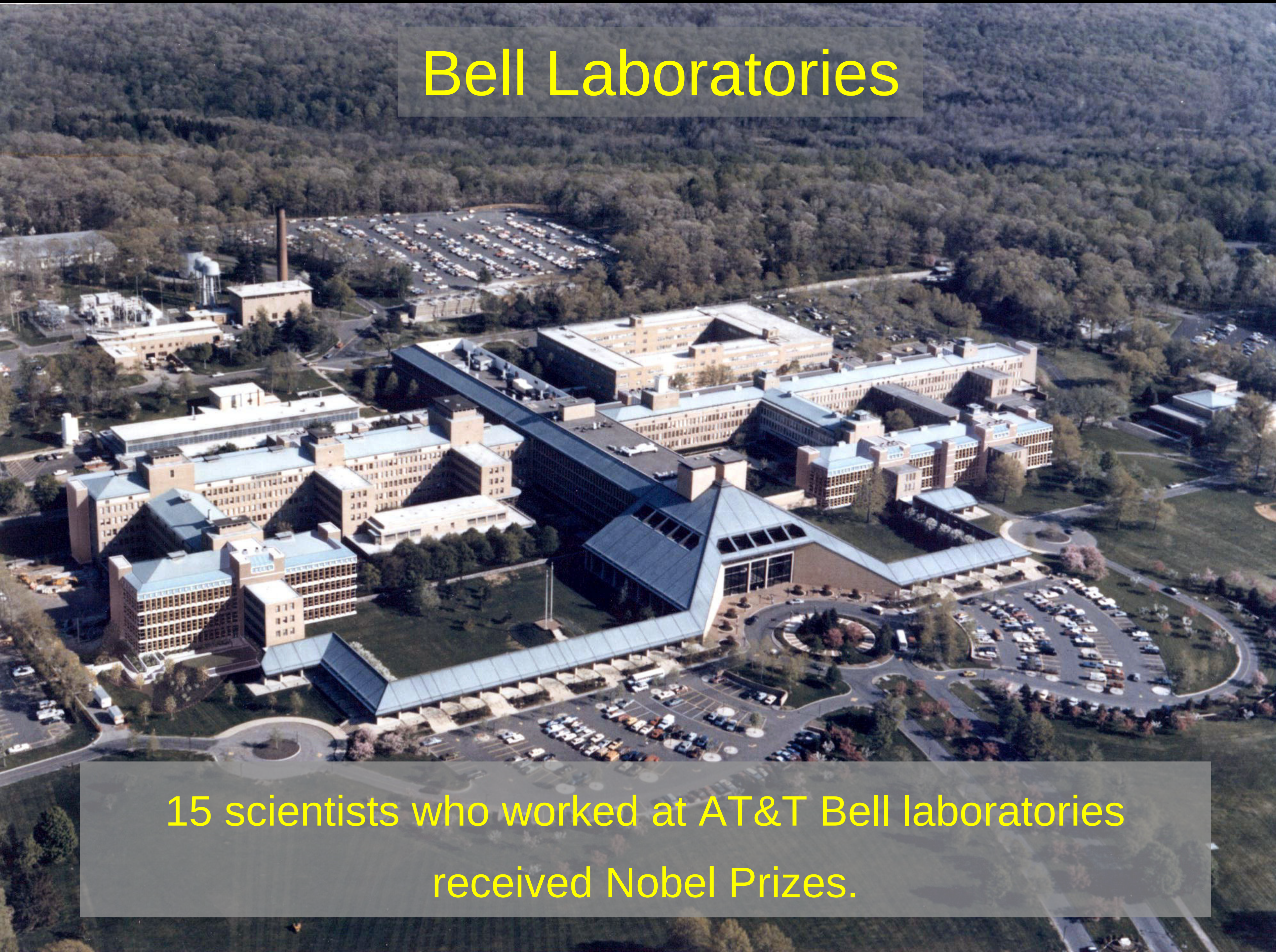
59 employees in the National Academy of Sciences,
18 in the National Academy of Engineering,
2 in the Institute of Medicine



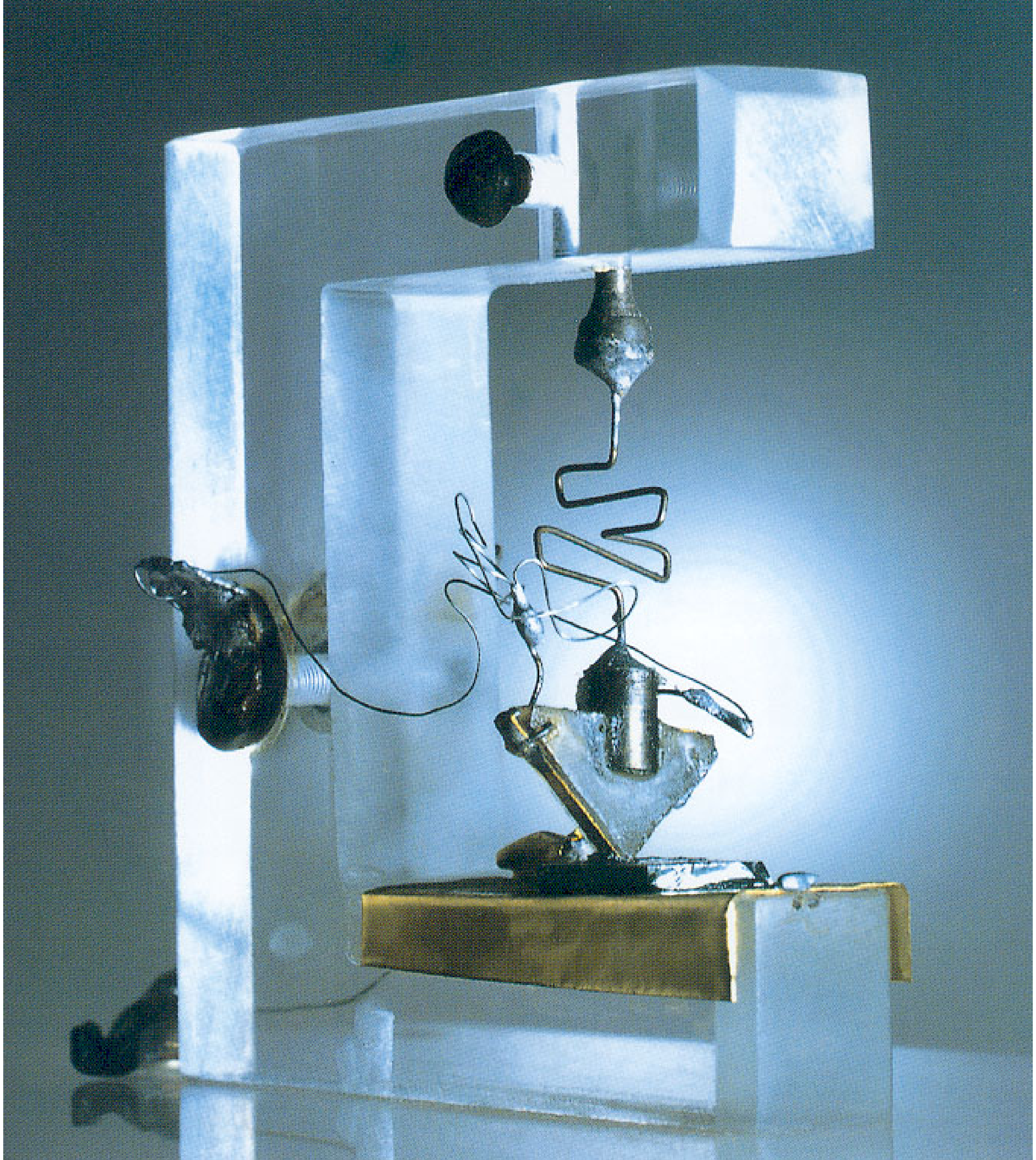
Helios: Lawrence Berkeley Laboratory's attack on the energy problem

