Environmental costs and benefits and oil substitution potential

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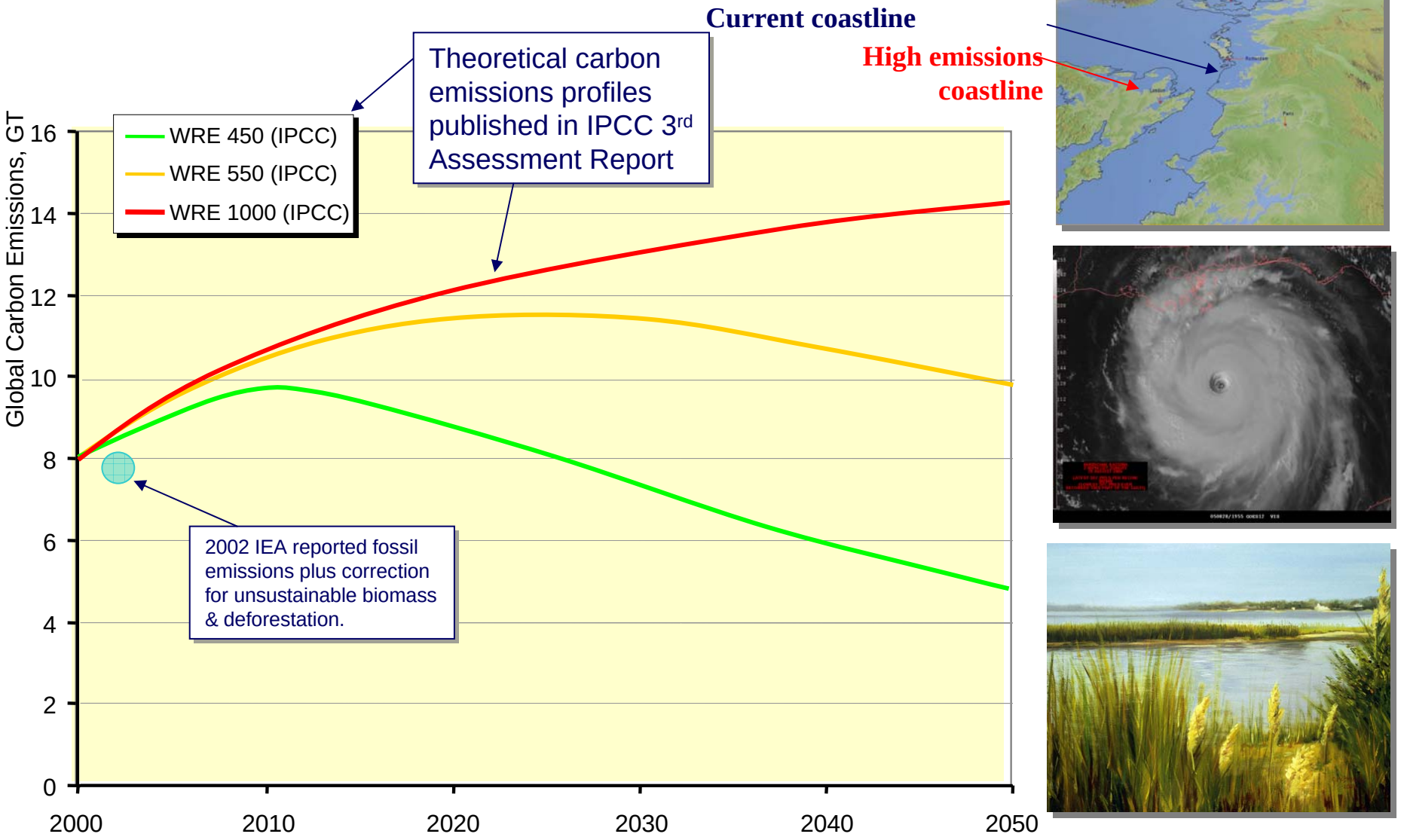
University of California, Berkeley

Materials online at: http://rael.berkeley.edu

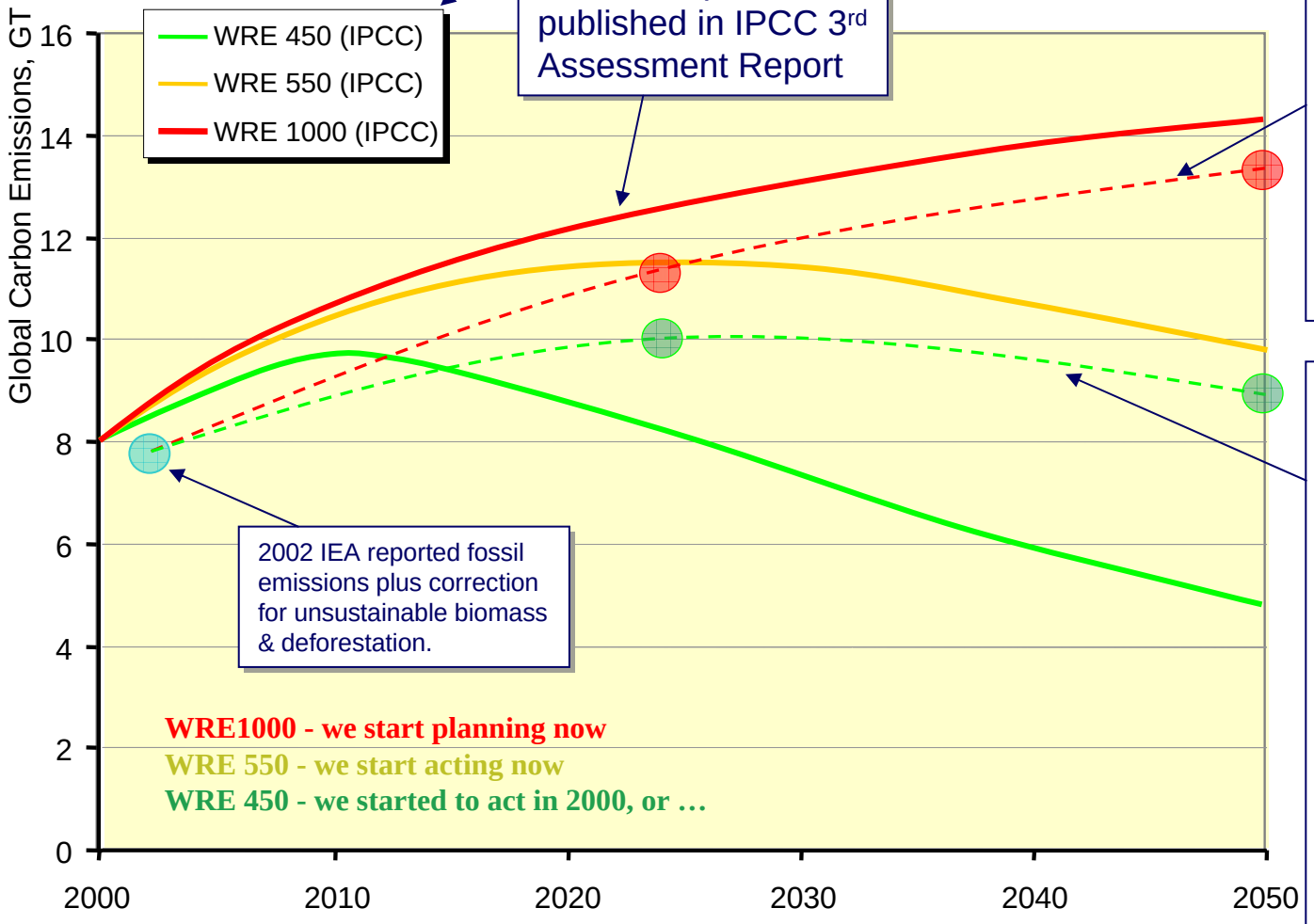
June 7/8, OECD Joint Transportation Research Centre, "Biofuels: Linking Support to Performance"

High and low carbon pathways



Thanks to the World Business Council for Sustainable Development

High and low carbon pathways



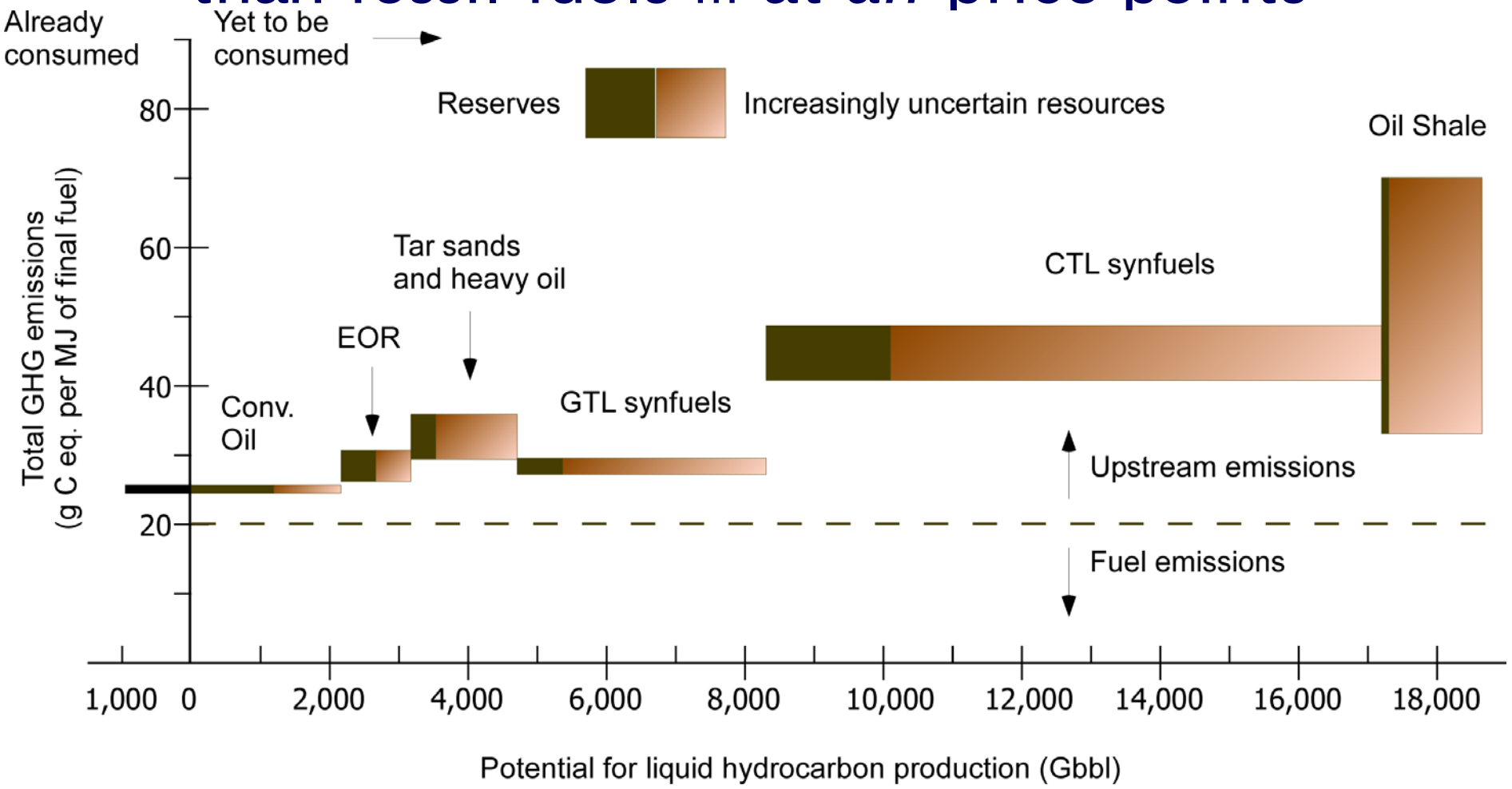
>900 ppm Trajectory Energy by 2050:

- **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:

