Science and Policy for Dramatic Cuts in Carbon Emissions

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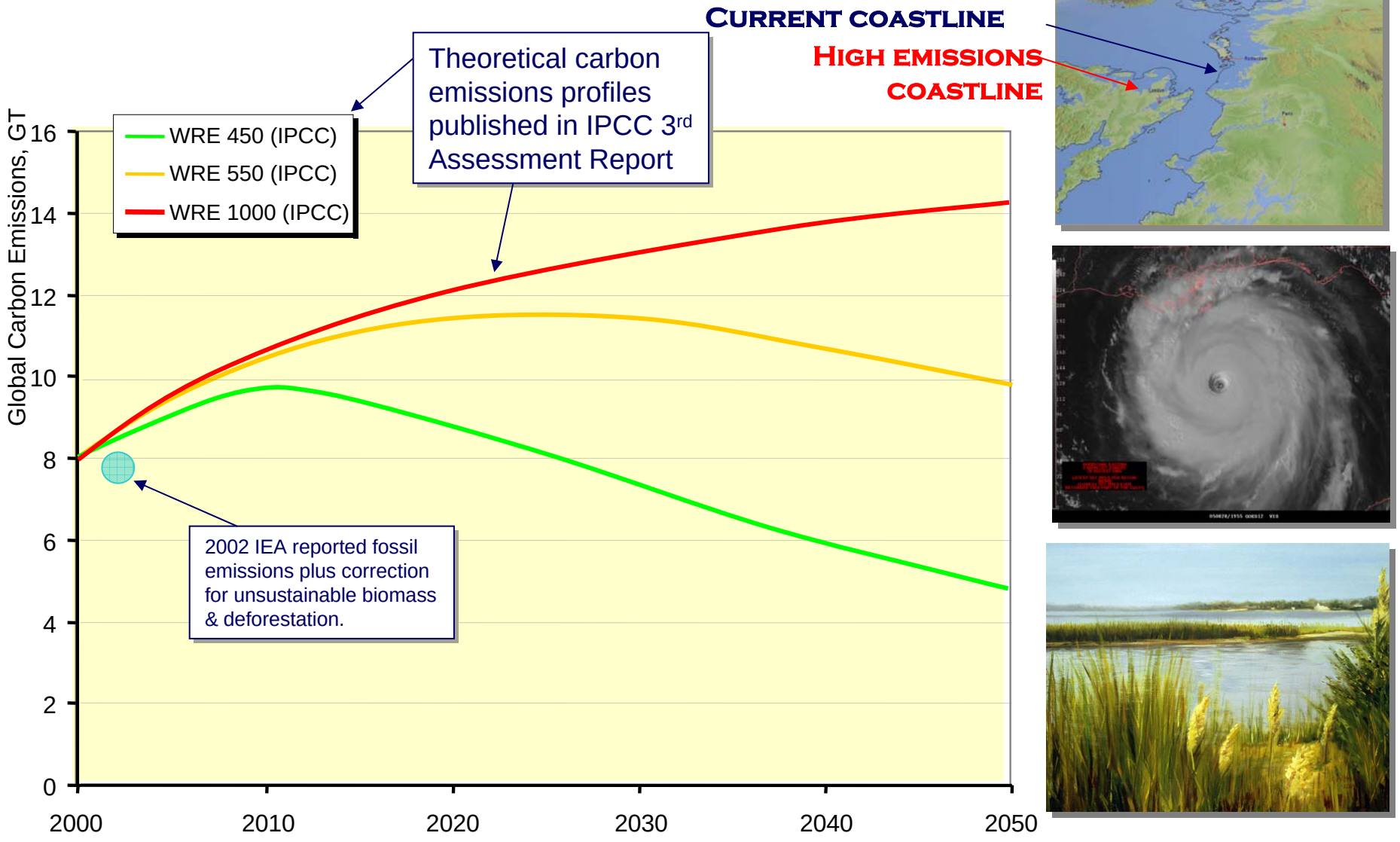
Department of Nuclear Engineering
University of California, Berkeley

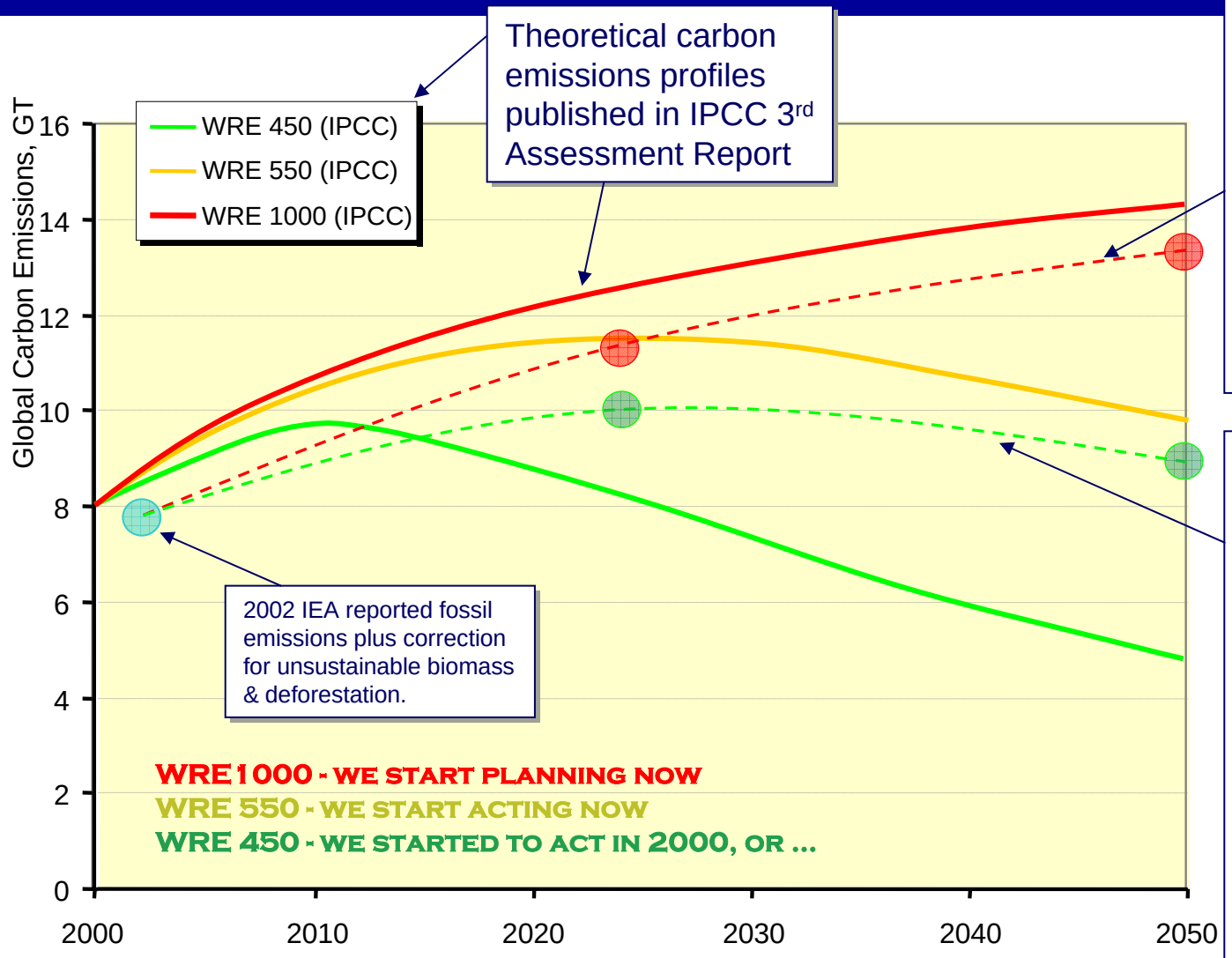
June 14, 2007, National Academy of Sciences Government-University-Industry Research Roundtable Meeting "Global Energy Policy Solutions II"

High and low carbon pathways



Thanks to the World Business Council for Sustainable Development

High and low carbon pathways



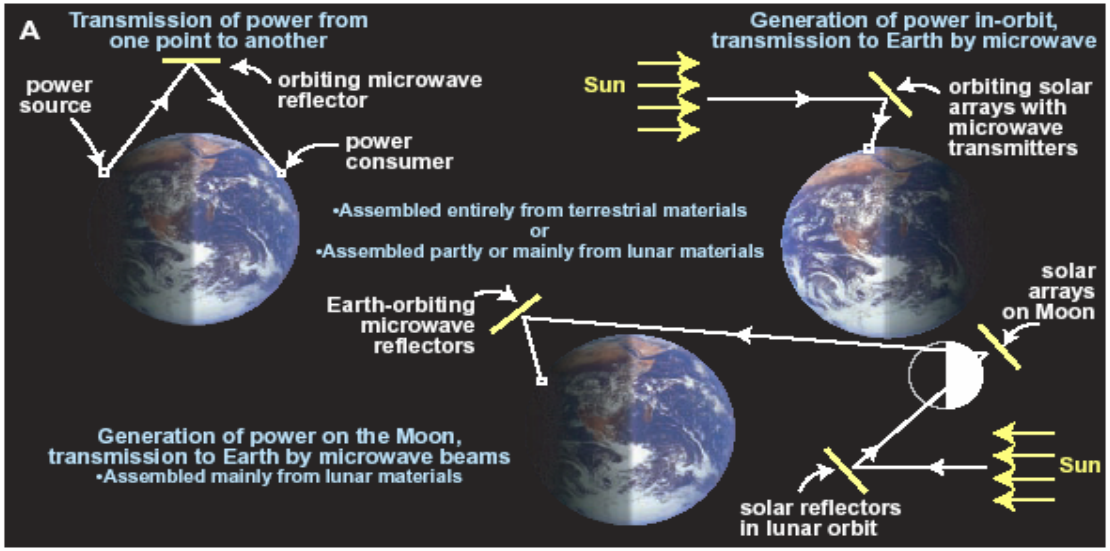
>900 ppm Trajectory Energy by 2050:

- **Coal over 2x, no Carbon Capture & Storage (CCS), some coal to liquids.**
- **Oil up 50%**
- **Gas over 2x**
- **Biofuels make up 10% of vehicle fuel mix.**
- Electricity 1/3 of final energy.
- **Modest increase in nuclear.**
- **Renewables provide 1/3 of electricity generation.**
- Vehicle efficiency up 50%.

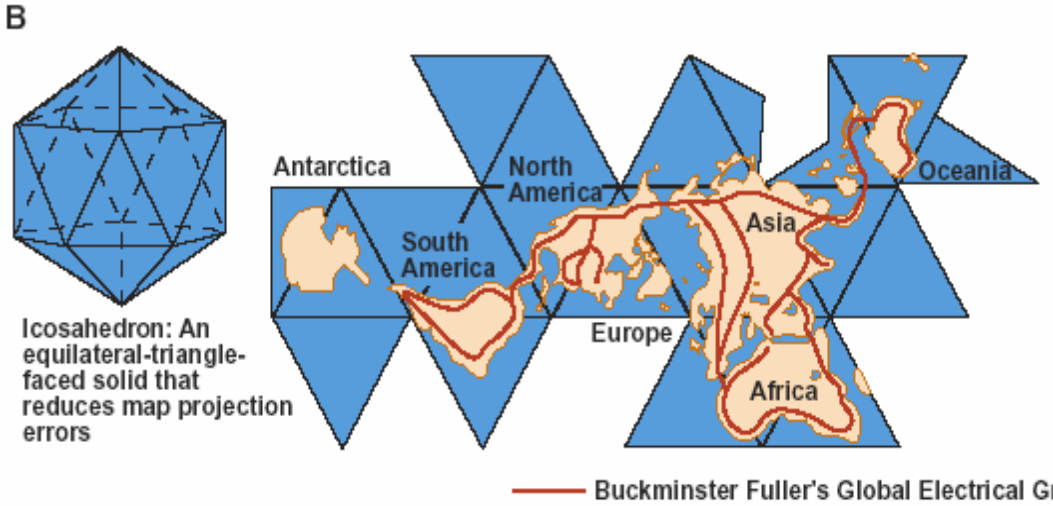
<550 ppm Trajectory Energy by 2050:

- **Coal up 50%, but half of power stations use CCS.**
- Oil down 10-15%.
- **Gas nearly 2-3x (note: adds volatility)**
- **Biofuels make up 20% of vehicle fuel mix.**
- **Hydrogen has arrived (if green)**
- **Strong shift to electricity as final energy (~50% final energy).**
- **Strong increase in nuclear.**
- **Renewables provide half of electricity generation.**
- **Vehicle efficiency up 100%**
- **Sustainable biomass practices**

‘Conventional radical’ view: Dramatic cuts in carbon emissions require dramatic solutions …

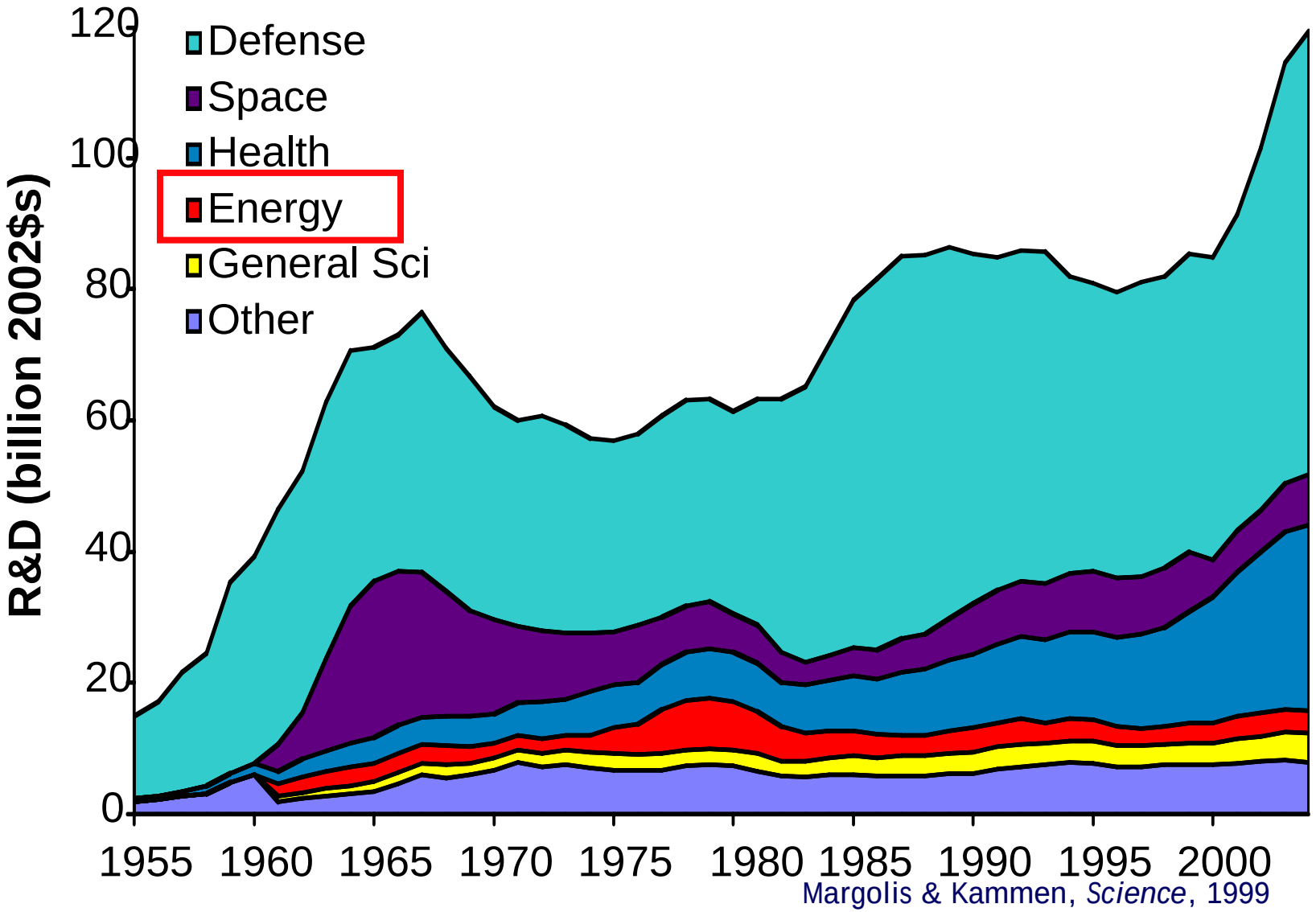


Capturing Solar Energy in space (Peter Glaser et al., 1970s)



Global Superconducting Transmission Grid (Buckminster Fuller, 1970s)