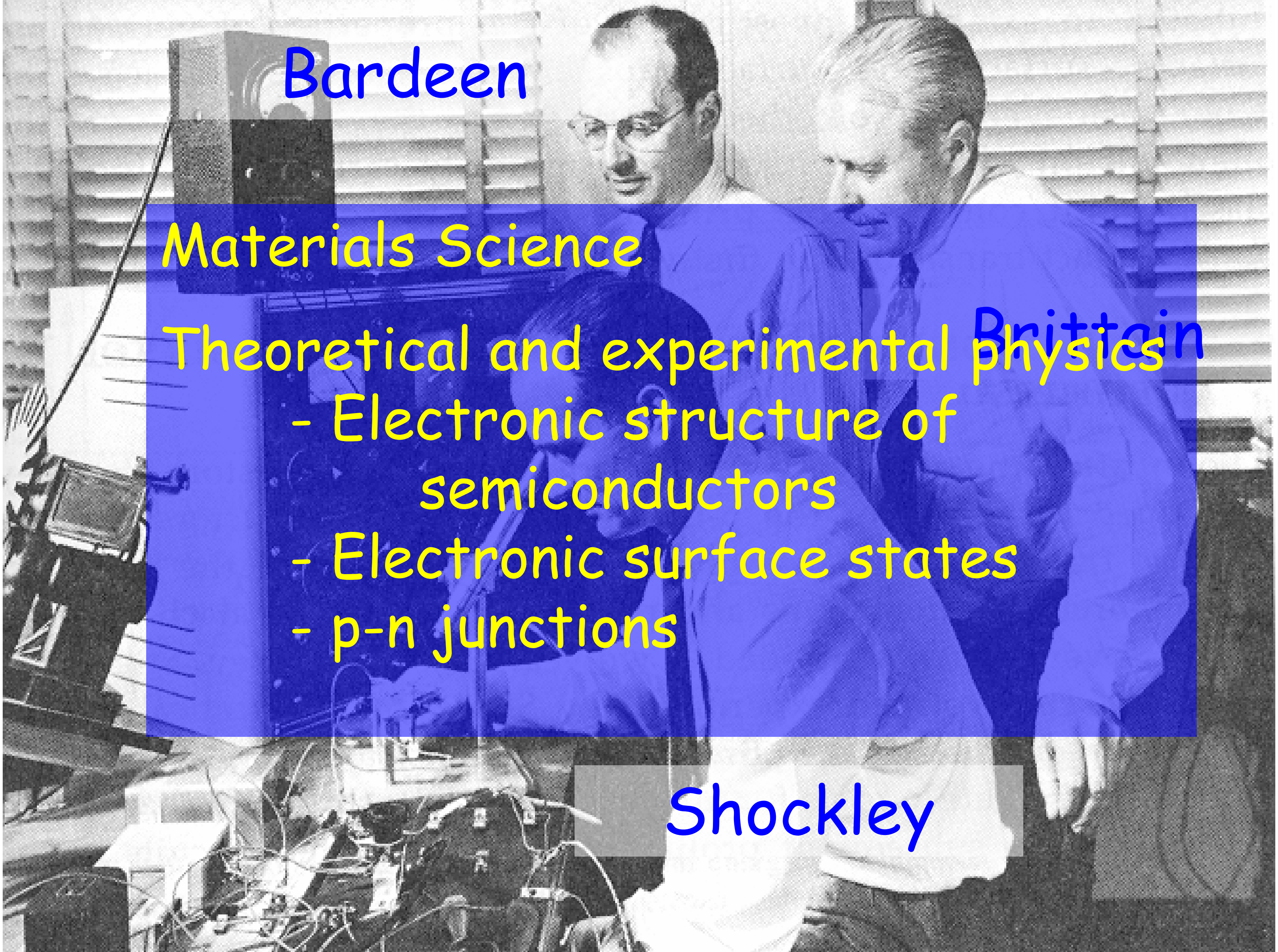


Bell Laboratories



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



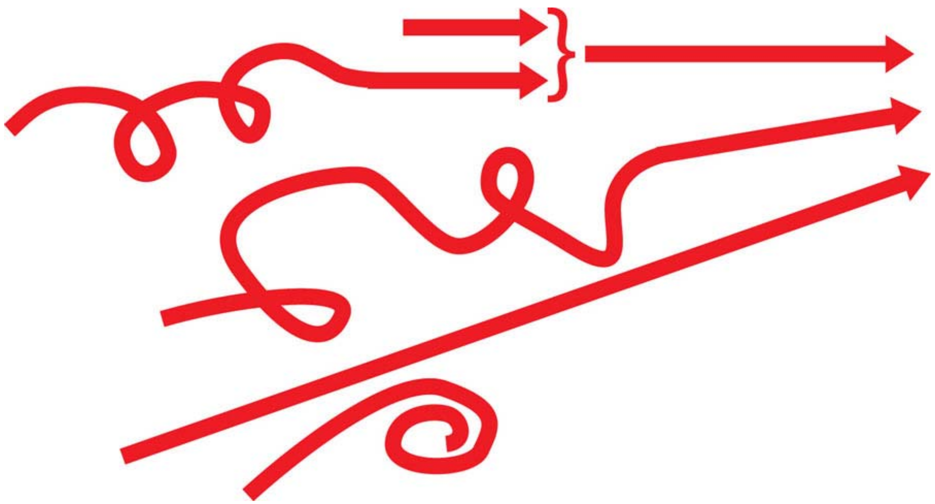


Materials Science

Theoretical and experimental physics

- Electronic structure of semiconductors
- Electronic surface states
- p-n junctions

Helios metrics for success



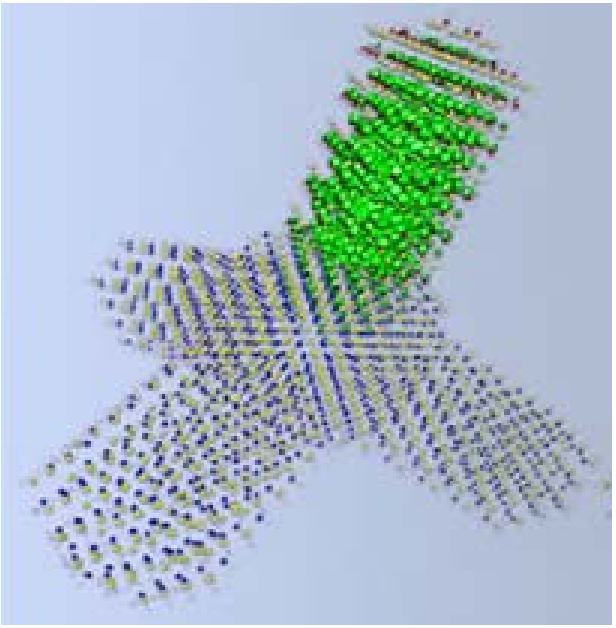
Fuels

- Address showstoppers as quickly as possible.
- Move on as soon as the potential solution will not scale properly.
- Constantly re-access milestones and goals: Failure ***is*** an option.

Is it possible to develop a new class of durable solar cells with high efficiency at 1/5 to 1/10th the cost of existing technology?

Distributed Junction Solar Cells

- Creation of electron-hole charges
- Conduction of charge carriers to electrodes



Tetrapod nanoparticle

Paul Alivisatos, Associate Lab Director, Physical Sciences and Division Director, Material Sciences

Distributed Junction Solar Cells

Introduced by Heeger and coworkers in 1994. Two nano-scale components used to generate exciton creation, charge separation and conduction to electrodes. Many losses when charges are trapped at dead ends within the random network. Problems of charge collection are exacerbated due to the fact the mobilities in the organic media are low, and the holes move much faster than the electrons.

- ***Organized Channel Junction Solar Cells***

Spatially organize the electron-hole transport pathways into an array of vertical columns.

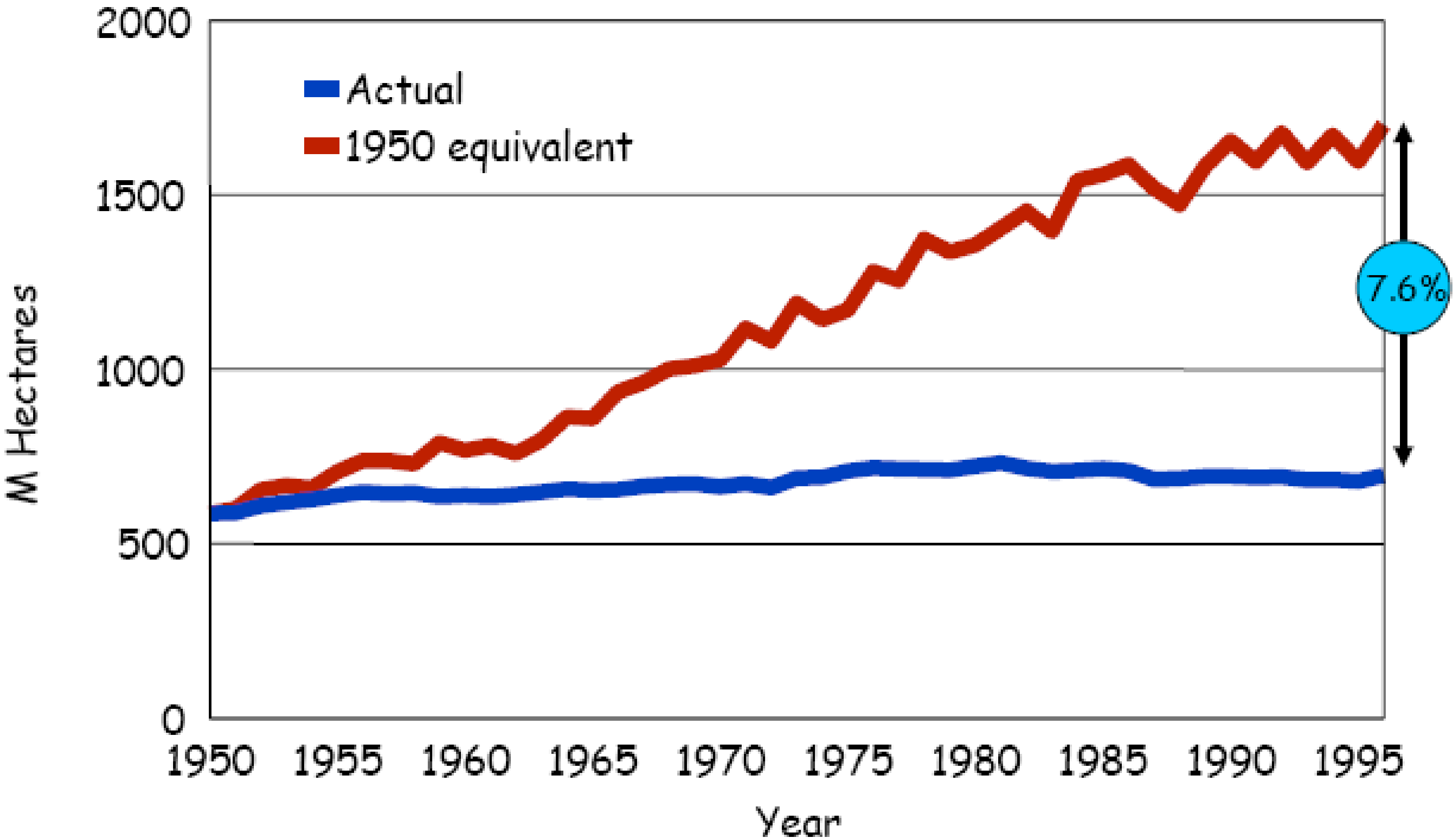
Solution phase growth of vertically aligned nanowire arrays as electron transport media