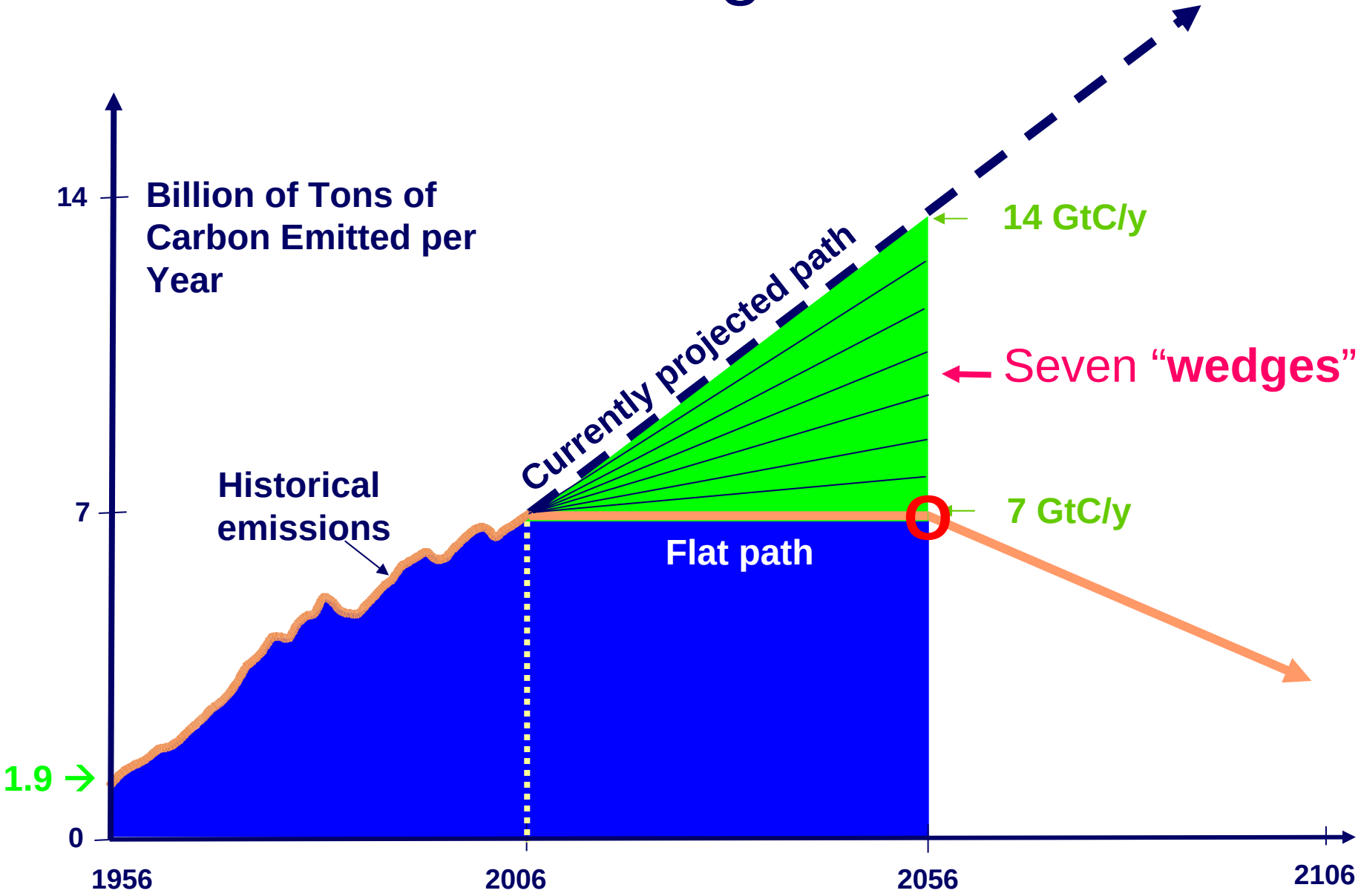
- **Coal up 50%, but half of power stations use CCS.**
- Oil down 10-15%.
- **Gas nearly 2-3x (note: adds volatility)**
- **Biofuels make up 20% of vehicle fuel mix.**
- **Hydrogen has arrived (if green)**
- **Strong shift to electricity as final energy (~50% final energy).**
- **Strong increase in nuclear.**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

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

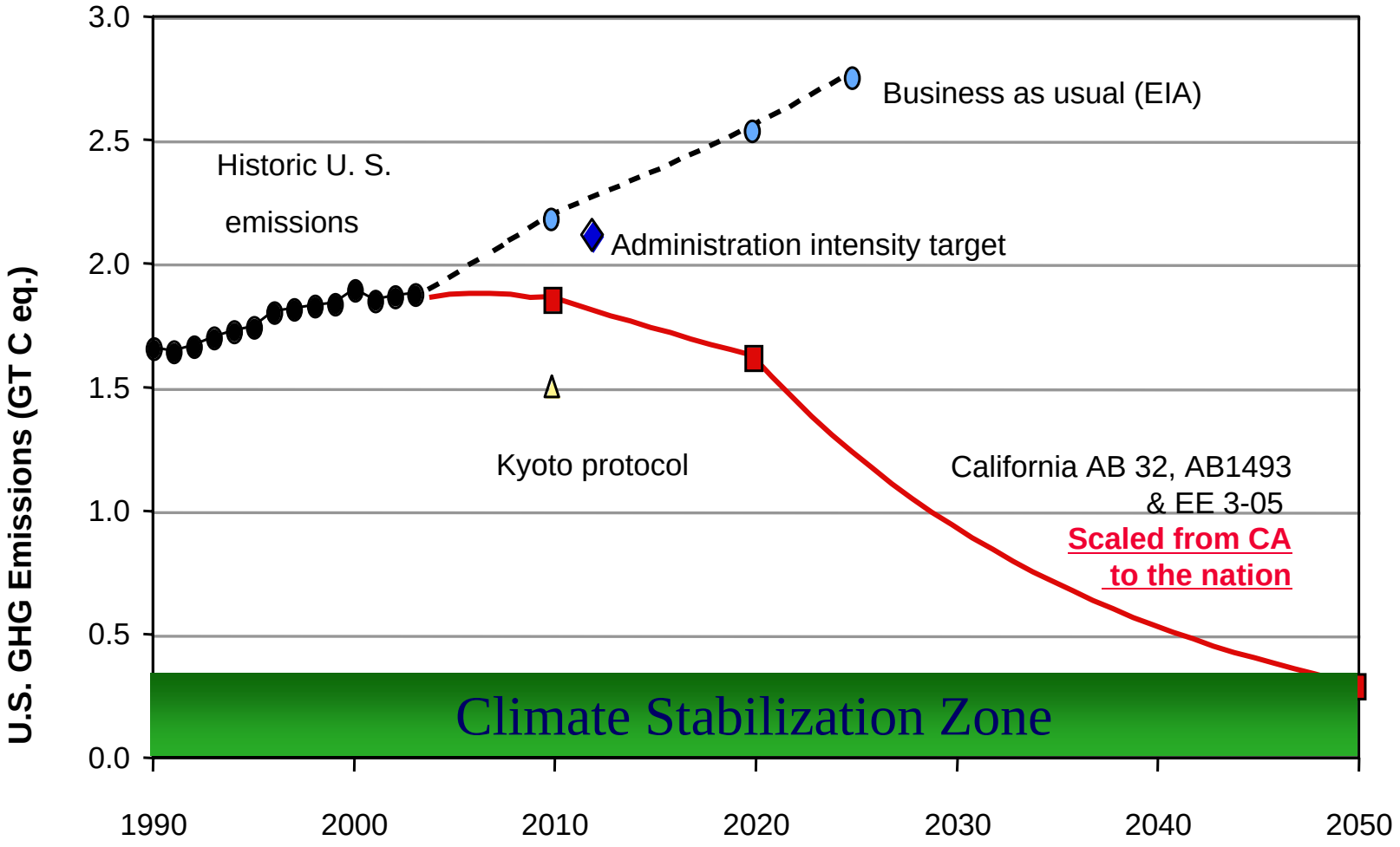


Source: Brandt and Farrell (2006) ***Environmental Research Letters (erl.iop.org)***

Wedges


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

The California commitment - scaled to the nation (rapidly moves beyond planning)



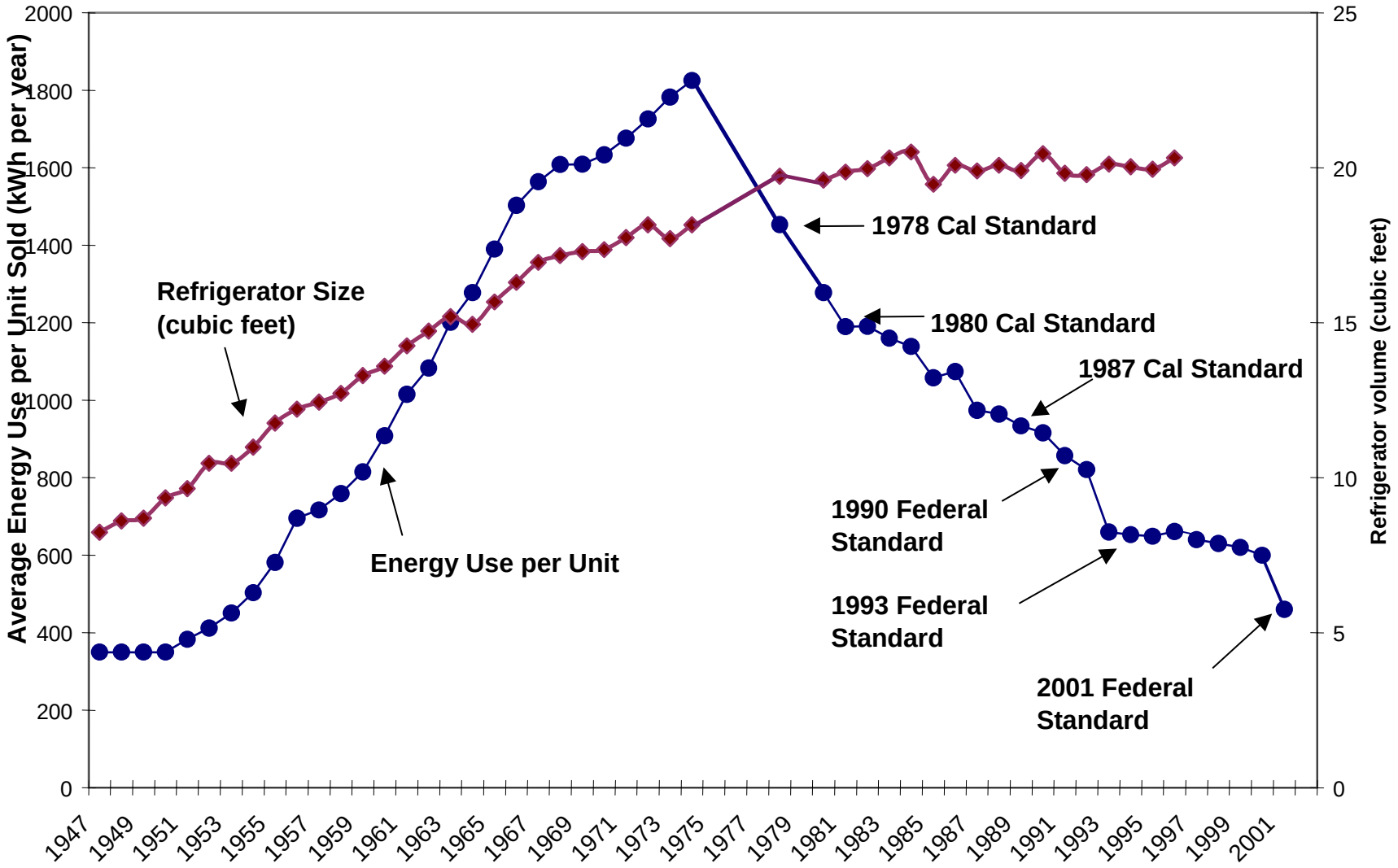
Kammen, "September 27, 2006 – A day to remember", *San Francisco Chronicle*, September 27,