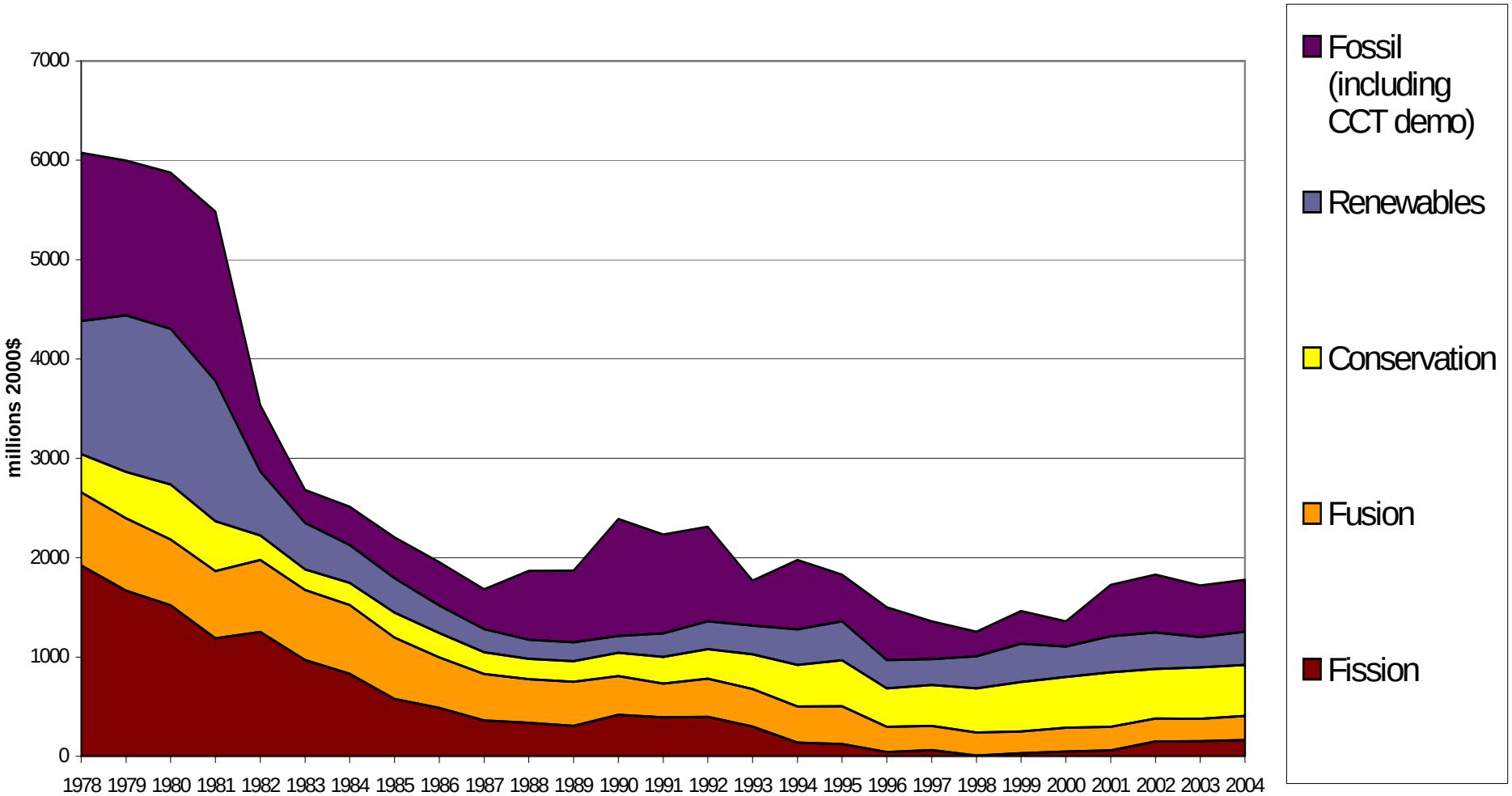
Federal R&D Investments, 1955 - 2004



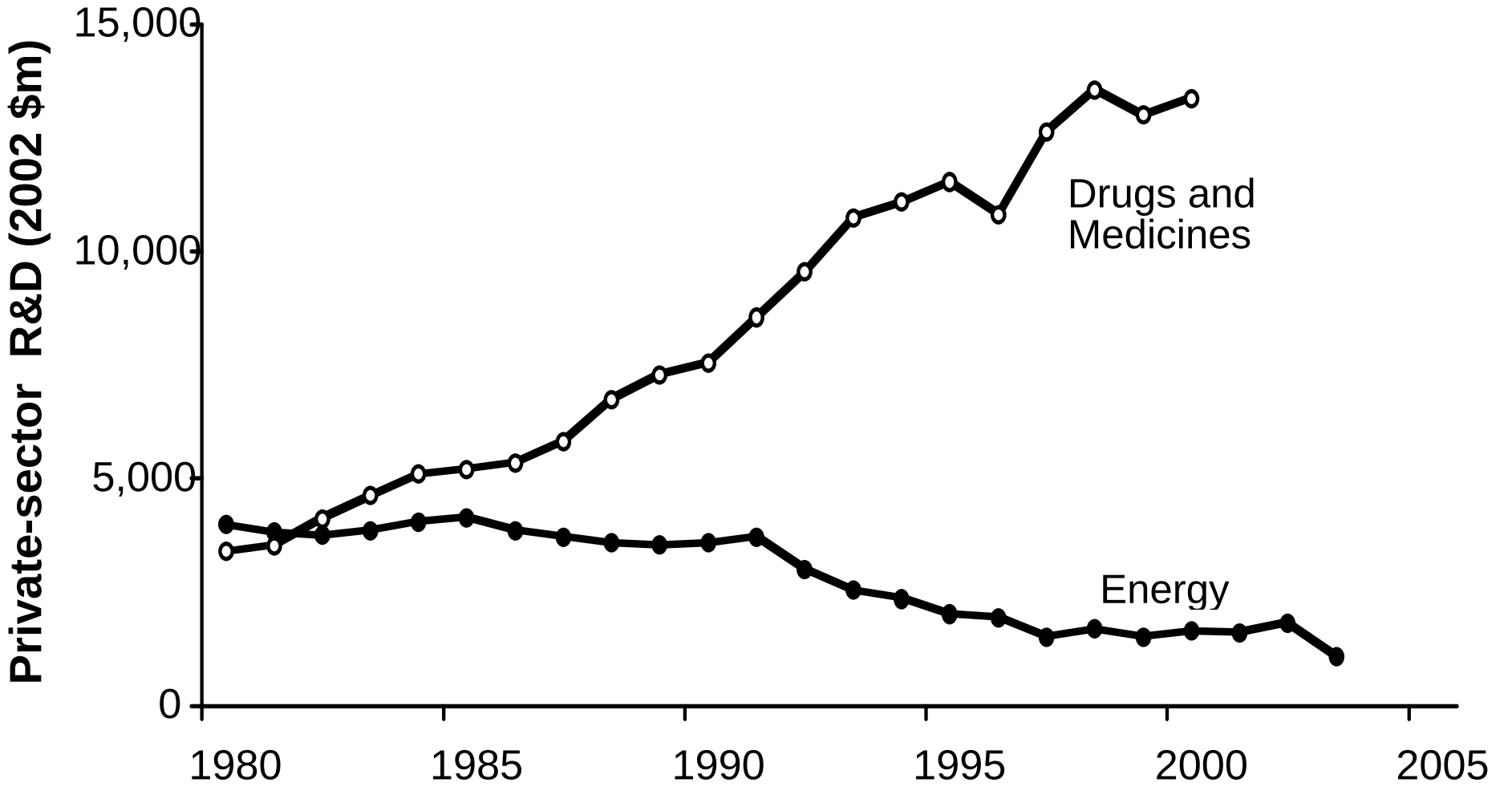
Margolis & Kammen, *Science*, 1999

U.S. DOE Energy RD&D 1978-2004

(millions 2000$)



Private Sector R&D Investment in Health and Energy



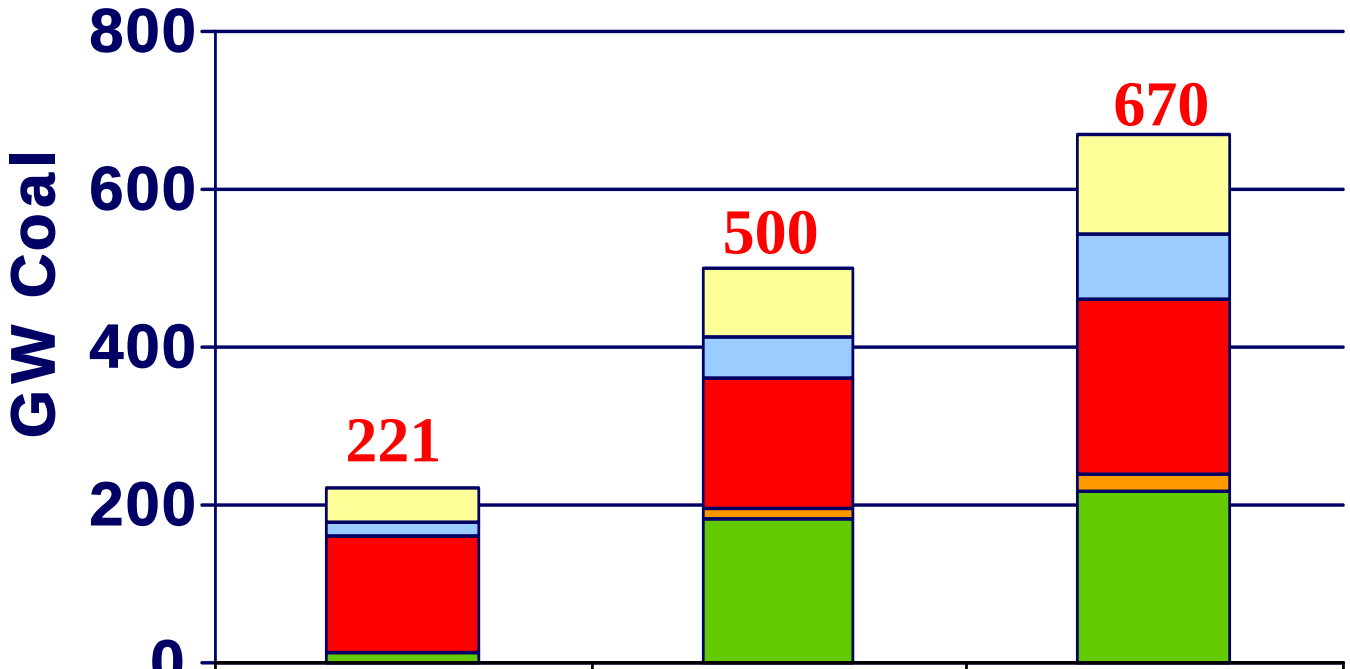
Kammen and Nemet (2005)
"Reversing the incredible shrinking energy R&D budget," *Issues in Science & Technology,* **Fall**, 84 – 88.

What is combustion:

Fuel + oxygen → energy + carbon dioxide (CO_2)

Coal + air → energy + carbon dioxide (CO_2)

New Coal by the Decades



	2003-2010	2011-2020	2021-2030
Other Developing	43	90	128
India	16	48	79
China	150	168	226
Transition	1	11	19
OECD	12	184	218

>$1 trillion in misallocated capital

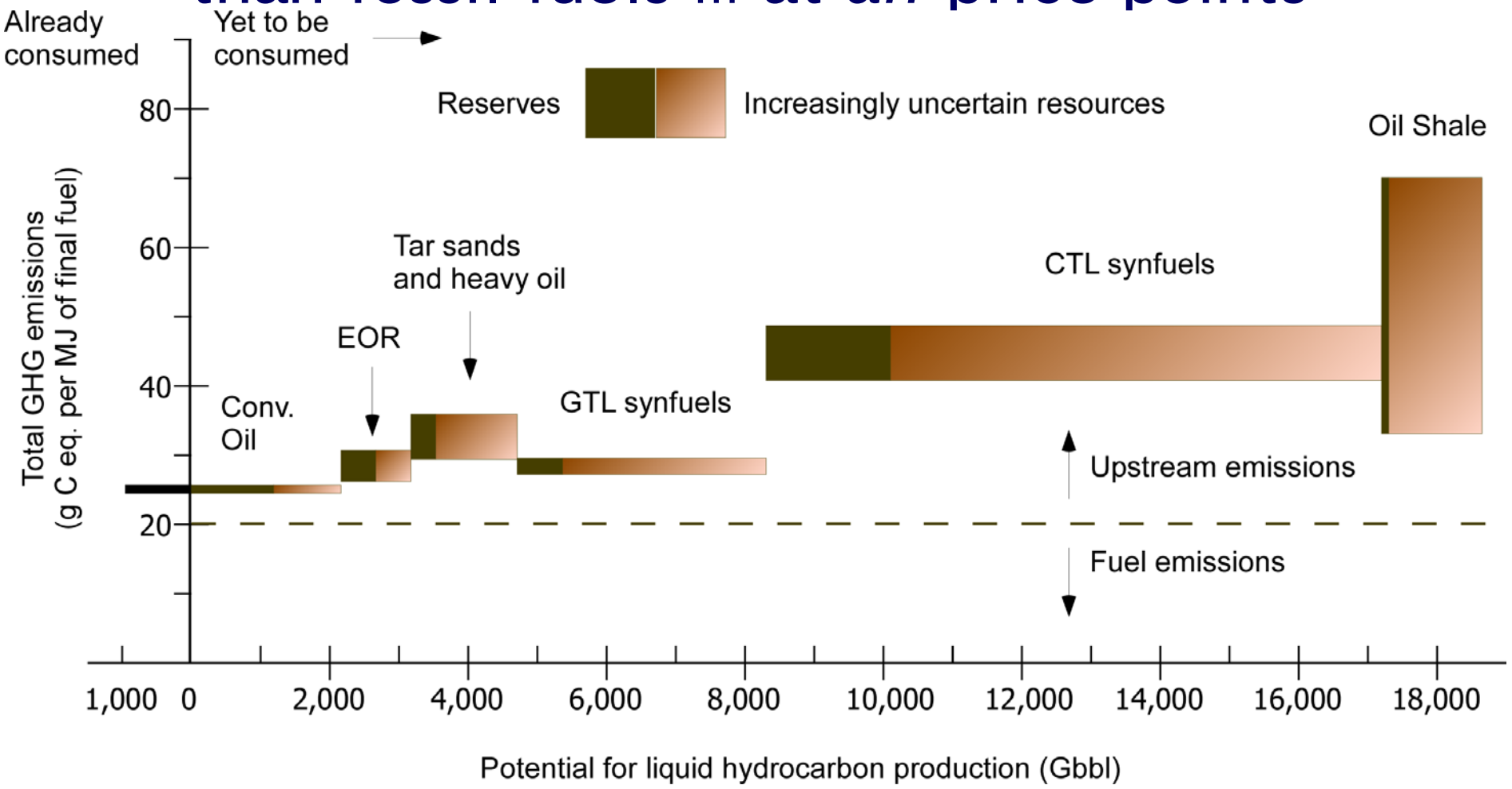
Source: IEA, WEO 2004


Athabasca basin tar sand mine:
10% bitumen by weight in the soil.
~ $30/barrel of energy required to refine


$CH_4 \rightarrow H_2S$ separation, then H_2 & elemental sulfur separation

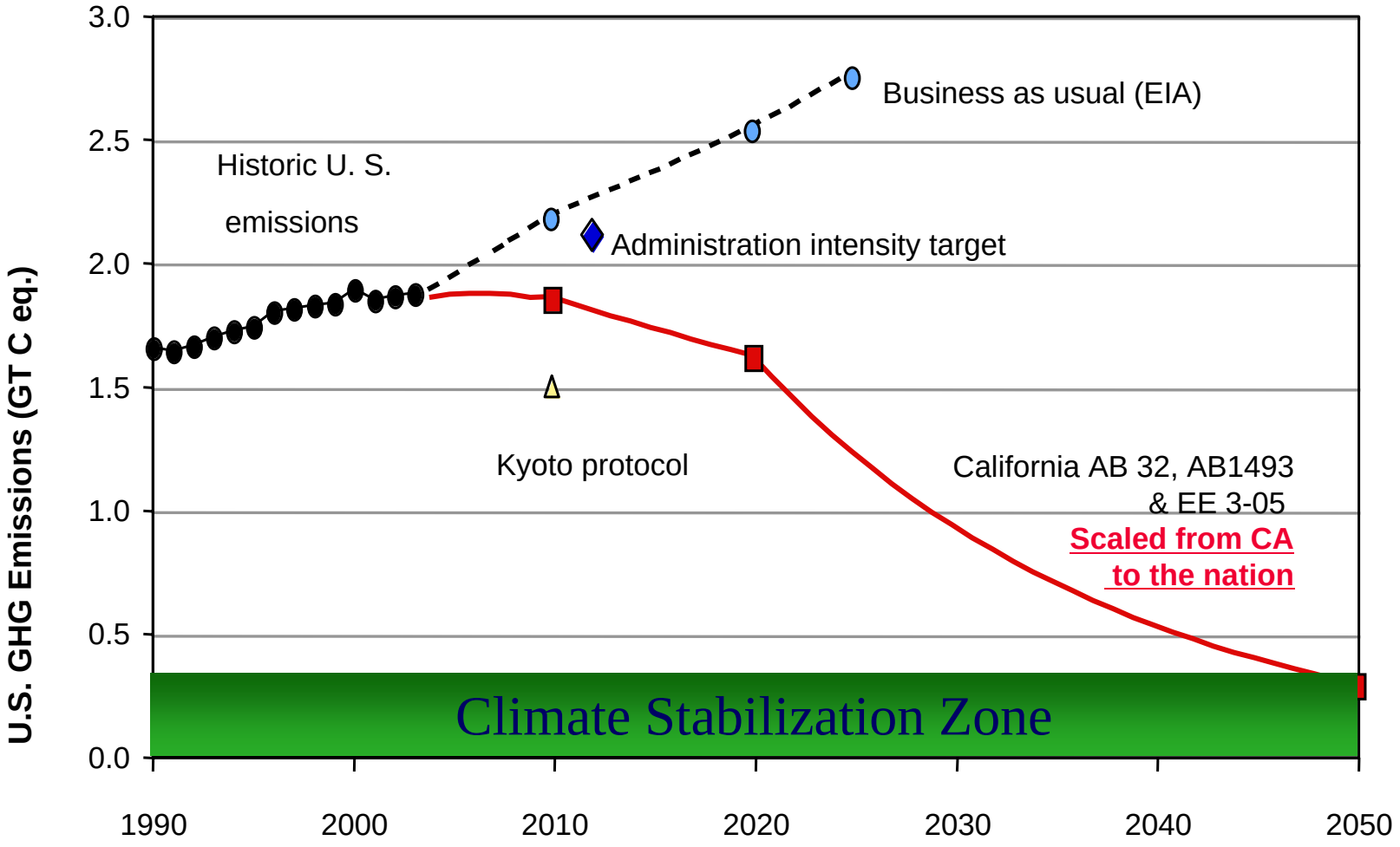

PLT. 36
SULFUR BLOCK & TANK AREA
RESTRICTED ACCESS
PERMITS CALL SECONDARY U/G
EMERGENCY CALL
911
FLAME RESISTANT COVERALLS REQUIRED
NO SMOKING, NO BEARDS