Formation of a liquid crystal phase consisting of colloidal nanorods or nanotubes.

Alignment of block copolymers

Hierarchical Junction Solar Cells using organic dendrimers

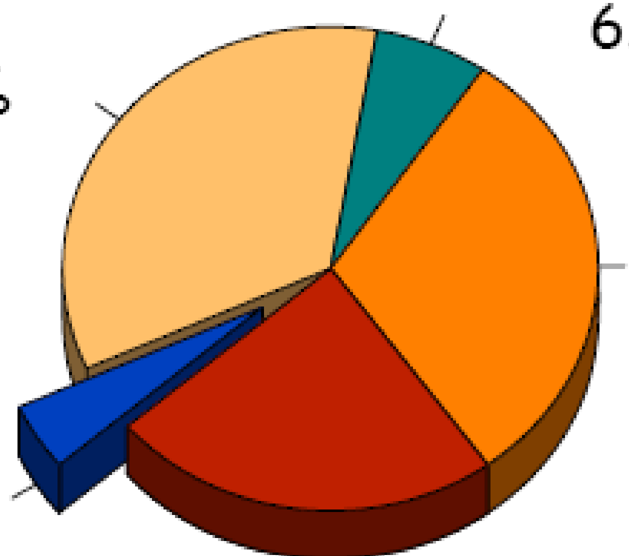
Hectares of Grain With and Without Yield Improvements



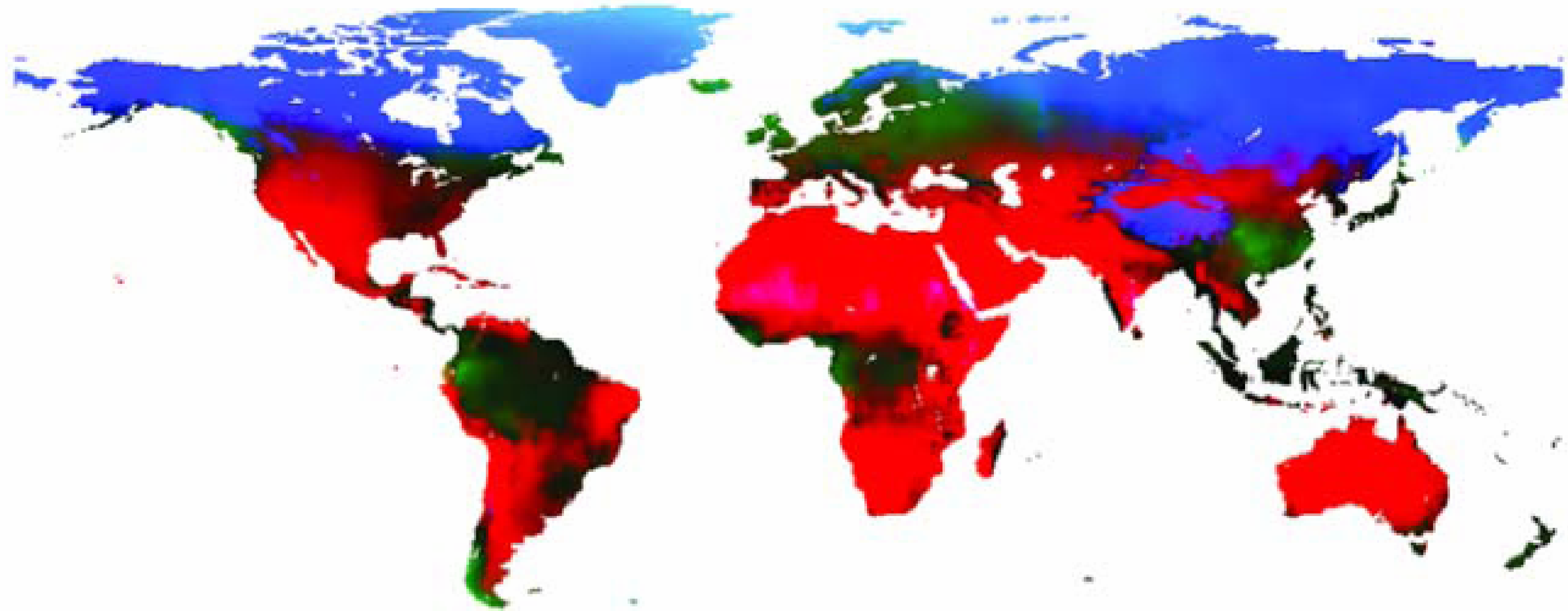
Data from Worldwatch database 1996, 1997

~13 B ha of land in the Earth

- 1.5 B ha for crops
- 3.5 B ha for pastureland
- 0.5 B ha are "built up"
- 7.5 B ha are forest land or "other"



