The Energy Problem and what we can do about it

Berkeley Repertory Theater
Berkeley, California
23 April, 2007

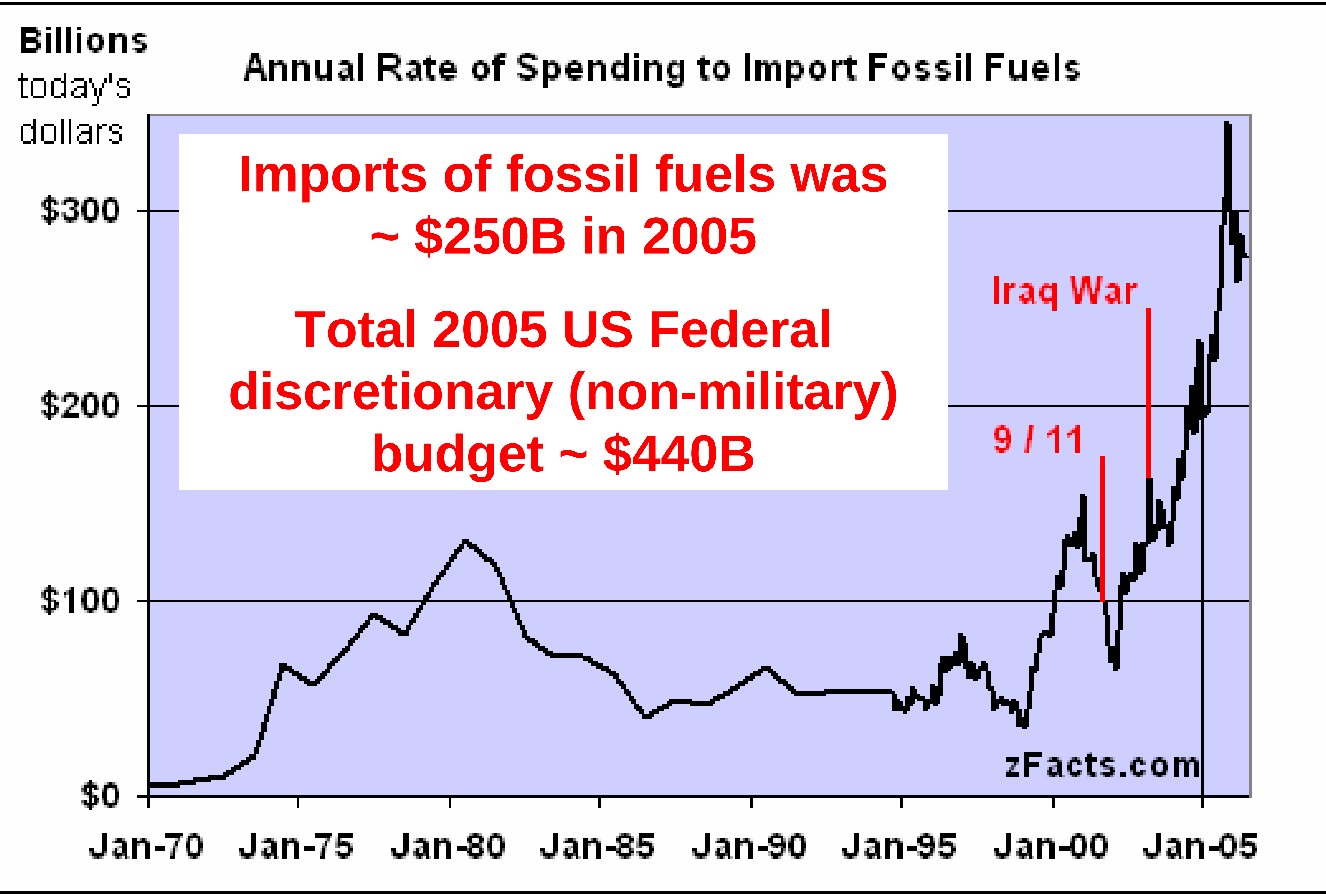
- National, international security and energy security
- Economic prosperity
- Environmental security

  Local pollution

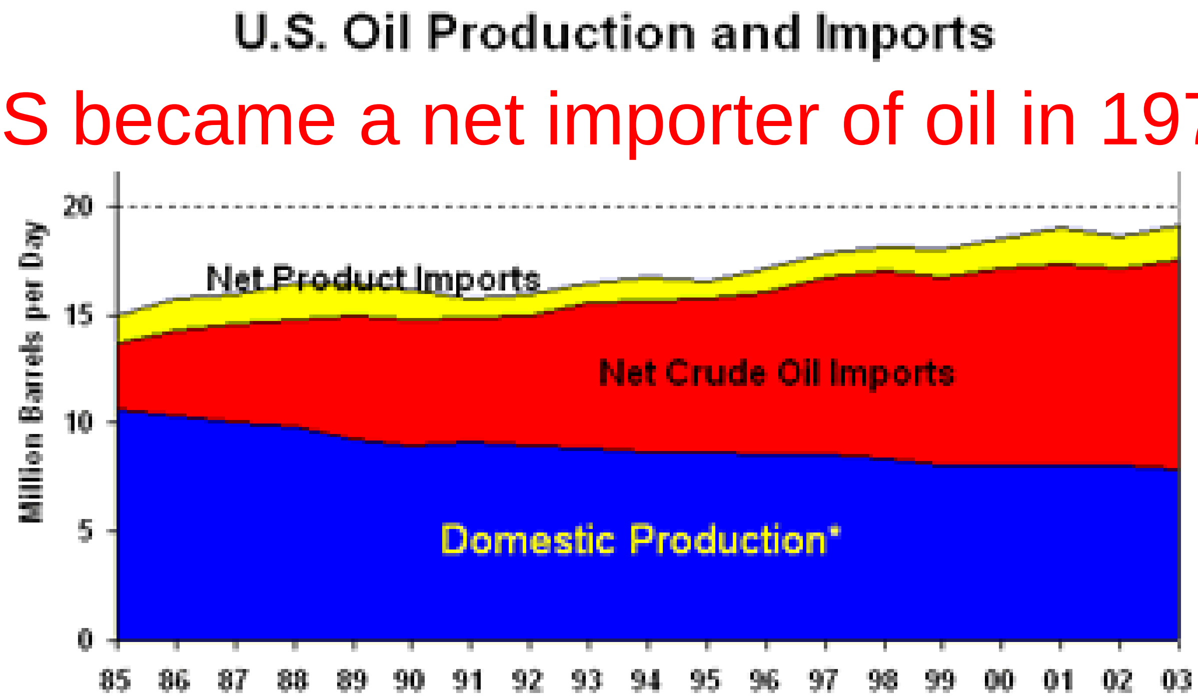
  Global pollution

Imports of fossil fuels was ~ $250B in 2005

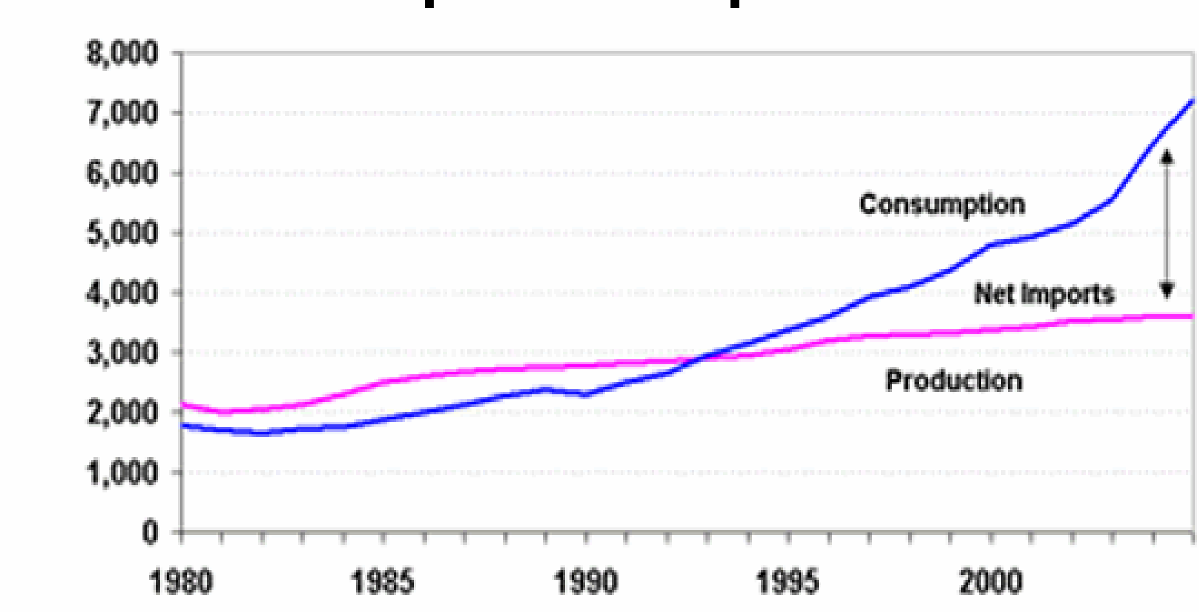
Total 2005 US Federal discretionary (non-military) budget ~ $440B



US became a net importer of oil in 1970



China oil consumption and production 1980 -2005

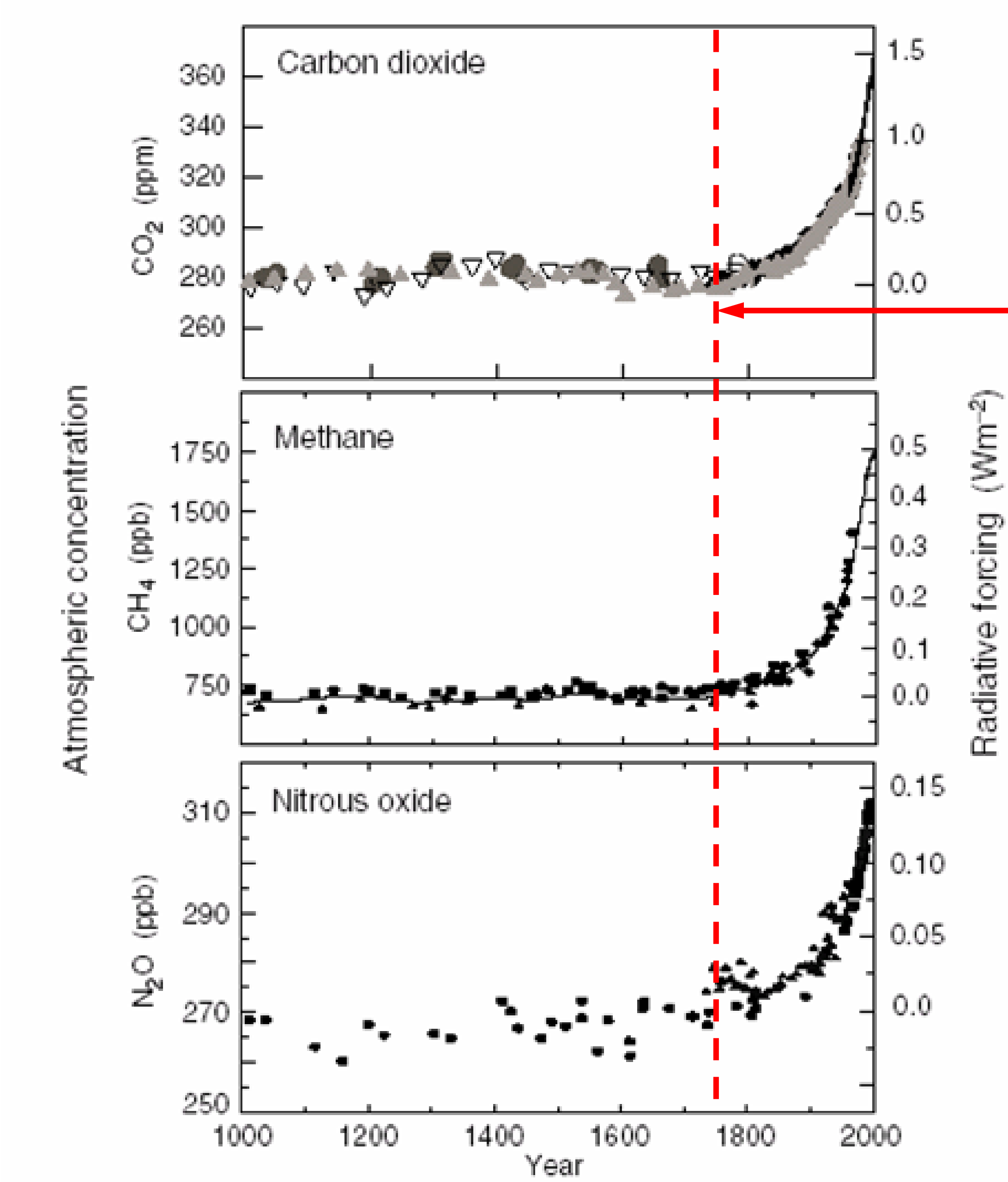


The Earth's climate is changing.

IPCC 2006 study:

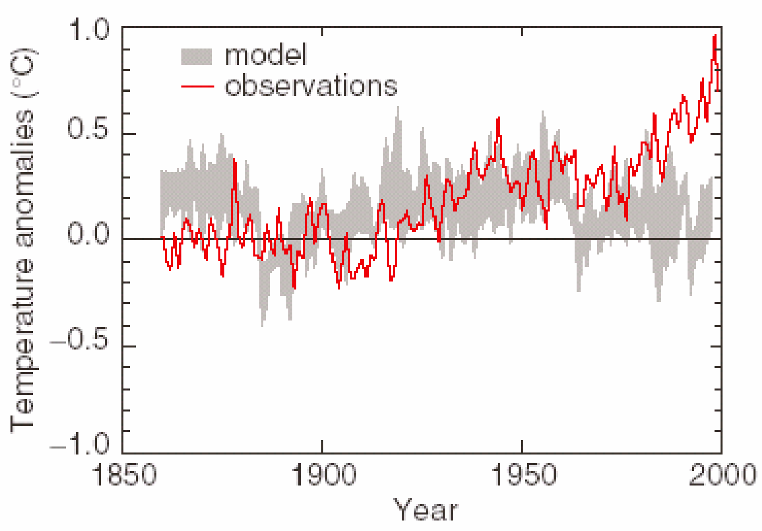
> 90% probable that change is caused by humans.

Concentration of Greenhouse gases

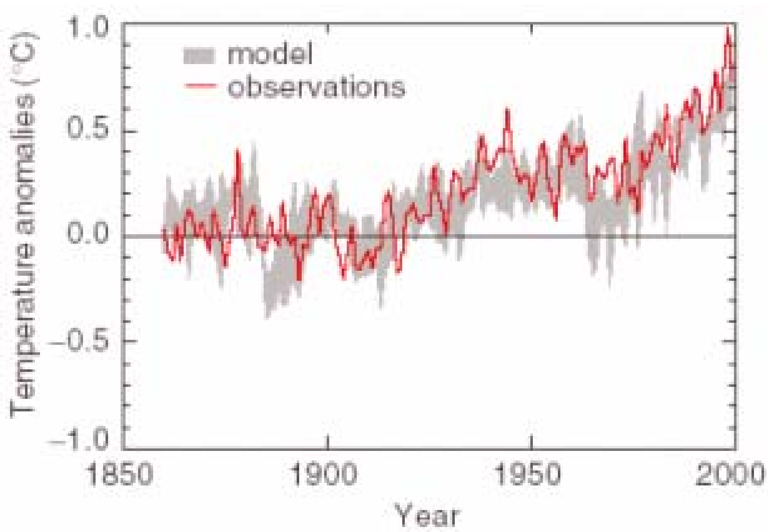


1750,
the
beginning of
the industrial
revolution

Temperature rise due to human emission of greenhouse gases

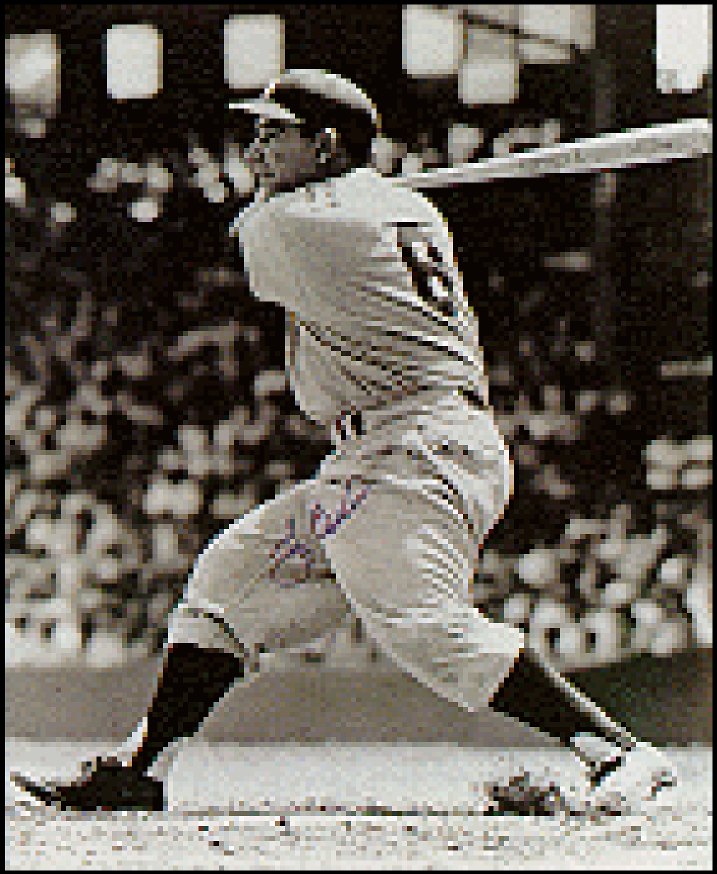


Climate change due to natural causes (solar variations, volcanoes, etc.)