We are running out of atmosphere *much* faster than fossil fuels … at *all* price points



Source: Brandt and Farrell (2006) ***Environmental Research Letters (erl.iop.org)***

The California commitment - scaled to the nation

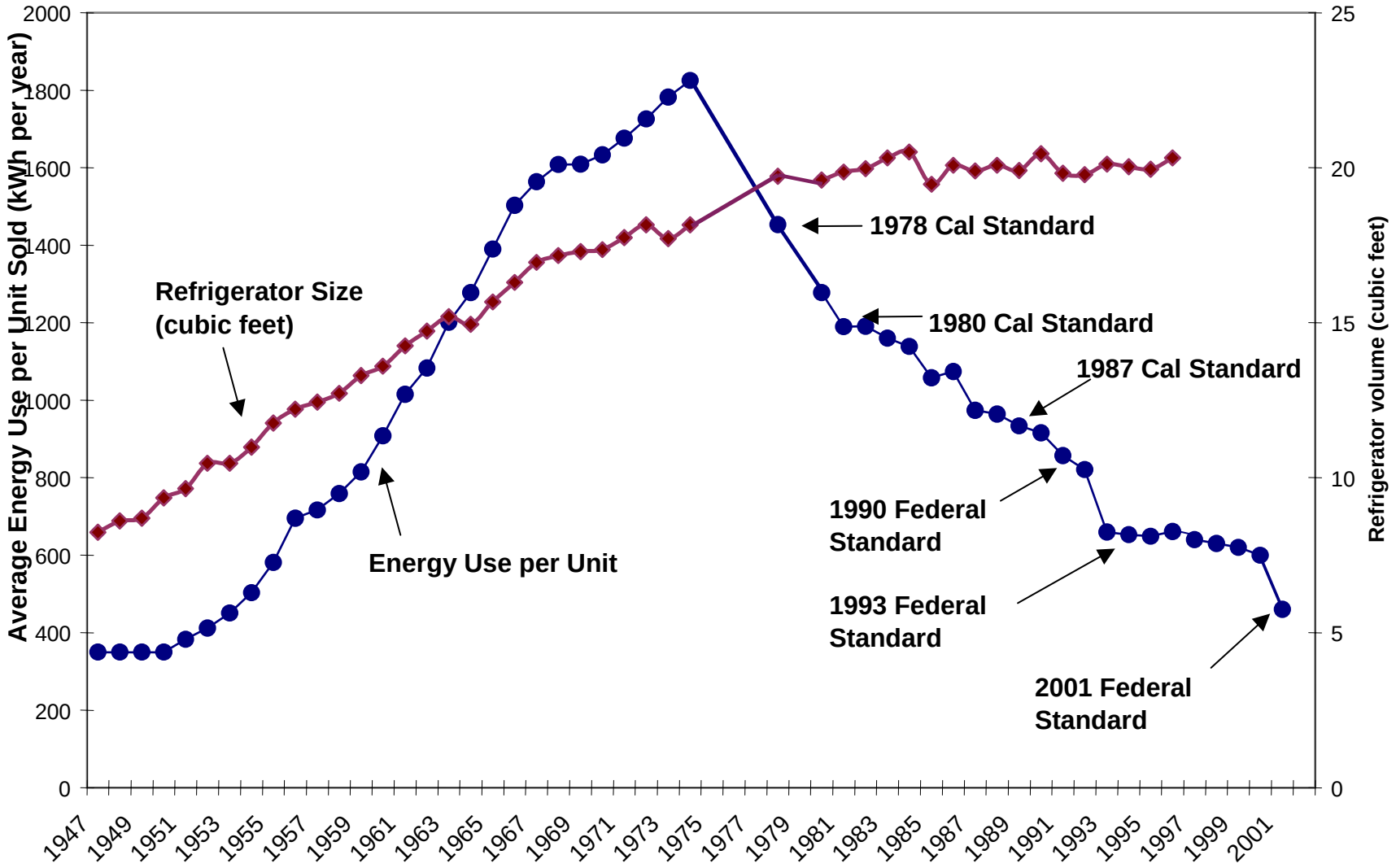


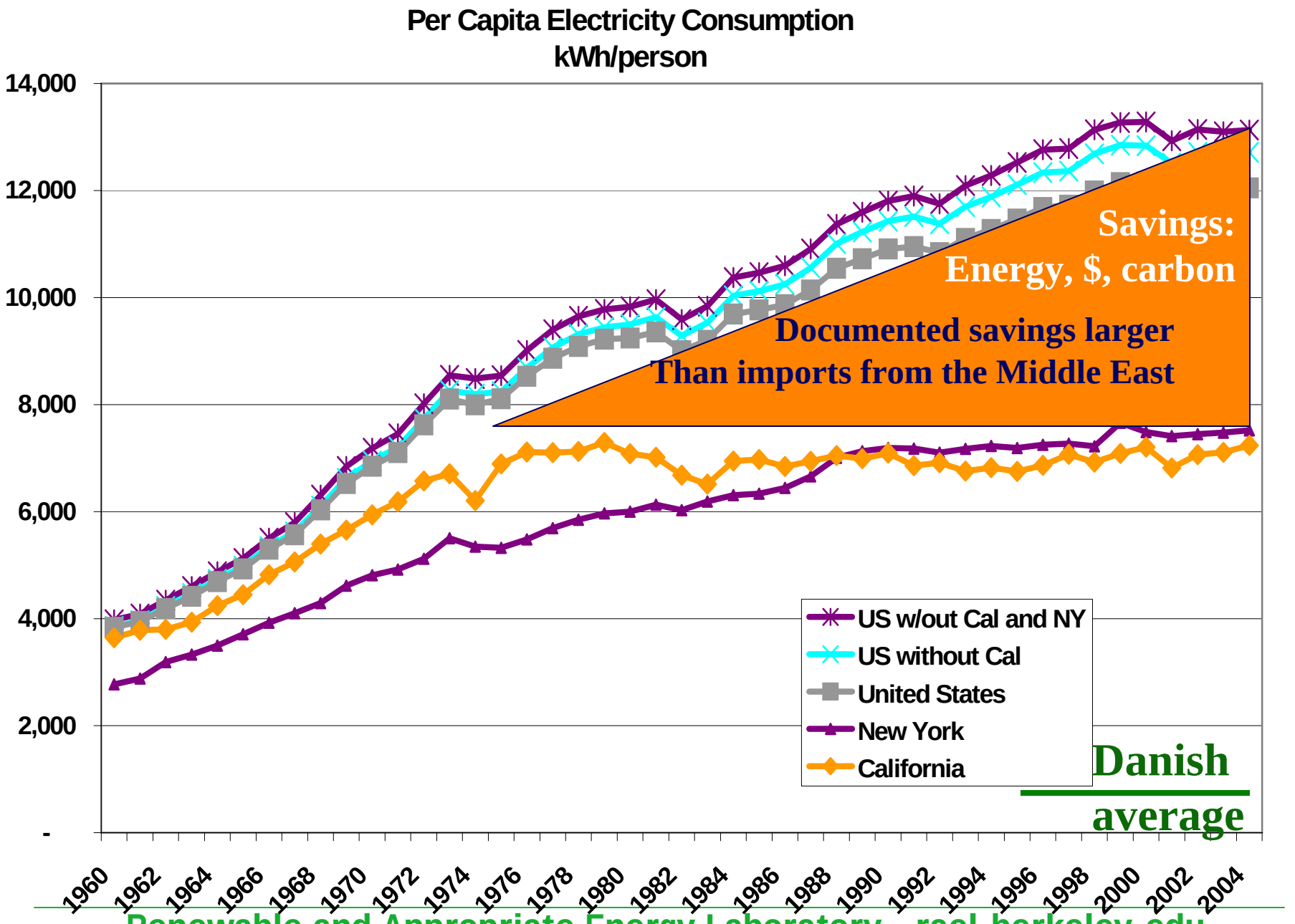
Kammen, "September 27, 2006 – A day to remember", *San Francisco Chronicle*, September 27,

Sectoral approaches are needed

- While an economy-wide approach would be efficient
- An economy-wide approach fails to meet other goals
  - At a "low" price (<$25/tonne), little would happen
  - At $25-$50 per tonne, electricity would start to decarbonize while little would happen in buildings and transport
  - Prices high enough to cause transportation to decarbonize might force disruptive change in the electricity sector or be politically infeasible
- Costs and fuel-on-fuel competition ($25/tonne CO_2)
  - Nuclear + Renewables $0.0/MWh
  - Integrated gasification combined cycle with carbon capture and storage (IGCC+CCS) $02.5/MWh
  - Natural gas combined cycle (NGCC) $12.5/MWh
  - Pulverized coal (PC) $20/MWh
  - Gasoline $0.24/gallon

United States Refrigerator Use versus Time
Annual drop from 1974 to 2001 = 5% per year




Per Capita Electricity Consumption
kWh/person
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Savings:
Energy, $, carbon
Documented savings larger
Than imports from the Middle East
US w/out Cal and NY
US without Cal
United States
New York
California
Danish
average

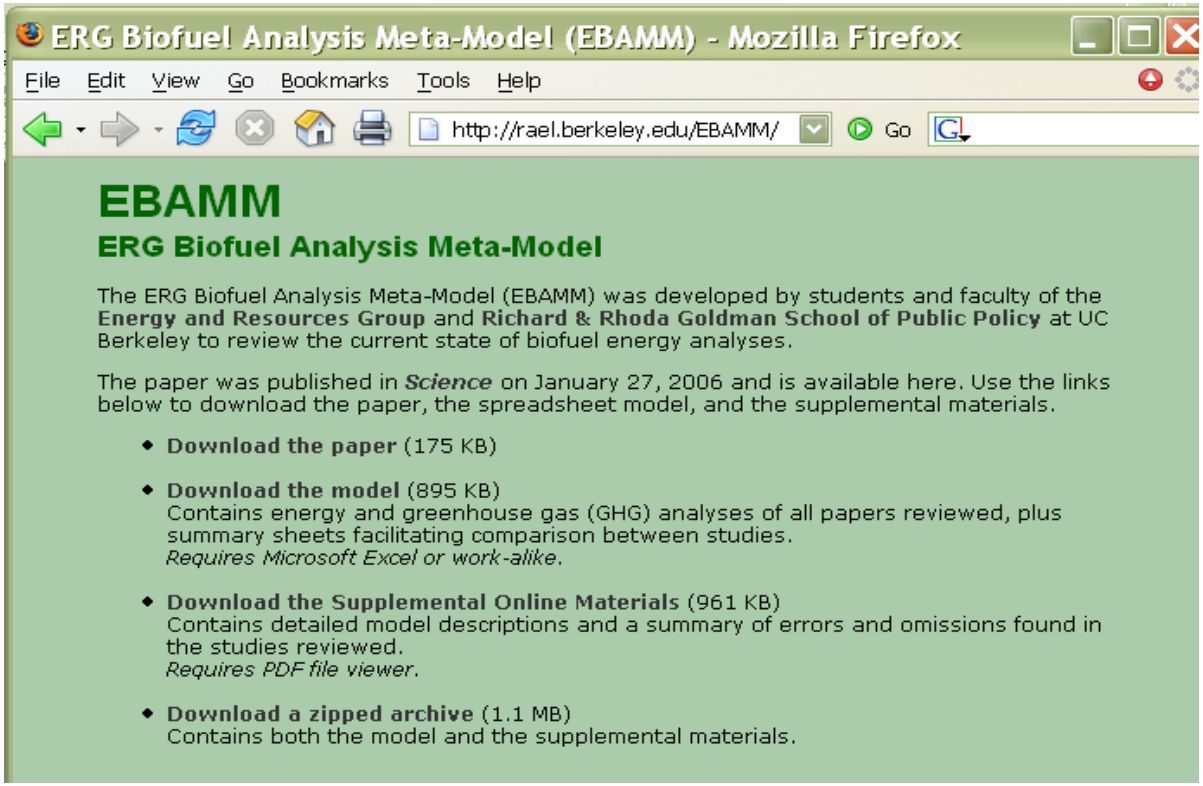
REPORTS

27 JANUARY 2006 VOL 311 SCIENCE www.sciencemag.org

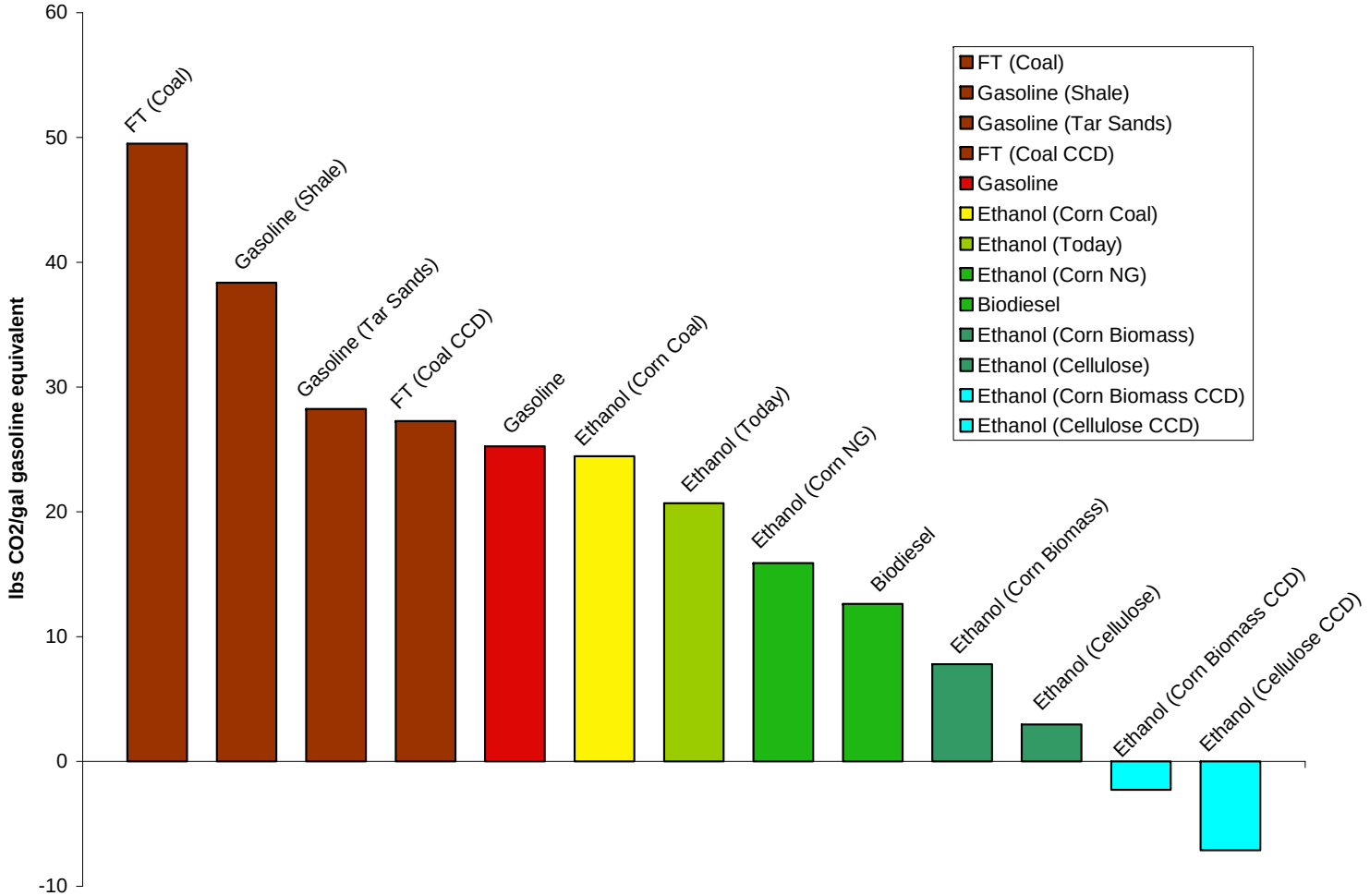
Ethanol Can Contribute to Energy and Environmental Goals

Alexander E. Farrell,[1*] Richard J. Plevin,[1] Brian T. Turner,[1,2] Andrew D. Jones,[1] Michael O'Hare,[2] Daniel M. Kammen[1,2,3]

Open access, online, biofuel calculator tools: **http://rael.berkeley.edu/ebamm**