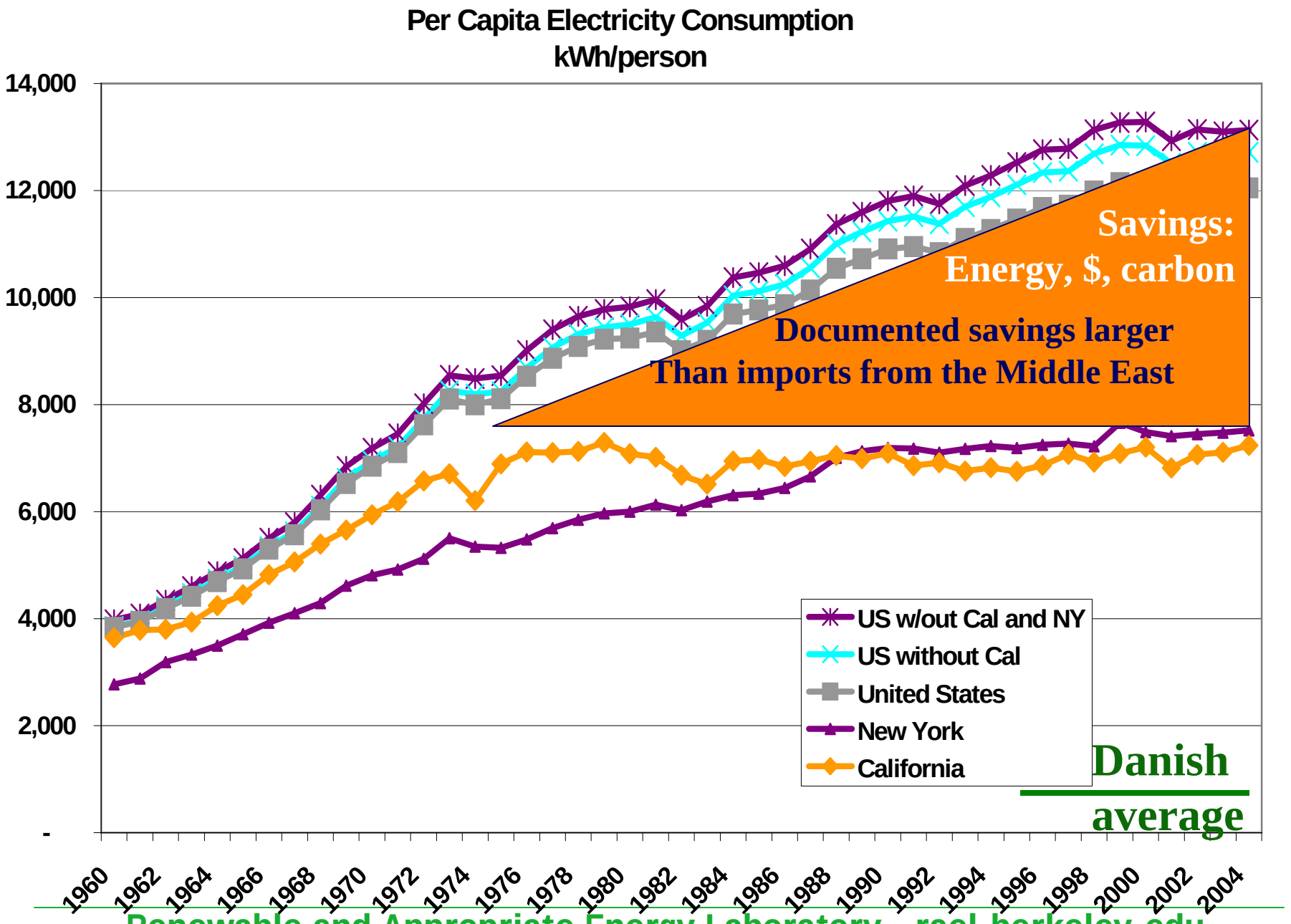
A comprehensive GHG strategy: California

- **Overall goals**
  - Executive Order S-3-05 (2005)
  - Global Warming Solutions Act 2006 (AB32)
- **Buildings and appliances**
  - Energy efficiency standards
- **Electricity (other large sources)**
  - Carbon Adder (CPUC)
  - Renewable portfolio standard for electricity (SB 107)
  - GHG performance standard and cap (CPUC decision, SB1368)
- **Transportation**
  - Vehicle GHG performance standard (AB 1493 Pavley)
  - Low Carbon Fuel Standard (Executive Order S-1-07)
  - Discussions linking growth and energy use (locality specific)
- **Significant state-level energy R&D**

The Critical Role of Standards
(an energy efficiency example)

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

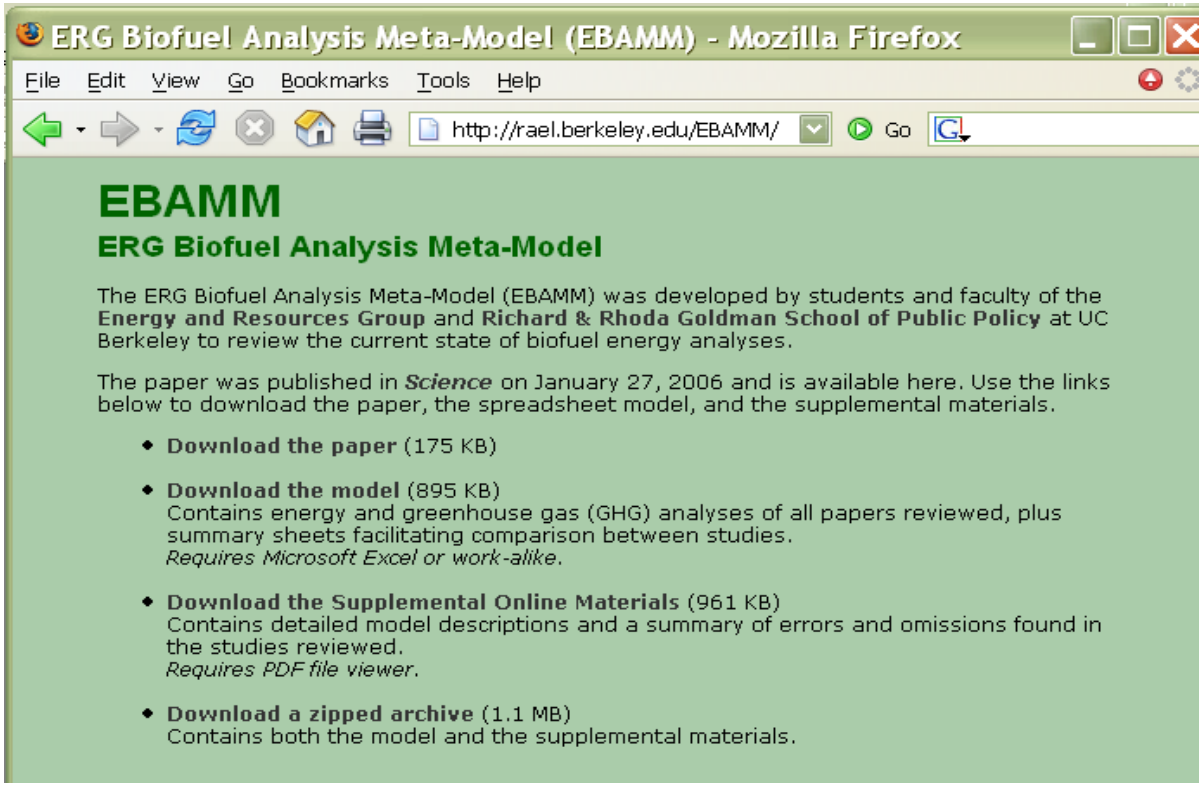
REPORTS

27 JANUARY 2006 VOL 311 SCIENCE www.sciencemag.org

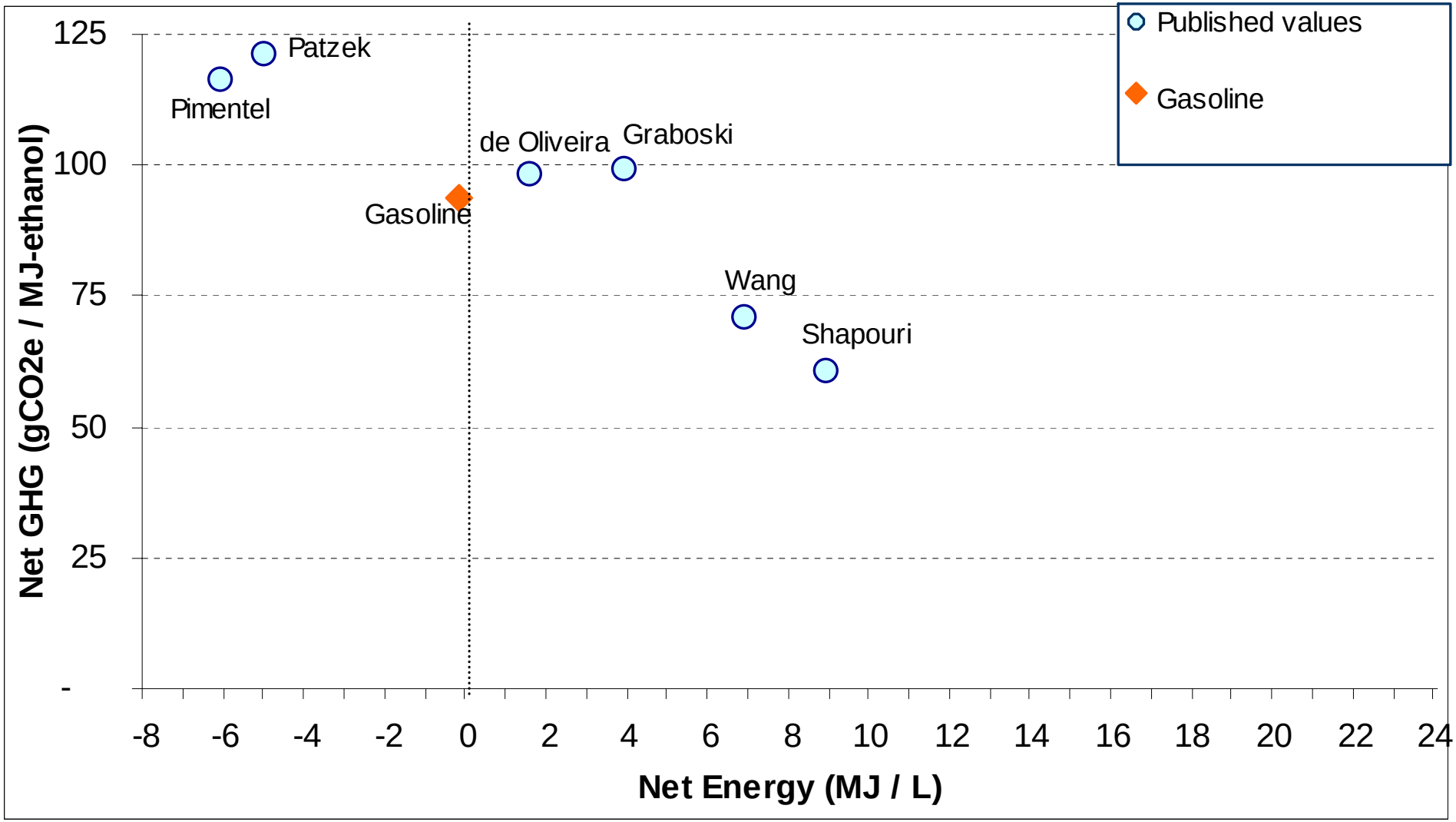
Ethanol Can Contribute to Energy and Environmental Goals