Climate change due to natural causes and human generated greenhouse gases

Can we predict climate change due to increased greenhouse gases?



"Predictions are hard to make, especially about the future."

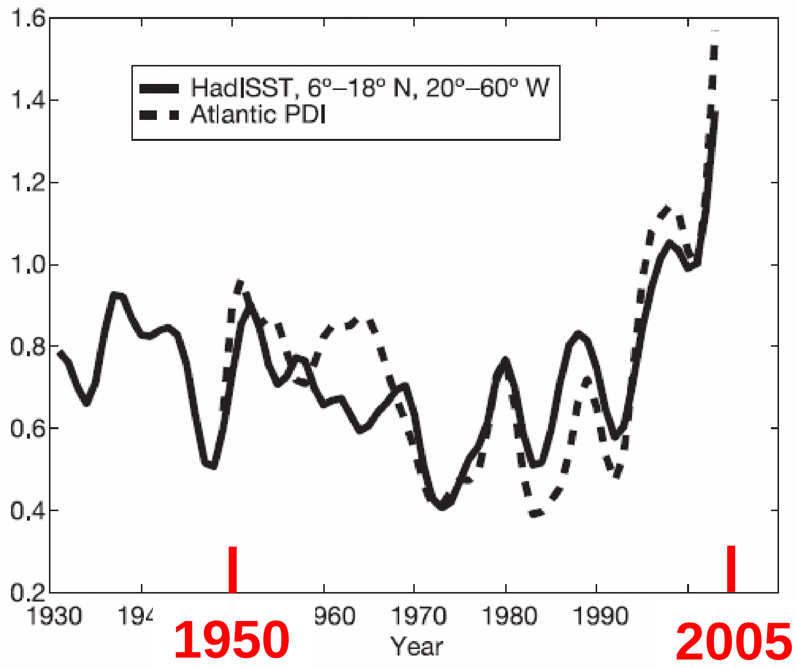
Warm up by predicting the past!

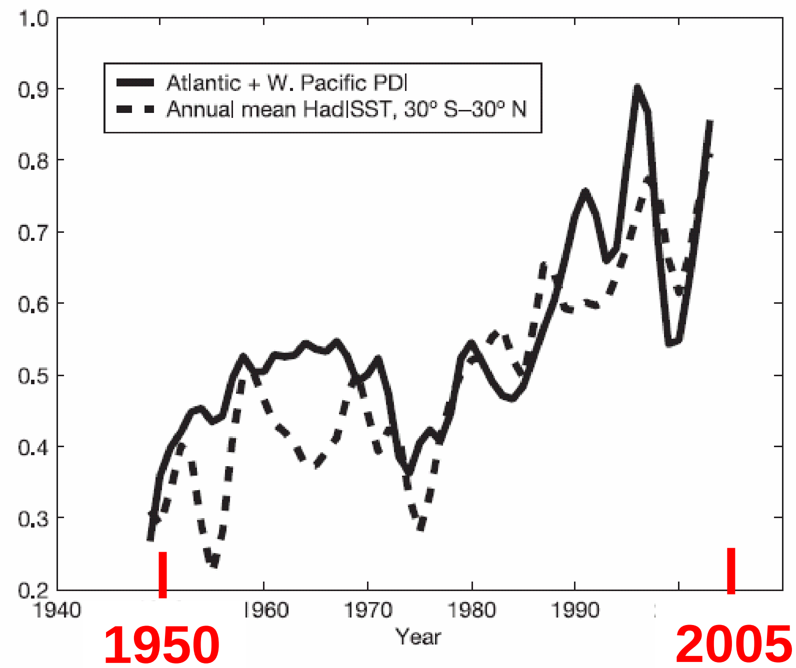
Significant climate change could lead to:

- Increased damage from storms, floods, wildfires
- Property losses and population displacement from sea-level rise
- Productivity of farms, forests, & fisheries
- Increased species extinction
- Spread of disease (malaria,
- **Water Shortages**

Nature, 2005

Correlation between surface ocean temperature and strength of tropical storms





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Hurricane power in the North Atlantic and Pacific have doubled in the last 30 years (Smoothed Data)

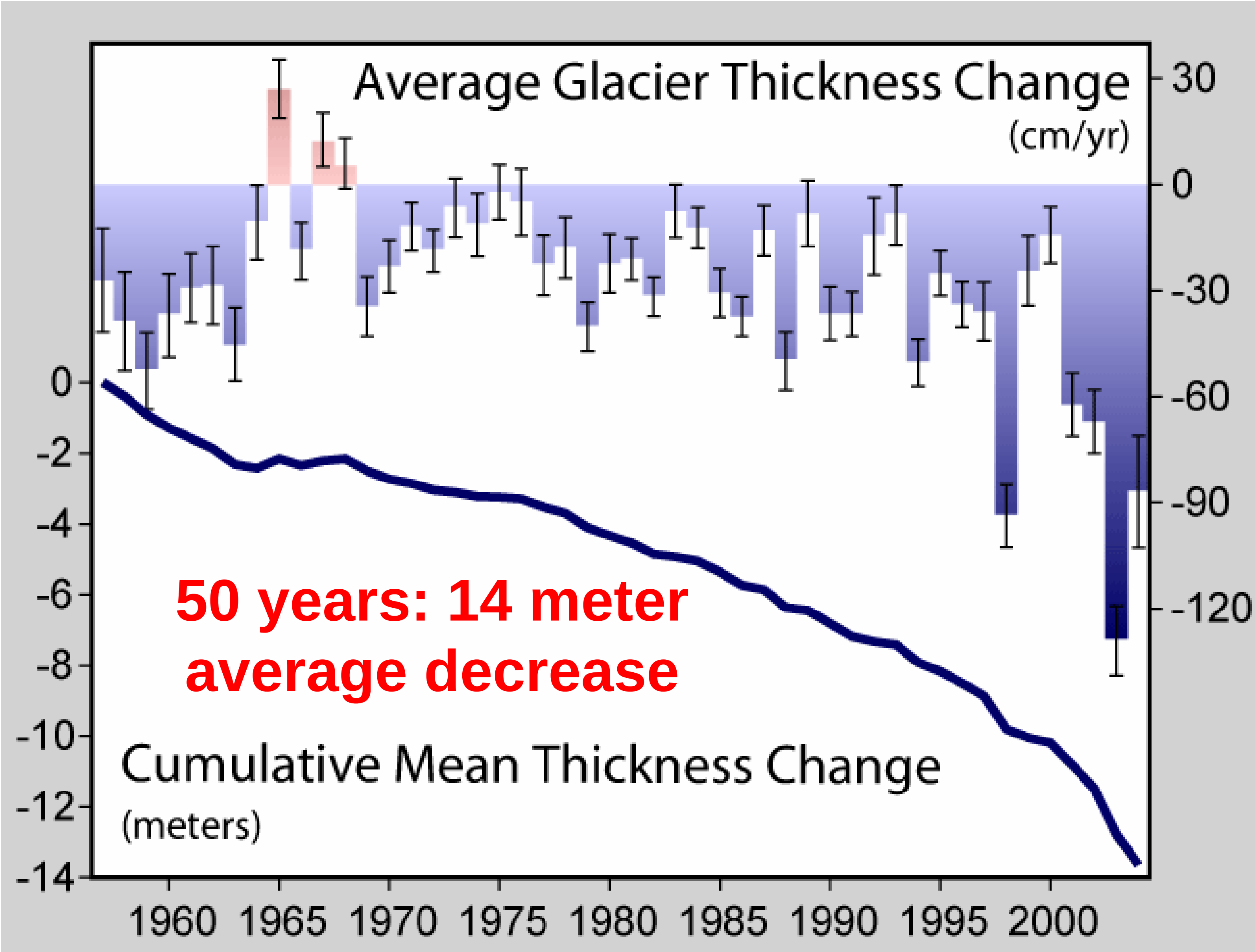
Emissions pathways, climate change, and impacts on California

K. Hayhoea, et al., PNAS **101**, 12422 (2004)

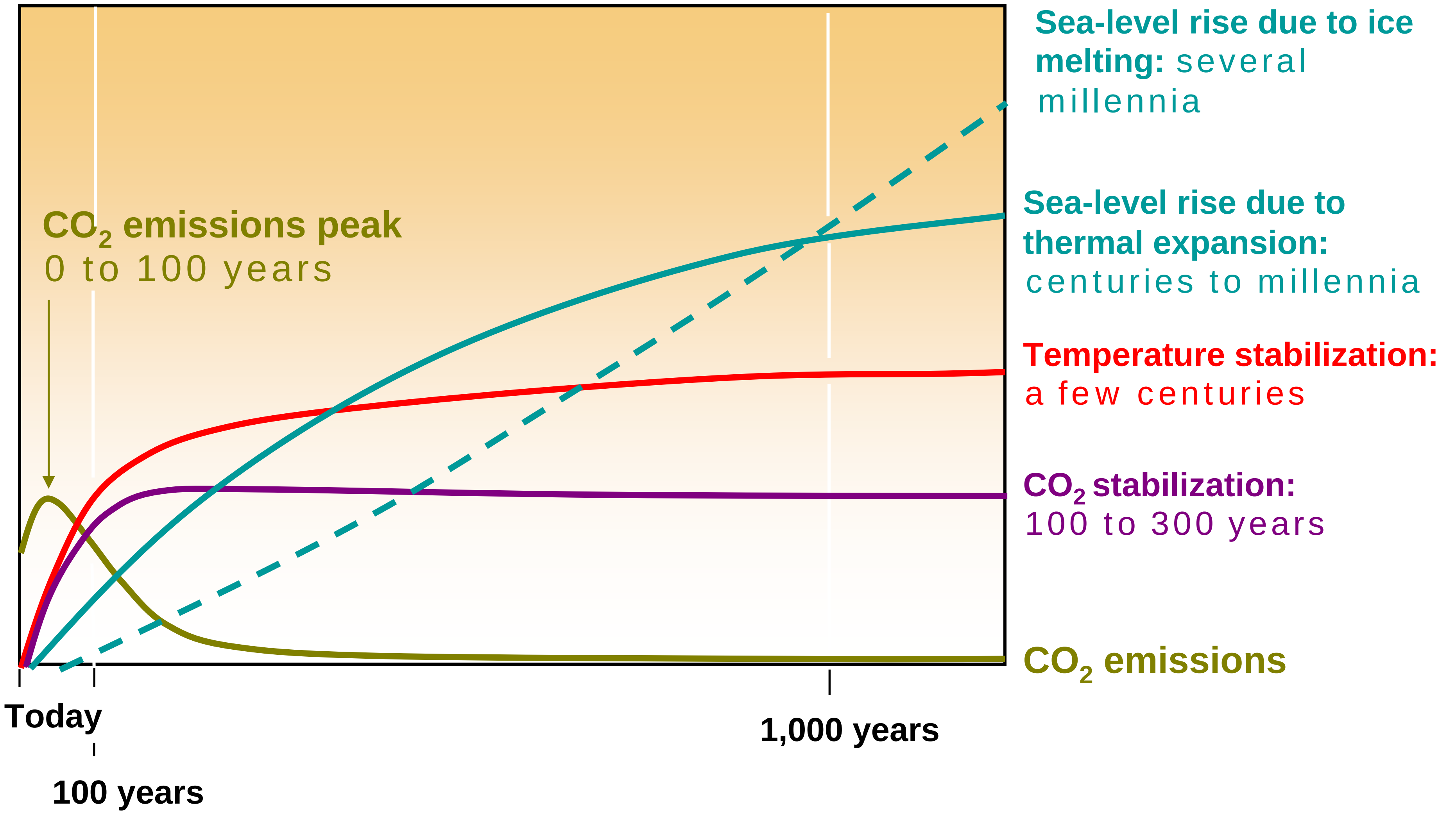
Using two climate models that bracket most of the IPCC emissions scenarios:

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

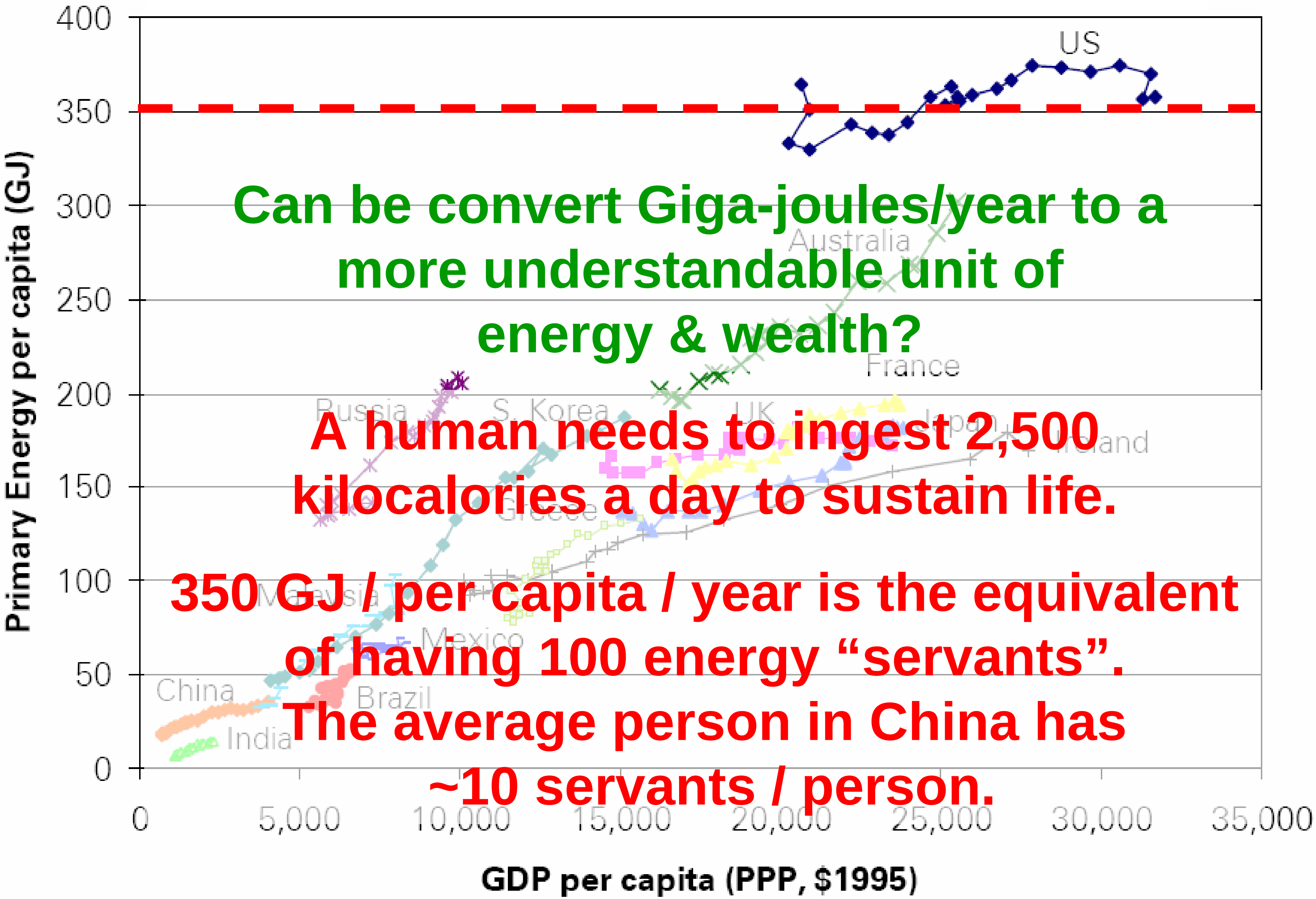
"…[this] could fundamentally disrupt California's water rights system."