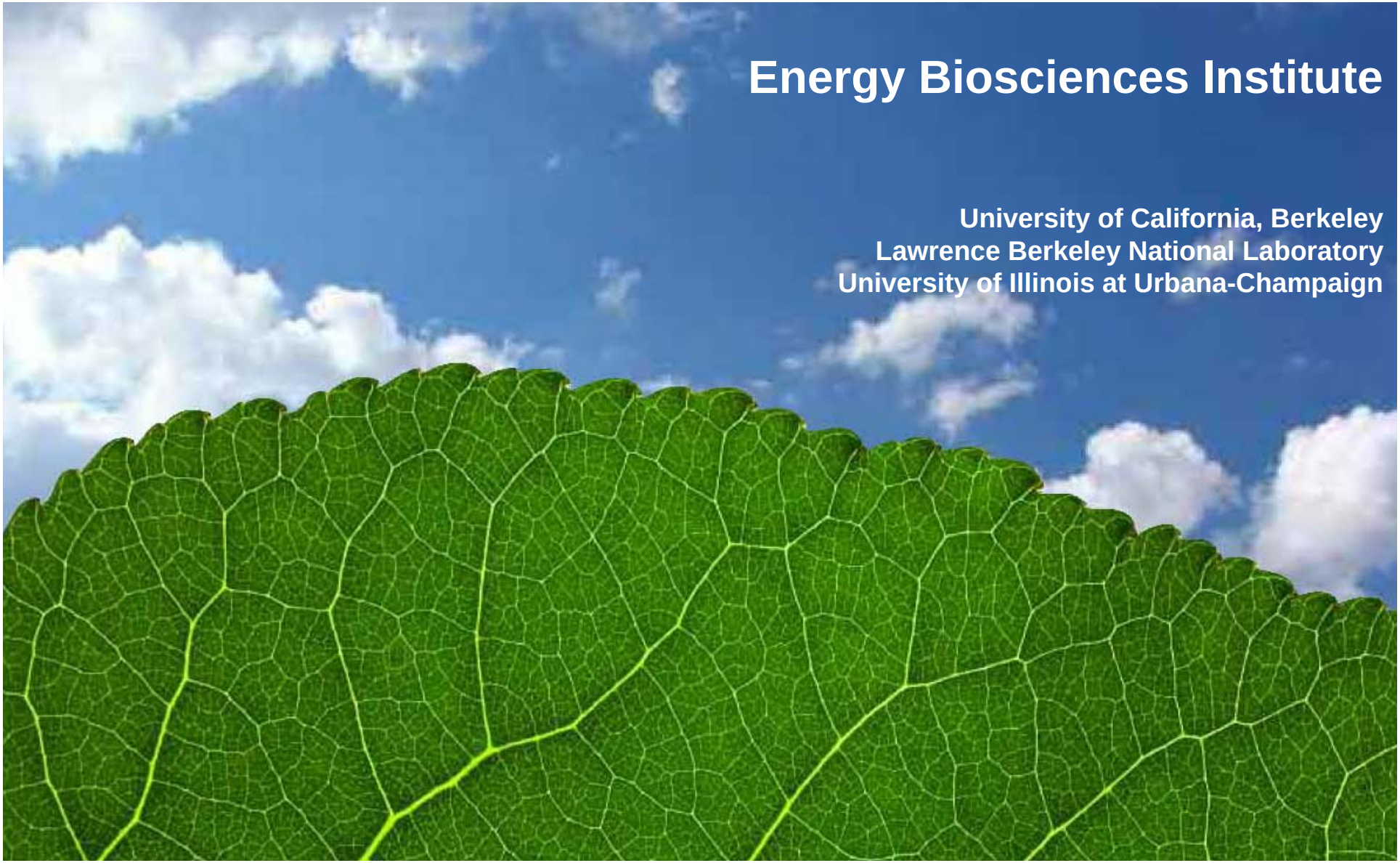


An Alternative Fuel is Not Necessarily a Low-Carbon Fuel, but it can be



Low Carbon Fuel Standard developments worldwide

- **California**: regulations to be in effect 2010
- **Other States**: Proposals in WA, OR, AZ, NM, MN, and potentially IL?
- **United Kingdom**: Renewable Transportation Fuel Obligation requires GHG monitoring, pilot in 2007
- **United States**: Bills by Boxer (D-CA), Feinstein (D-CA), Obama (D-IL) Inslee (D-WA)
- **European Union**: monitoring in 2009, reductions start in 2011

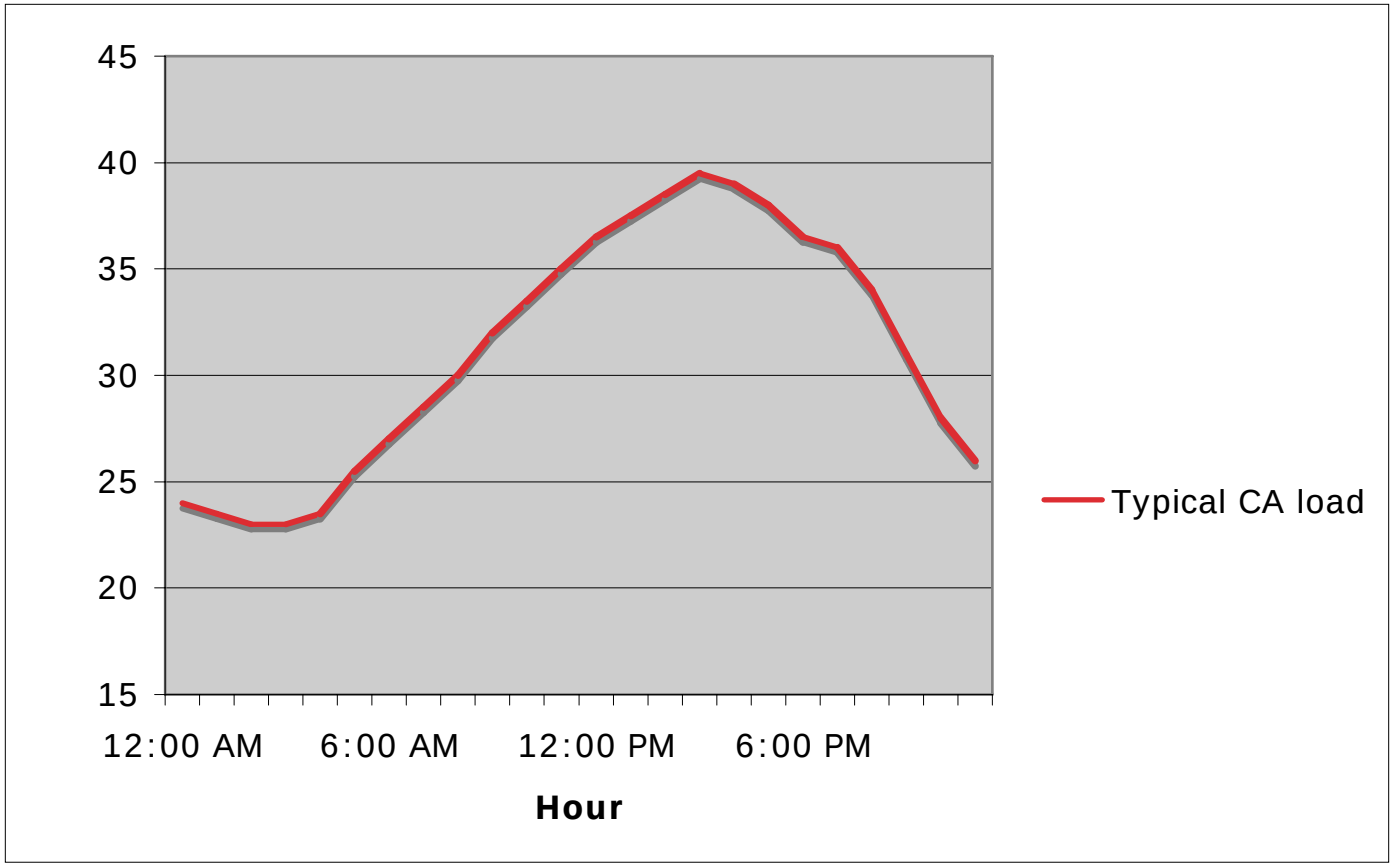


A $500 million biofuel development collaboration with BP

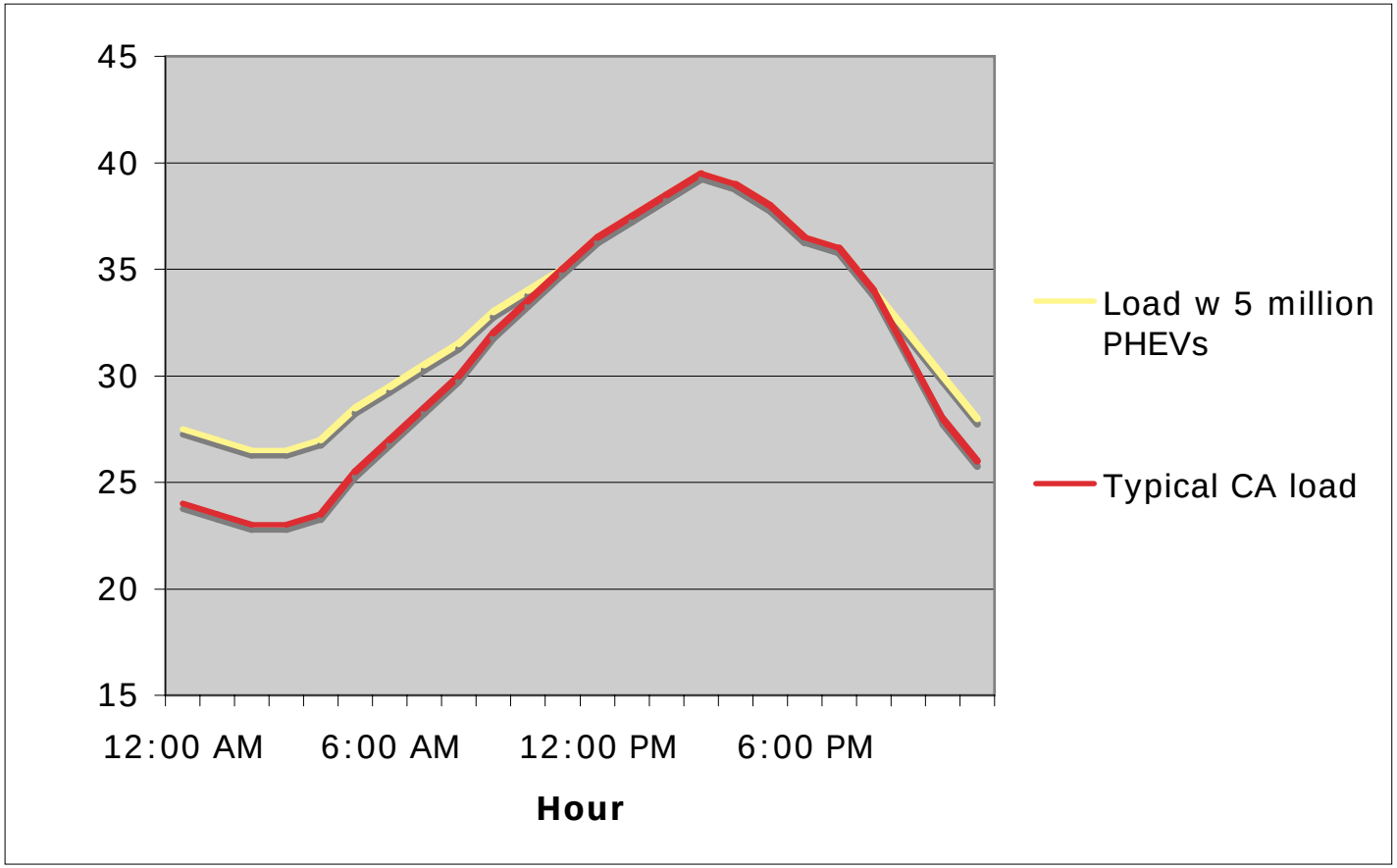
Many Other Areas in Need of Dedicated Programs

- **Energy efficiency not simply a first/least cost action, a facilitator of *all* clean energy options**
- **Transmission, distribution, storage neglected (need for science and engineering)**
- **Vehicle sector**
- **Carbon sequestration with full technical and economic life-cycle assessment**

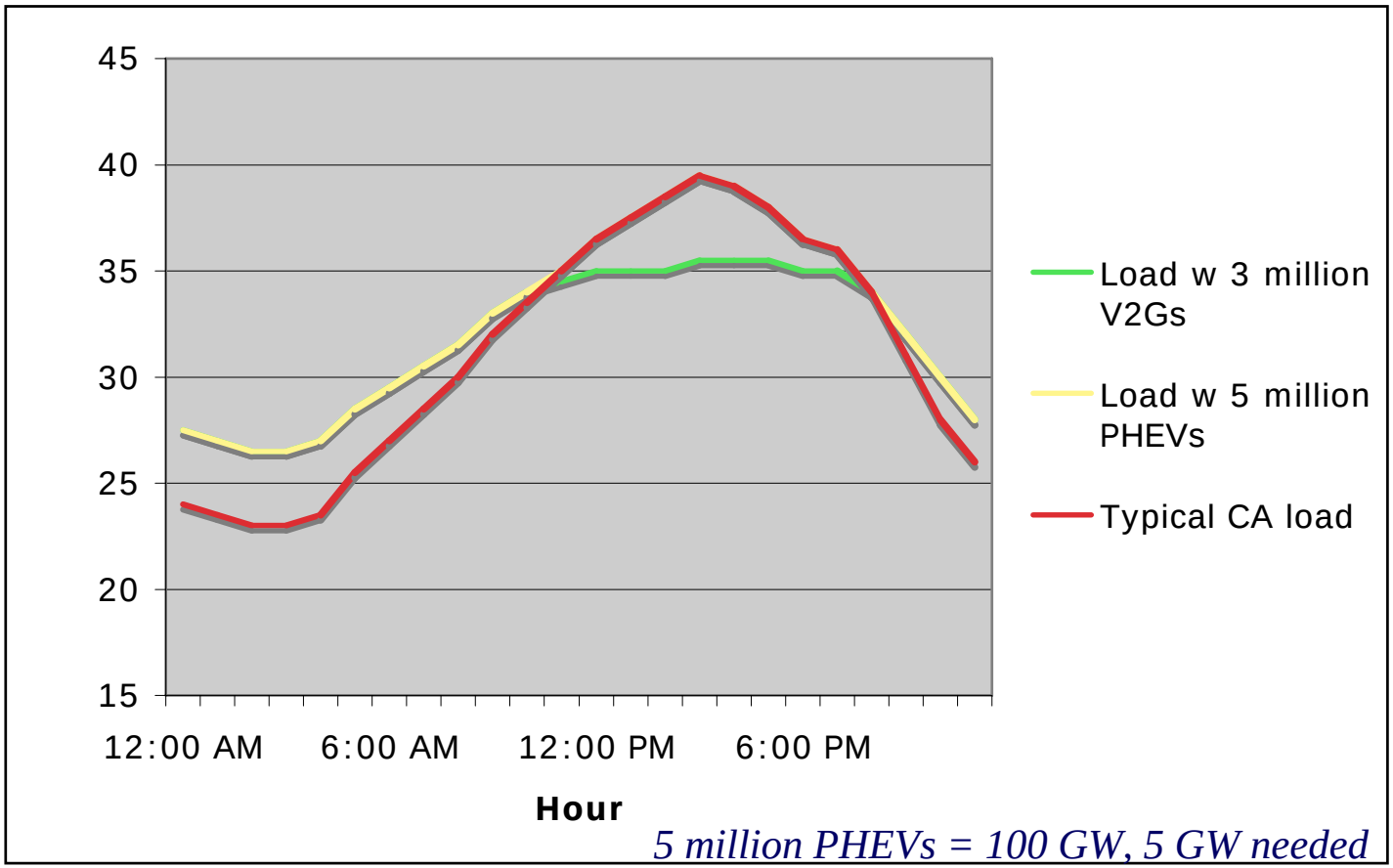
Grid integration of plug-in hybrids could address night time load problems, assuming that most battery charging occurs at night



Grid integration of plug-in hybrids could address night time load and storage problems and absorb wider range of off-peak wind output, emissions



Grid integration of plug-in hybrids could also provide storage for vehicle-to-grid (V2G), as cars are parked 95% of the time; reducing peak demand by 5000 MW