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**

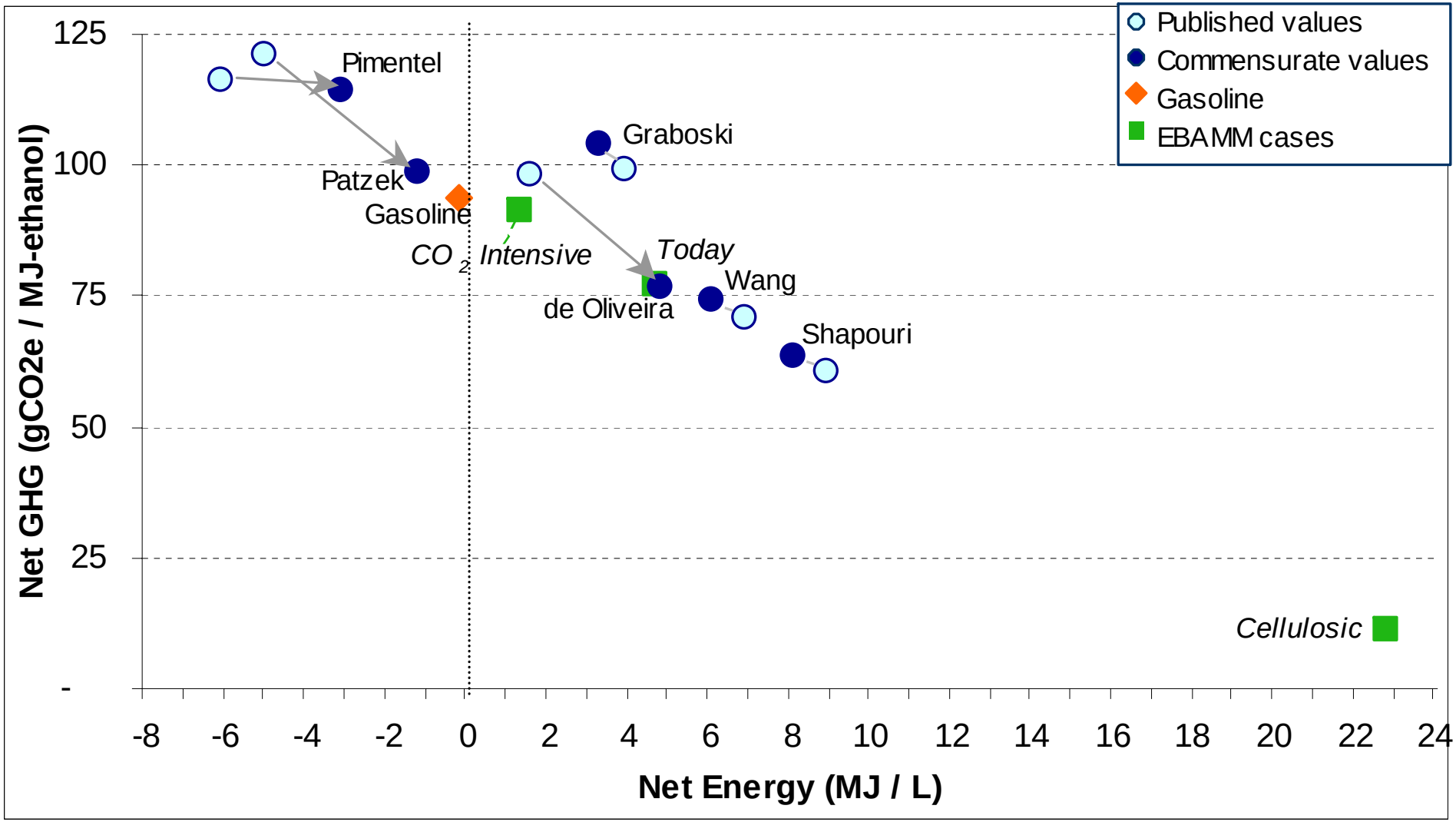


Net energy and greenhouse gases



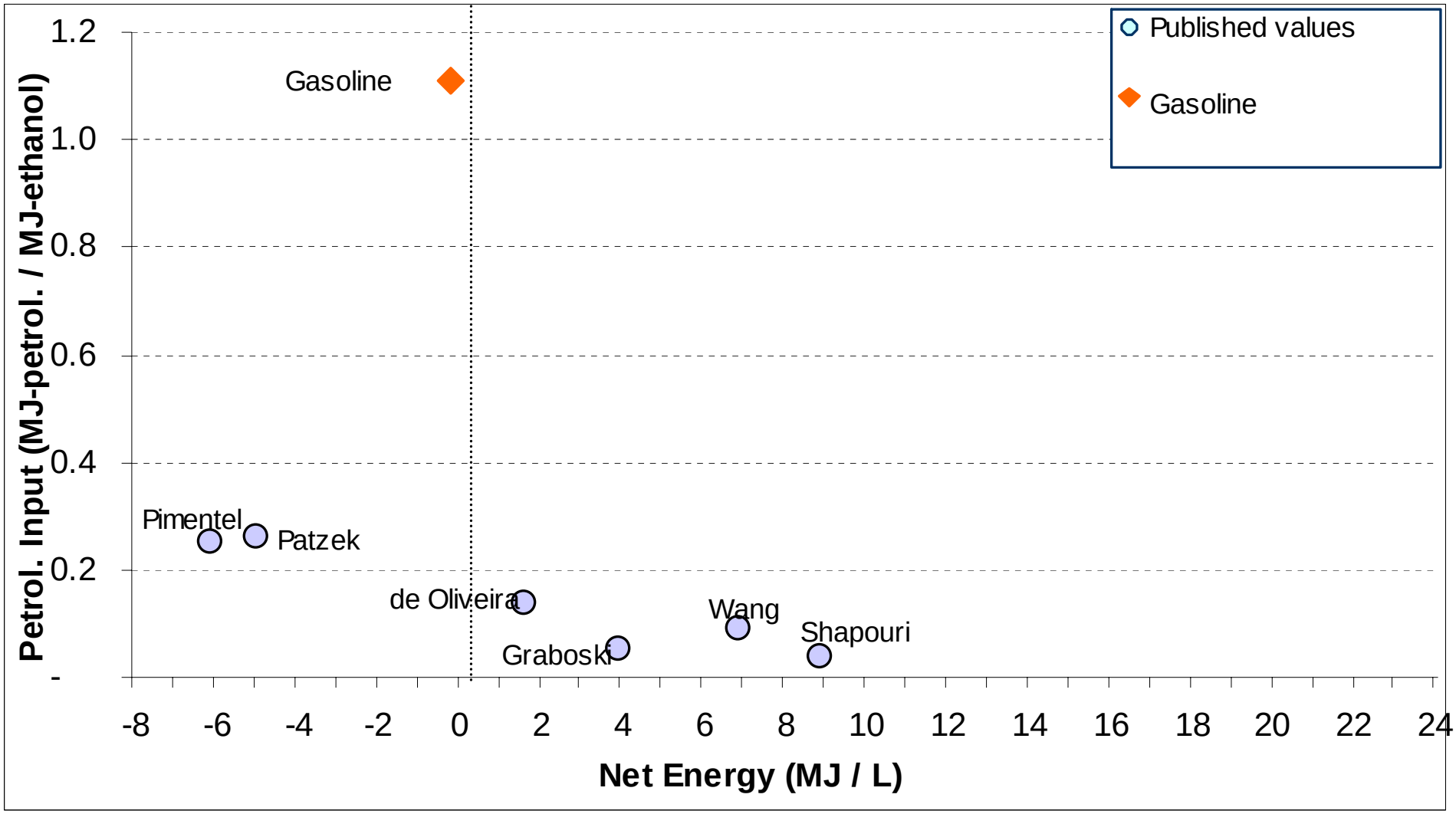
Farrell, Plevin, Turner, Jones, O'Hare & Kammen, "Ethanol can contribute to energy and environmental goals," *Science*, **311**, 506 (2006).

Net energy and greenhouse gases



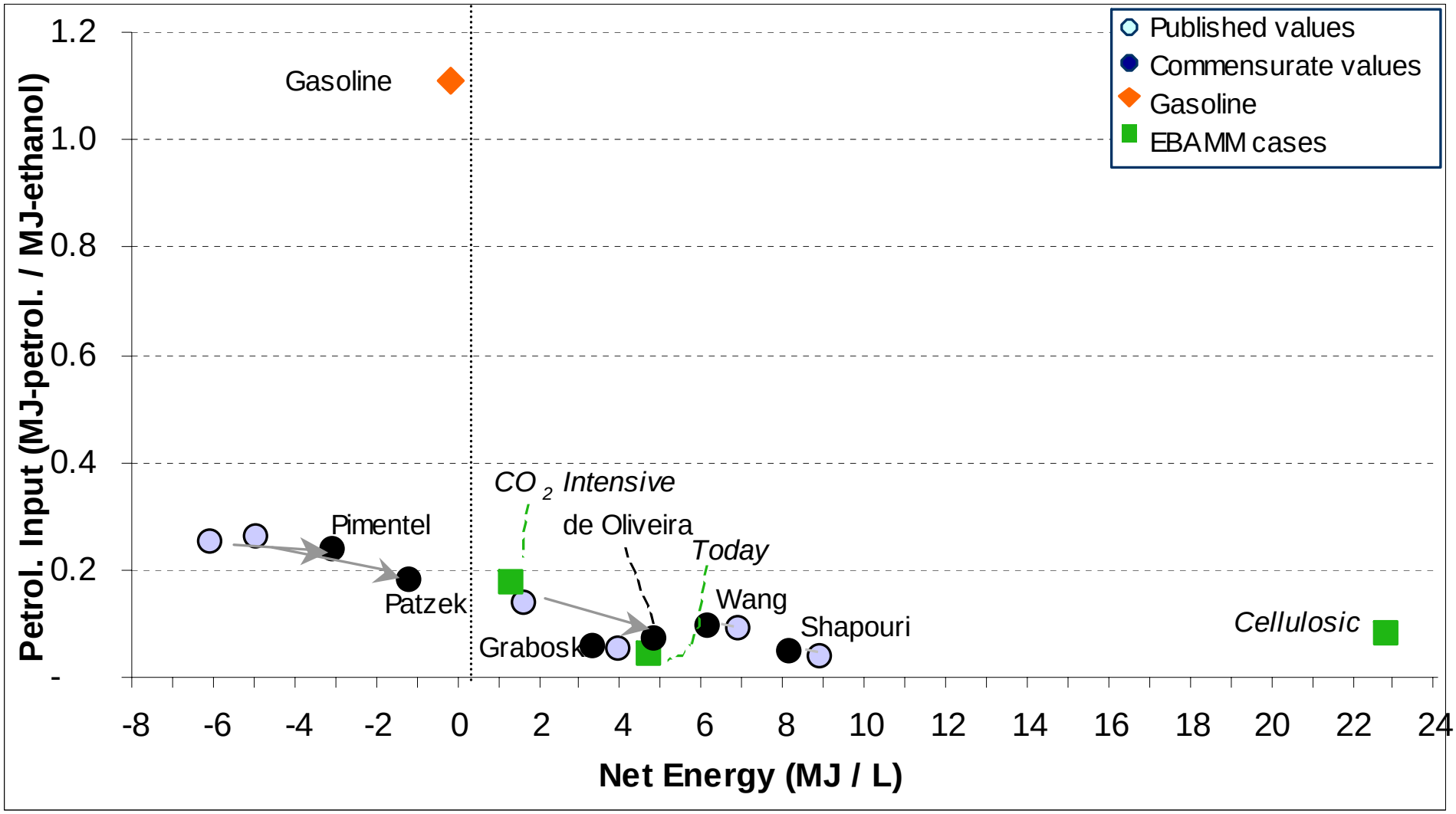
Farrell, Plevin, Turner, Jones, O'Hare & Kammen, "Ethanol can contribute to energy and environmental goals," *Science*, **311**, 506 (2006).