Average Glacier Thickness Change
(cm/yr)
30
0
-30
-60
-90
-120
0
-2
-4
-6
-8
-10
-12
-14
50 years: 14 meter
average decrease
Cumulative Mean Thickness Change
(meters)
1960
1965
1970
1975
1980
1985
1990
1995
2000

CO_2 Concentration, Temperature, and Sea Level will rise long after Emissions are Reduced



Energy demand vs. GDP per capita



Source: UN and DOE EIA

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.

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
Steven Chu, USA

A dual strategy is needed to solve the energy problem:

1) Maximize energy efficiency and minimize energy use

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.)

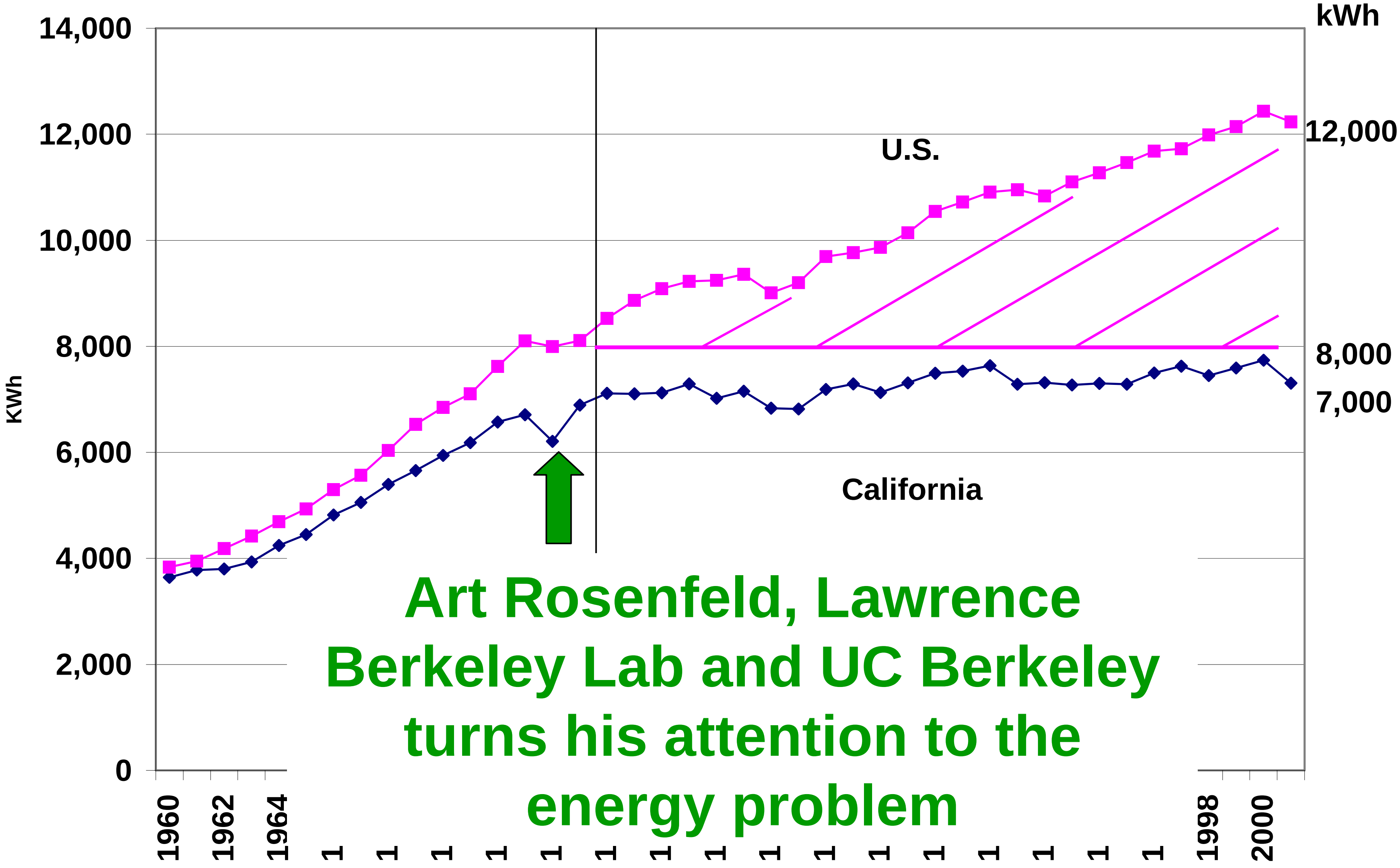
Berkeley Lab 200-acre site

Today:

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

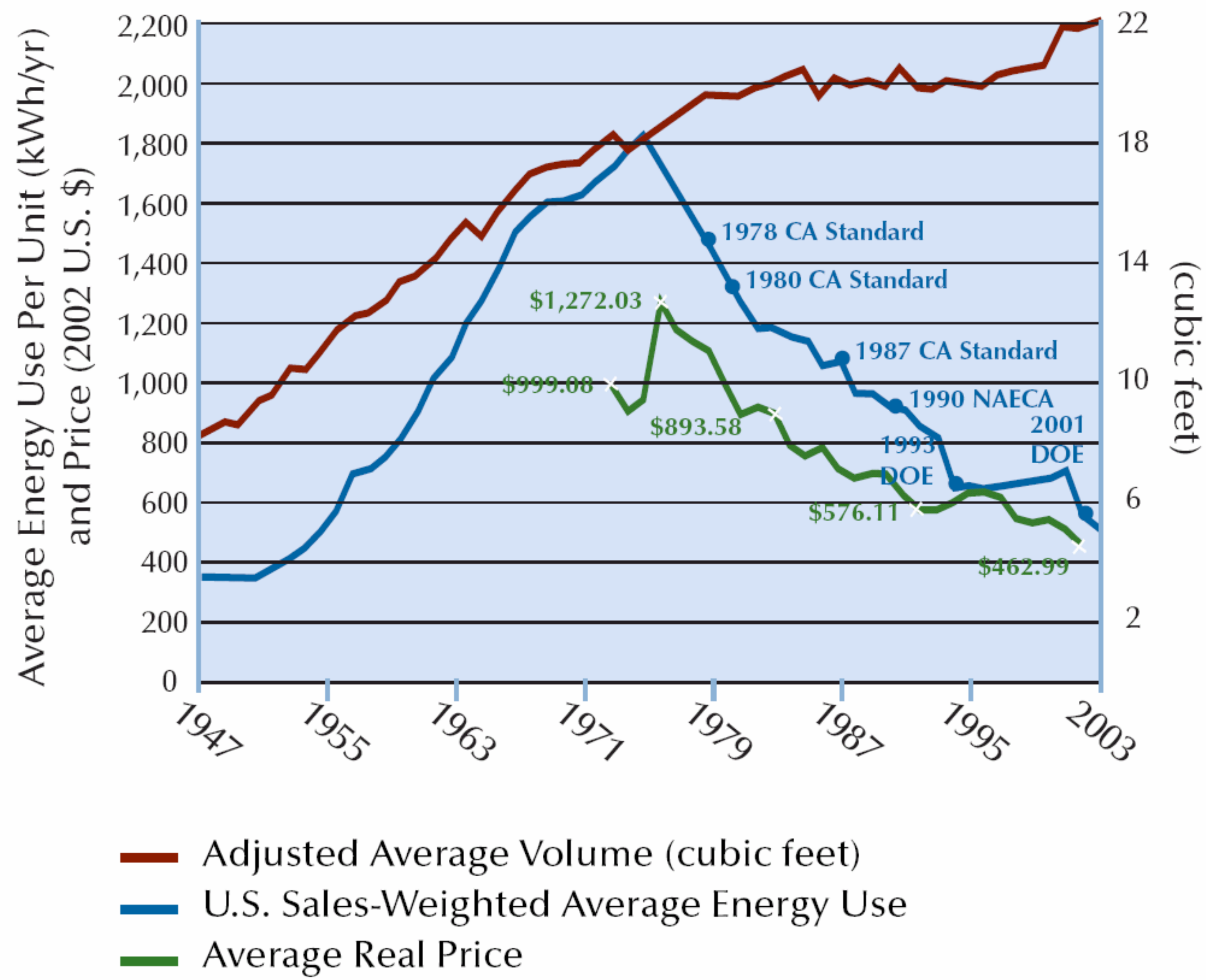
UC Berkeley Campus

Electricity Consumption/person in the US and California

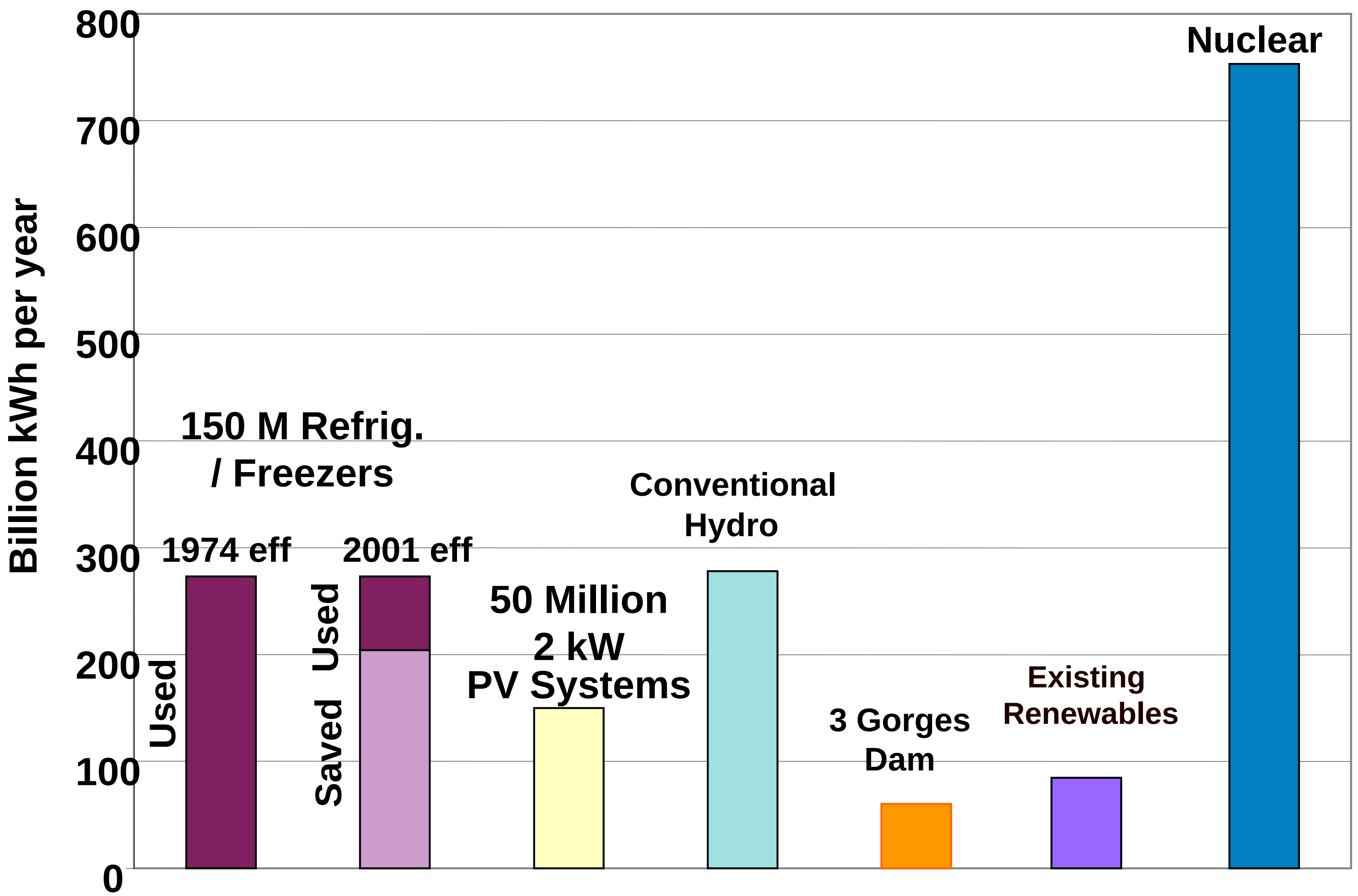


Art Rosenfeld, Lawrence Berkeley Lab and UC Berkeley turns his attention to the energy problem

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

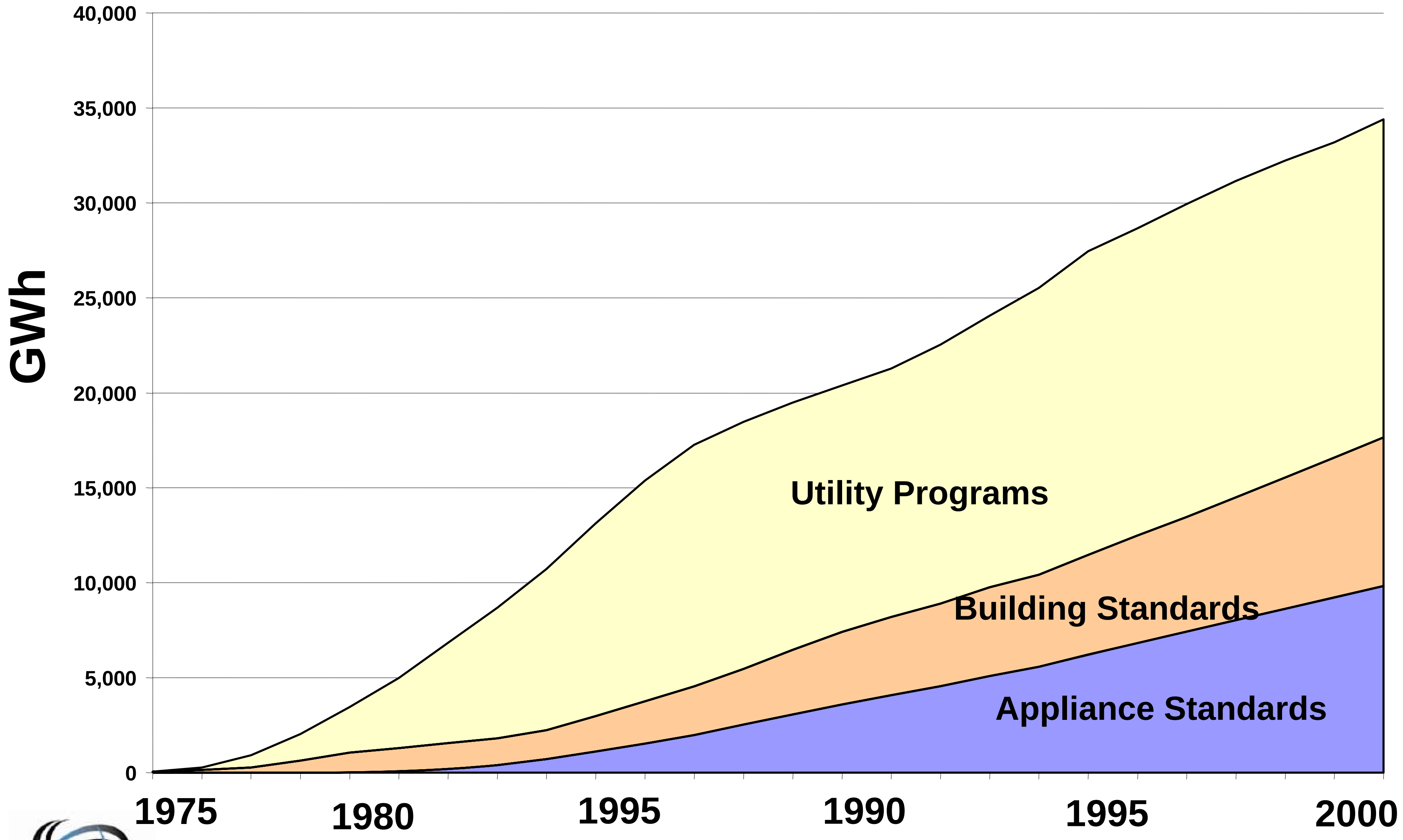


US Electricity Use of Refrigerators and Freezers compared to sources of electricity



Data from 2001

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



Efficiency

Energy for the Future

Source: Mike Messenger, Calif. Energy Commission Staff, April 2003

Potential supply-side solutions to the Energy Problem

- Coal, tar sands, shale oil, …
- Fusion
- Fission
- Wind
- Solar photocell and thermal
- Bio-mass
- Energy storage

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!