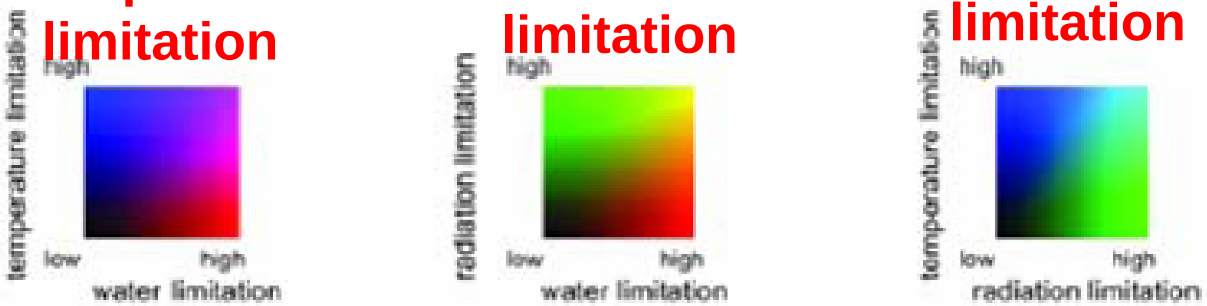
Limiting factors for plant productivity



Temp/water limitation

Rad/water limitation

temp/water limitation



Baldocchi et al. 2004 SCOPE 62

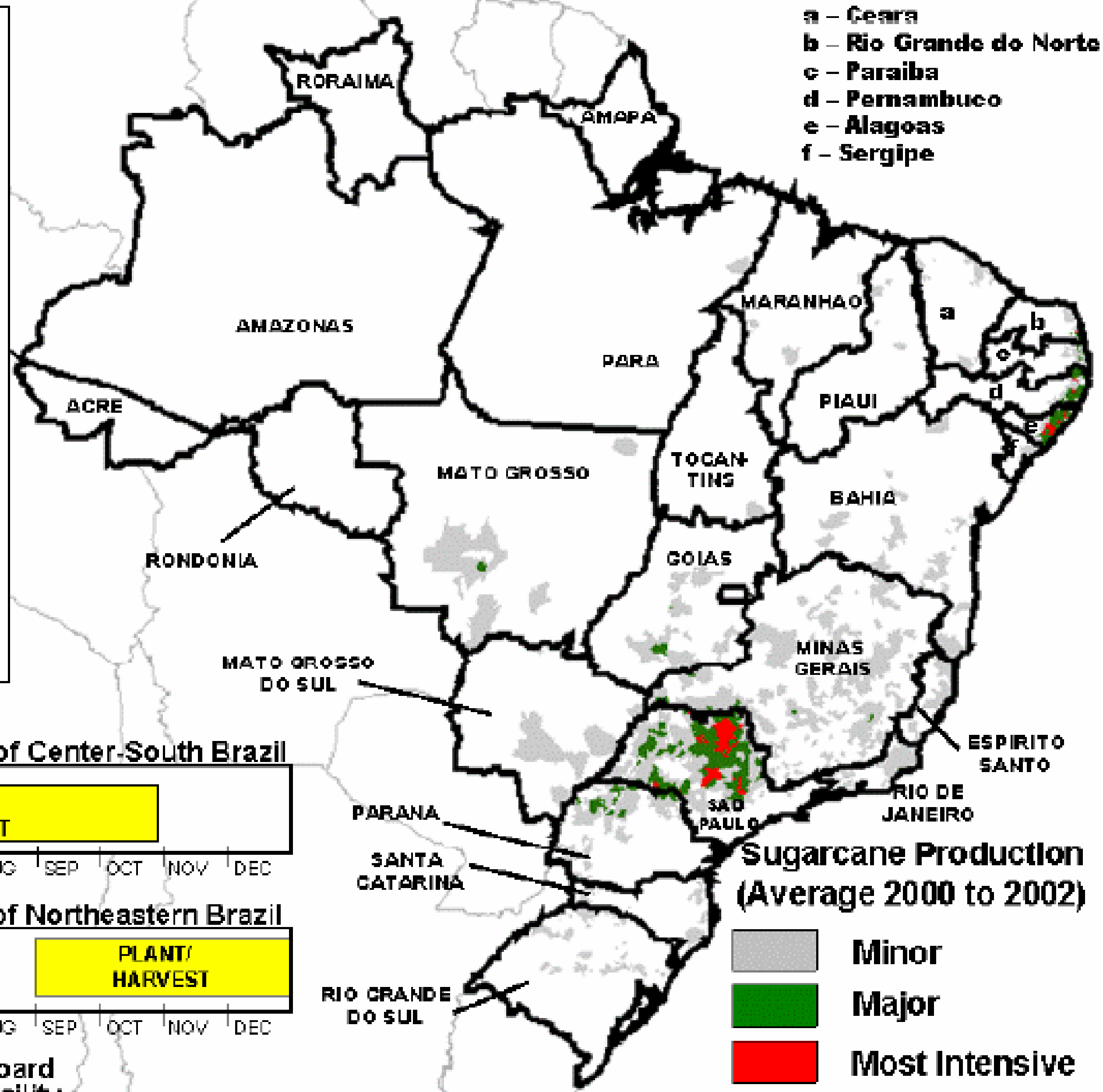
Brazil Sugarcane

*** State-Level Production (as % of total)**

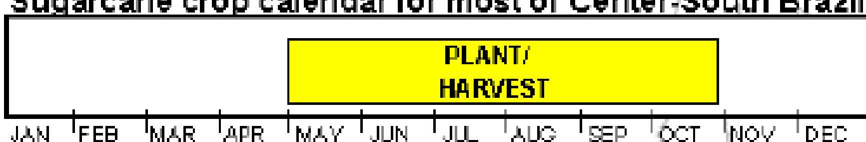
State	%
Sao Paulo	58
Alagoas	8
Parana	8
Minas Gerais	5
Pernambuco	5
Mato Grosso	3
Goias	3
Mato Grosso do Sul	2
Rio De Janeiro	2
Other States	6

•1999/2000 to 2001/02 Average

Source: IBGE Brazil



Sugarcane crop calendar for most of Center-South Brazil



Sugarcane crop calendar for most of Northeastern Brazil

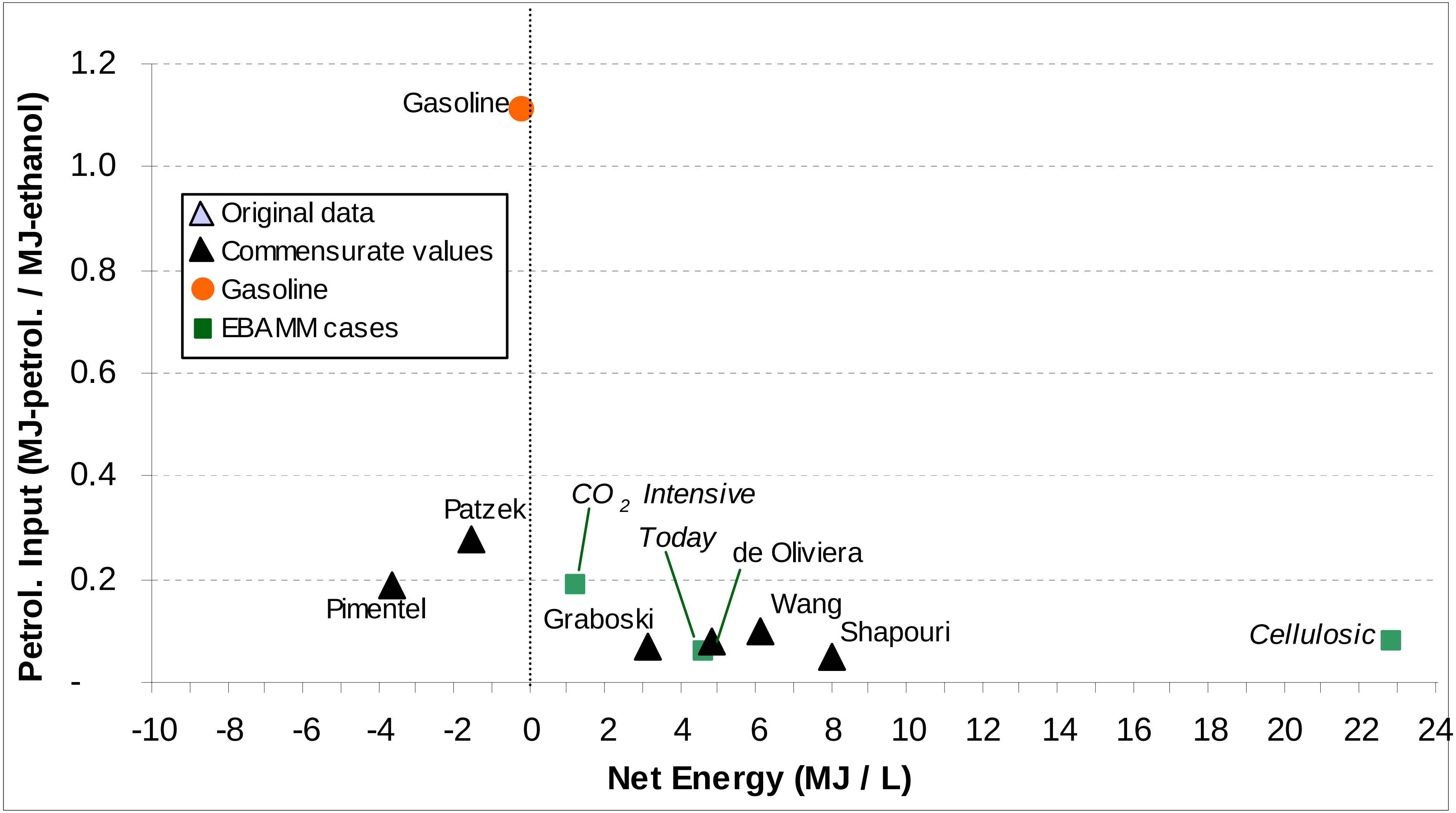
USDA World Agricultural Outlook Board
Joint Agricultural Weather Facility

Total Surface Area by Land Cover/Use and Year in Millions of Acres, with Margins of Error

Year	Cropland*	CRP Land*	Pastureland	Rangeland
1982	419.9 ± 2.1	0.0 ± 0.0	131.1 ± 1.4	415.5 ± 3.5
1992	381.3 ± 2.0	34.0 ± 0.2	125.2 ± 1.3	406.8 ± 3.3
1997	376.4 ± 2.0	32.7 ± 0.0	119.5 ± 1.2	404.9 ± 3.3
2001	369.5 ± 2.0	31.8 ± 0.3	119.2 ± 1.8	404.9 ± 3.4
2003	367.9 ± 2.4	31.5 ± 0.3	117.0 ± 1.8	405.1 ± 3.5