Net energy and petroleum use



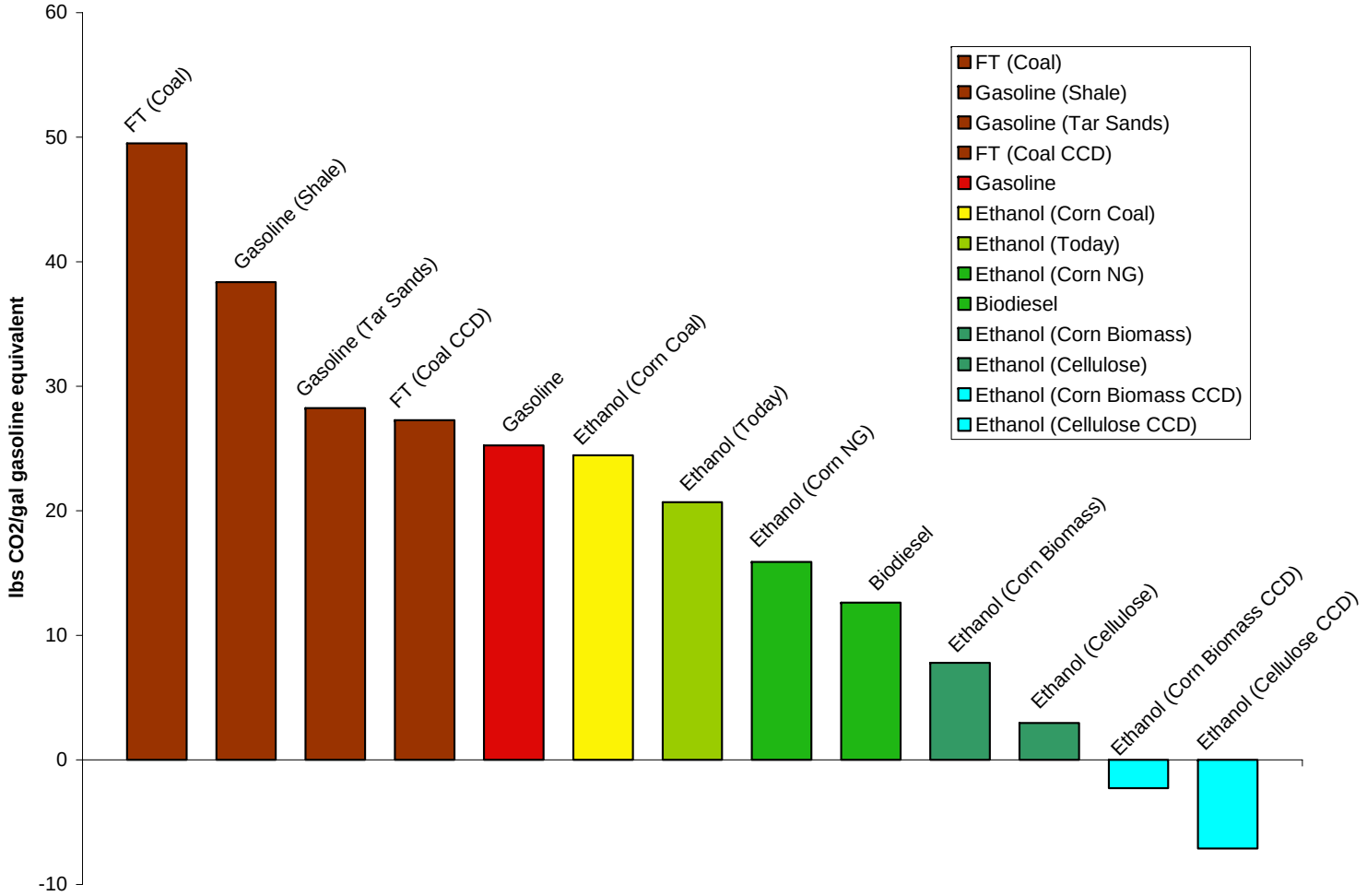
Farrell, Plevin, Turner, Jones, O'Hare & Kammen, "Ethanol can contribute to energy and environmental goals," *Science*, **311**, 506 (2006).

Net energy and petroleum use



Farrell, Plevin, Turner, Jones, O'Hare & Kammen, "Ethanol can contribute to energy and environmental goals," *Science*, **311**, 506 (2006).

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



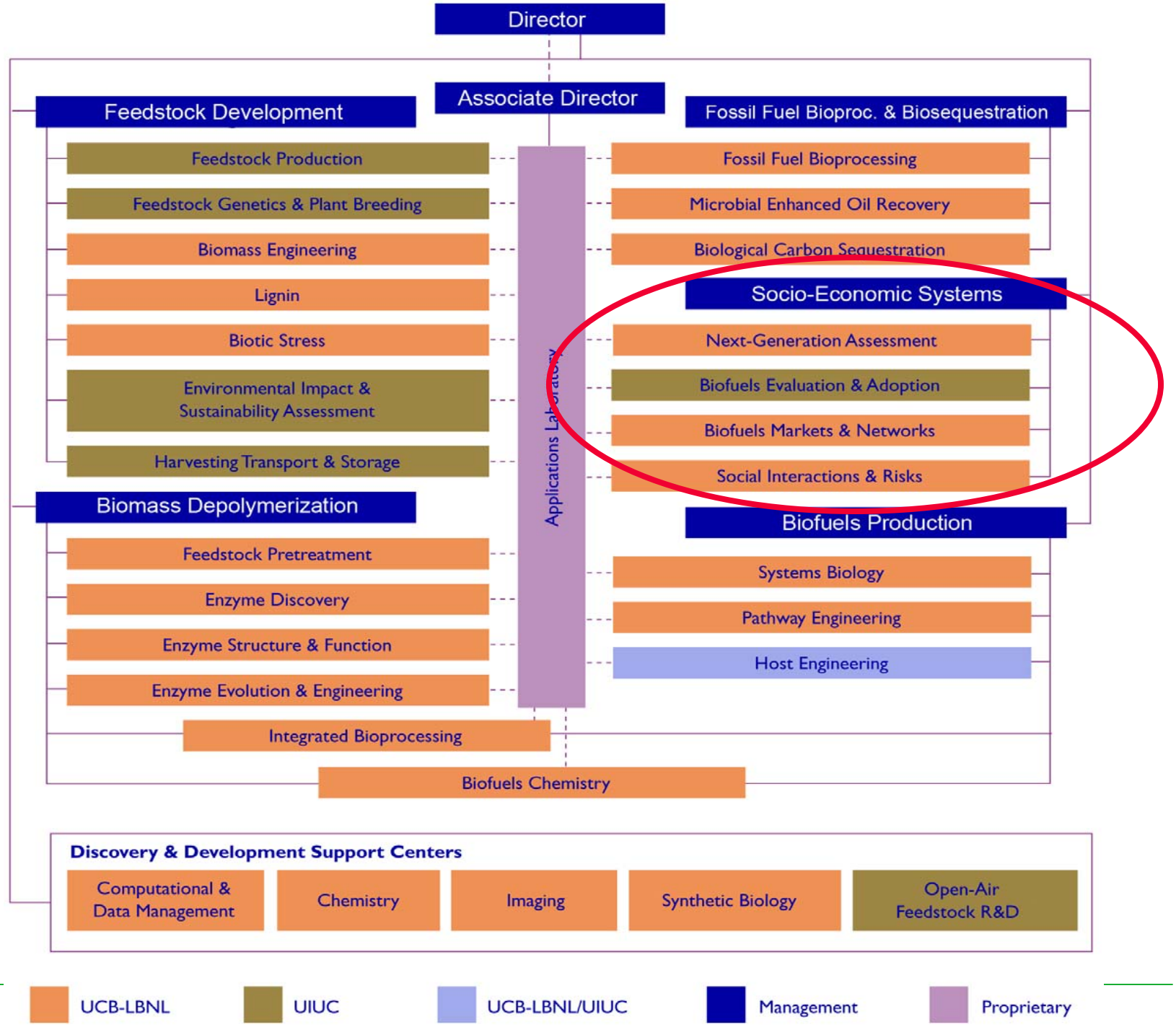
Gasoline example
(courtesy Alex Farrell, UCB)

	Input	Energy		CI
Baseline	Gasoline	96.3%		92.7
	Ethanol	3.7%	Midwest average (Et1)	75.9
			Weighted Total	92.0
			-1% target	**91.1**
Default	Gasoline	96.3%		92.7
	Ethanol	3.7%	Midwest corn dry mill (Et2)	114.0
			Weighted Total	**93.5**
Opt-in	Gasoline	96.3%		92.7
	Ethanol	3.7%	CA corn NG dry mill wet DDGS (Et74)	51.5
			Weighted Total	**91.1**

Note: The uncertainty and variability in these values is large but rarely acknowledged. Our report highlights this issue and discusses some possible ways to manage this uncertainty, and research needs.

LCFS developments worldwide

- **Renewable Fuel Standard (RFS)**
  - United States: double biofuel use by 2012 to ~6% of gasoline.
  - UK Renewable Transportation Fuel Obligation (RTFO): 5% by 2010
- **Low Carbon Fuel Standard (LCFS)**
  - California: regulations to be in effect 2010
  - Federal bills: Boxer, Feinstein, Obama, Inslee, etc.
  - European Union: monitoring in 2009, reductions start in 2011
  - United Kingdom: RTFO requires GHG monitoring, pilot in 2007
  - British Columbia (May, 2007), WA, OR, AZ, NM, MN, and…?
- **Current and forthcoming analysis**
  - *Draft Carbon Reporting Methodology under the RTFO.* E4Tech. Dec06
  - *Sustainability Reporting within the RTFO.* ECOFYS. Feb07
  - *Creating Markets for Green Biofuels*. UC Berkeley study. April07
  - *AB1007 Well-to-Wheels Analysis.* CEC/CARB study. May07
  - *Low Carbon Fuel Standard for California*. UC Berkeley/Davis. May07

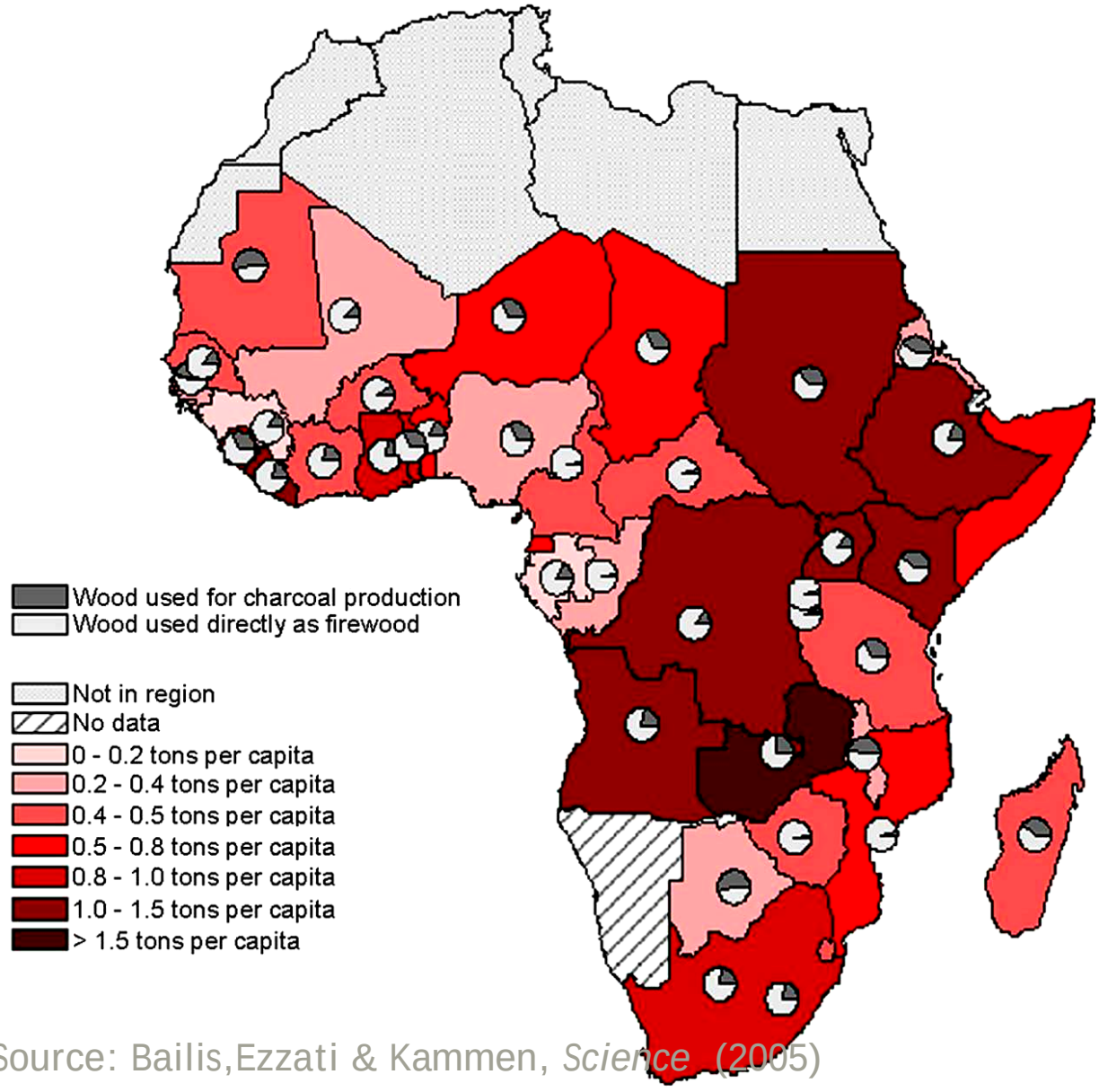

Director
Associate Director
Feedstock Development
Feedstock Production
Feedstock Genetics & Plant Breeding
Biomass Engineering
Lignin
Biotic Stress
Environmental Impact & Sustainability Assessment
Harvesting Transport & Storage
Biomass Depolymerization
Feedstock Pretreatment
Enzyme Discovery
Enzyme Structure & Function
Enzyme Evolution & Engineering
Integrated Bioprocessing
Biofuels Chemistry
Applications Laboratory
Fossil Fuel Bioproc. & Biosequestration
Fossil Fuel Bioprocessing
Microbial Enhanced Oil Recovery
Biological Carbon Sequestration
Socio-Economic Systems
Next-Generation Assessment
Biofuels Evaluation & Adoption
Biofuels Markets & Networks
Social Interactions & Risks
Biofuels Production
Systems Biology
Pathway Engineering
Host Engineering
Discovery & Development Support Centers
Computational & Data Management
Chemistry
Imaging
Synthetic Biology
Open-Air Feedstock R&D
UCB-LBNL
UIUC
UCB-LBNL/UIUC
Management
Proprietary