67% of the world supply of coal:

US	27%
Russia	17%
China	13%
India	10%

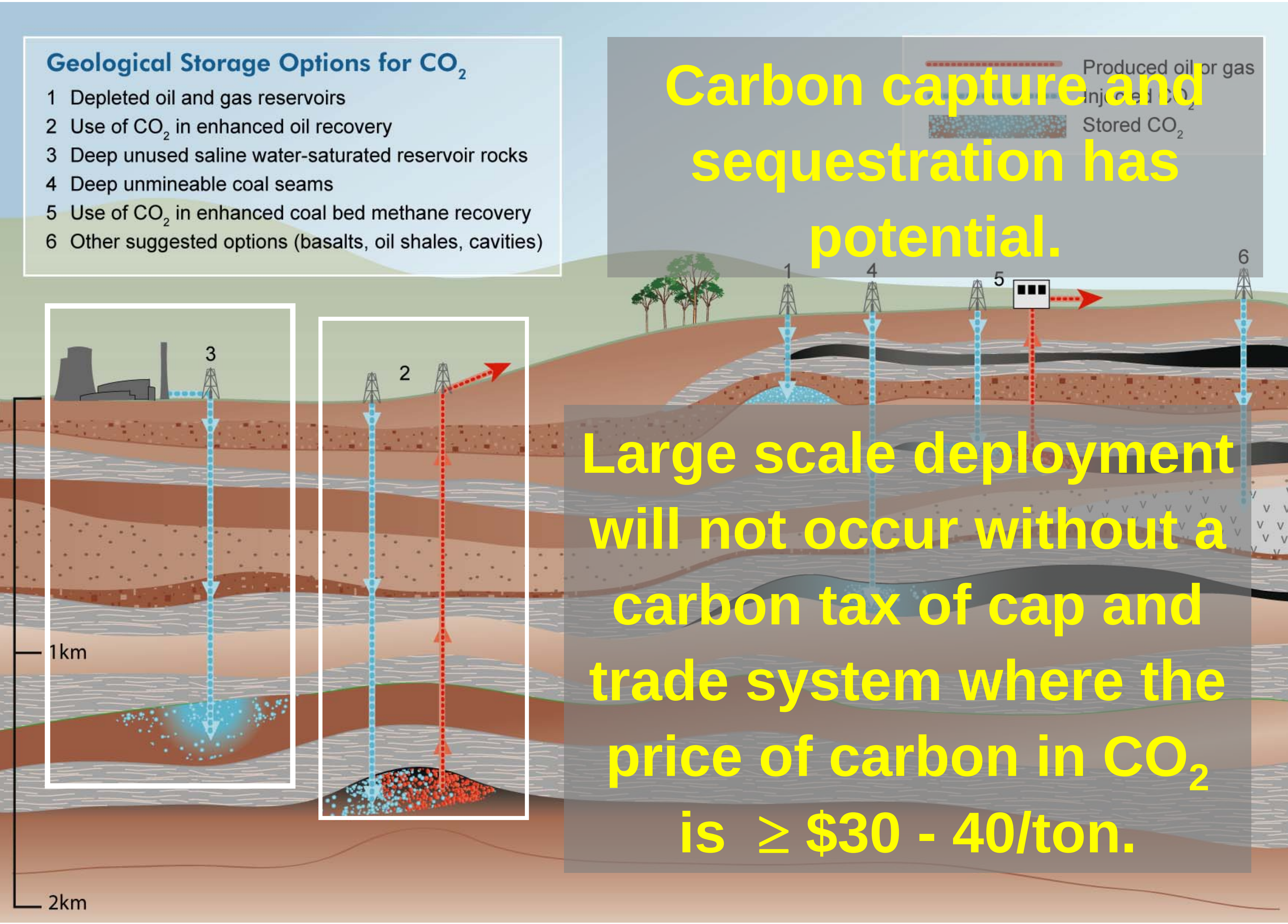
There is abundant fossil energy from coal, methane coal beds, tar sands, shale oil, … for at least 400 years.

Liquefaction of coal remains a possibility to reduce oil dependency.

Coal is the default option of the US, China, and India.

Carbon capture and sequestration has potential.

Large scale deployment will not occur without a carbon tax of cap and trade system where the price of carbon in CO_2 is $\geq$ \$30 - 40/ton.



Google satellite image of a tars sands open pit mining facility near Fort McMurray Canada.

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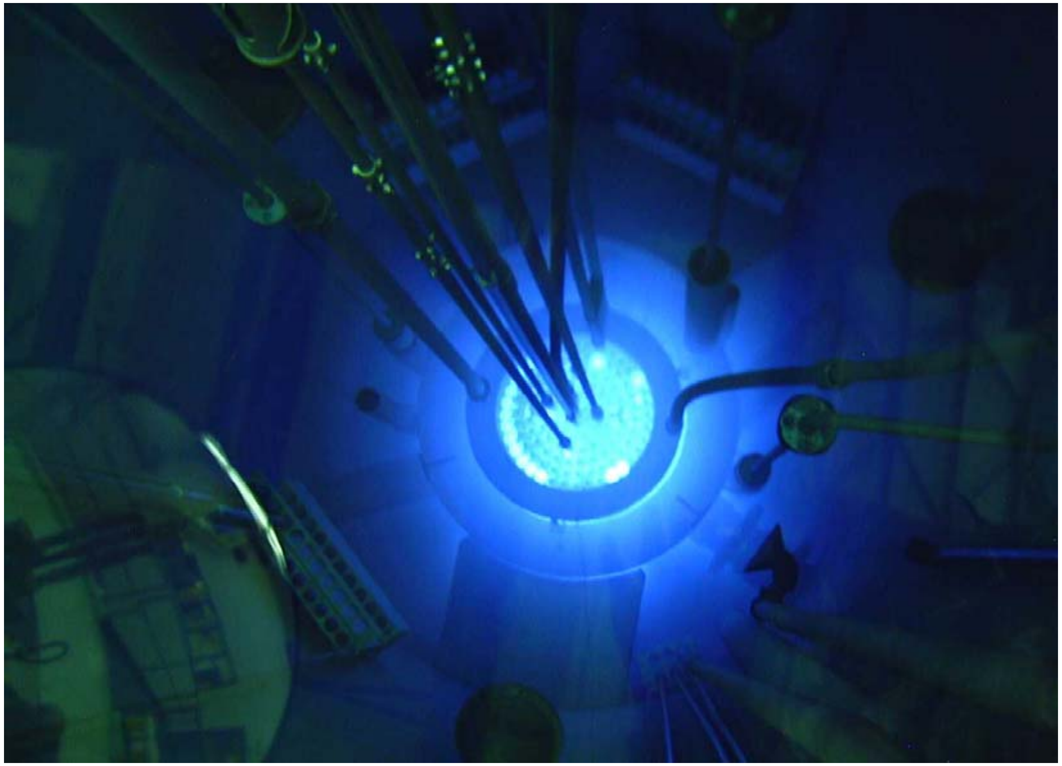
Nuclear Fission



Waste and Nuclear Proliferation

Burning coal releases radioactivity

A 1,000 MW coal plant emits roughly 100 times the radioactivity of a similar sized nuclear power plant.

Ore mining, fuel processing, operation and waste disposal increases nuclear emissions to ~ $\frac{1}{4}$ of coal radioactive emissions.

The equivalent total dose from coal use, from mining to power plant operation to waste disposal is not known.

Source: Alex Gabbard
Oak Ridge National Laboratory
www.ornl.gov/info/ornlreview/rev26-34/text/colmain.html

Potential supply-side solutions to the Energy Problem

- Coal, tar sands, shale oil, …
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- Fission
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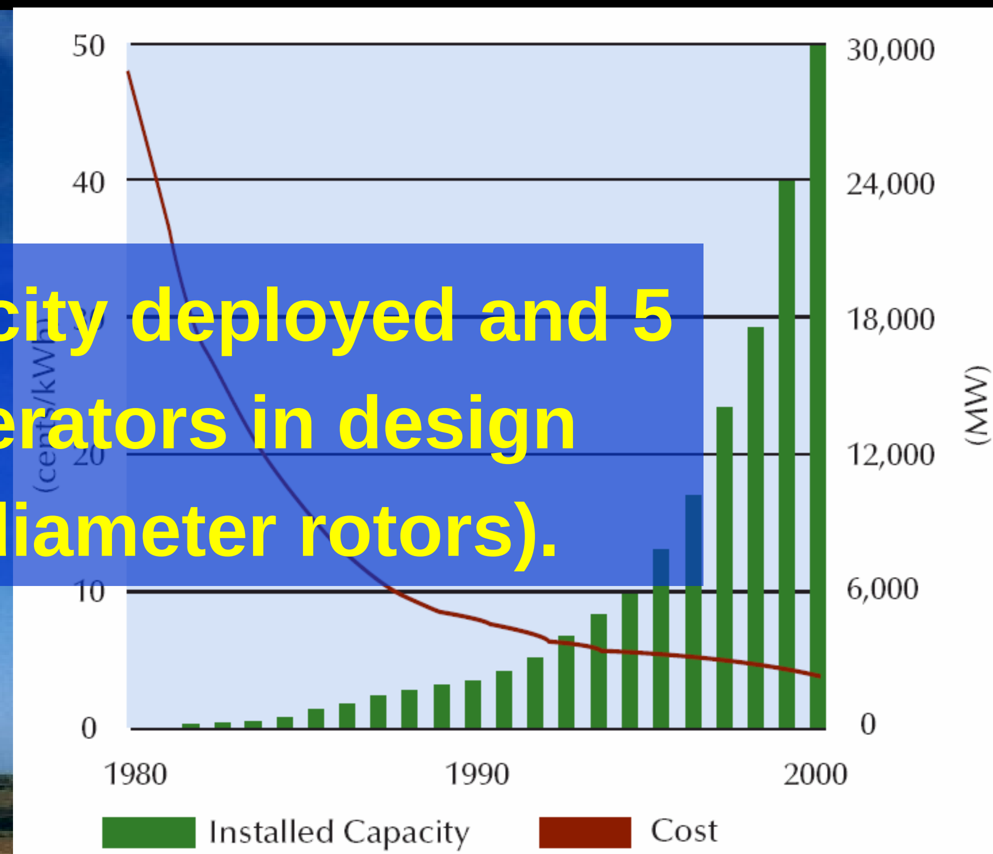
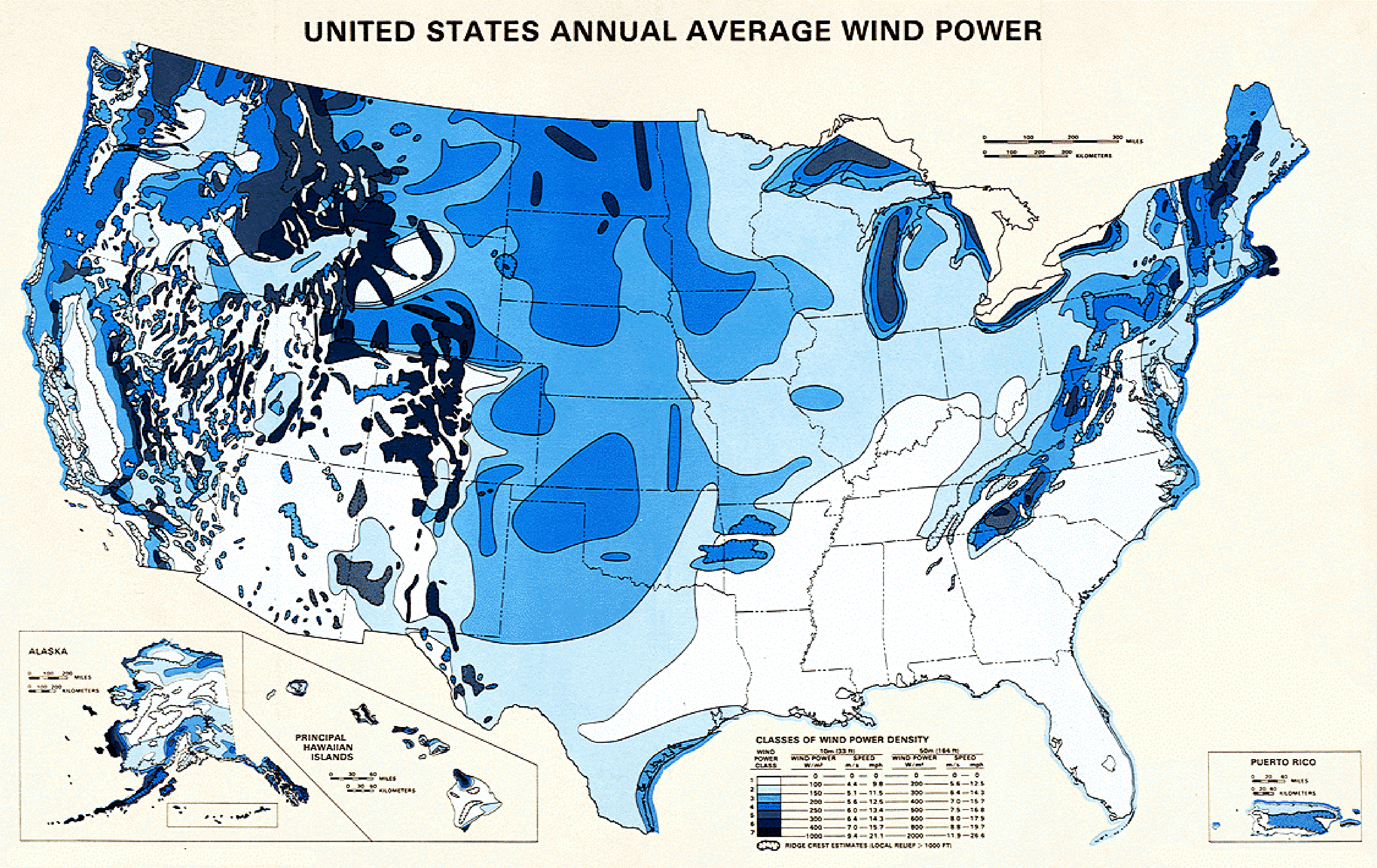
Modest but **stable** fiscal incentives were essential to stimulate long term development of power generation from wind