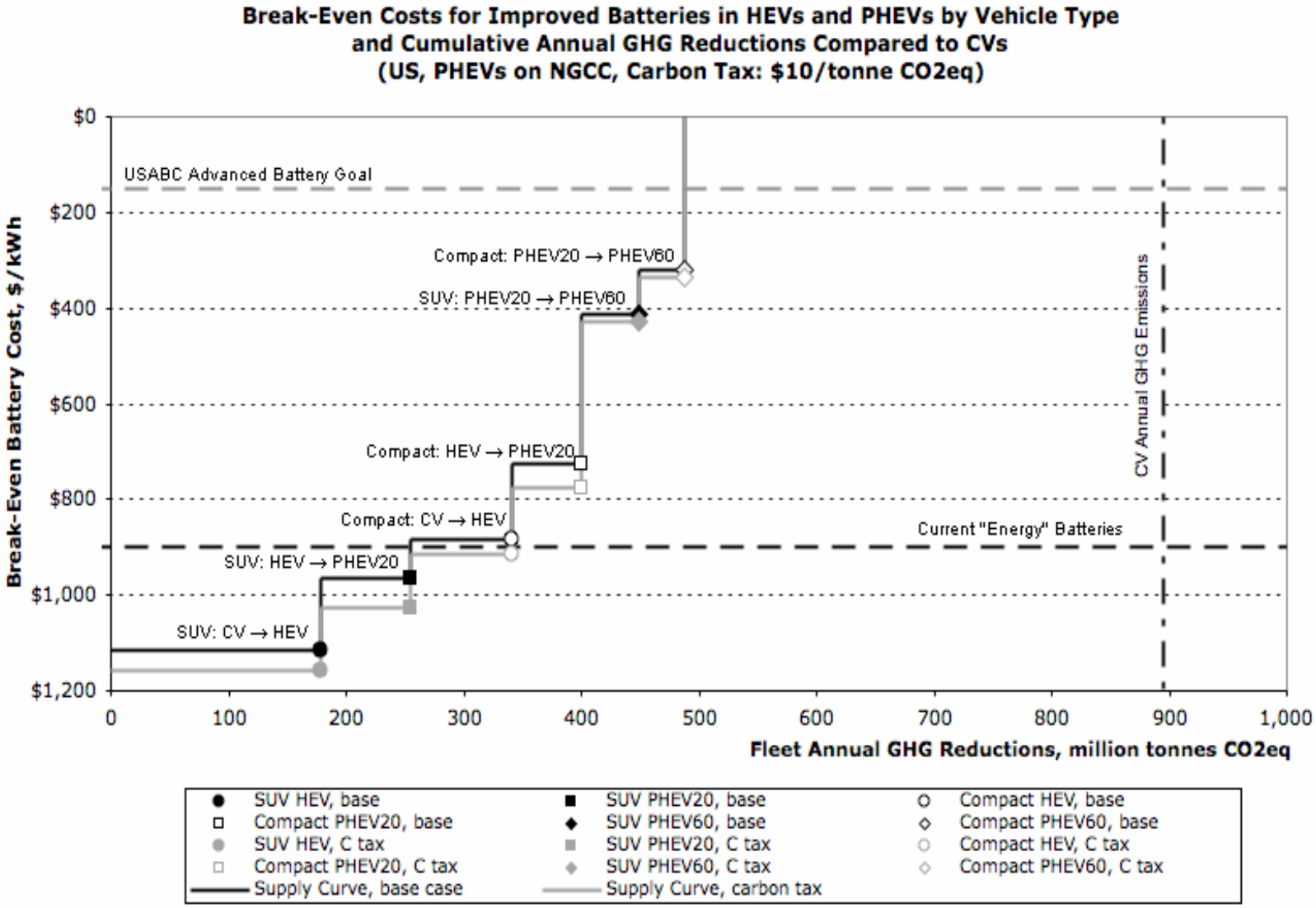
5 million PHEVs = 100 GW, 5 GW needed

Embrace the Possibilities

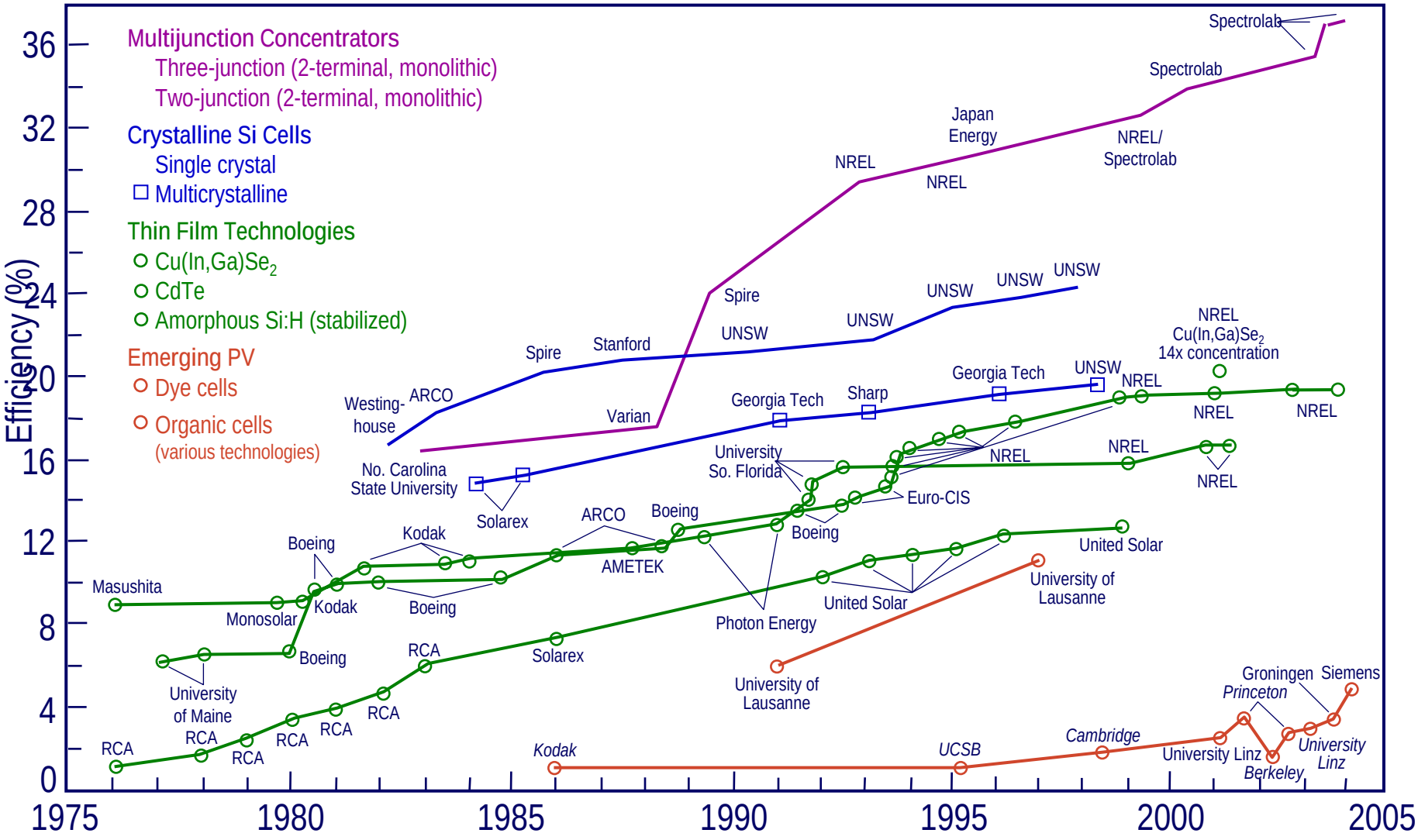
Plug in hybrid with cellulosic ethanol in the tank: 100+ miles per gallon

Breakthrough: stationary and mobile energy sources now linked

PLUG-IN HYBRID'S use of gasoline and electricity will minimize overall emissions of carbon dioxide by vehicles in the future, especially as utility power generation grows greener.


Break-Even Costs for Improved Batteries in HEVs and PHEVs by Vehicle Type
and Cumulative Annual GHG Reductions Compared to CVs
(US, PHEVs on NGCC, Carbon Tax: $10/tonne CO2eq)
Break-Even Battery Cost, $/kWh
$0
$200
$400
$600
$800
$1,000
$1,200
USABC Advanced Battery Goal
Compact: PHEV20 → PHEV60
SUV: PHEV20 → PHEV60
Compact: HEV → PHEV20
Compact: CV → HEV
SUV: HEV → PHEV20
SUV: CV → HEV
Current "Energy" Batteries
CV Annual GHG Emissions
0
100
200
300
400
500
600
700
800
900
1,000
Fleet Annual GHG Reductions, million tonnes CO2eq
SUV HEV, base
Compact PHEV20, base
SUV HEV, C tax
Compact PHEV20, C tax
Supply Curve, base case
SUV PHEV20, base
SUV PHEV60, base
SUV PHEV20, C tax
SUV PHEV60, C tax
Supply Curve, carbon tax
Compact HEV, base
Compact PHEV60, base
Compact HEV, C tax
Compact PHEV60, C tax

Best Research-Cell Efficiencies



Solar Energy for Many Applications

Moscone Center, SF: 675,000 W

Residential Solar: 1000 - 4000 Watts/home

CA Million Solar Roofs Program:

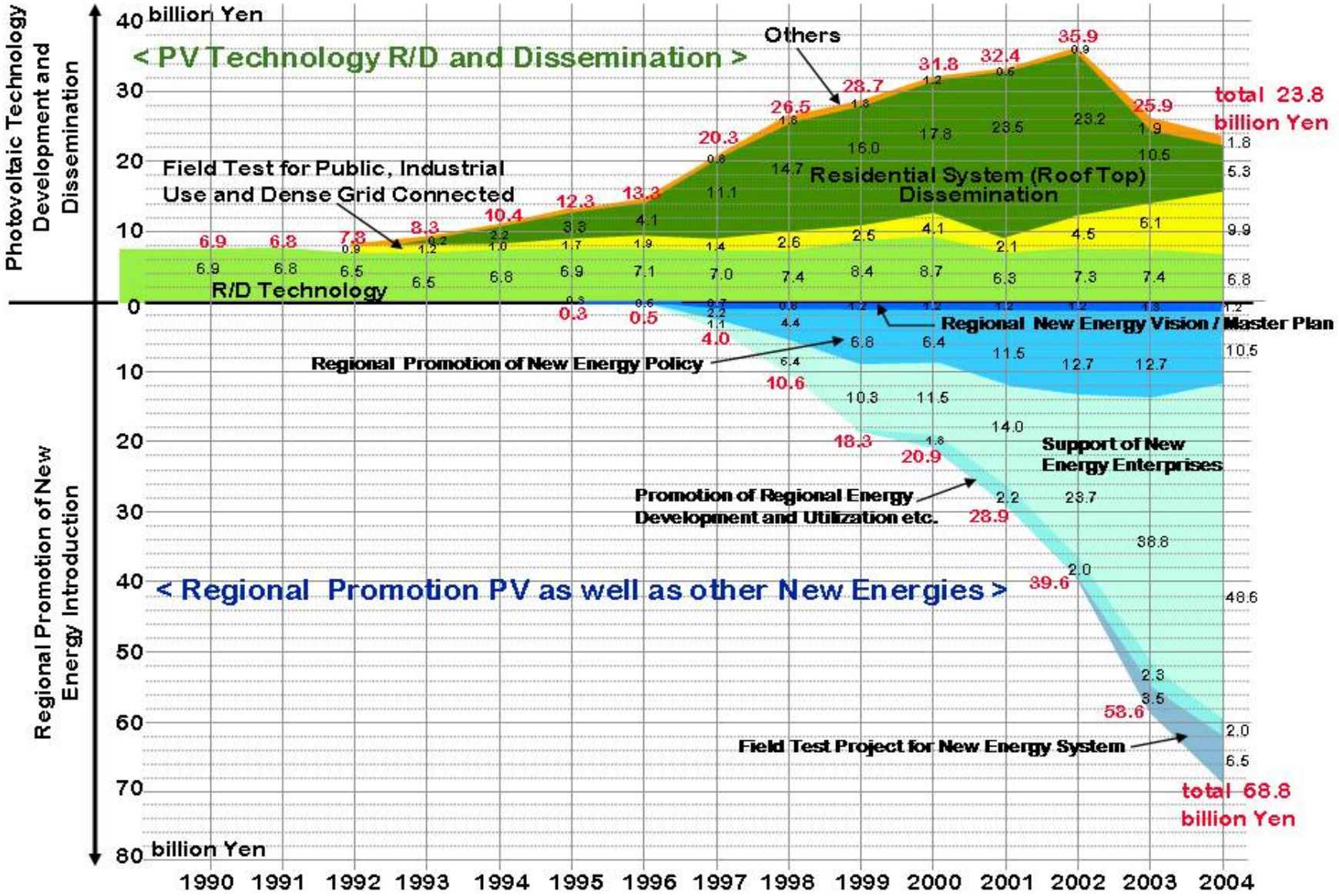
3,000 - 10,000 MW of solar to be built

Kenyan PV market: Average system: 18W

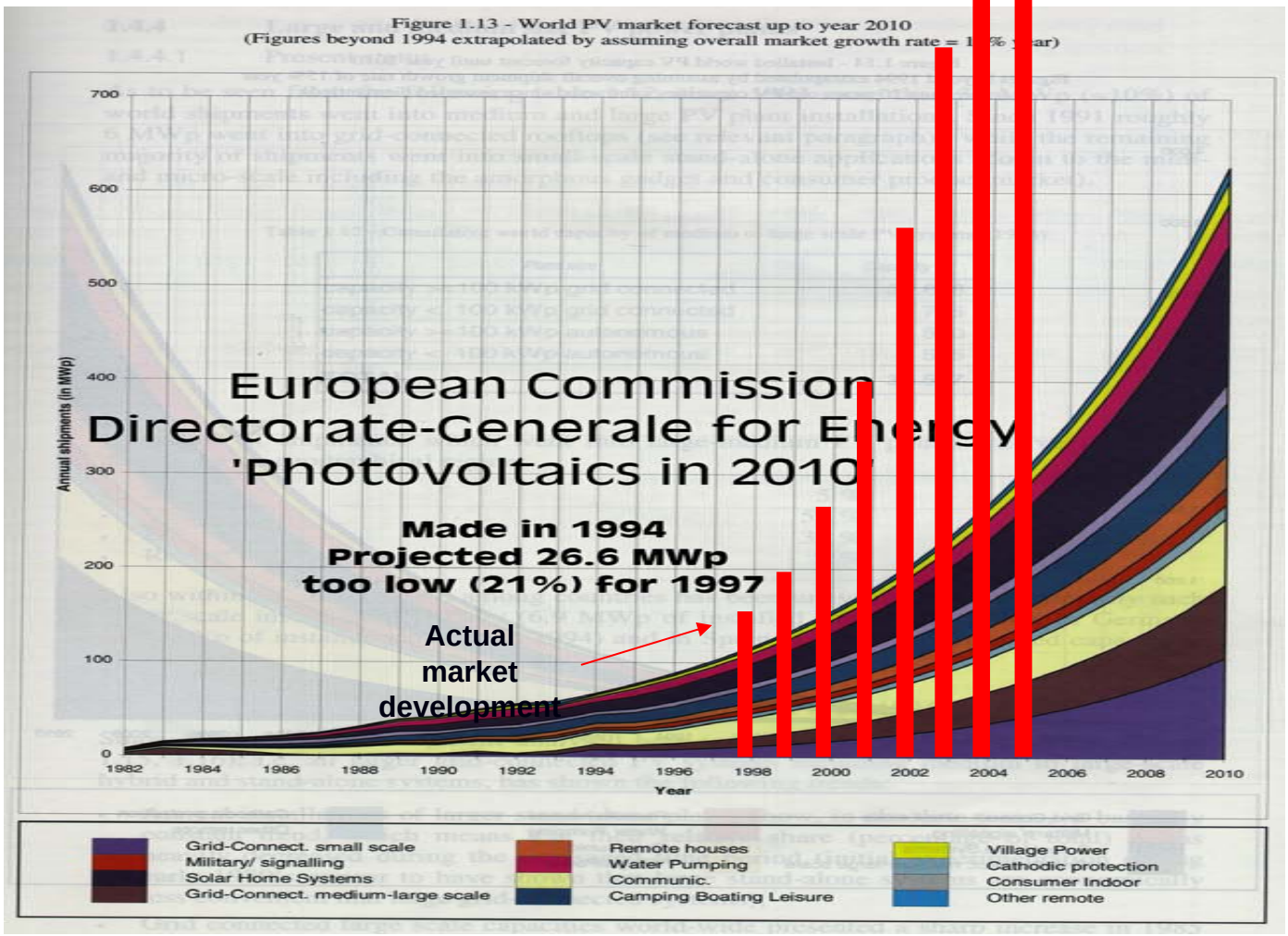
Largest penetration rate of any nation

	California	Japan
2005 Annual PV Installations	50 MW	290 MW
Average Cost for Residential System	$8.8/Wac	$7.4/Wac
Average Cost Reduction from 99-04	5.2%/year	8.9%/year