Sub-Saharan Africa's wood-energy consumption is the highest in the world

Primary production of biomass energy in 2000 (10^{18} Joules)

Sub Saharan Africa	10.2
China	8.9
India	8.4
Latin America	3.2

Source: IEA, 2003



Source: Bailis,Ezzati & Kammen, *Science* (2005)

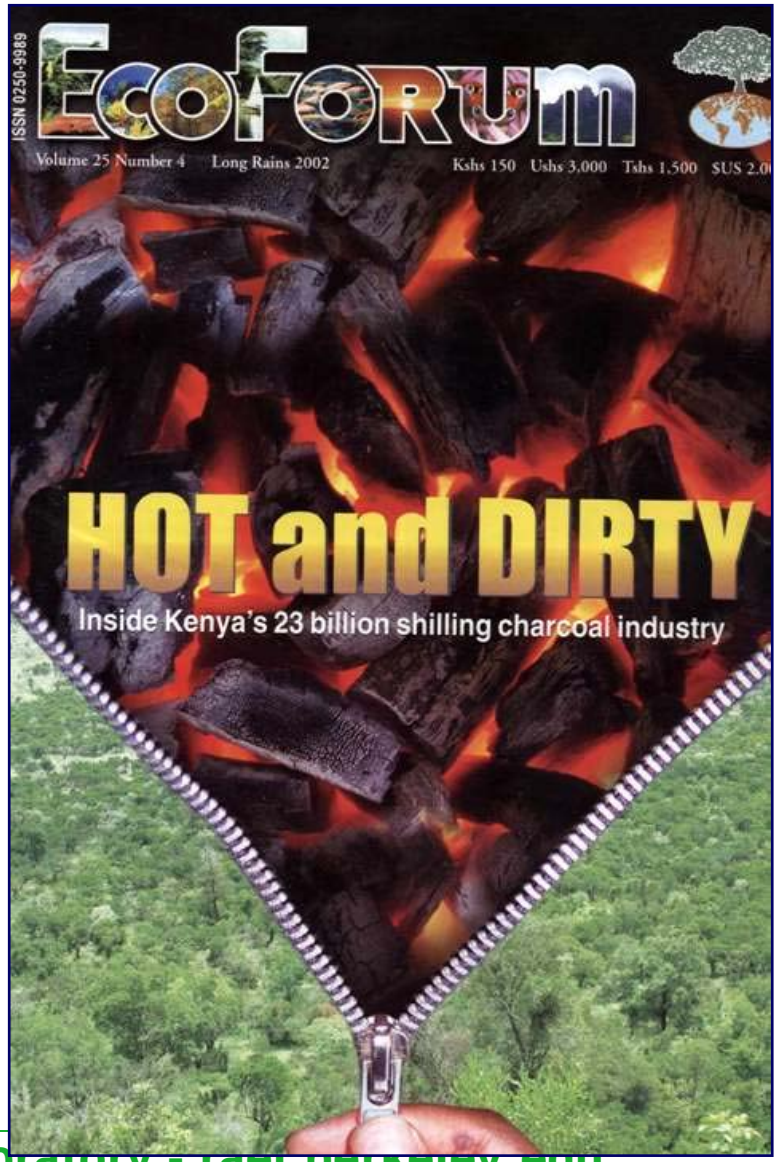
Charcoal is *not* just an African issue

Renewable and Appro

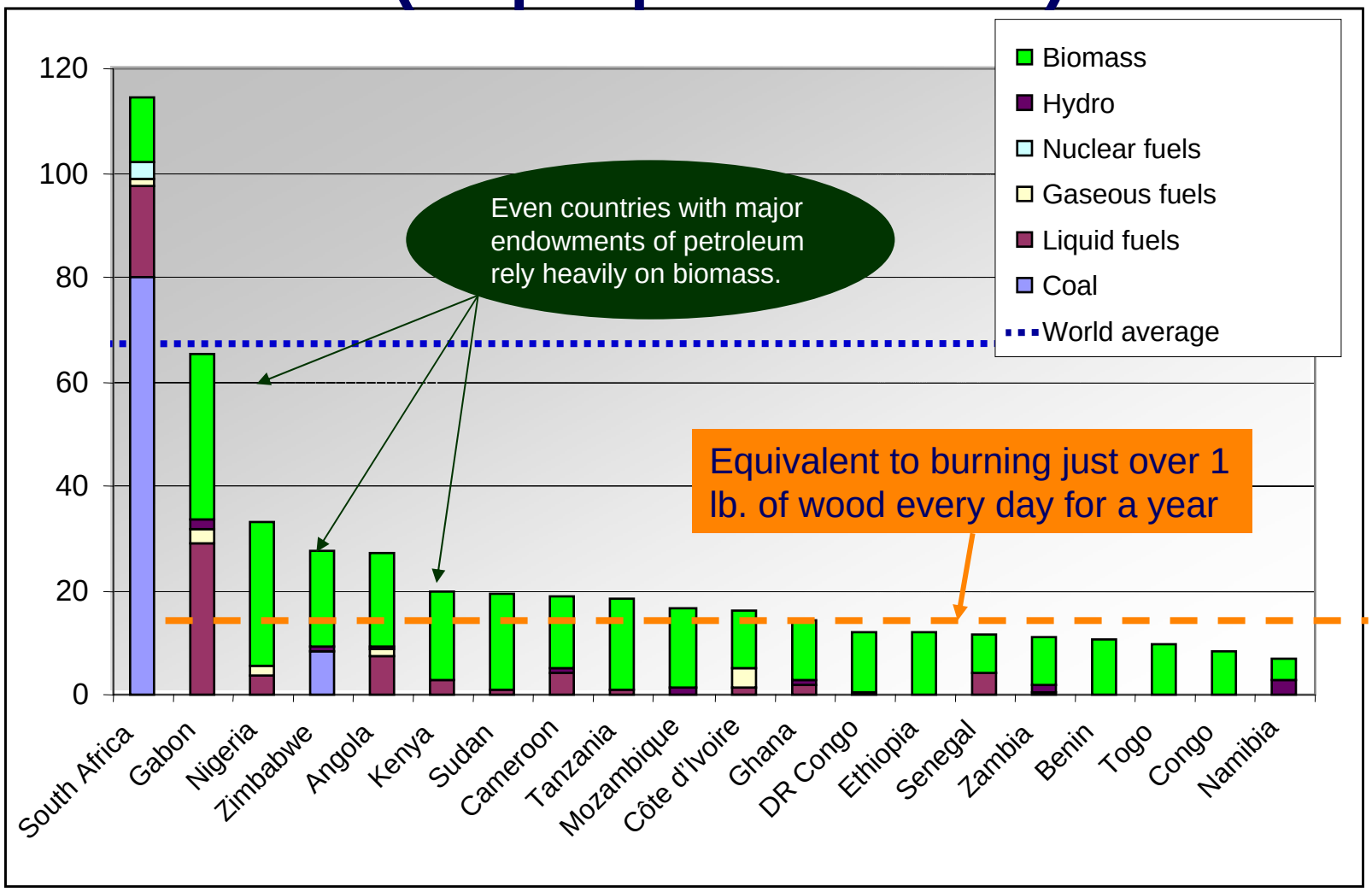
The Developing Country Context: Africa Example

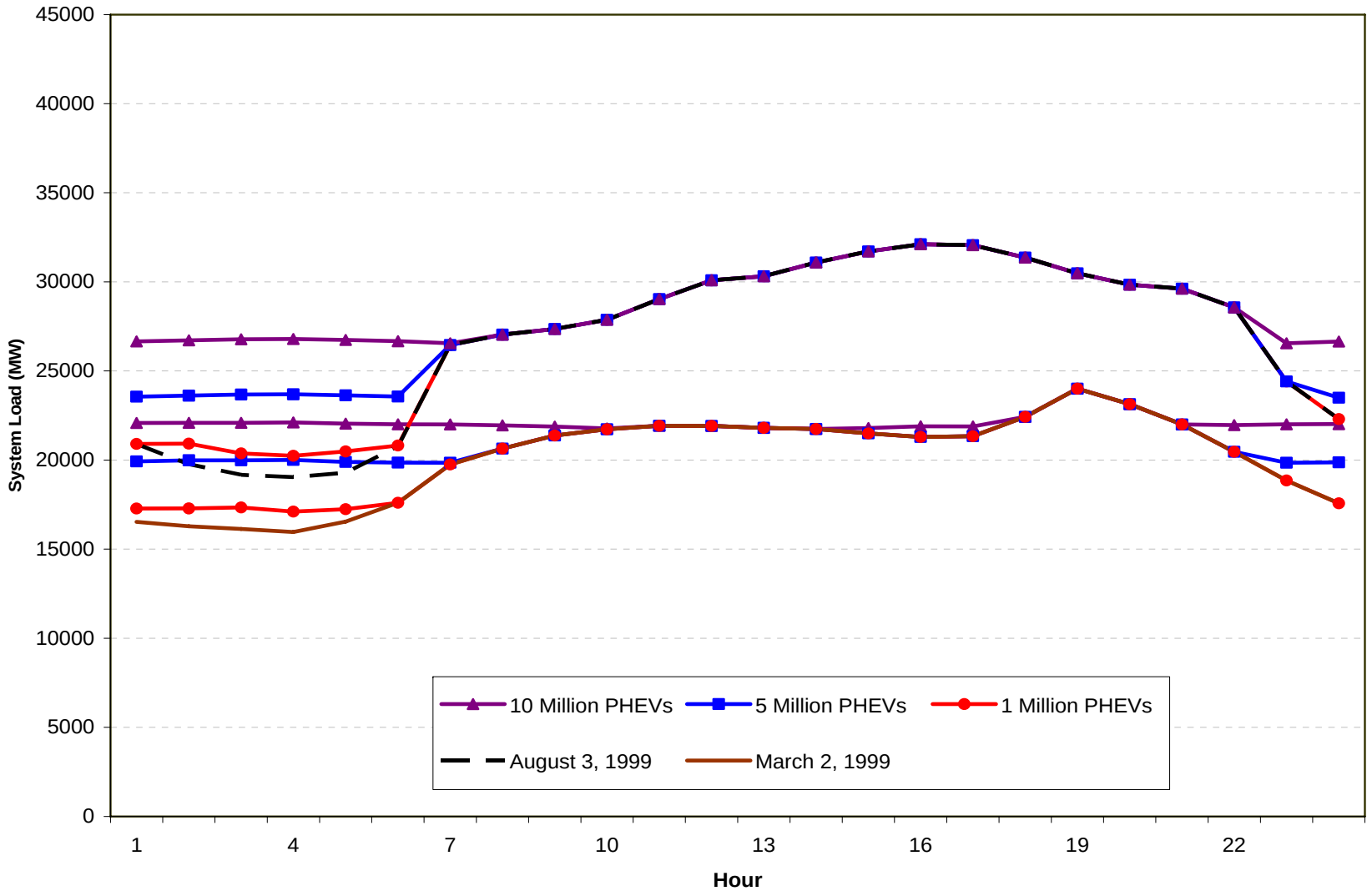
Social-ecological Impacts:

- 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

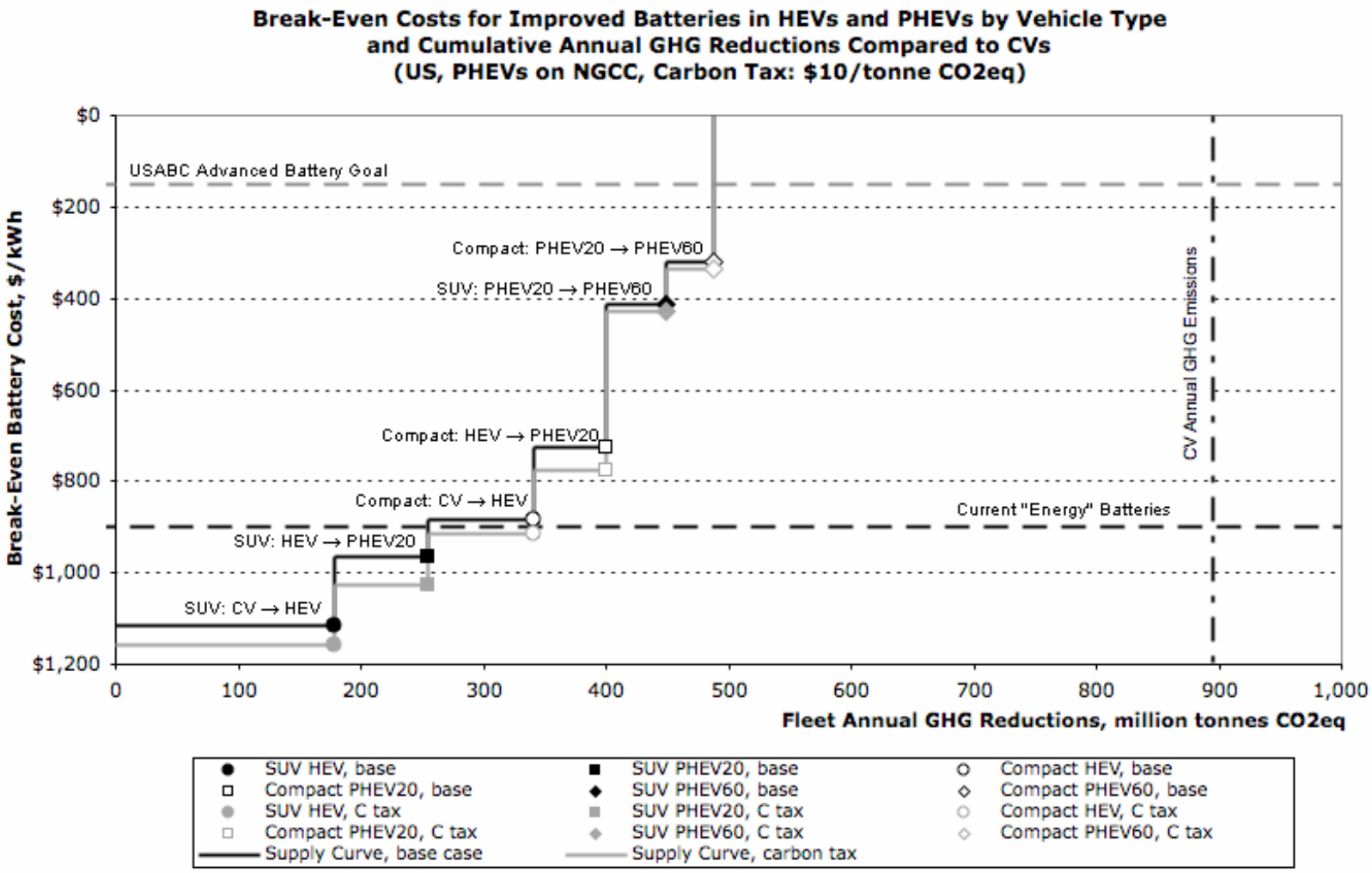


Annual per capita energy consumption (GJ per person - 1999)





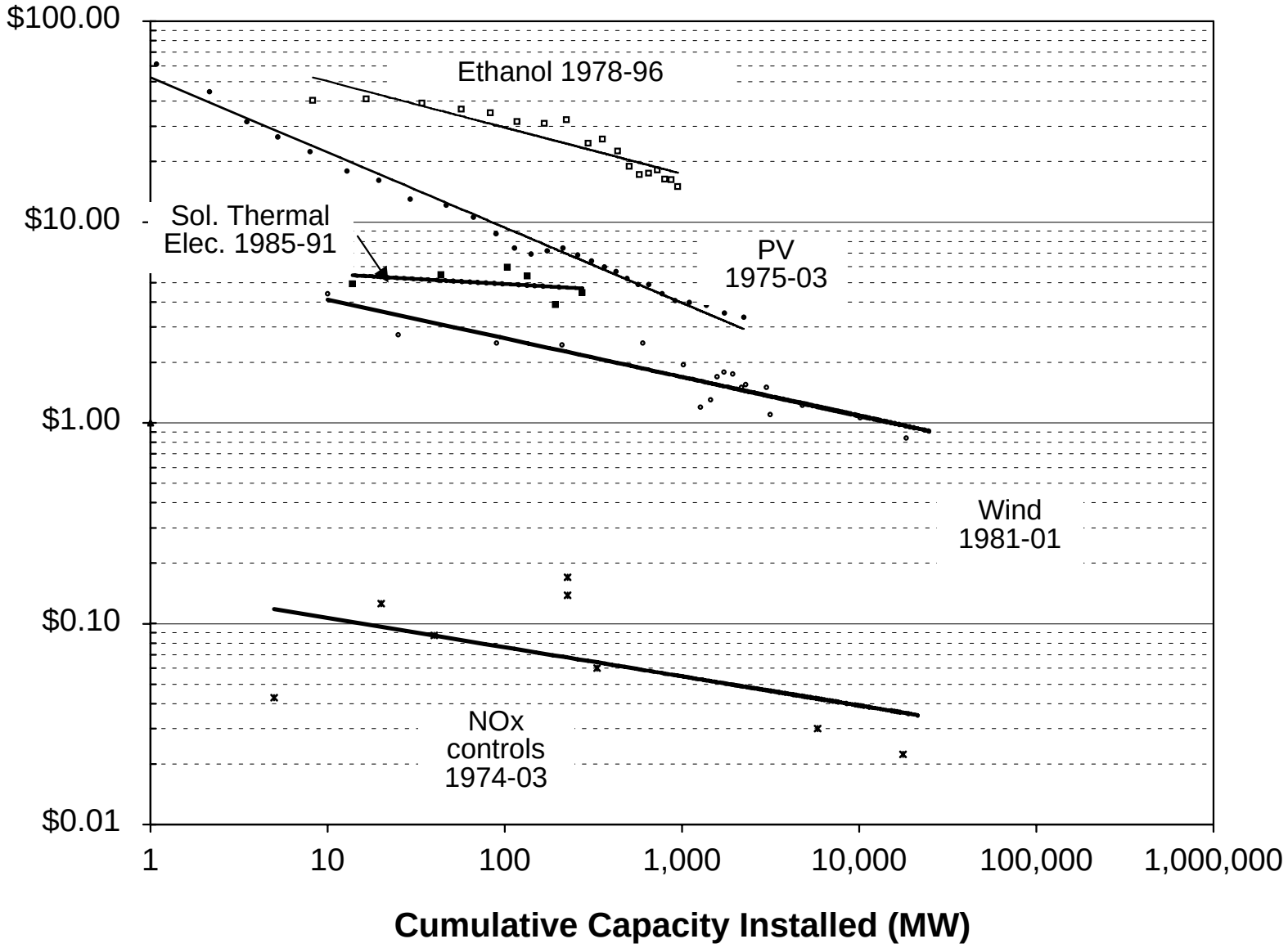
Daily load curves for optimal charging scenario with compact cars


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
CV Annual GHG Emissions
Current "Energy" Batteries
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

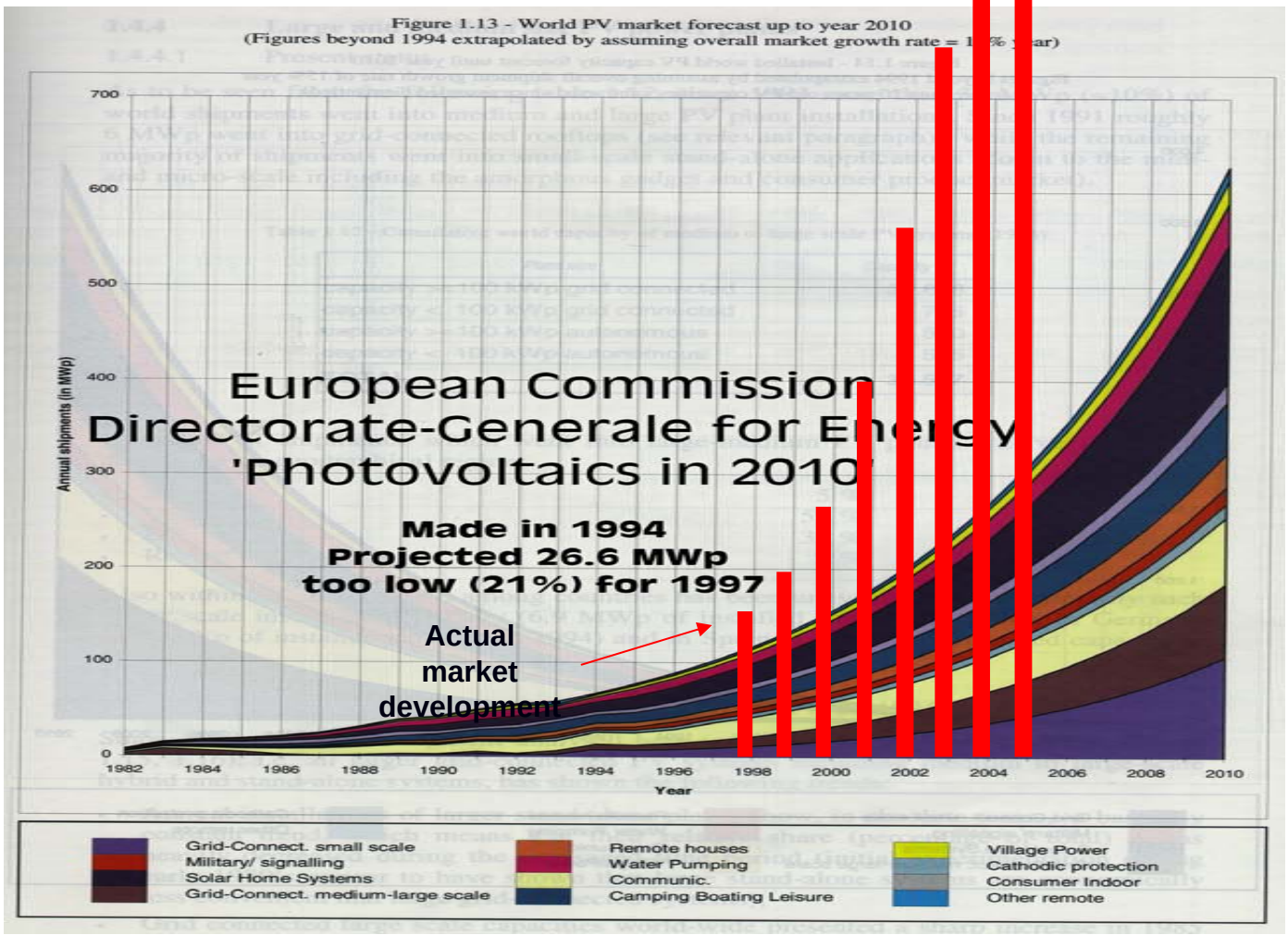
Envisioning a R&D Plan for Sustainable Biofuels

A sectoral approach (courtesy Alex Farrell, UCB)