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

Wind sites in the US



Potential supply-side solutions to the Energy Problem

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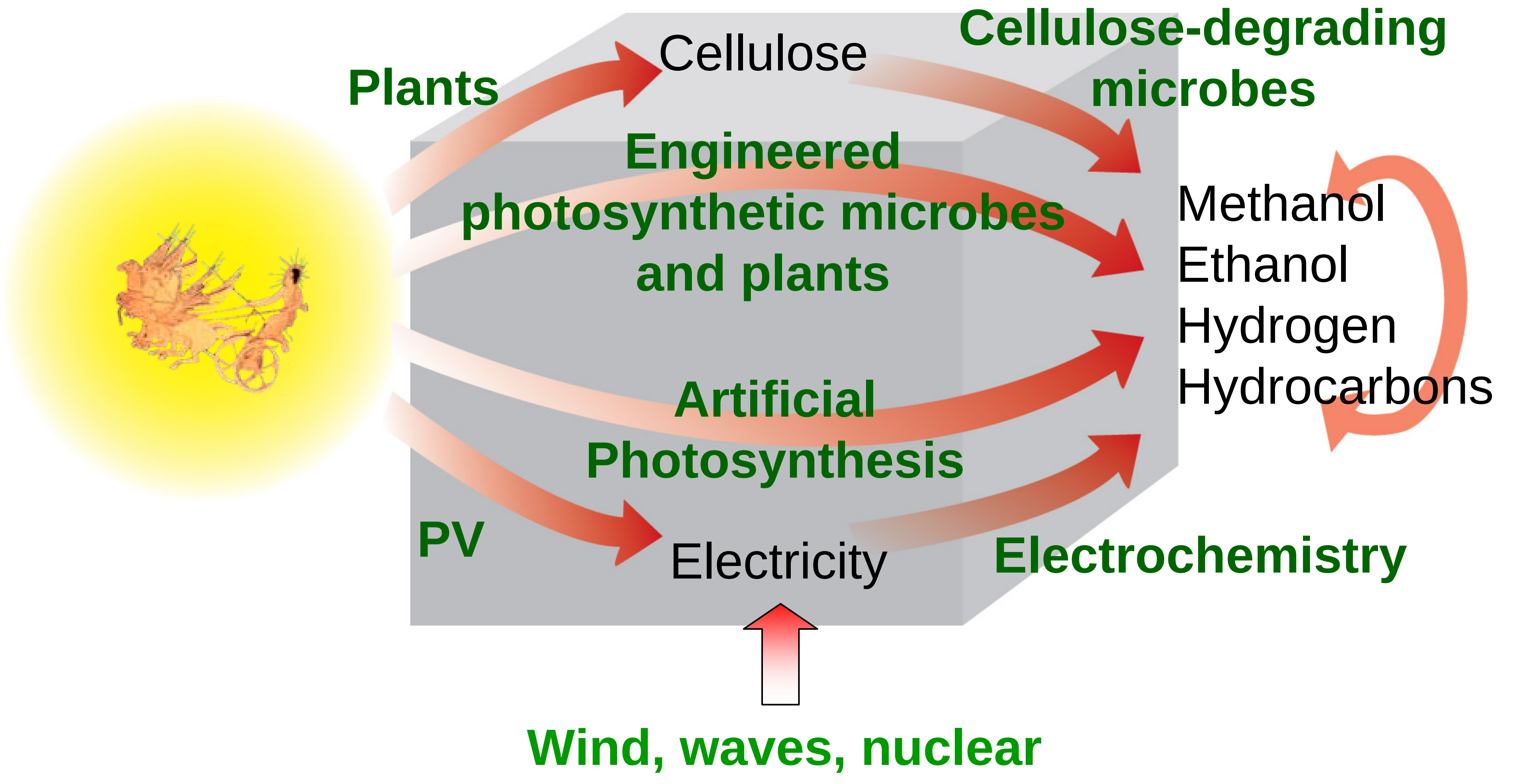
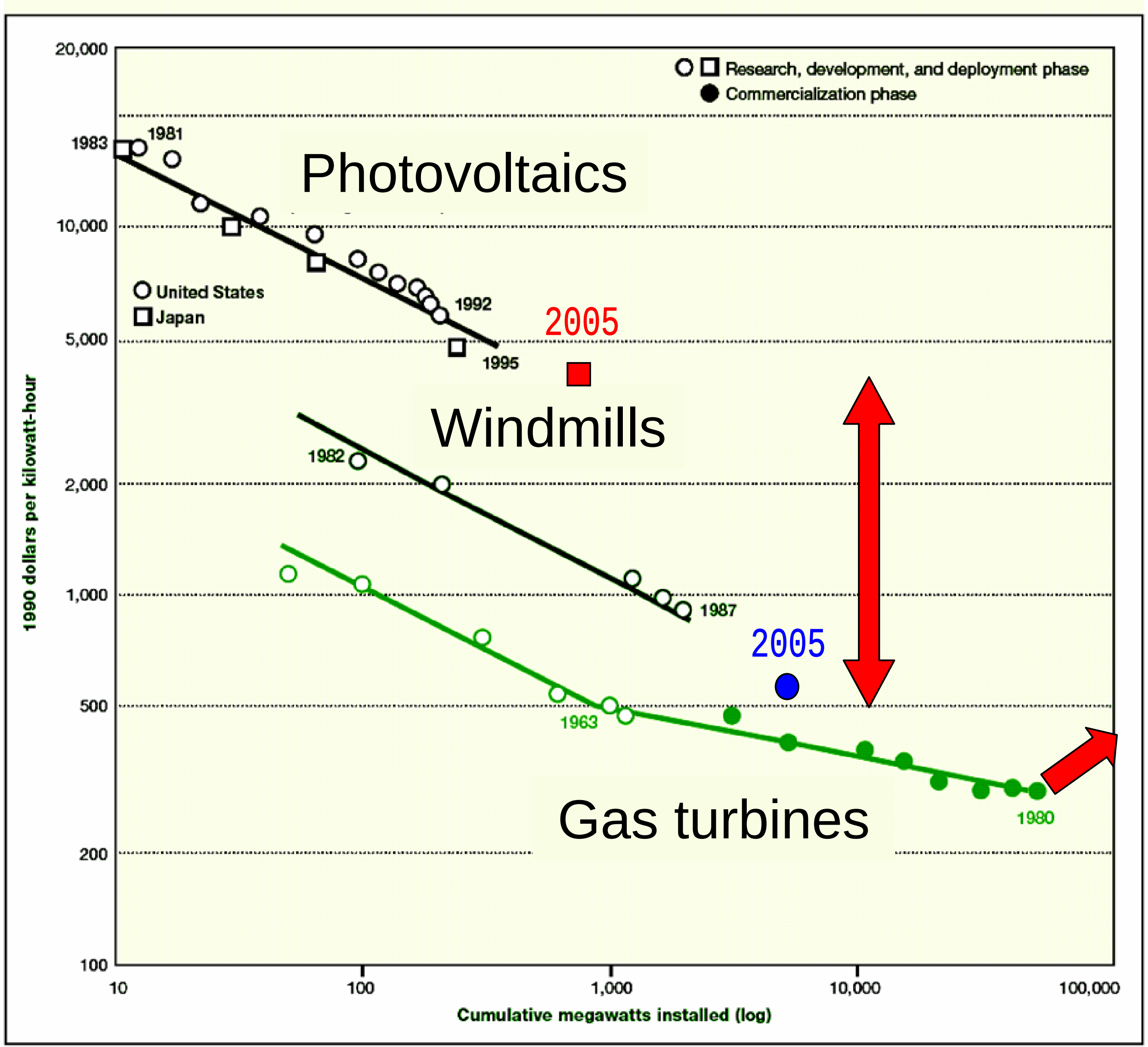
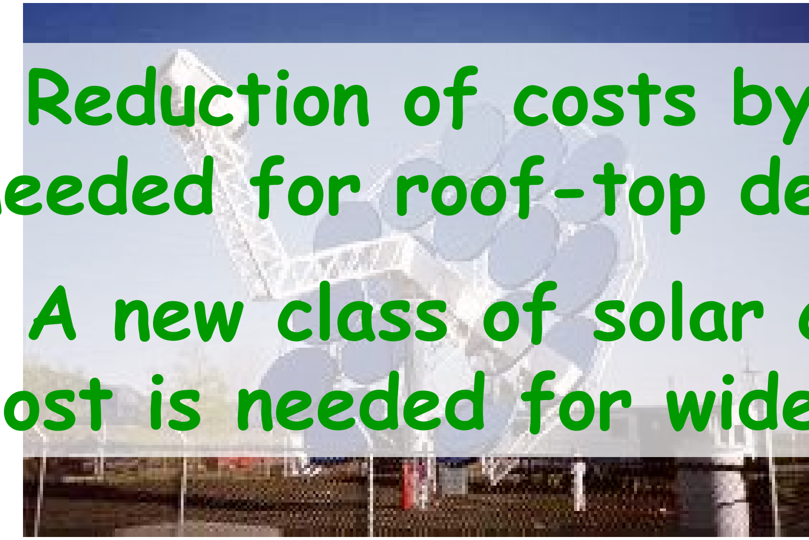
Helios: Lawrence Berkeley Laboratory and UC Berkeley's attack on the energy problem

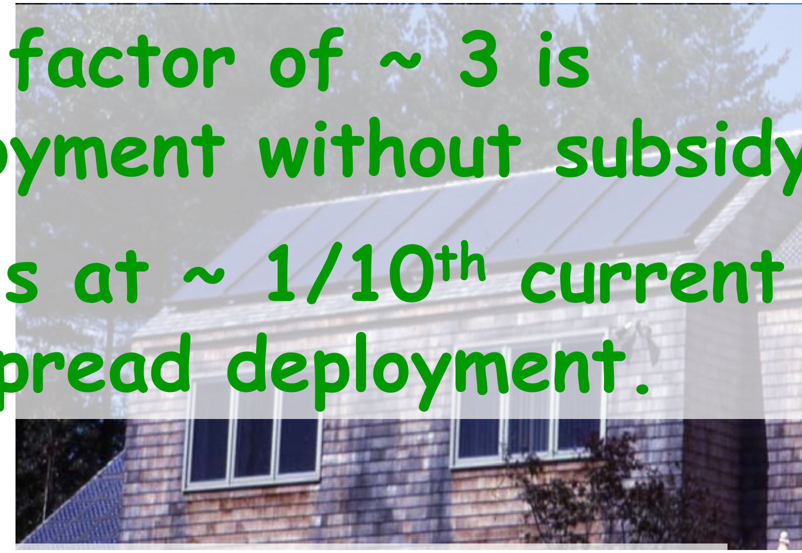


Cost of electricity generation
(1990 dollars/kilowatt hour)

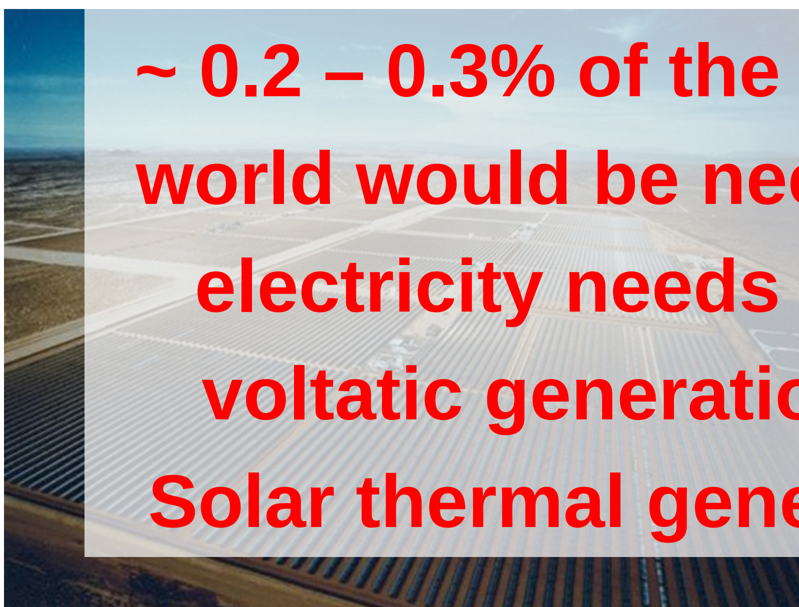


Solar thermal | **Solar photovoltaic**

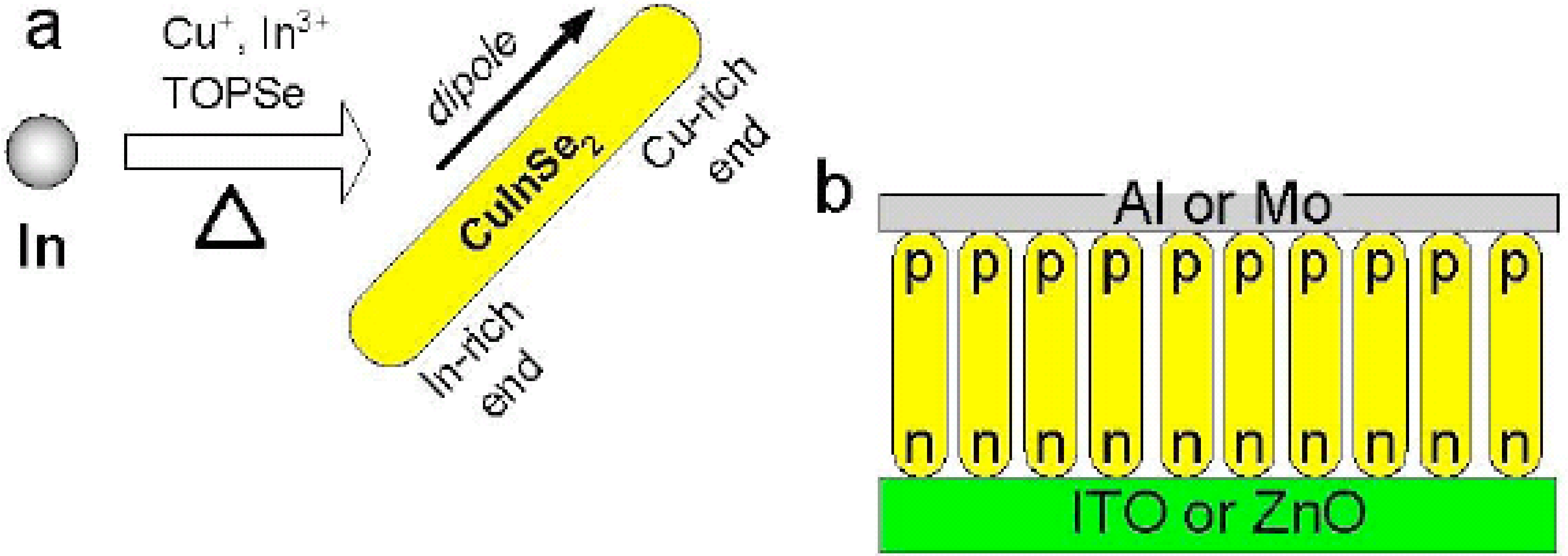




- Reduction of costs by a factor of ~ 3 is needed for roof-top deployment without subsidy.
- A new class of solar cells at ~ 1/10th current cost is needed for wide-spread deployment.



~ 0.2 – 0.3% of the non-arable land in the world would be need to generate current electricity needs (~ 4 TW) with photo-voltatic generation at 20% efficiency. Solar thermal generation is a possiblity.



$CuInSe_2$ electric dipoles conduct electrons and holes to opposite electrodes.

An electric field can be used to align the nano-particles in assembly.

D.A. Durkee, et al. Adv. Materials, **2005**, 17 (2003)

Reel-to-reel mass production of solar cells?