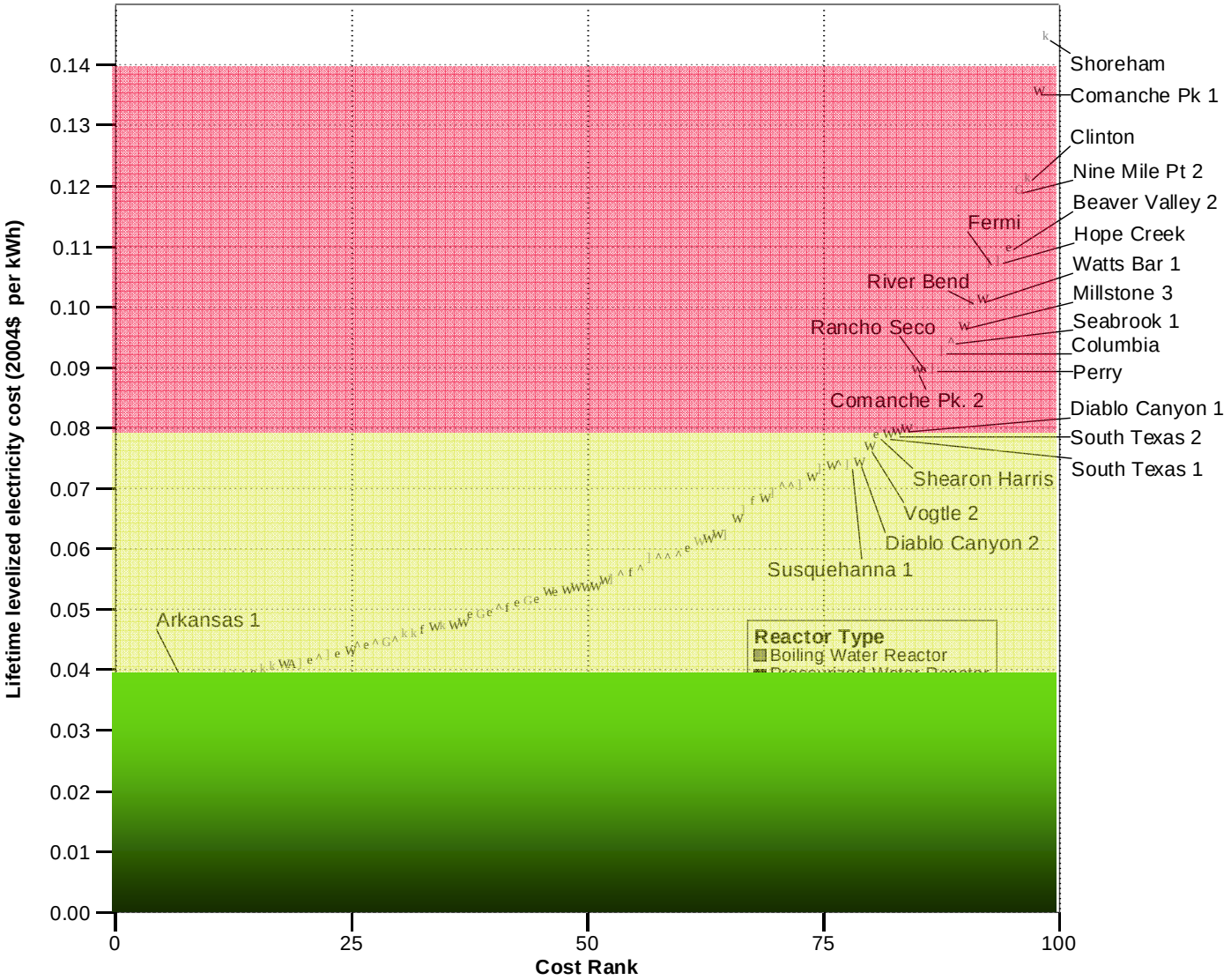
Japanese “Sunshine” Program



Actual Growth vs. Historic Forecasts

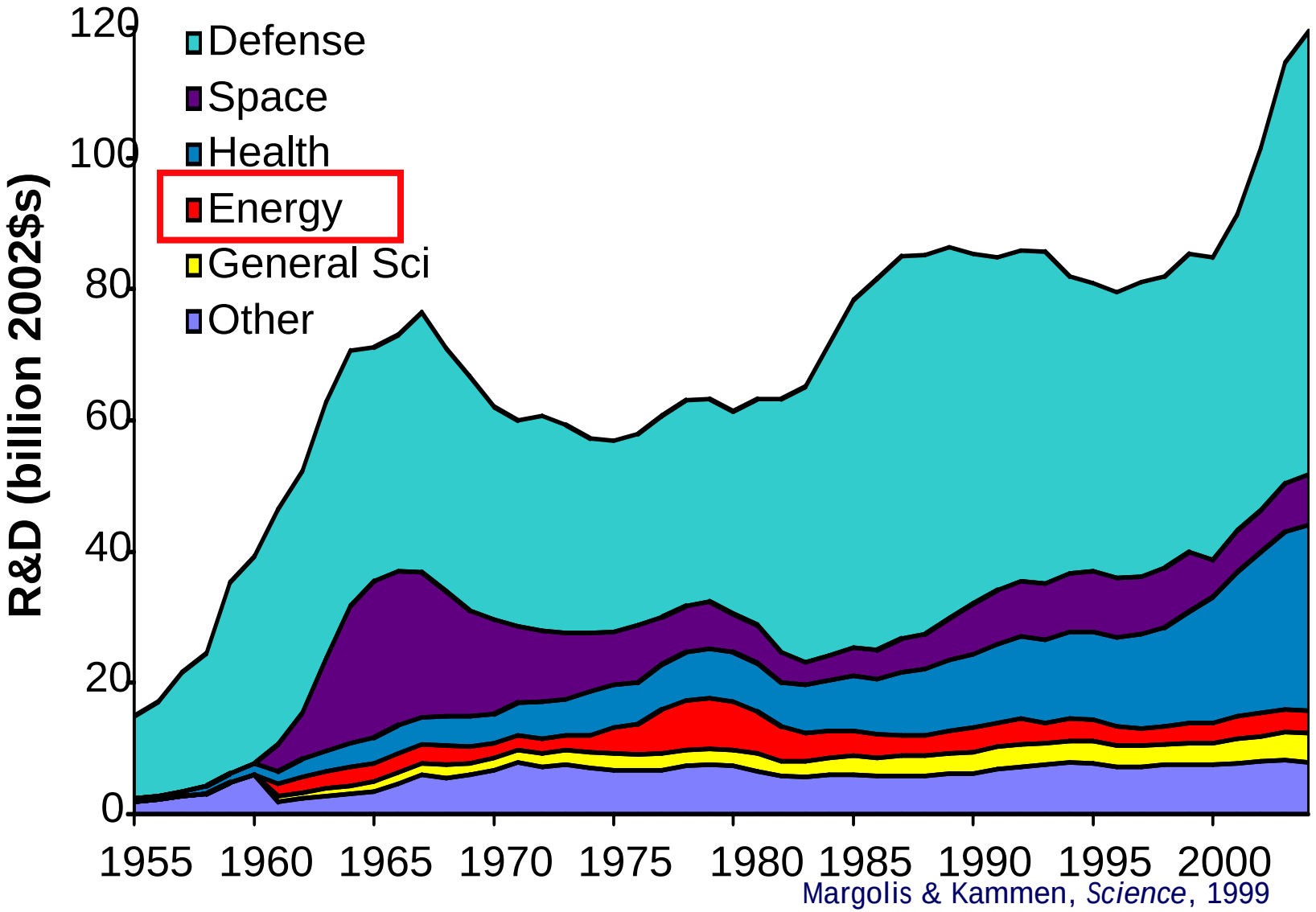


The Cost of Nuclear Power from the U. S. Civilian Reactor Fleet



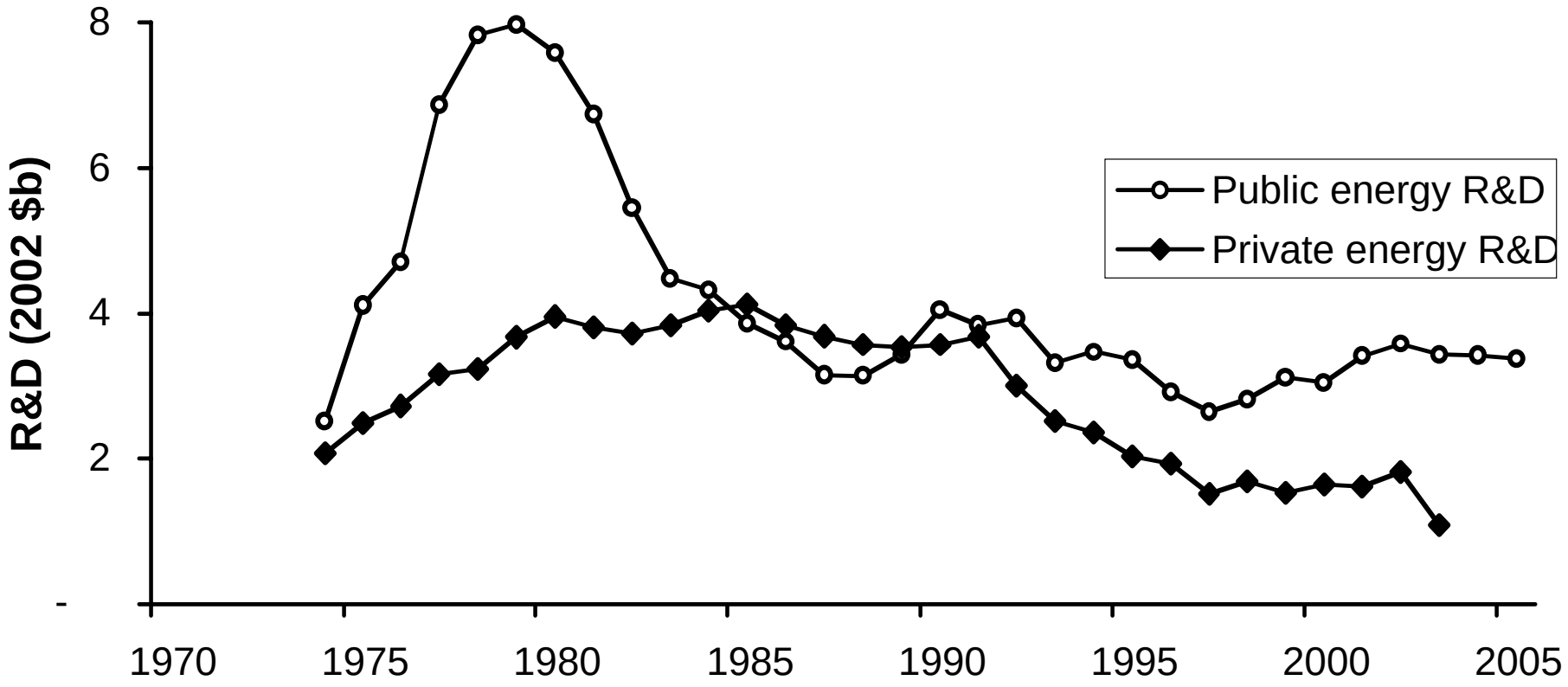
Hultman, Koomey & Kammen (2007) *ES&T*

Federal R&D Investments, 1955 - 2004



Margolis & Kammen, *Science*, 1999

US Public and Private Sector Energy R&D History



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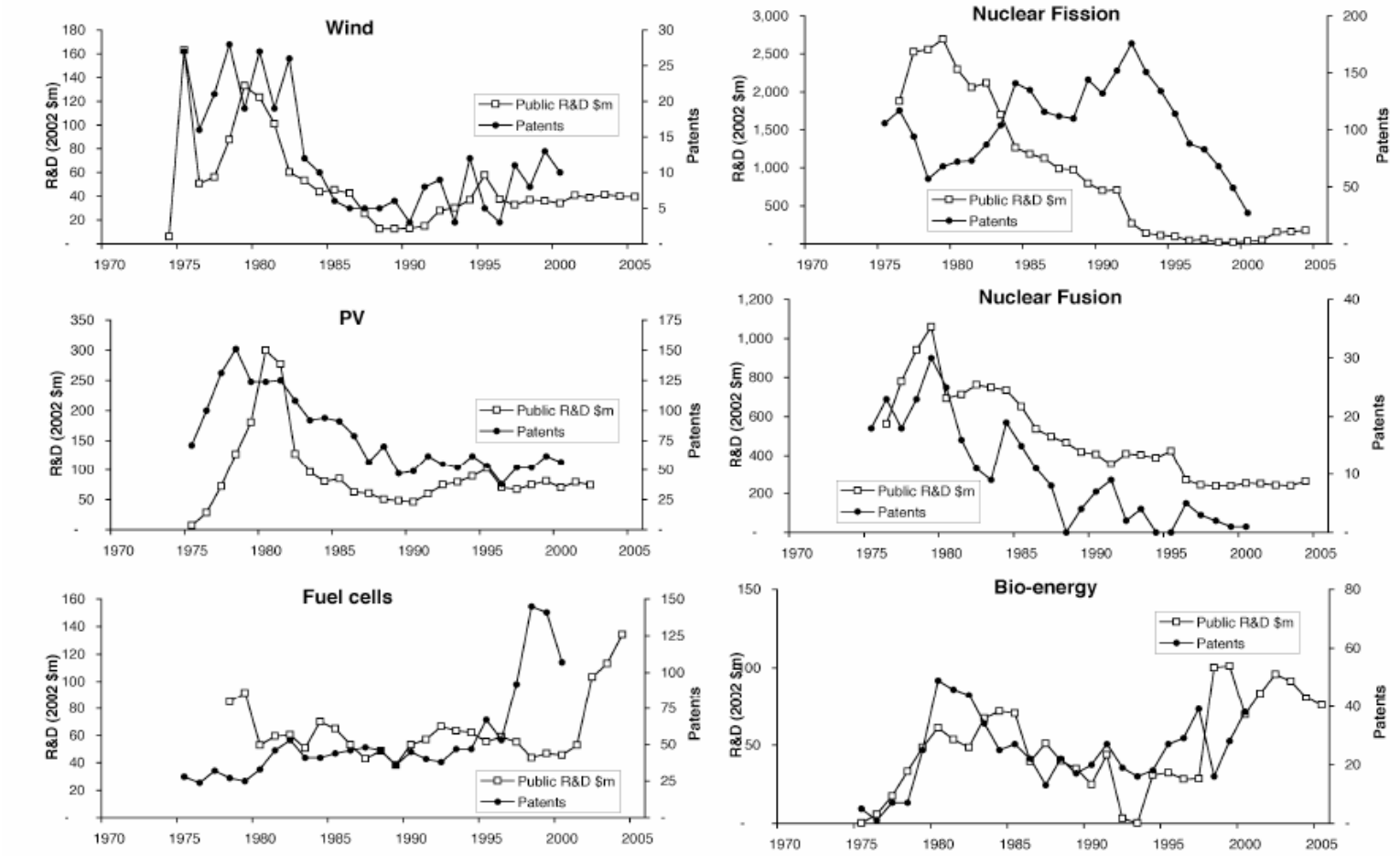
"Reversing the incredible shrinking energy R&D budget," *Issues in Science & Technology,* **Fall**, 84 – 88.

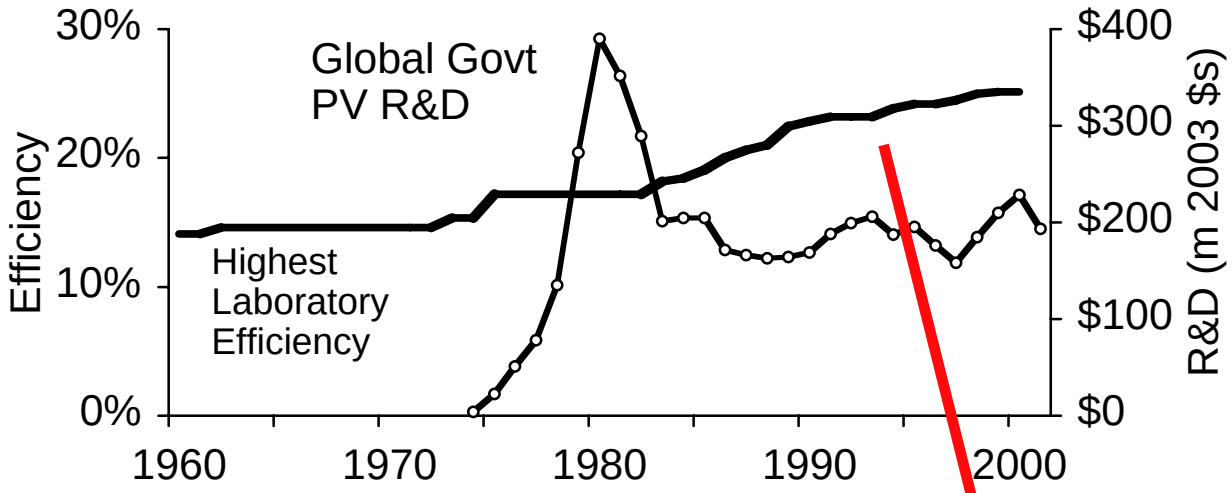
Patents and R&D Funding Correlated



Kammen and Nemet (2005)
"Reversing the incredible shrinking energy R&D budget," *Issues in Science & Technology,* **Fall**, 84 – 88.
And Nemet, dissertation, 2007

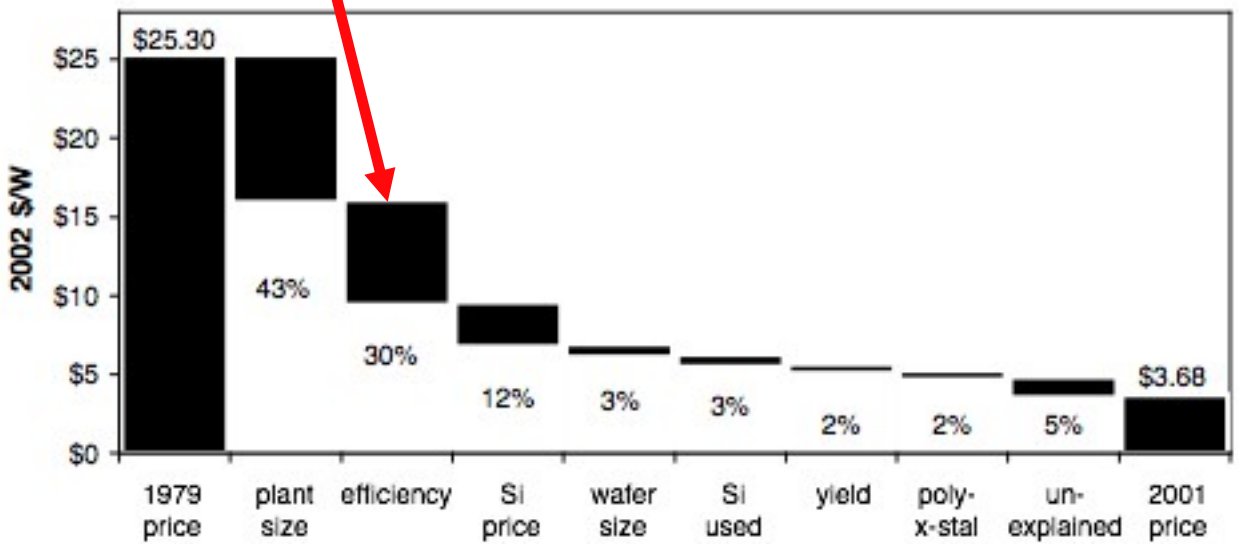
Quantifying the benefits of R&D

R&D Funding → Technological change → Cost reductions



50% increase in PV efficiency occurs immediately after unprecedented >$1b global investment in PV R&D (1978-85)…