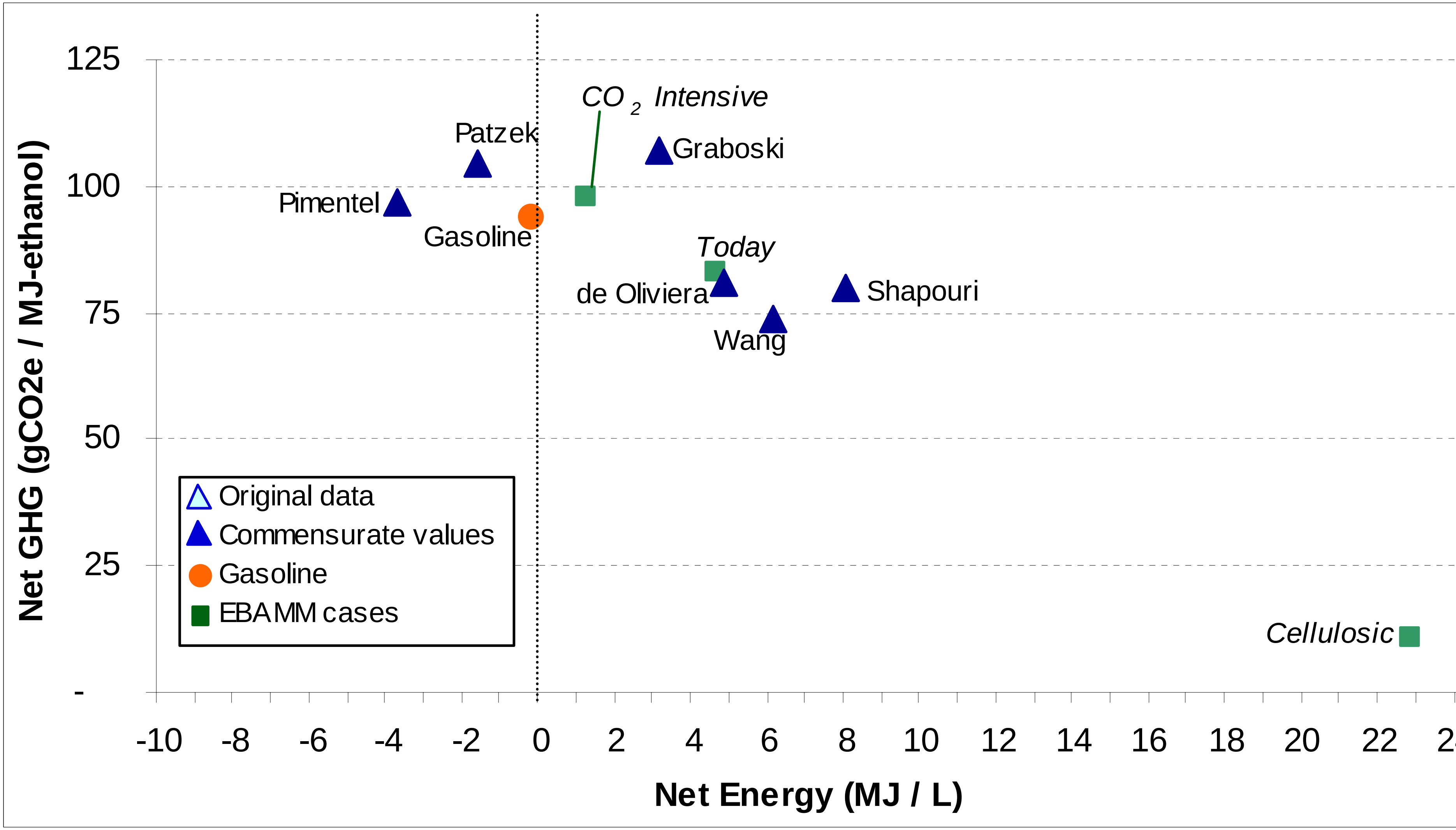
Source: US Dept of Agriculture

Petroleum Use



Courtesy Dan Kammen analysis

Greenhouse Gases



Courtesy Dan Kammen analysis

The majority of a plant is structural material

Cellulose	40-60% Percent Dry Weight
Hemicellulose	20-40%
Lignin	10-25%

Sunlight

CO_2, H_2O,

Nutrients

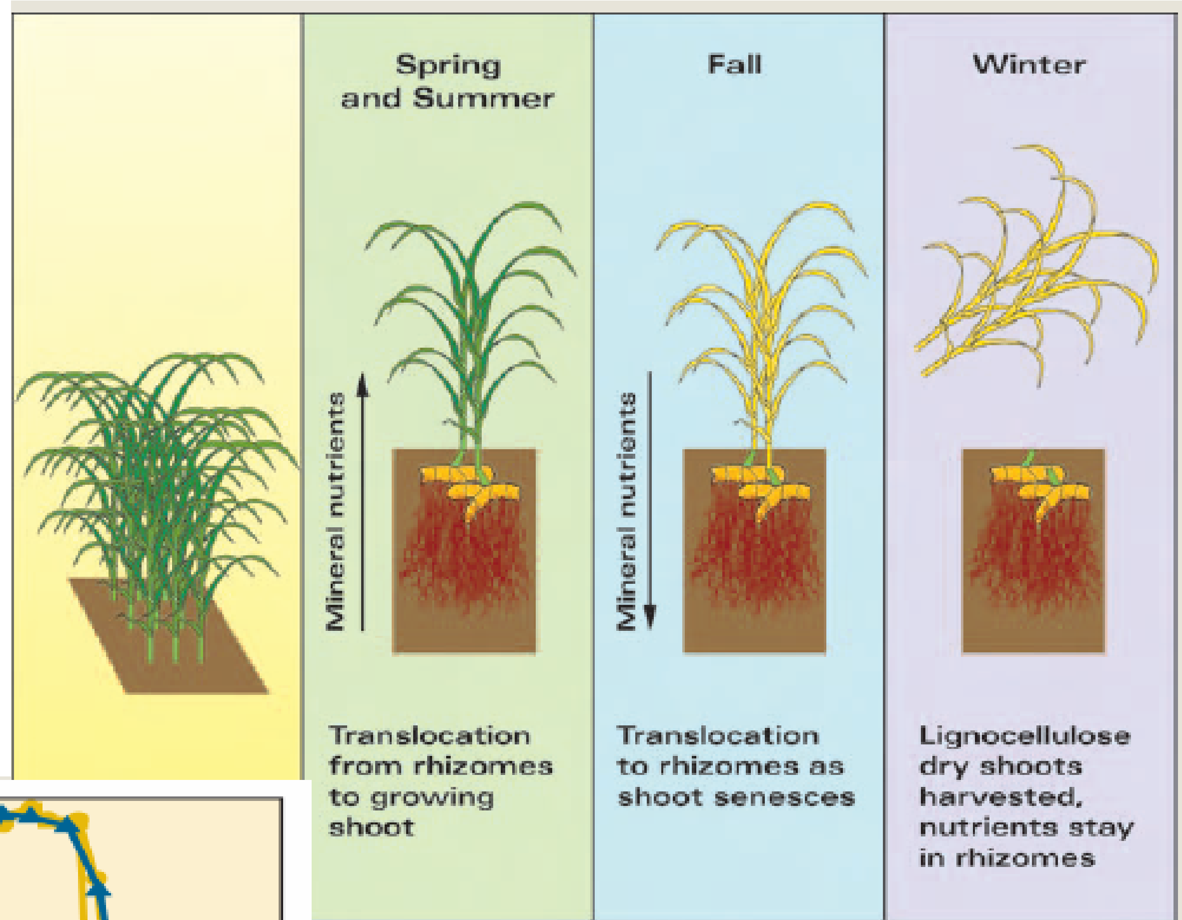
→ Biomass → Chemical energy

Self-fertilizing, drought and pest resistant

Improved conversion of cellulose into chemical fuel

Advantages of perennial species:

- higher annualized photosynthesis
- nutrient conservation



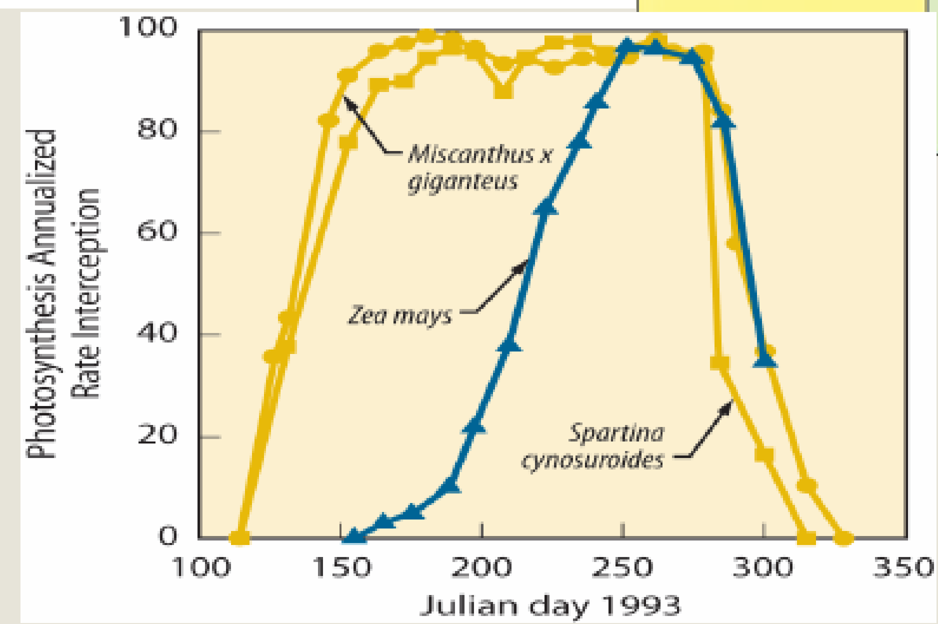


Fig. B. Comparing Net Photosynthesis of Corn and Several Perennial Species. Annualized net photosynthesis is proportional to the area under the curve. Thus, if maximal rates of photosynthesis are similar, the perennial crops (yellow) have much higher annualized net photosynthesis than the annual crop (blue), corn (*Zea mays*). [Source: S. Long, University of Illinois]

• Miscanthus yields**:** **30** dry tons/acre

• 100 gallons of ethanol / dry ton possible ⇒ 3,000 gal/acre.