Energy Biosciences Institute

Joint Bio-Energy Institute (JBEI)

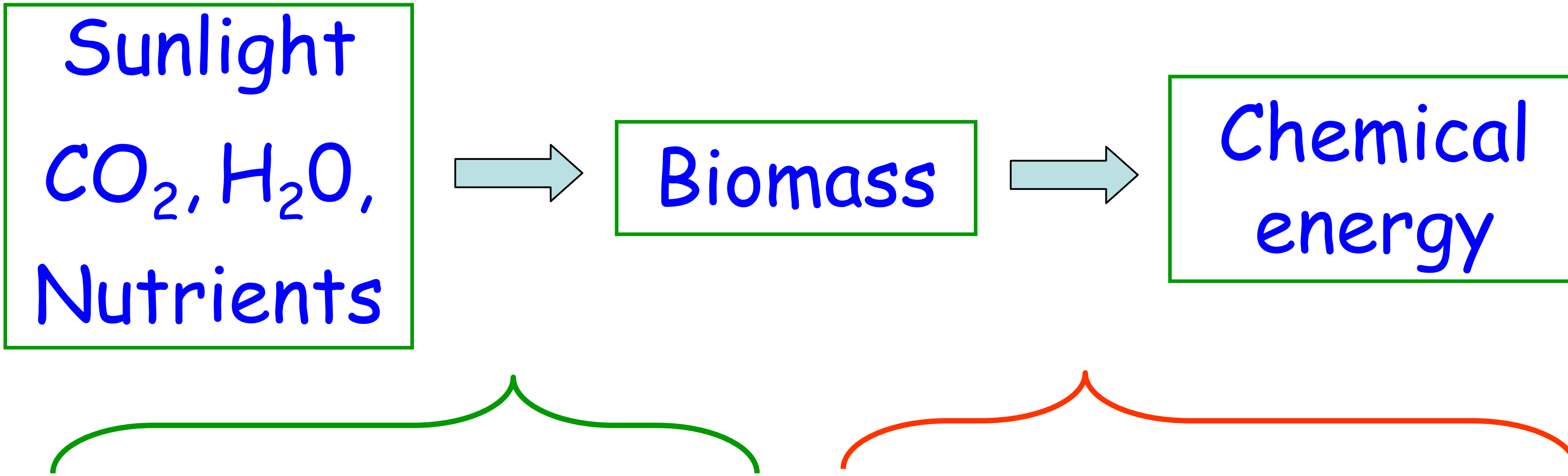
LBNL, Sandia, LLNL, UC Berkeley, Stanford, UC Davis

Univ. California, Berkeley

Lawrence Berkeley National Lab

Univ. Illinois, Urbana-Champaign

Sunlight to energy via Bio-mass



More efficient use of water, sunlight, nutrients.

Drought and pest resistant

Improve conversion of cellulose into fuel.

Develop new organisms for biomass conversion.

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 [illegible]	0.0 [illegible]	131.1 [illegible]	415.5 [illegible]
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 [illegible]	[illegible]	119.2 [illegible]	404.9 [illegible]
2003	367.9 ± 2.4	31.5 ± 0.3	117.0 ± 1.8	405.1 ± 3.5

In 21 years, Agriculture land use decreased by:

Cropland	52.0 M acres
Pasture land	14.1 M acres
Range land	10.4 M acres
Total	74.5 M acres

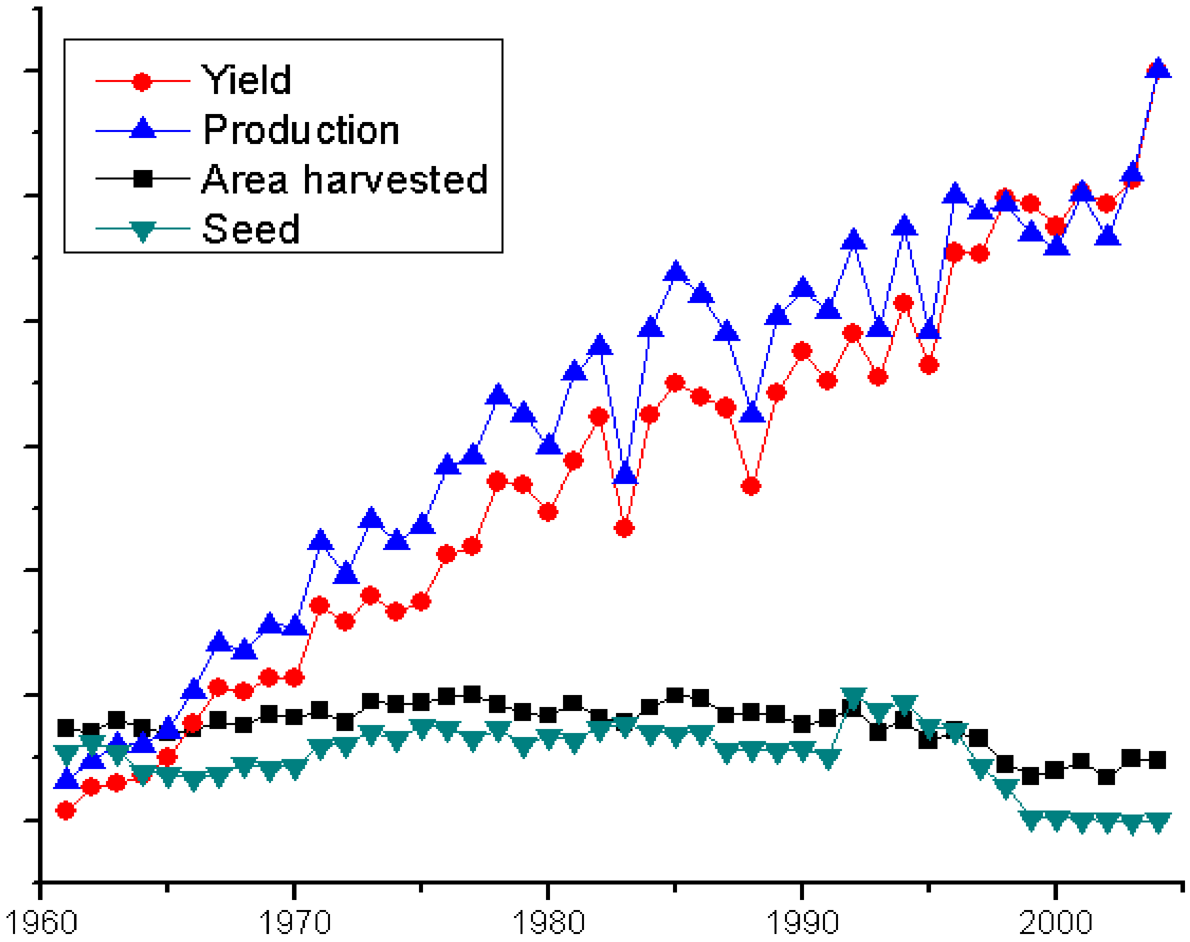
Conservation Reserve Program begun:

31.5 M acres

In the future, tens of millions more acres may be pulled out of production because of WTO agreements

Source: US Dept of Agriculture

World Production of Grain (1961 – 2004)

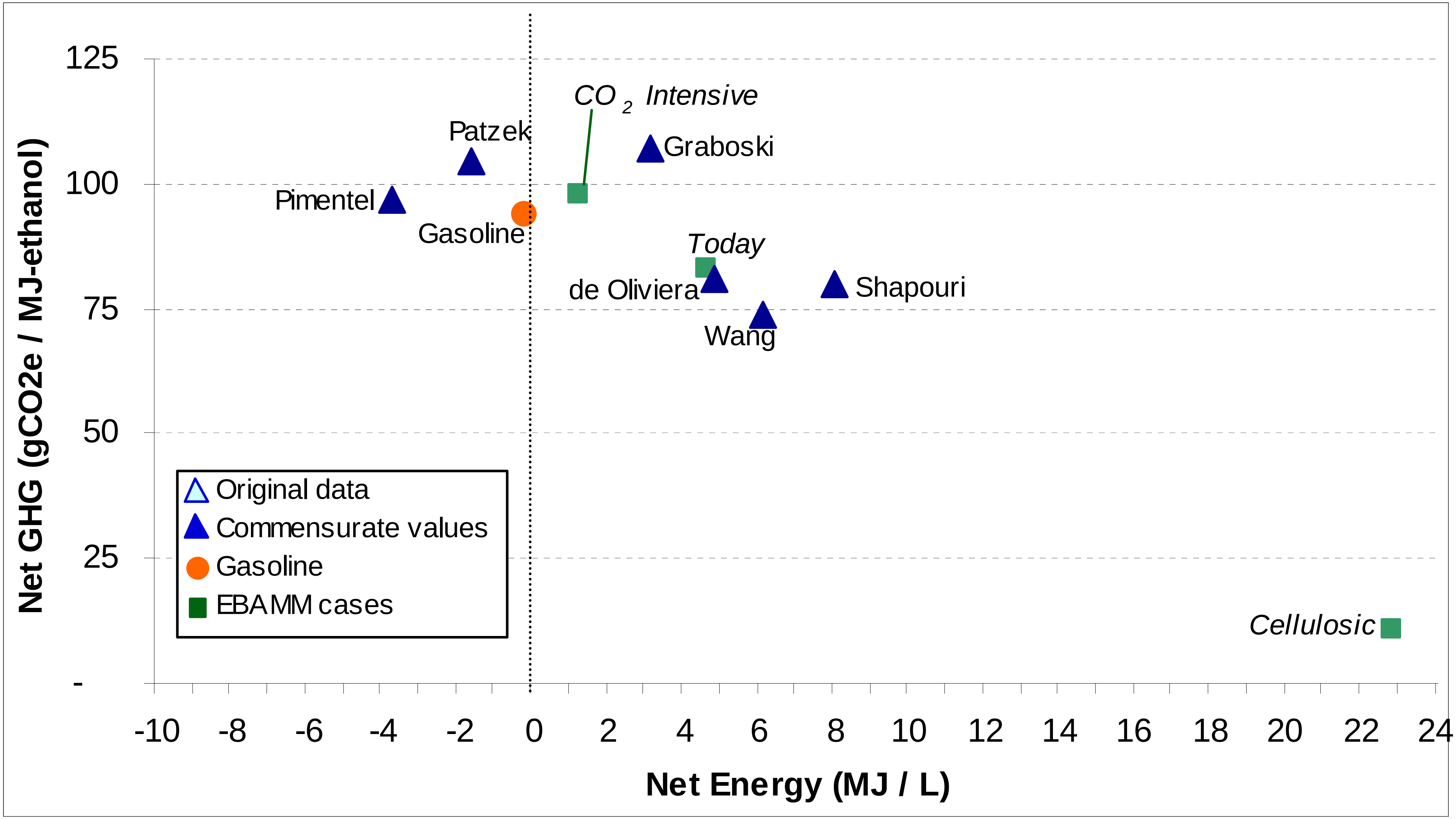


1960:
Population = 3 B

2005:
Population = 6.5 B

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

Greenhouse Gases



Alex Farrell, Dan Kammen, et. al.,
“Meta-analysis” of existing literature, Science 2006

Feedstock Development

Feedstock grasses (*Miscanthus* and Switchgrass) are largely unimproved crops.

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.

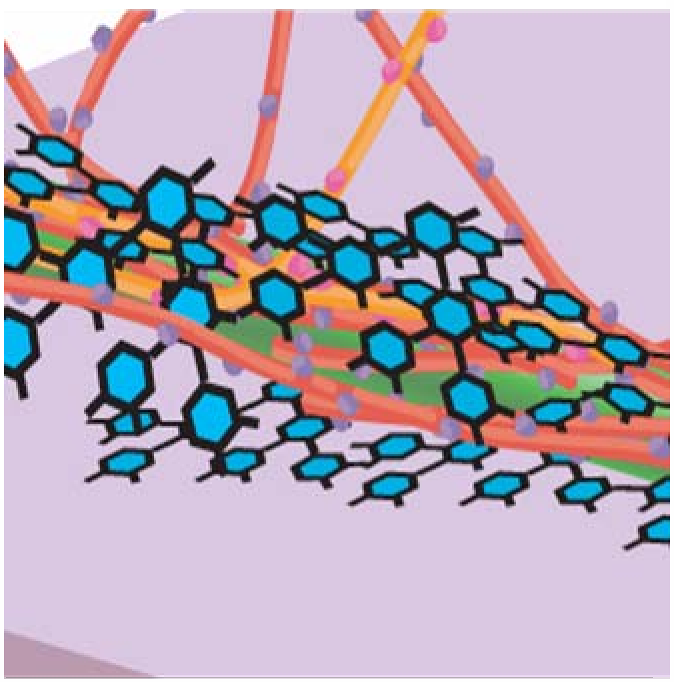
Miscanthus

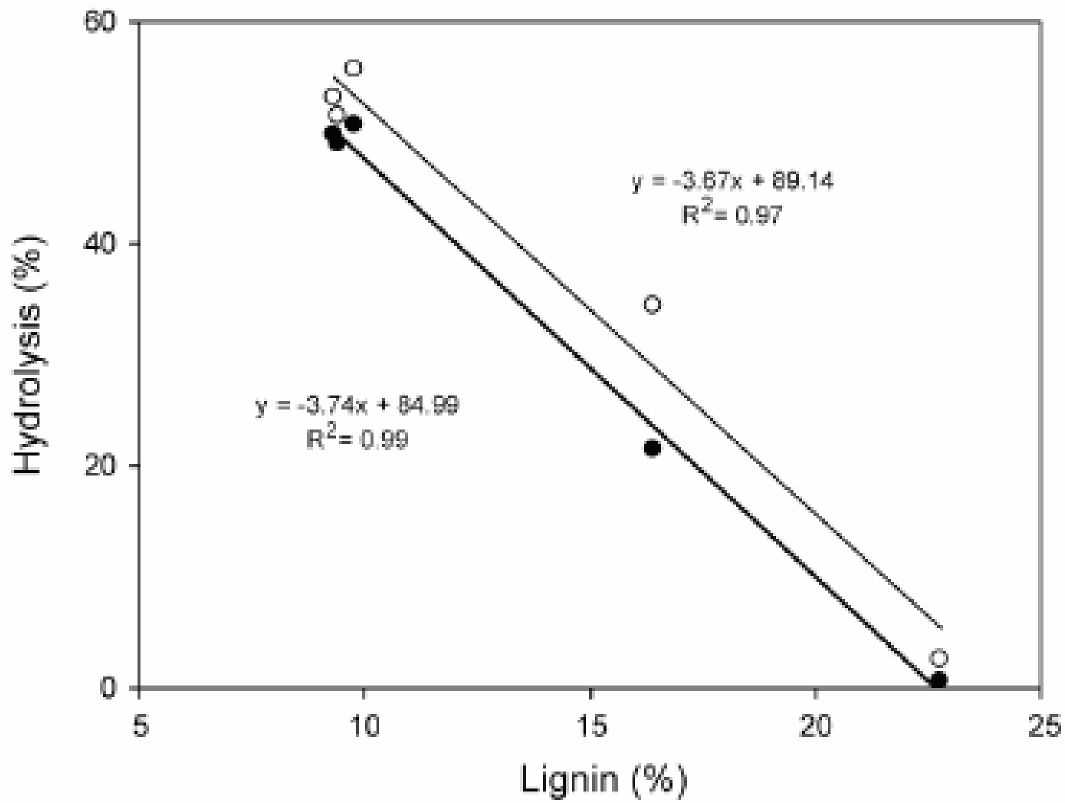
Advantages of perennial plants such as grasses:

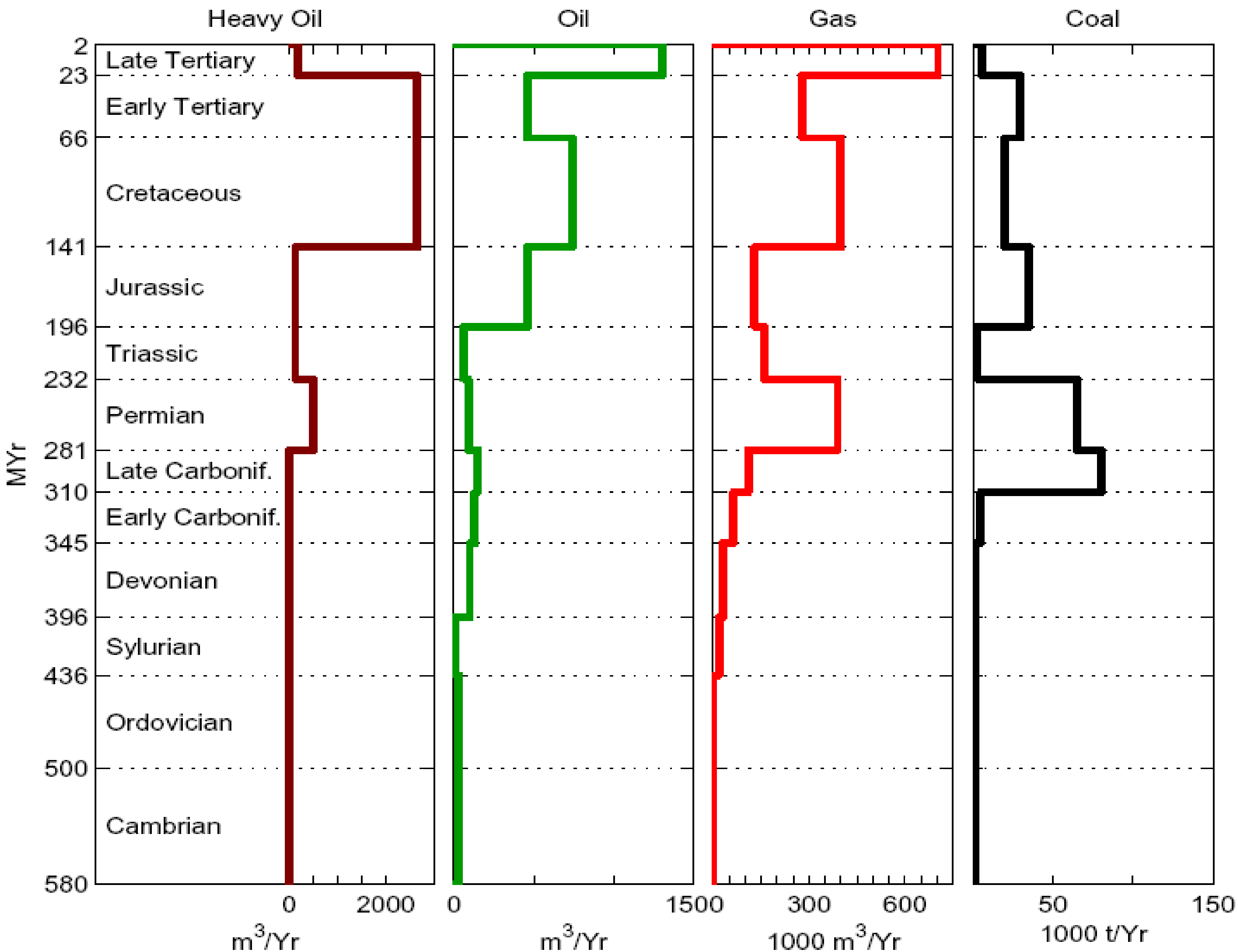
- No tillage for ~ 10 years after first planting
- Long-lived roots establish symbiotic interactions with bacteria to acquire nitrogen and mineral nutrients.
- Some perennials withdraw a substantial fraction of mineral nutrients from above-ground portions of the plant before harvest.
- Perennials have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

The effect of lignin on enzyme recovery of sugars in miscanthus

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



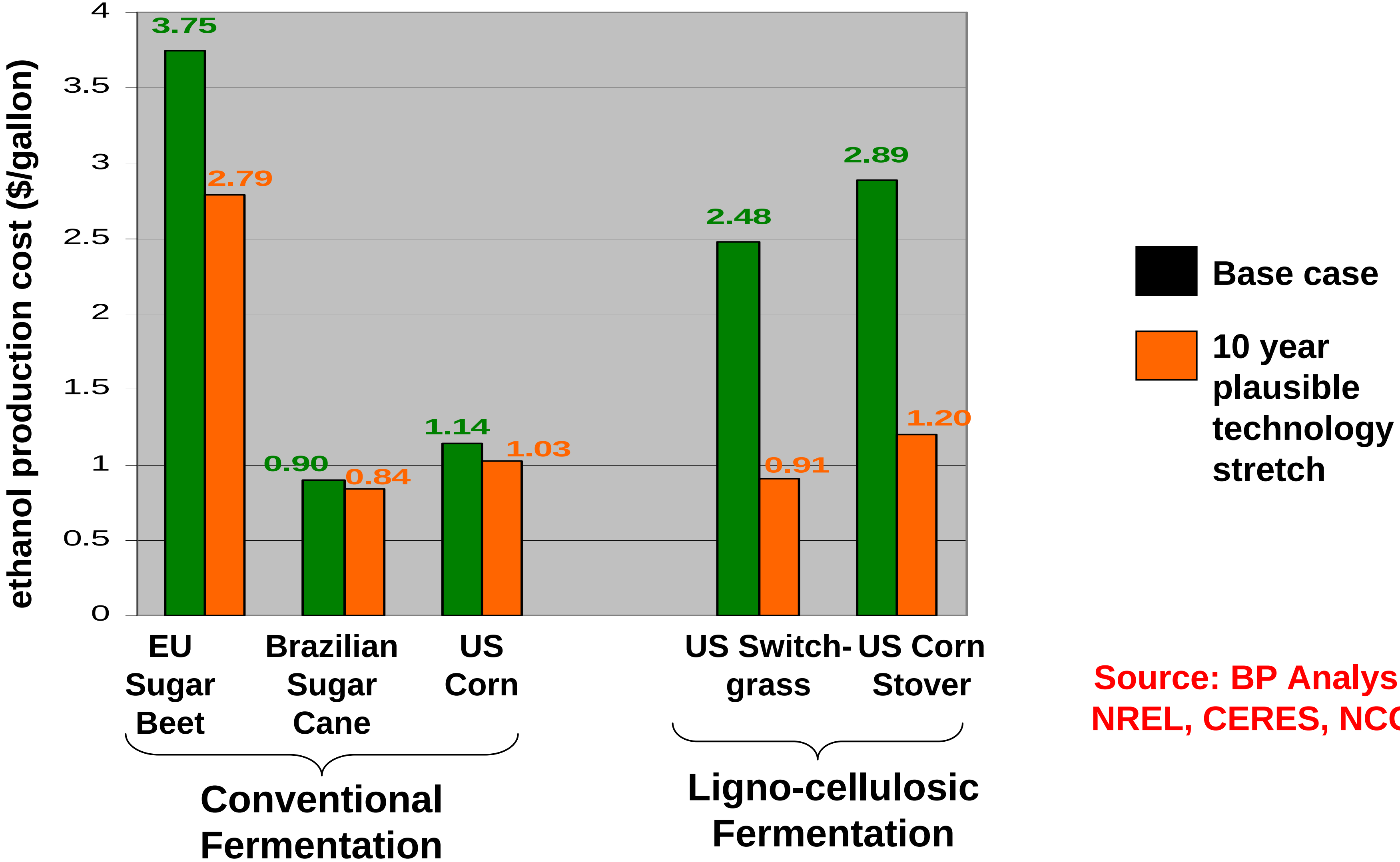




Heavy Oil
Oil
Gas
Coal
MYr
2
23
66
141
196
232
281
310
345
396
436
500
580
Late Tertiary
Early Tertiary
Cretaceous
Jurassic
Triassic
Permian
Late Carbonif.
Early Carbonif.
Devonian
Sylurian
Ordovician
Cambrian
0
2000
m3/Yr
0
1500
m3/Yr
0
300
600
1000 m3/Yr
50
150
1000 t/Yr

Current and projected production costs of ethanol

Courtesy Steve Koonin, BP Chief Scientist

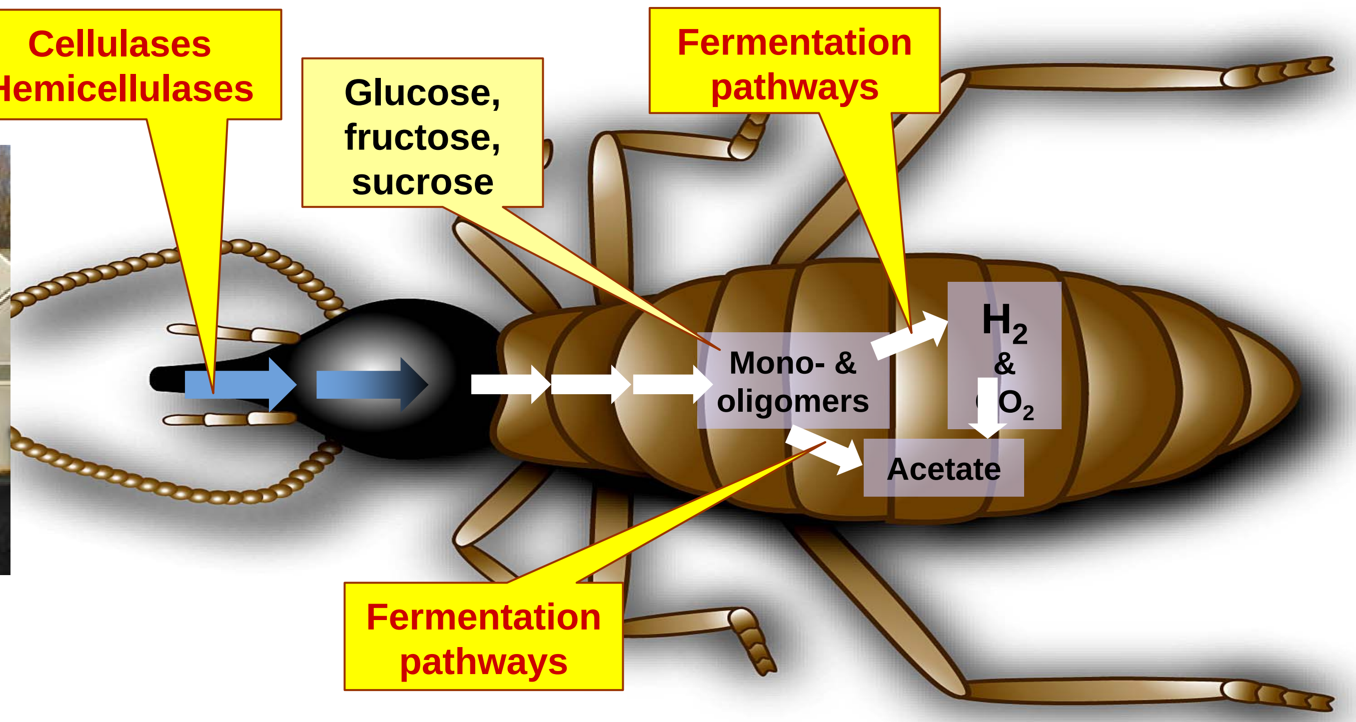


Source: BP Analysis, NREL, CERES, NCGA

Commercial ethanol production from cellulose

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

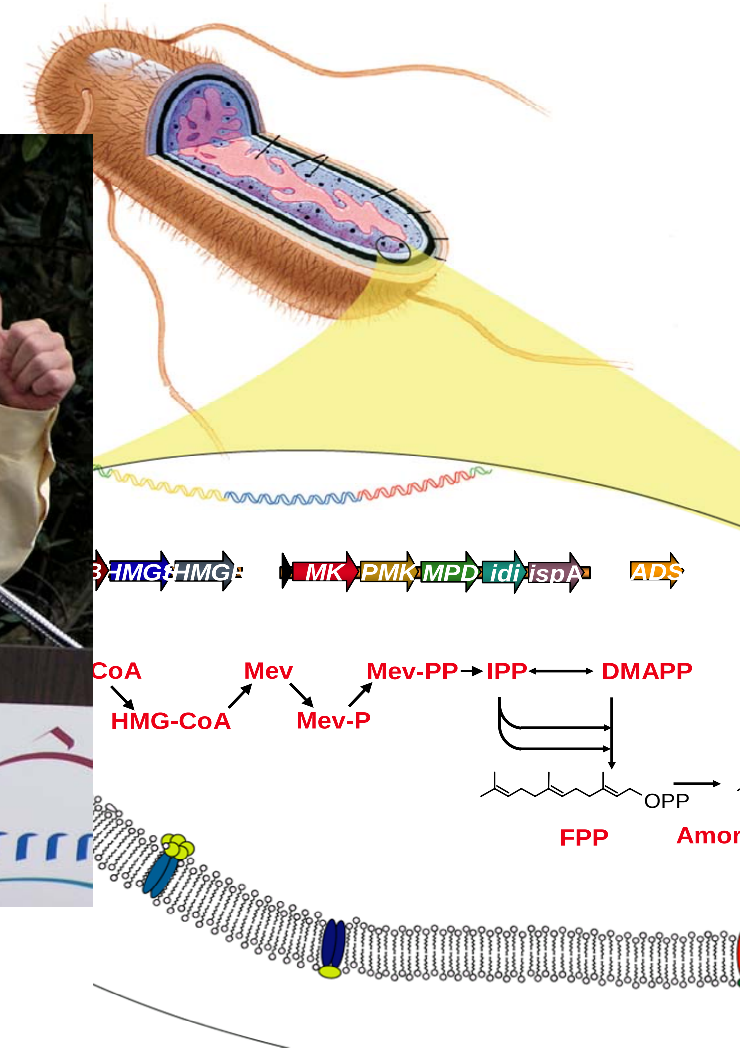
Termites have many specialized enzymes for efficiently digesting lignocellulosic material

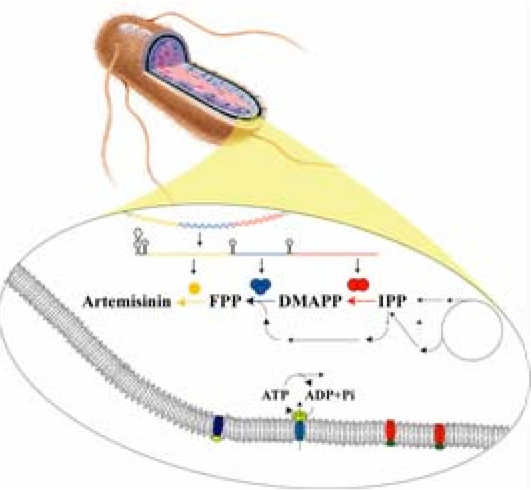


Production of artemisinin in bacteria

Jay Keasling

Director of Physical Biosciences Division



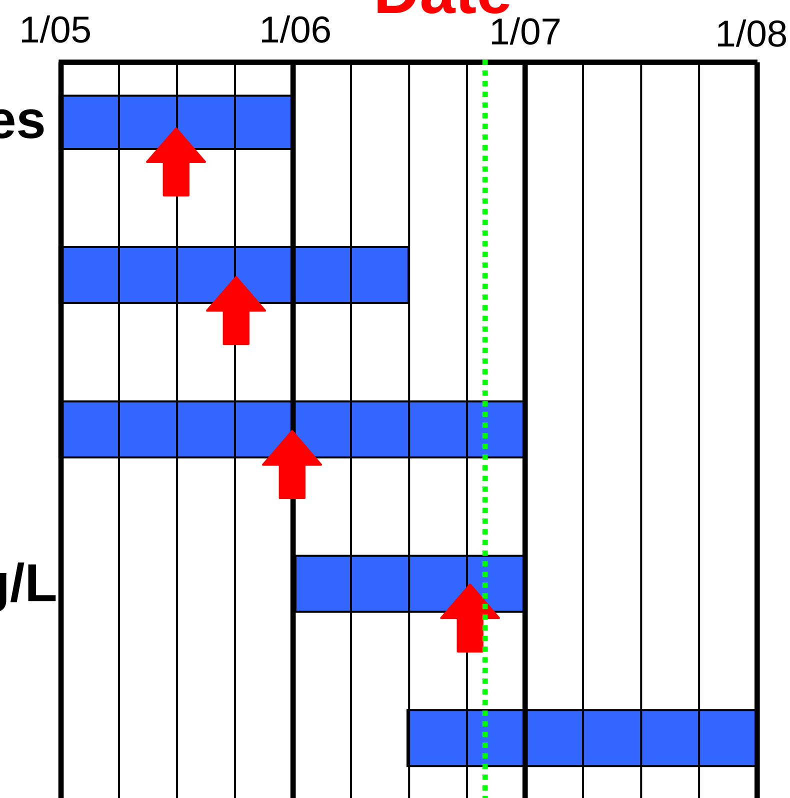


Synthetic Biology

Anti-malarial drugs from microbes

Early milestone completion due to careful project management!