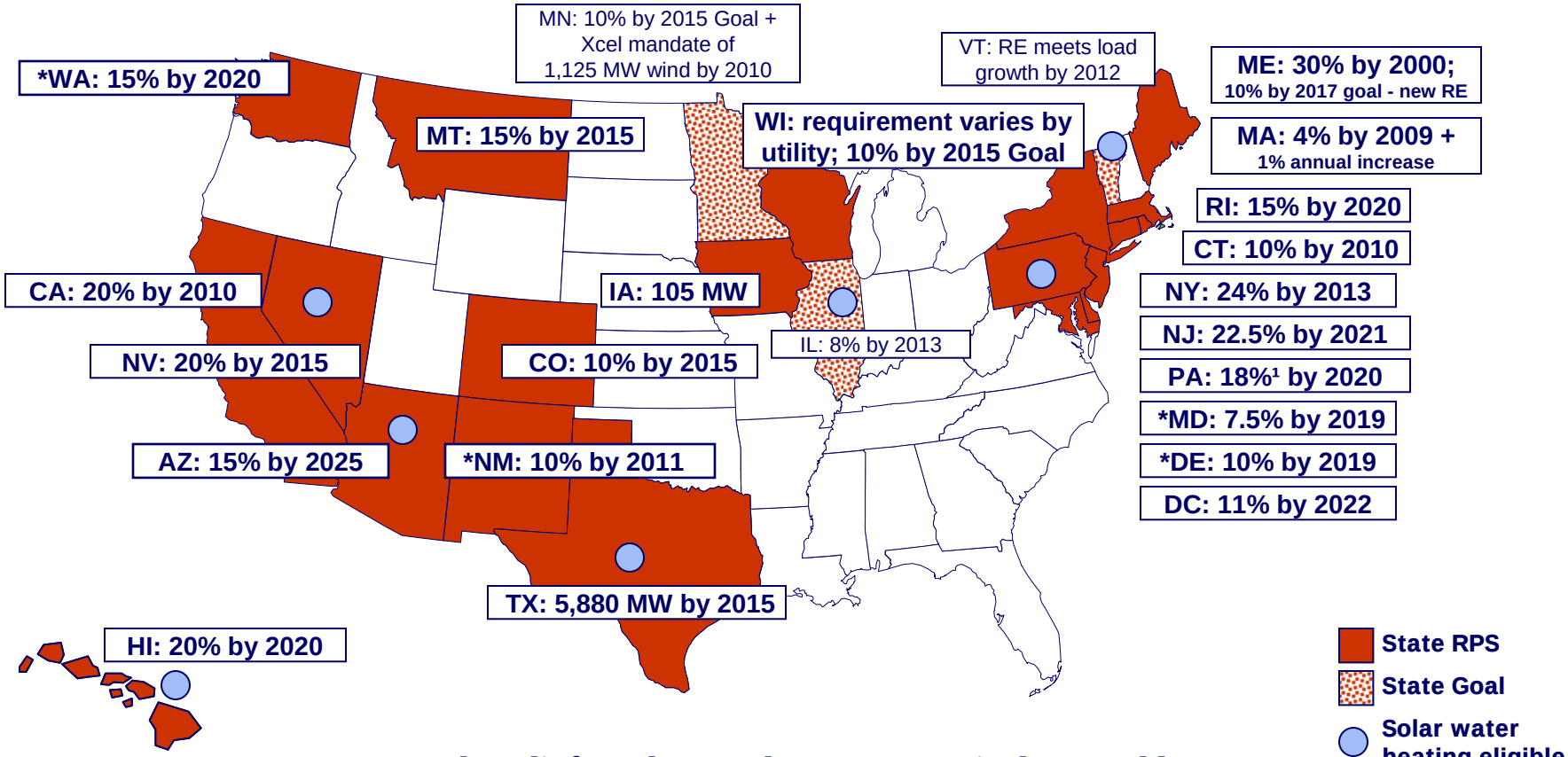
…efficiency improvements account for 30% of the cost reductions in PV over the past two decades.



Nemet, G. F. (2006) *Energy Policy* **34(17)**: 3218 - 3232.

Renewable Energy Portfolio Standards

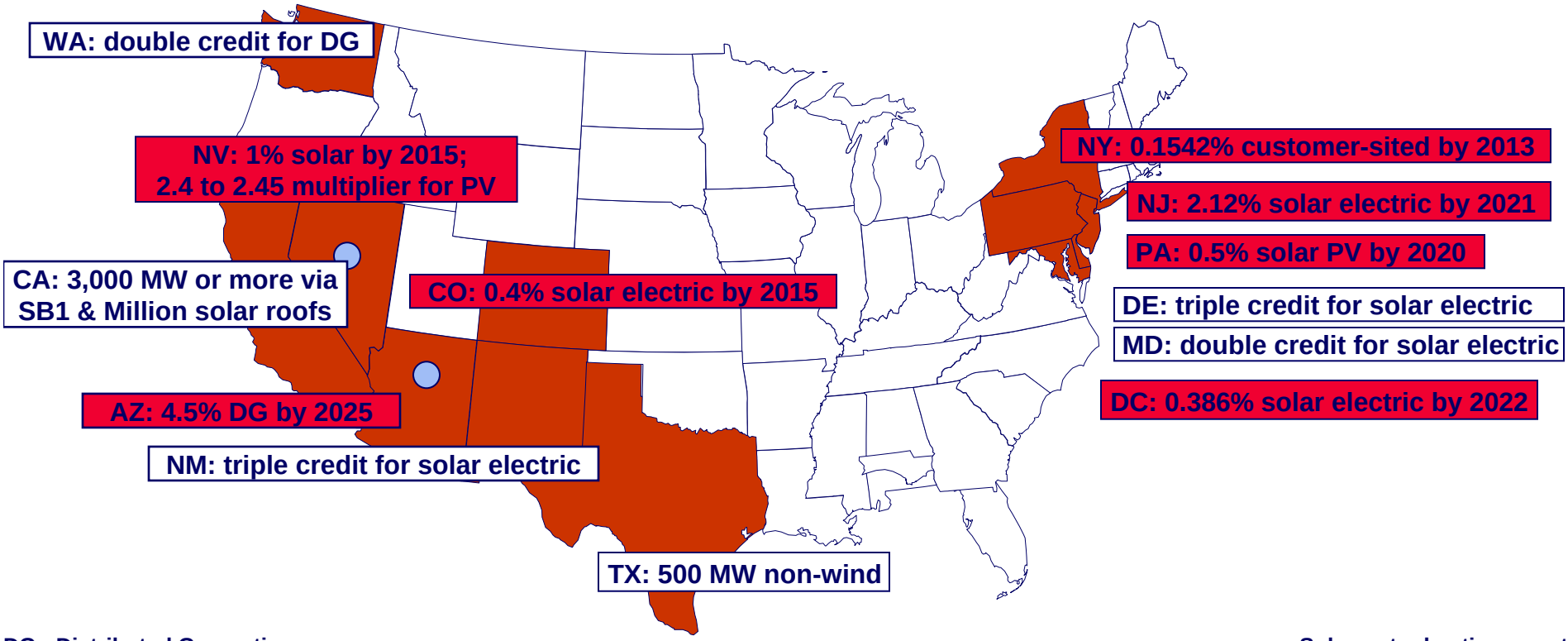
23 states + DC, and counting



*** Increased credit for solar or other customer-sited renewables**

PA: 8% Tier I (renewables)

Solar & Distributed Generation Provisions in RPS Policies

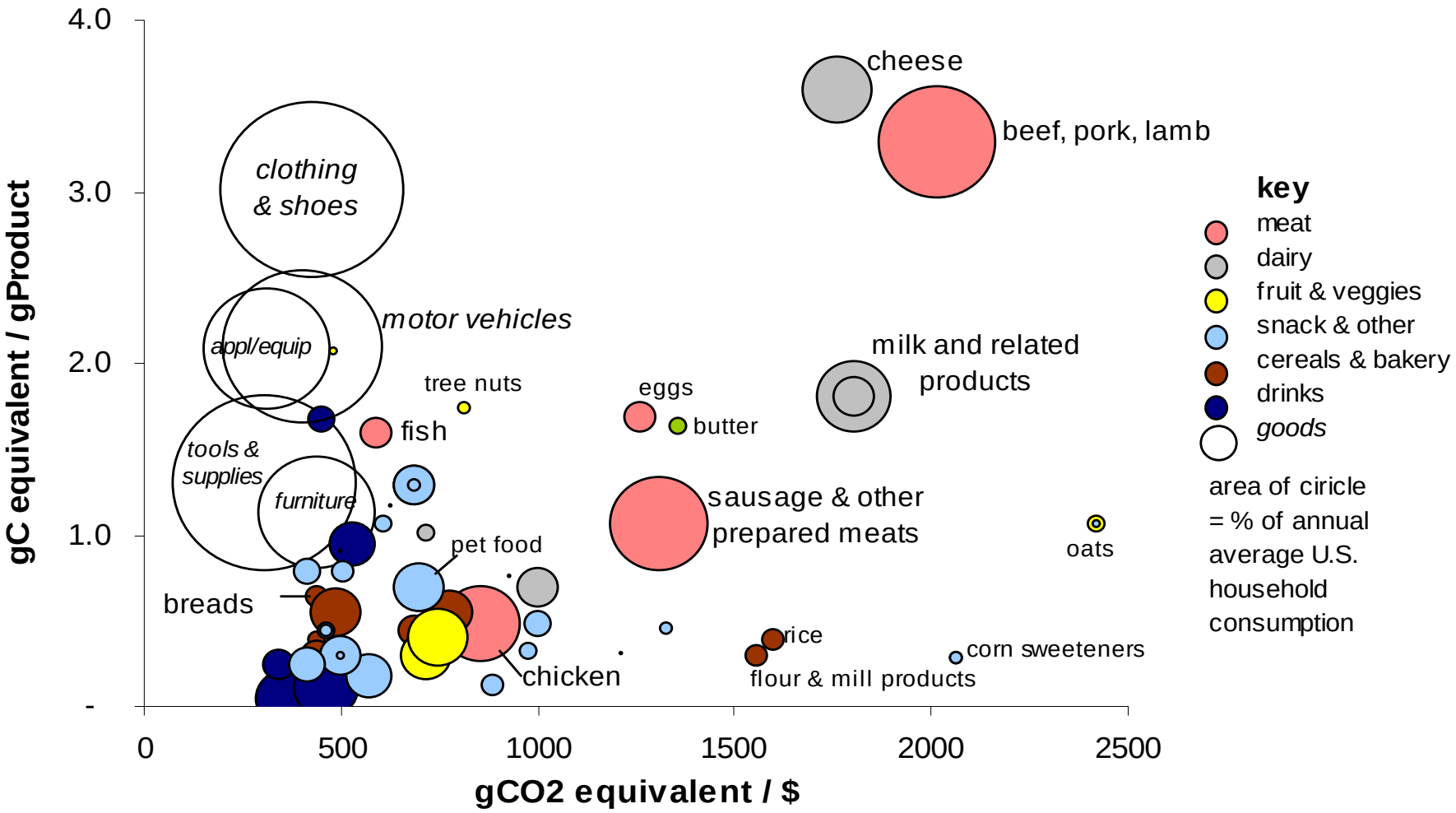


DG: Distributed Generation

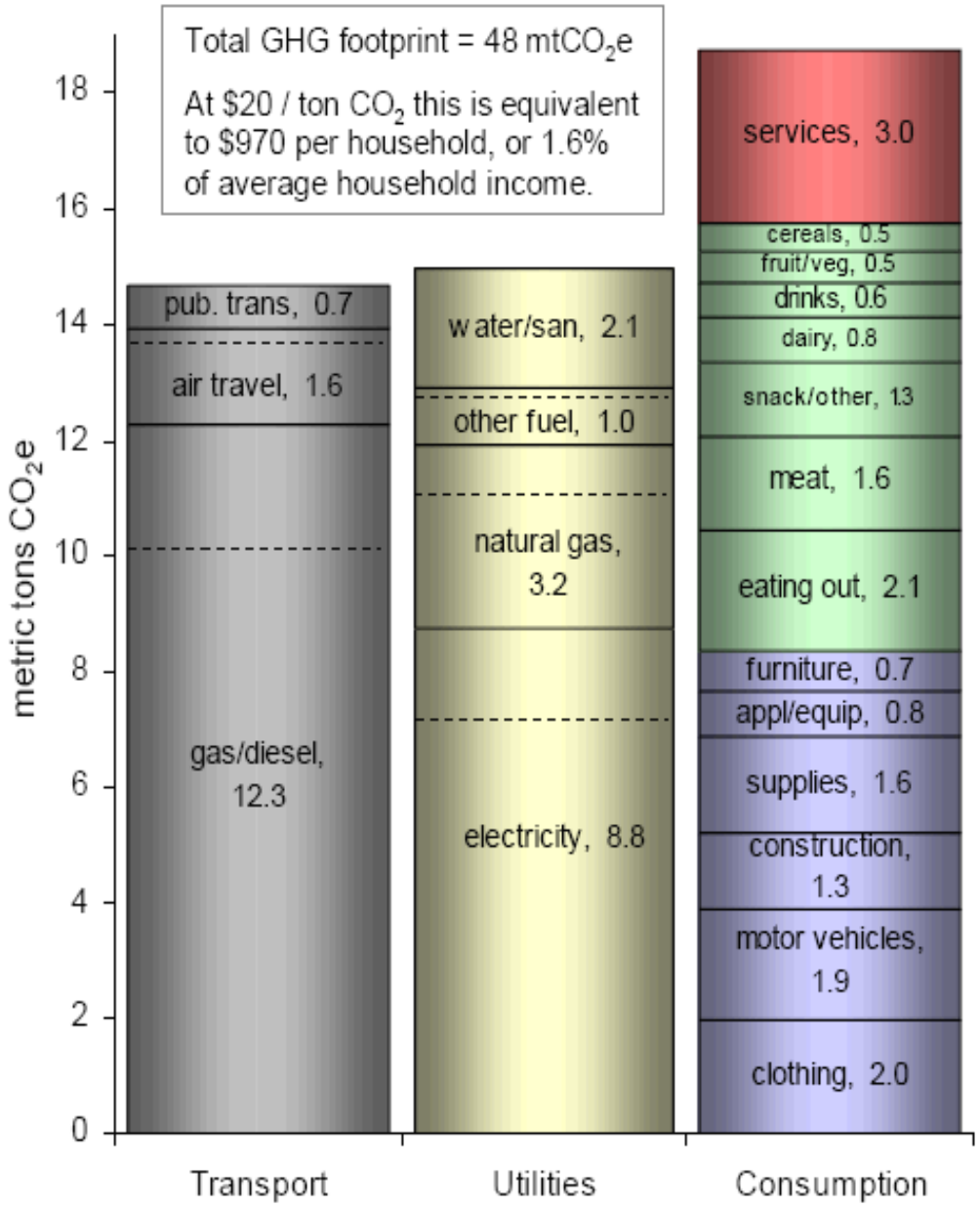
Solar water heating counts towards solar set-aside

Greenhouse Gas Emissions: Lifveycles & Lifestyle Sources

(Jones, Horvath & Kammen, in press)