• 100 M out of 450 M acres ⇒ ~300 B gal / year of ethanol

• US consumption (2004) = 141 B gal of gasoline
~ 200 B gal of ethanol / year

• US also consumes 63 B gal diesel

> 1% conversion efficiency may be feasible.

Cellulose (40 – 60% of dry mass)

- Linear polymer of the glucose-glucose dimer
- Hydrolysis ⇒ glucose (6C sugar) ⇒ ethanol

Hemicellulose (20 -40%)

Highly branched, short chain, 5C and 6C sugars such as xylose arabinose, galactose

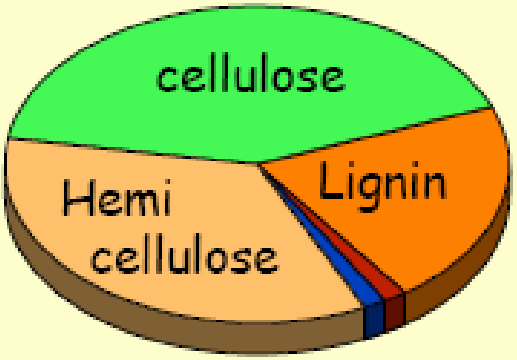
Fermentation of hemicellulose in infancy

(Ethanol substituted for other hydrocarbon e.g. butanol, octanes, etc. ?)

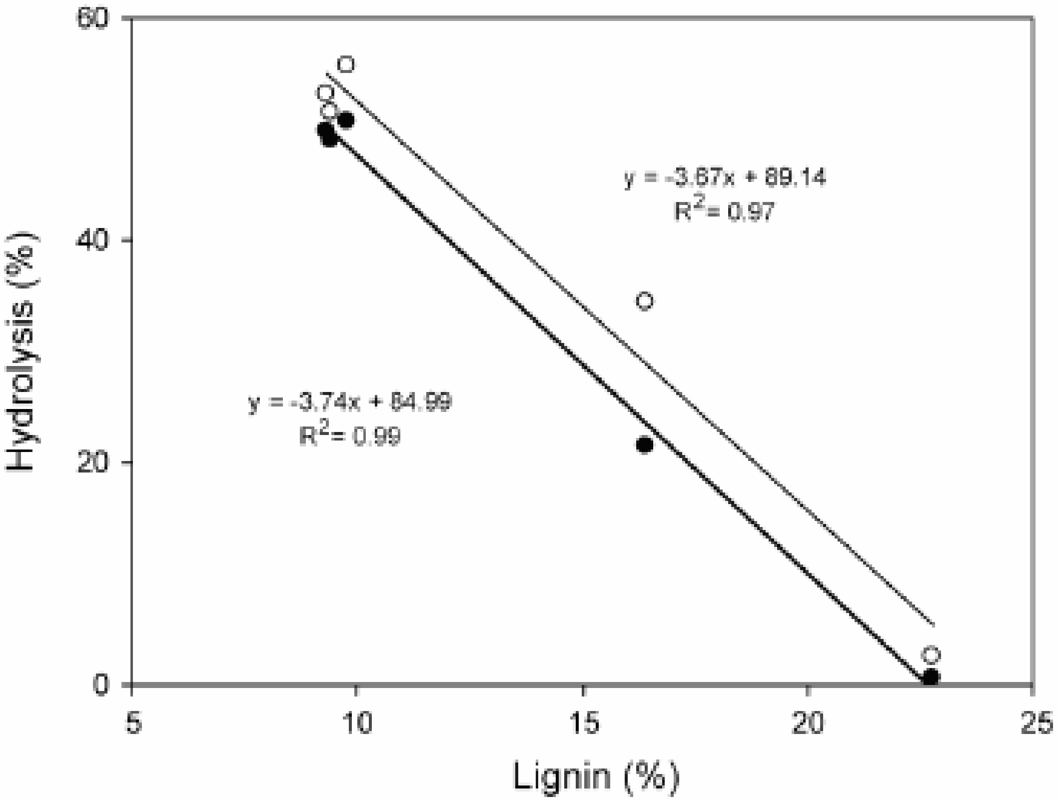
Lignin (10 – 25%)

- Does not lead to simple sugar molecules

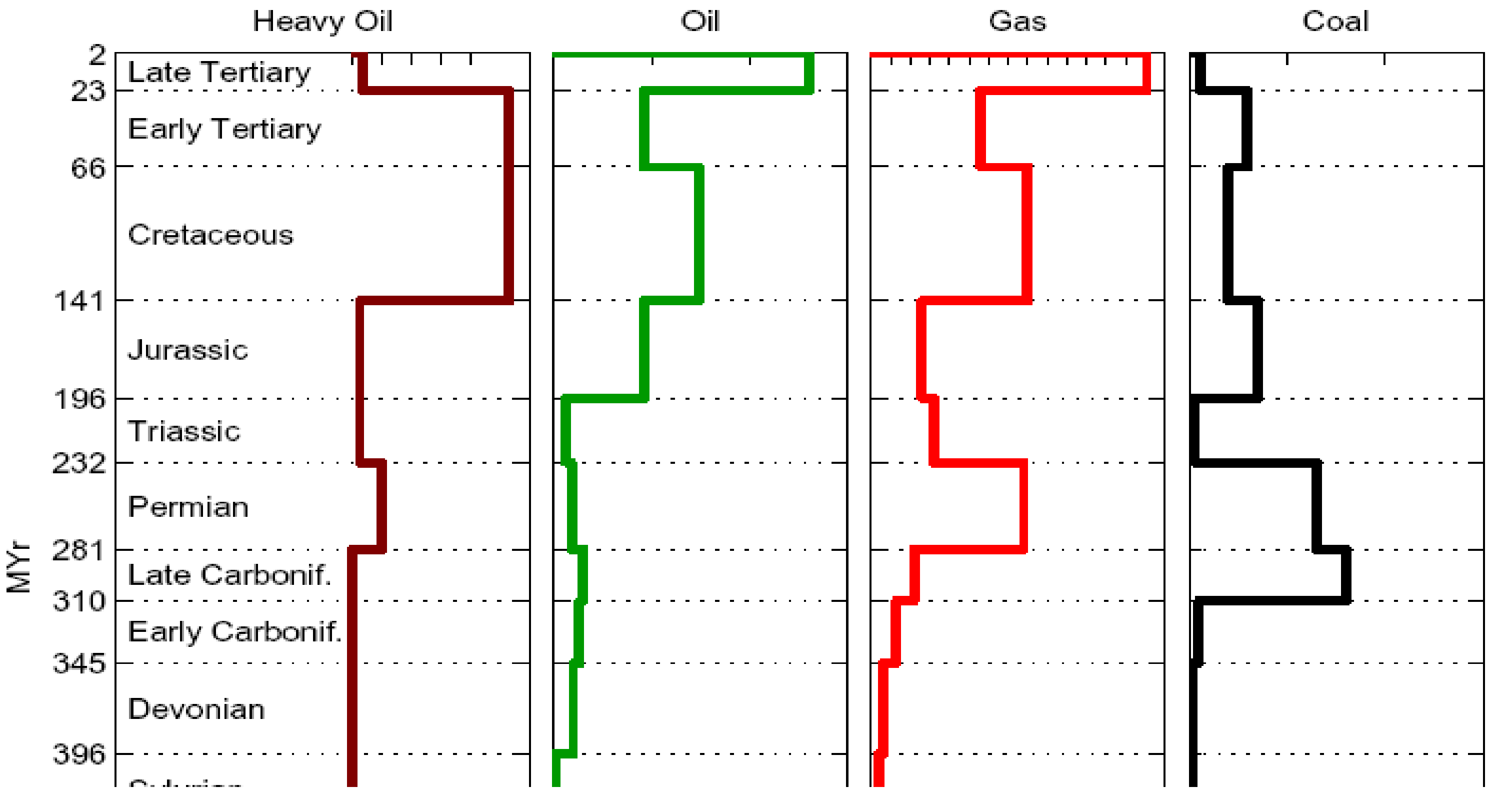
Effect of lignin content on enzymatic recovery of sugars from Miscanthus