Milestone — **Date**



Pathway elucidation and cloning of genes

Functional expression of genes

Production of amorphadiene at 25 g/L

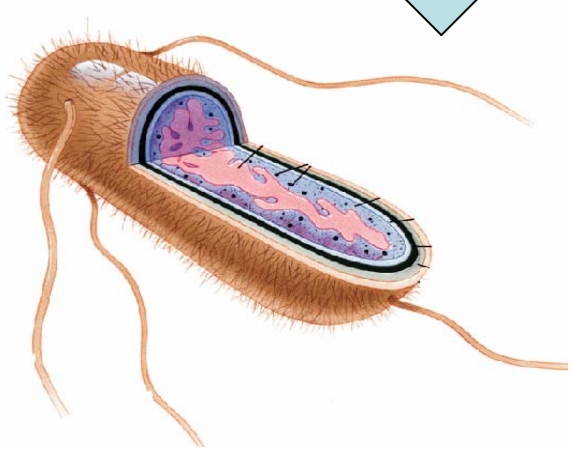
Production of artemisinic acid at 100 mg/L

Production of artemisinic acid at 25 g/L

= proposed work period

= milestone completion

Research, Development & Delivery



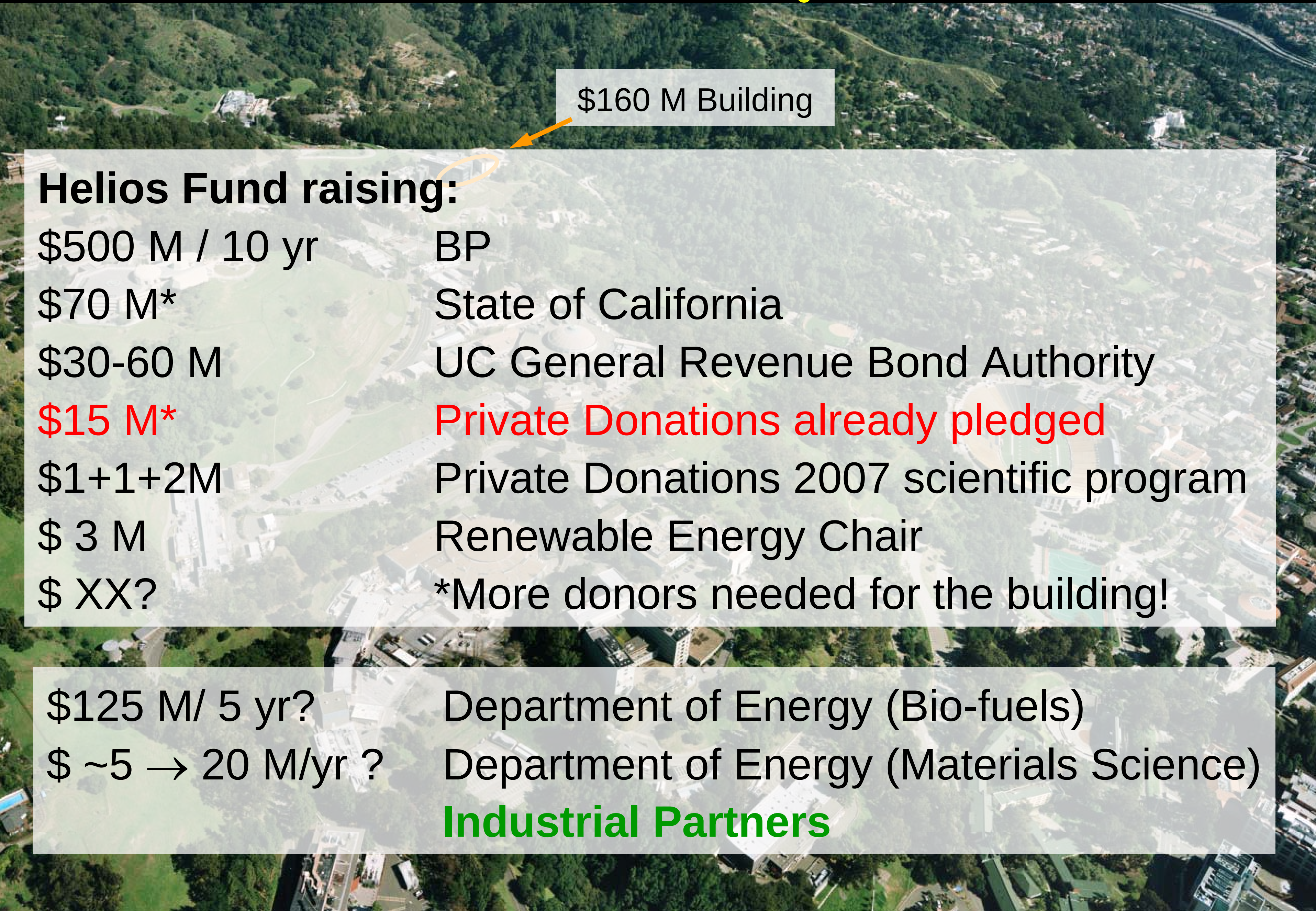
Keasling Laboratory

Amyris Biotechnologies

Institute for OneWorld Health

Cost 20¢ /cure

The Helios Project



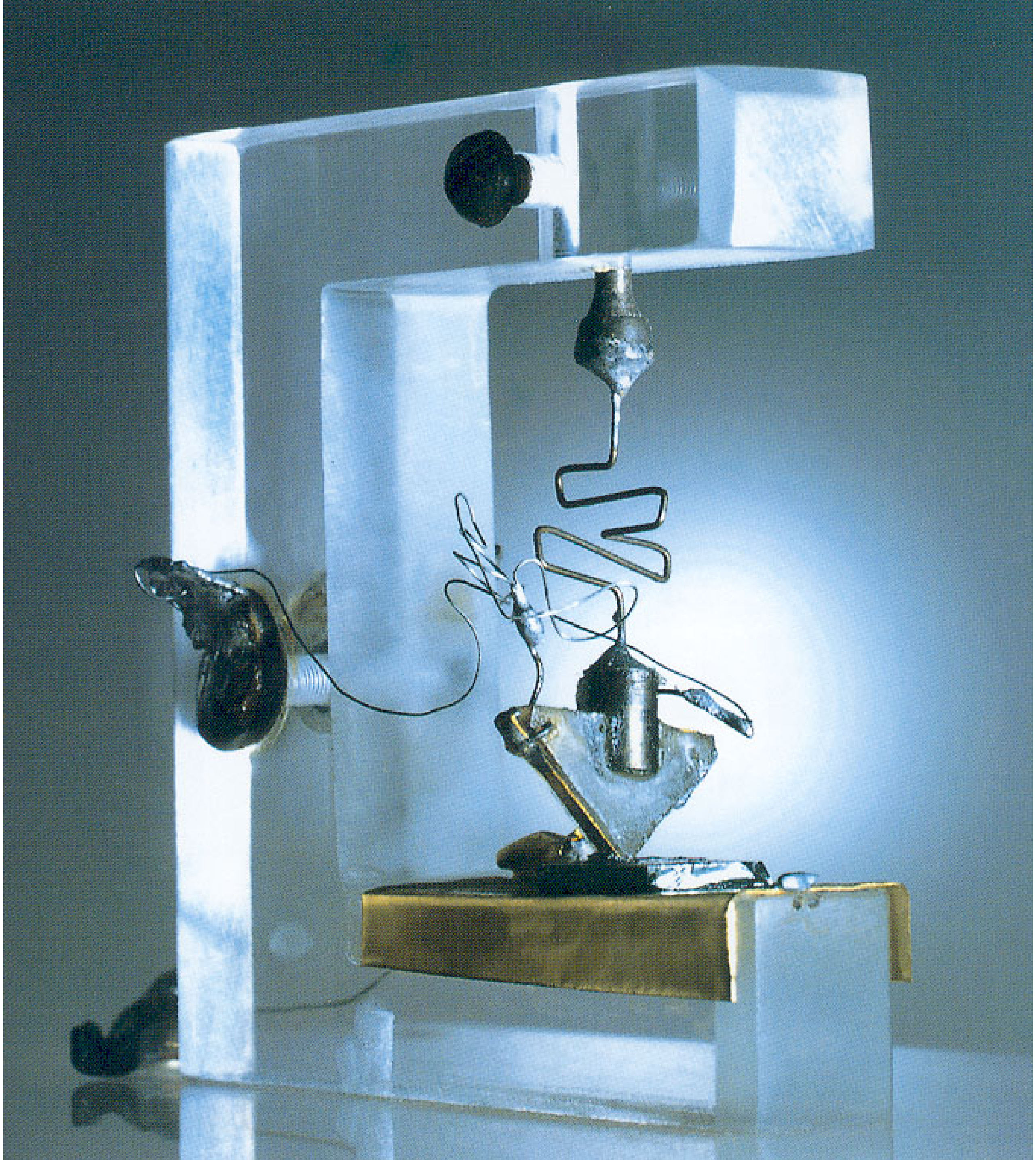
Helios Fund raising:

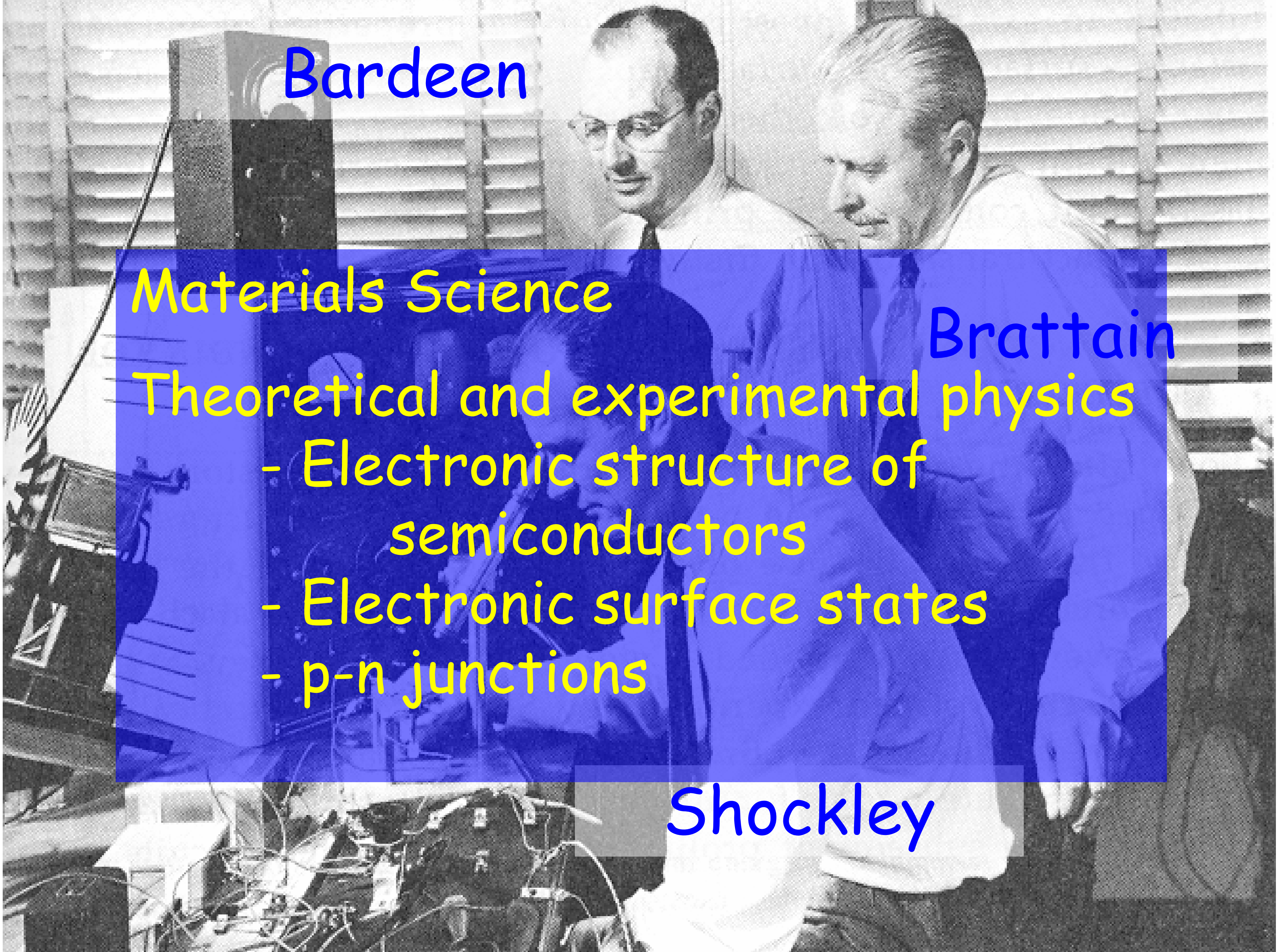
$500 M / 10 yr	BP
$70 M*	State of California
$30-60 M	UC General Revenue Bond Authority
$15 M*	Private Donations already pledged
$1+1+2M	Private Donations 2007 scientific program
$ 3 M	Renewable Energy Chair
$ XX?	*More donors needed for the building!

$125 M/ 5 yr?	Department of Energy (Bio-fuels)
$ ~5 $\rightarrow$ 20 M/yr ?	Department of Energy (Materials Science)
	Industrial Partners

Bell Laboratories (Murray Hill, NJ)

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





Materials Science

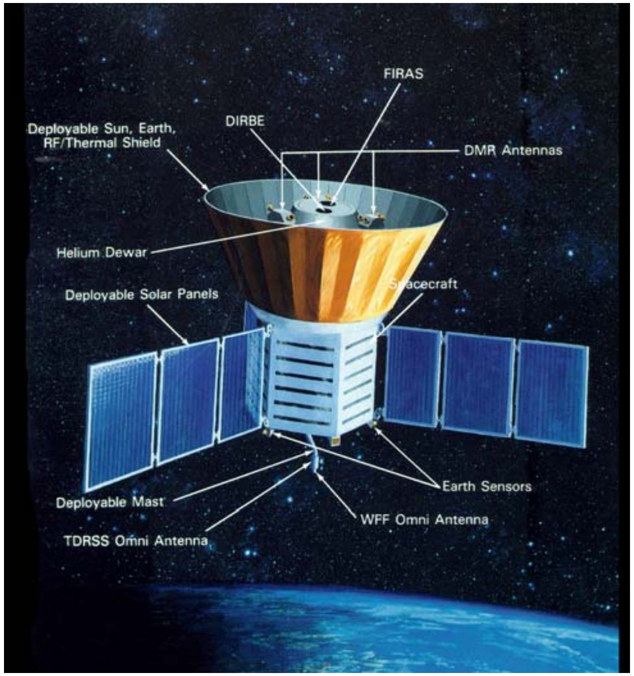
Theoretical and experimental physics

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

E.O. Lawrence introduced the idea of “team science”

Ernest Lawrence, Robert Serber, Luis Alverez, Edwin McMillian, Robert Oppenheimer, Robert R. Wilson, …

The tradition of E.O. Lawrence continues …

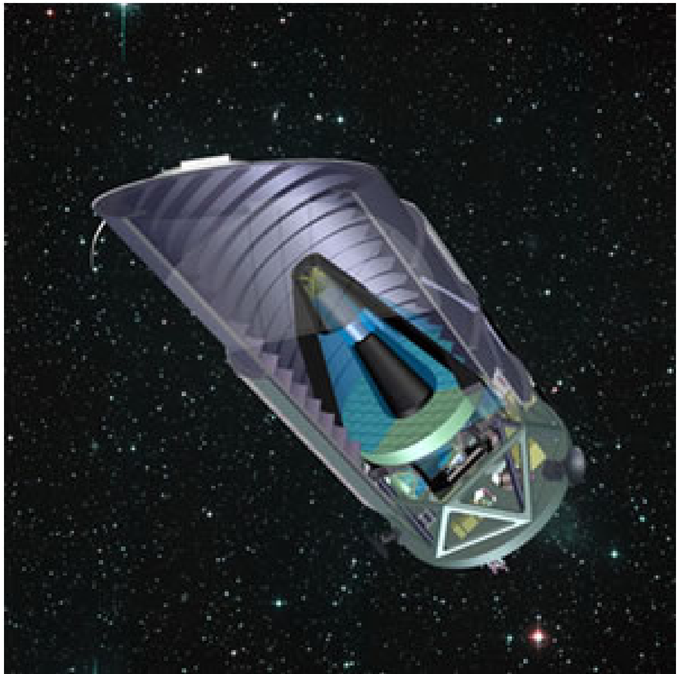


COBE: Cosmic Background Explorer

2006 Nobel Prize in Physics
George Smoot (LBNL & UCB) and John Mather (Goddard)

Dark Energy

Saul Perlmutter (LBNL and UCB)
(2006 Run Run Shaw Prize, Fretinelli Prize)



Organizational culture

- Individual genius was nurtured, but individuals were also 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.