Lifecycle Greenhouse Gas Emissions from U.S. Household Consumption



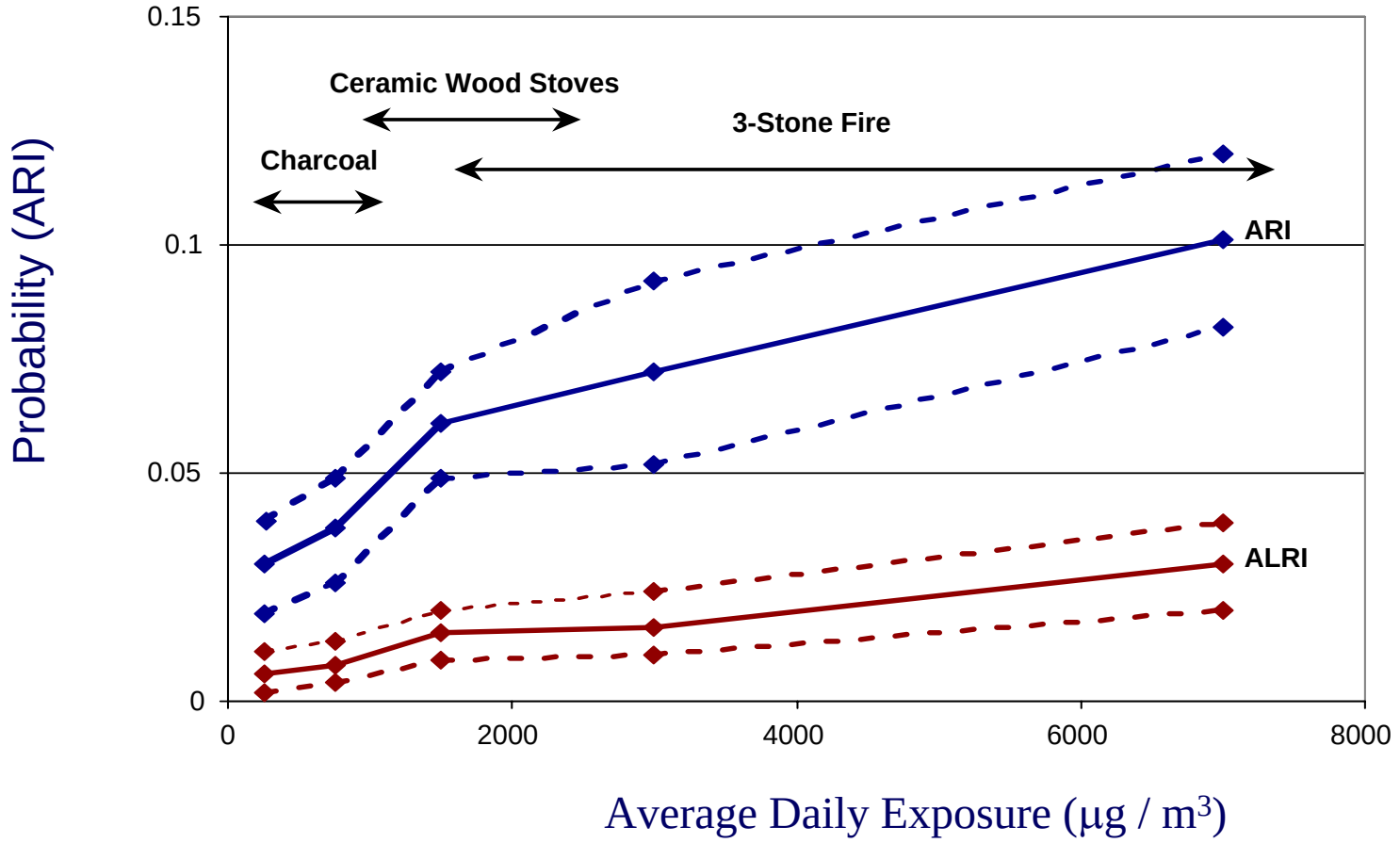
Needs & Opportunities for Action

- Major RD&D programs needed
- Raise our expectations, and investments, in clean energy
  - We now must have 'one California' per year…
    for decades
- Balance all-economy w/sectoral approaches
- Recognize (monetize) the benefits of clean, secure energy options
- Recognize the benefits of carbon finance
  Oil in 2003 ($28/barrel), oil in 2006 ($60/barrel)
  This is equivalent to a $271/ton carbon tax

Exposure Reduction (> age 5)

(Ezzzati and Kammen, *The Lancet*, **358**, 2001)

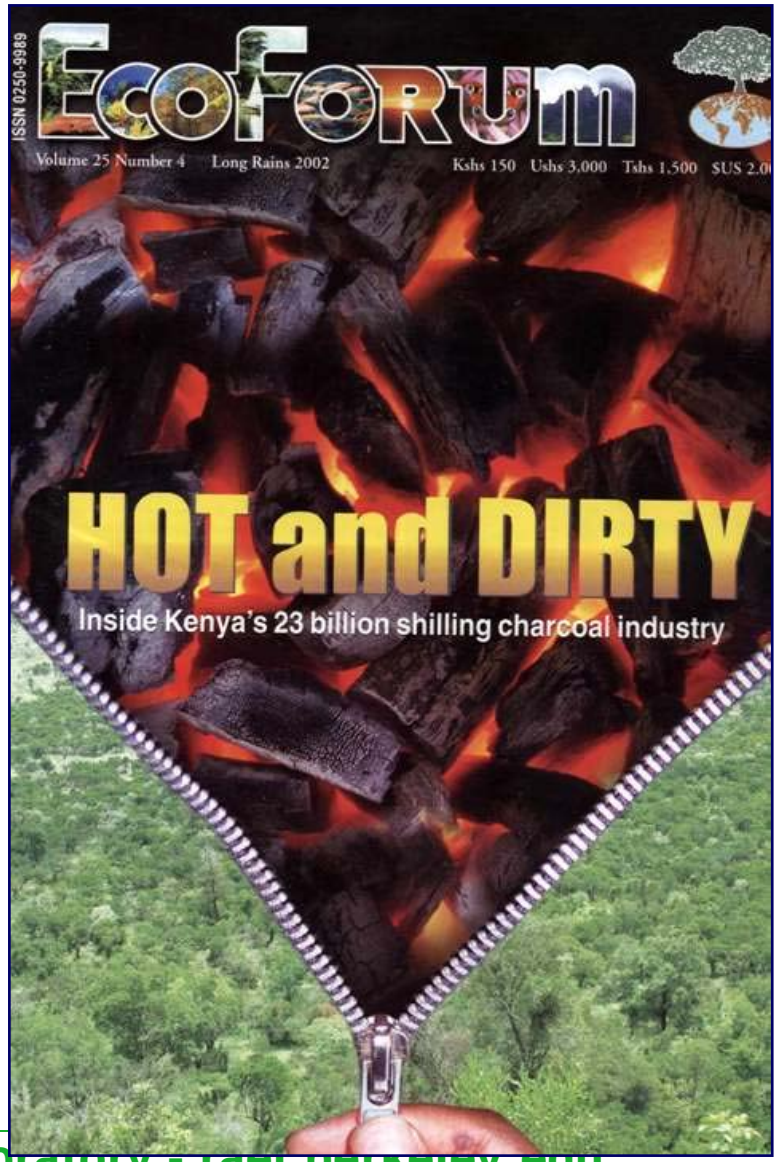
http://socrates.berkeley.edu/~rael/papers.html



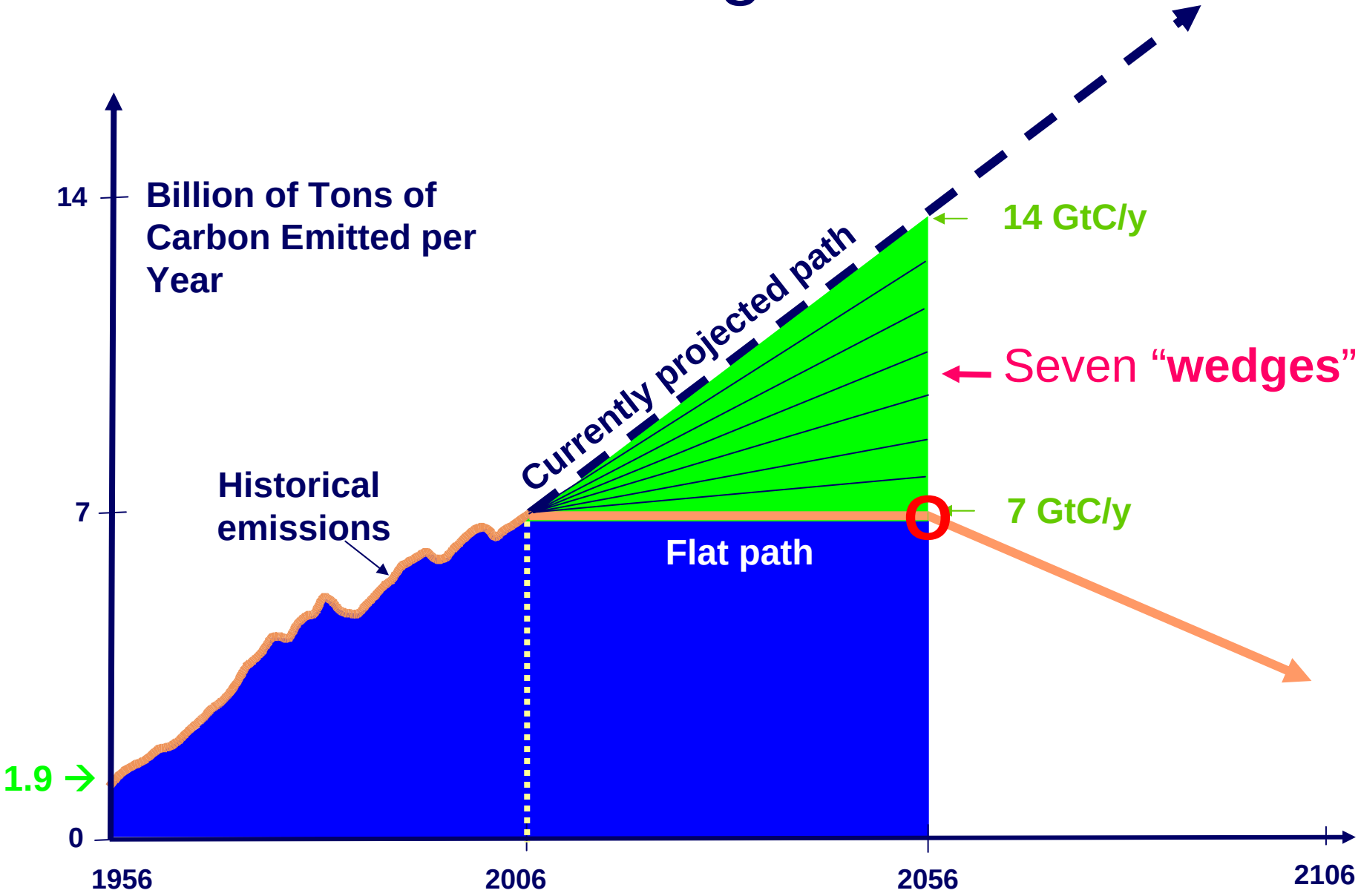
Charcoal Trade Now Under Scrutiny

Social-ecological Impacts:

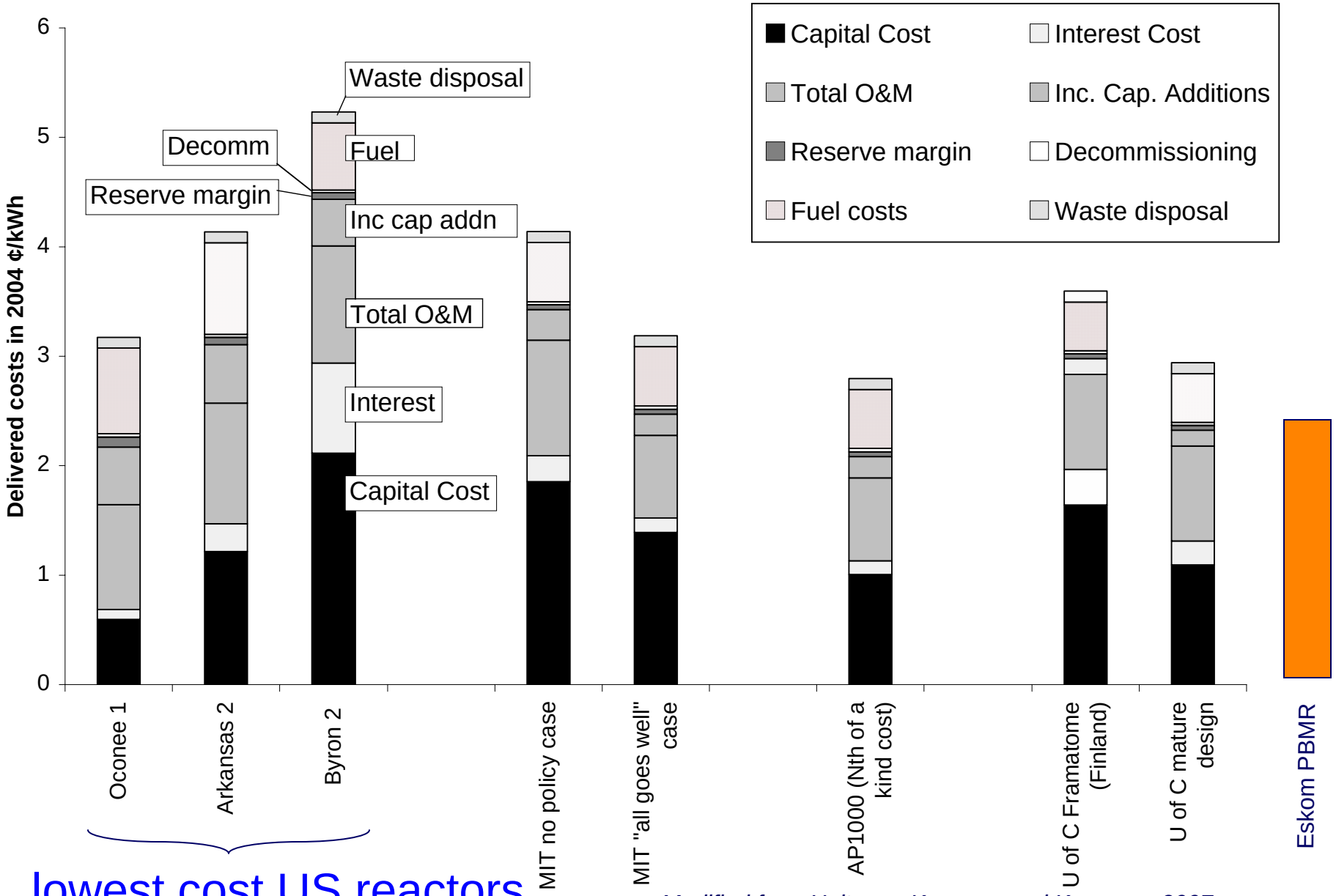
- Over 200,000 people employed in Kenya
- ~ $300 million in annual revenue (equivalent to tourism)
- Extensive but poorly characterized supply chains
- Ambiguous and inconsistent regulations
- Strong association with environmental degradation



Wedges

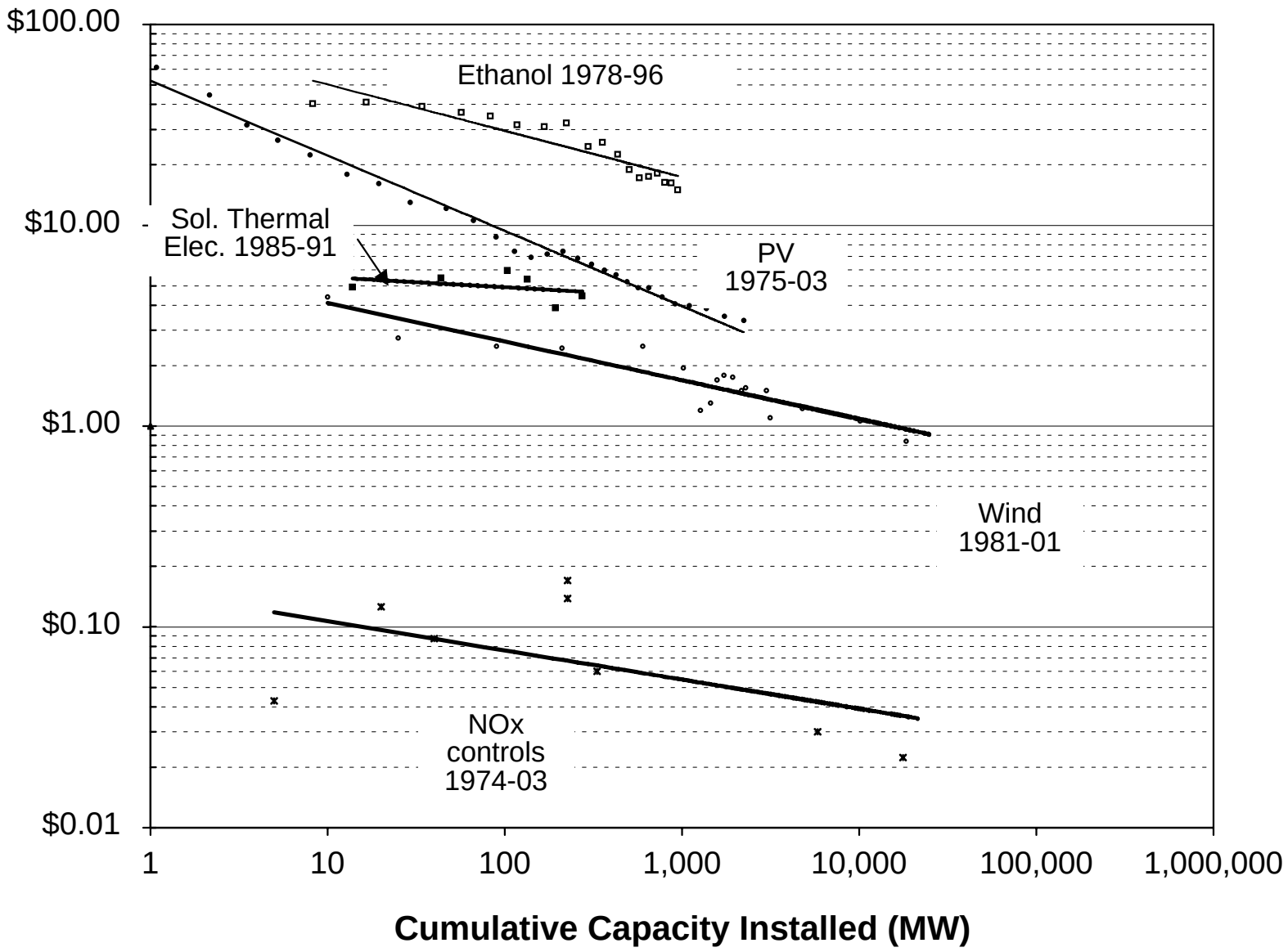

14
Billion of Tons of Carbon Emitted per Year
7
1.9
0
1956
2006
2056
2106
Historical emissions
Currently projected path
14 GtC/y
Seven "wedges"
7 GtC/y
Flat path

Comparison to Projections



lowest cost US reactors

Modified from Hultman, Koomey, and Kammen, 2007


$100.00
$10.00
$1.00
$0.10
$0.01
Ethanol 1978-96
Sol. Thermal
Elec. 1985-91
PV
1975-03
Wind
1981-01
NOx
controls
1974-03
1
10
100
1,000
10,000
100,000
1,000,000
Cumulative Capacity Installed (MW)