Switchgrass composition

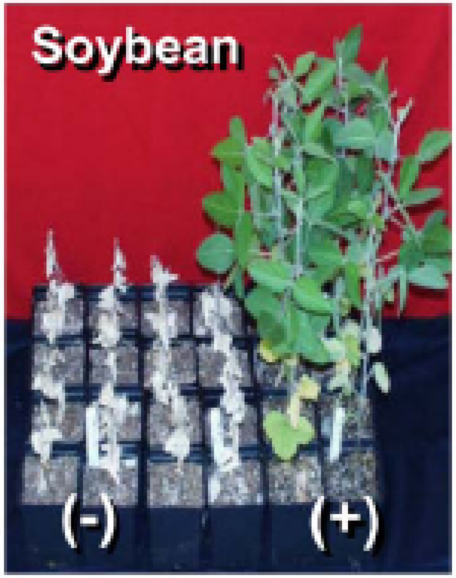


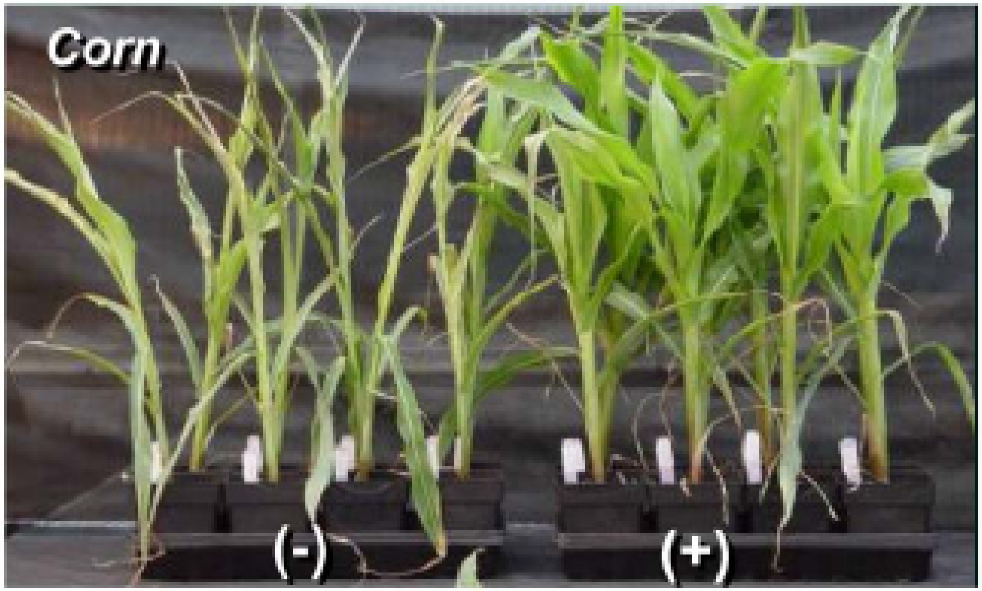
D Vrije et al (2002) Int J Hydrogen Energy 27,1381



“The large coal deposits of the Carboniferous primarily owe their existence to two factors… the appearance of bark-bearing trees (and in particular the evolution of the bark fiber lignin) [and] the development of extensive lowland swamps and forests in North America and Europe. It has been hypothesized that large quantities of wood were buried during this period because animals and decomposing bacteria had not yet evolved that could effectively digest the new lignin.”

Progress in engineering crops plants for drought resistance





From Christopher Somerville, IAC workshop, 2006

Commercial ethanol production from cellulose

The biggest energy gains will come from improved fuel production from cellulose/lignin

Microbial Production of Bio-fuels and Synthetic Biology

Jay Keasling

Director, Physical Biosciences Division

Lawrence Berkeley National Laboratory

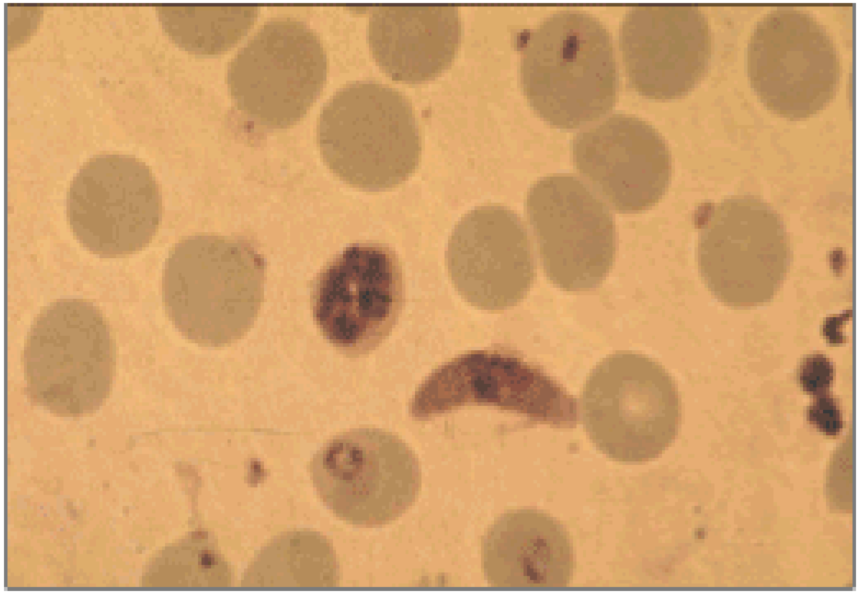
&

Depts. of Chemical Engineering & Bioengineering

University of California, Berkeley

Malaria

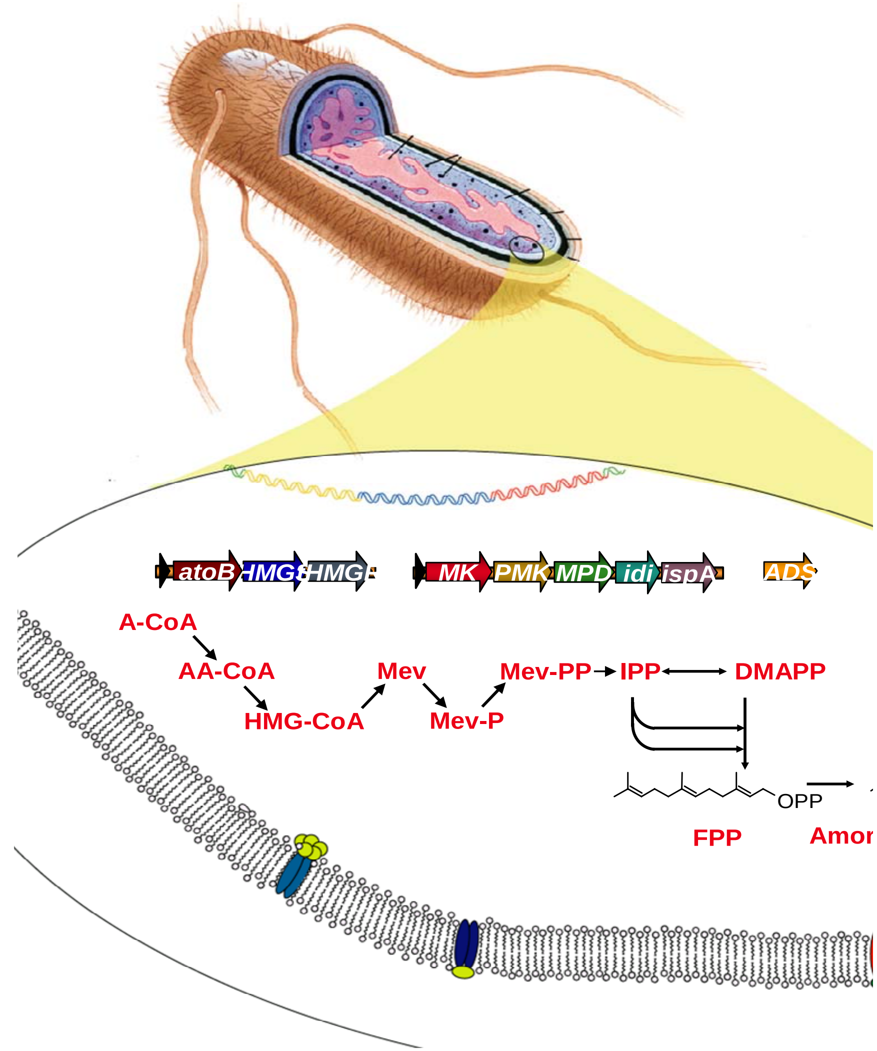
- Caused by *Plasmodium*, a single-cell protozoan
  - Transmitted by Anopheles mosquito
  - Destroys red blood cells
  - *Plasmodium* in South America and Southeast Asia is largely resistant to chloroquine – based drugs



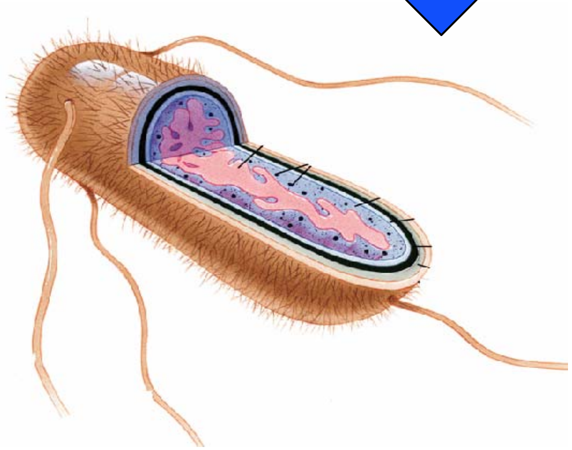
Synthetic Biology:

Production of artemisinin in bacteria Jay Keasling

Identify the biosynthesis pathways in *A. annua*



Research, Development & Delivery



Amyris Biotechnologies

Institute for OneWorld Health

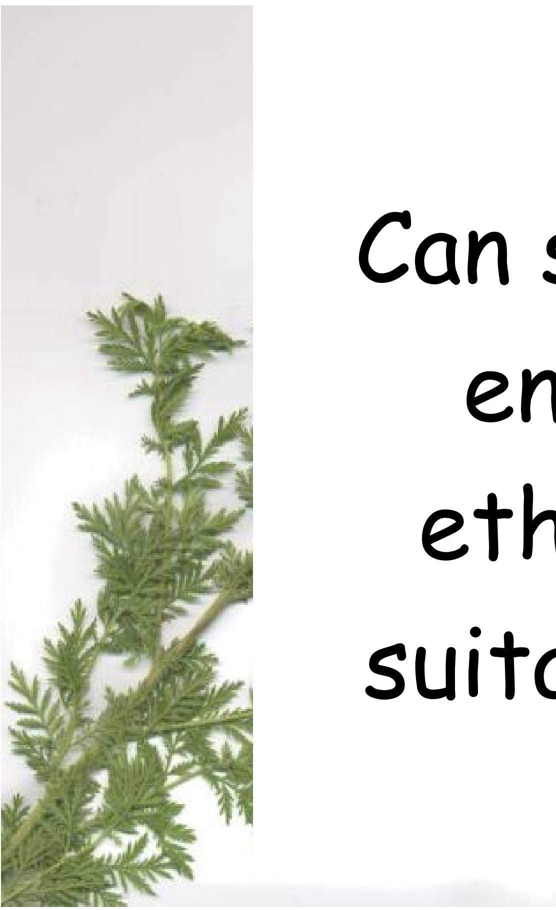
Keasling Laboratory

Artemisinin costs

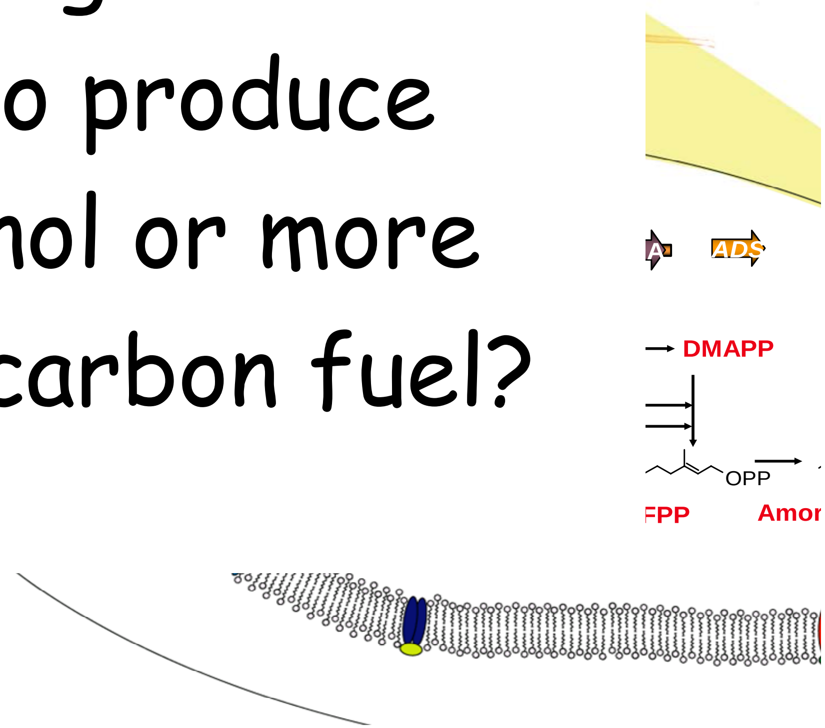
	Artesunate combination treatment
Current cost of drug	$2.25-2.50
Cost with new process	$.21/.12 ?

Synthetic Biology:

Production of artemisinin in bacteria Jay Keasling

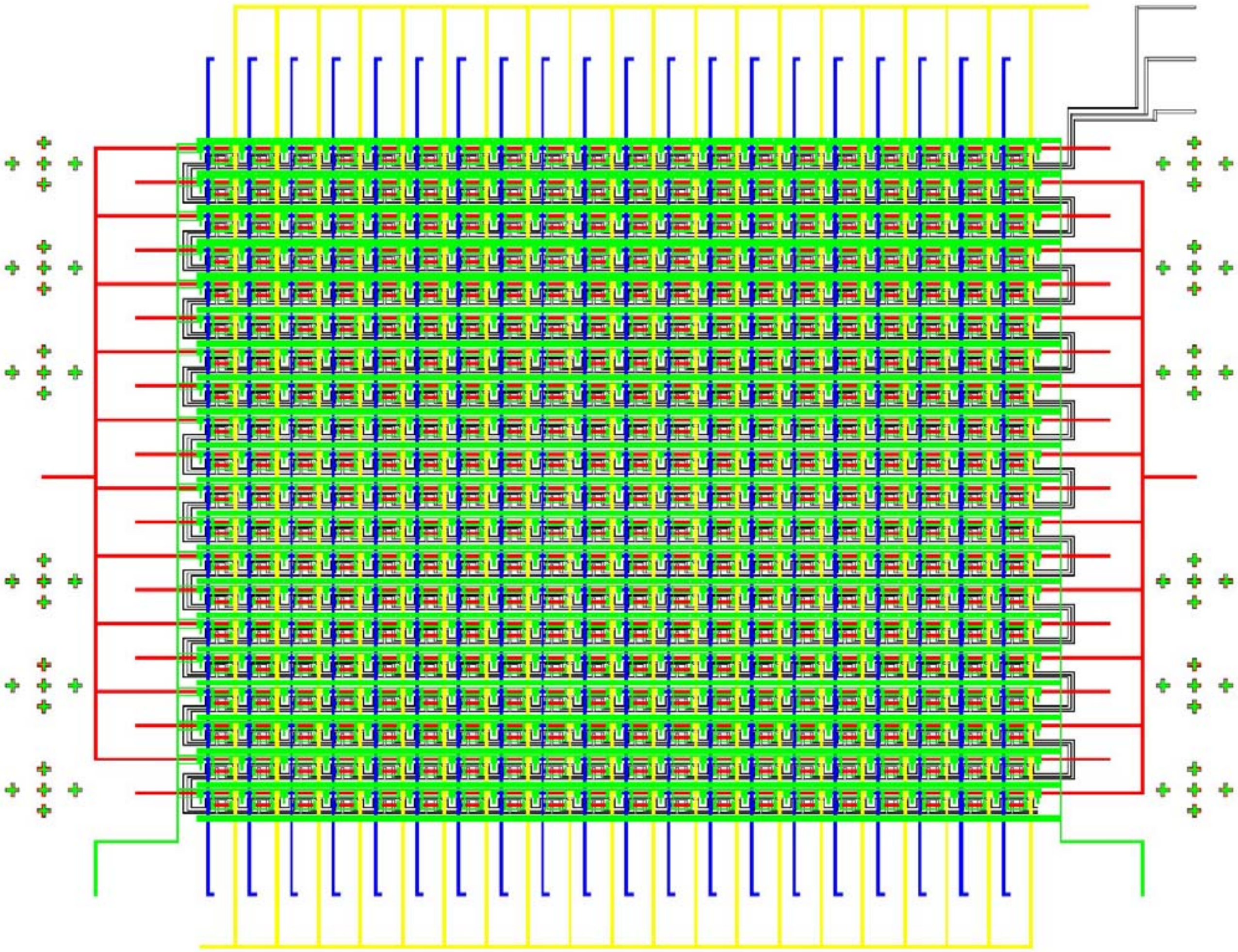


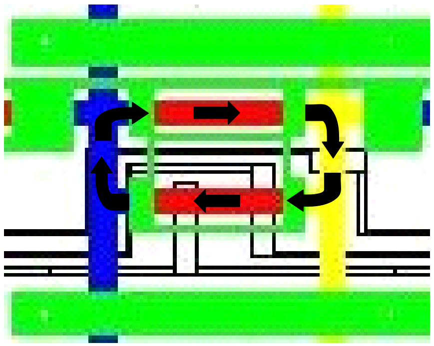
Can synthetic organisms be engineered to produce ethanol, butanol or more suitable hydrocarbon fuel?



Matrix Polymerase Chain Reaction (PCR)
Solving the Macro-Micro Interface Problem

Steve Quake





Red: Primer Input
(Multiplexed by N)

Blue: Template Input
(Multiplexed by N)

Yellow: Taq Input
(Multiplexed by N^2)

N^2 independent PCR reactions performed with 2N+1 inputs!

Can we modify existing organisms (algae) or design new ones to directly produce energy?