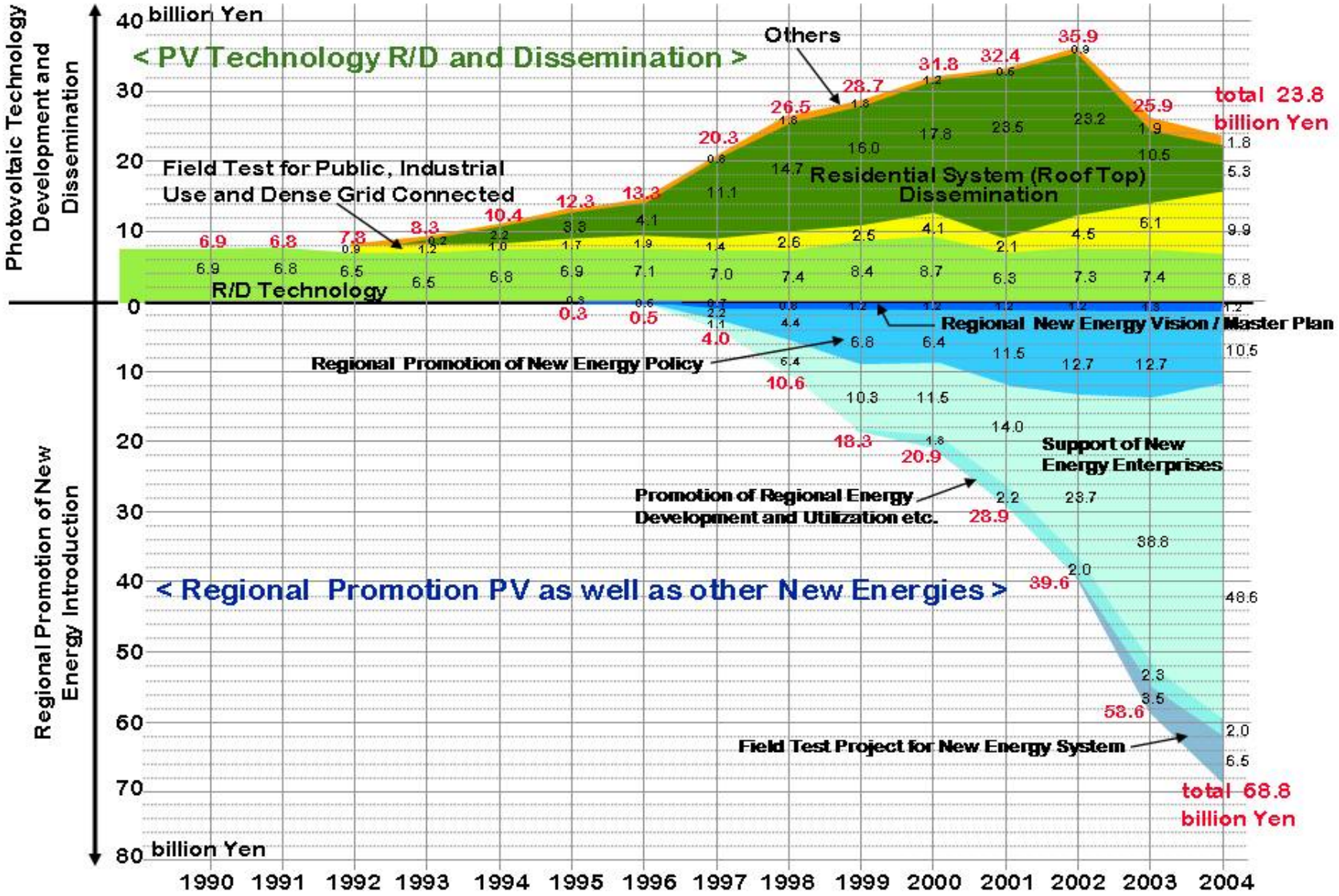
- An economy-wide approach fails to meet other goals
  - At a "low" price (<$25/tonne), little would happen
  - At $25-$50 per tonne, electricity would start to decarbonize significantly while little would happen in buildings and transport
    - Innovation would be narrowly focused (goal #2), maybe not dynamically efficient
    - The "side benefits" of cutting petroleum use are lost (goals #3, #4)
  - Prices high enough to cause transportation to decarbonize might force disruptive change in the electricity sector
- Costs and fuel-on-fuel competition (@ $1/tonne CO_2)
  - Nuclear + Renewables $0.0/MWh
  - Integrated gasification combined cycle with carbon capture and storage (IGCC+CCS) $0.1/MWh
  - Natural gas combined cycle (NGCC) $0.5/MWh
  - Pulverized coal (PC) $0.8/MWh
  - Gasoline $0.01/gallon


$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)

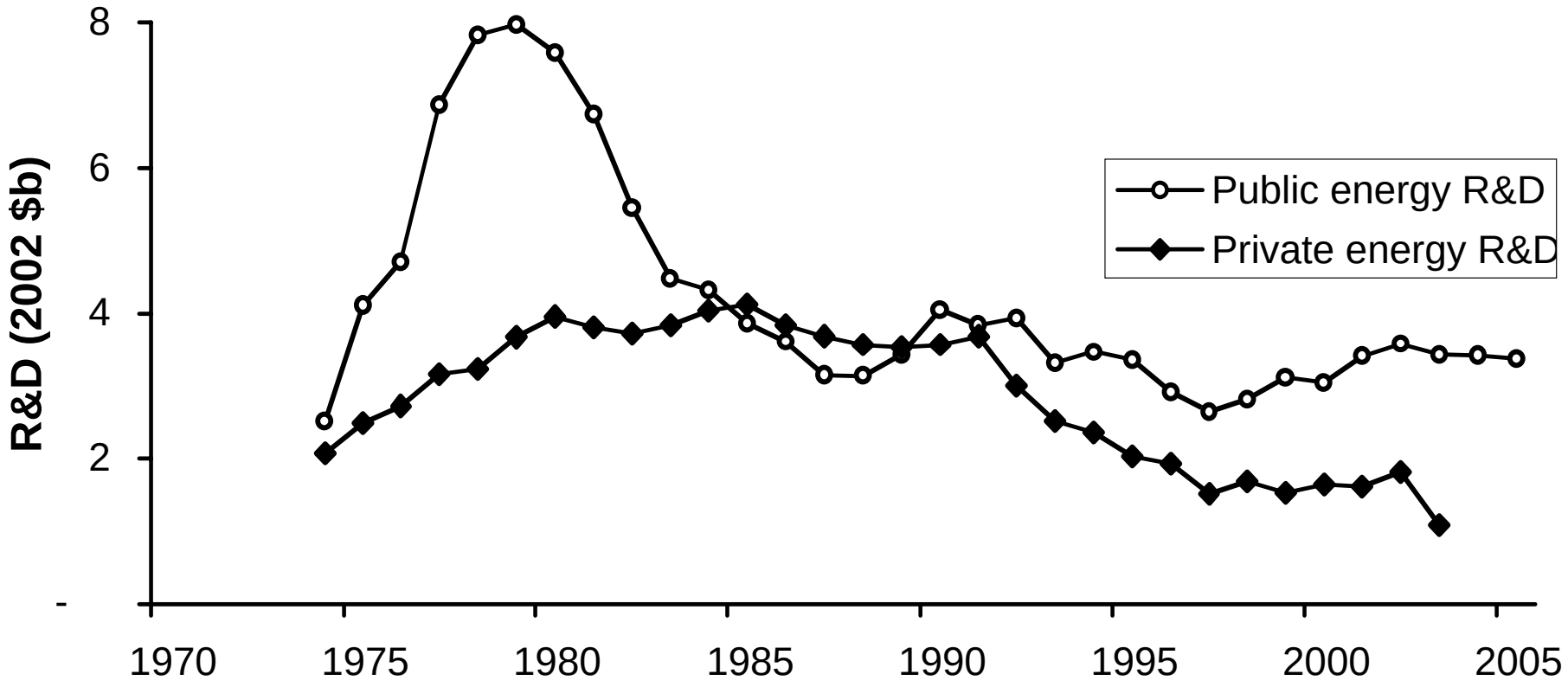
Actual Growth vs. Historic Forecasts



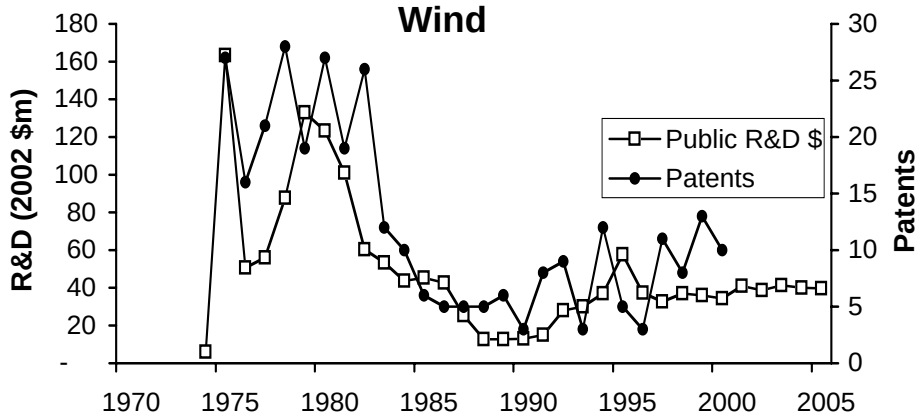
Japanese “Sunshine” Program

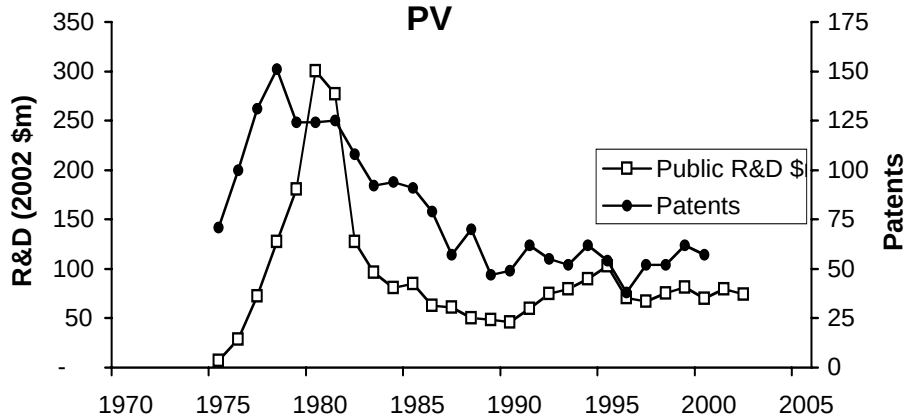


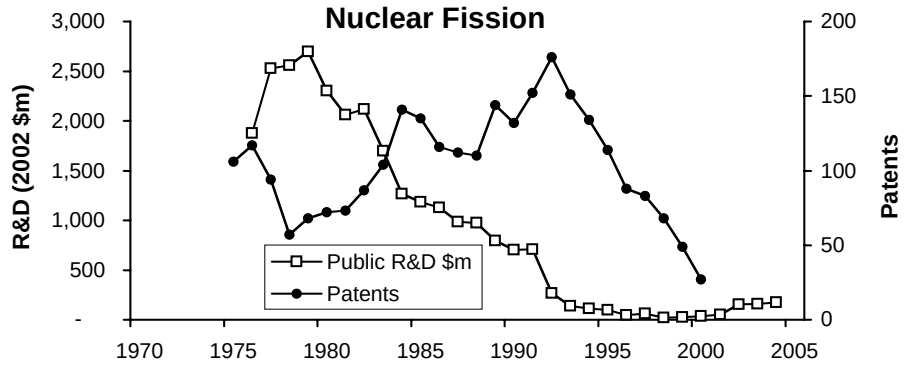
If you think US public sector energy R&D funding is doing poorly …

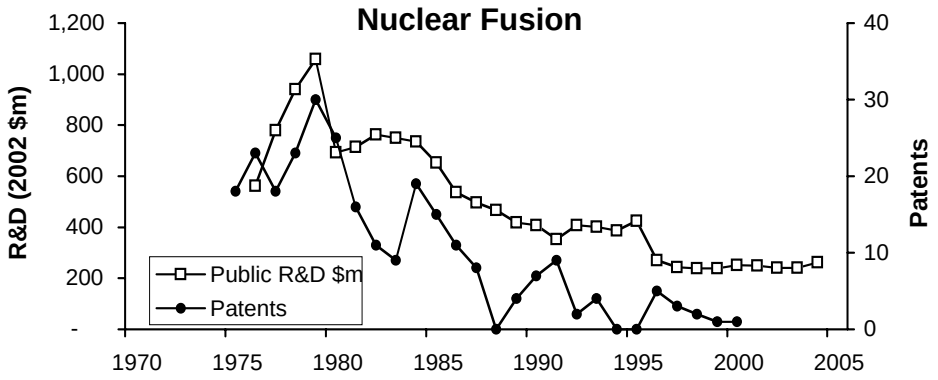


Kammen and Nemet (2005)
"Reversing the incredible shrinking energy R&D budget," *Issues in Science & Technology*, **Fall**, 84 – 88.





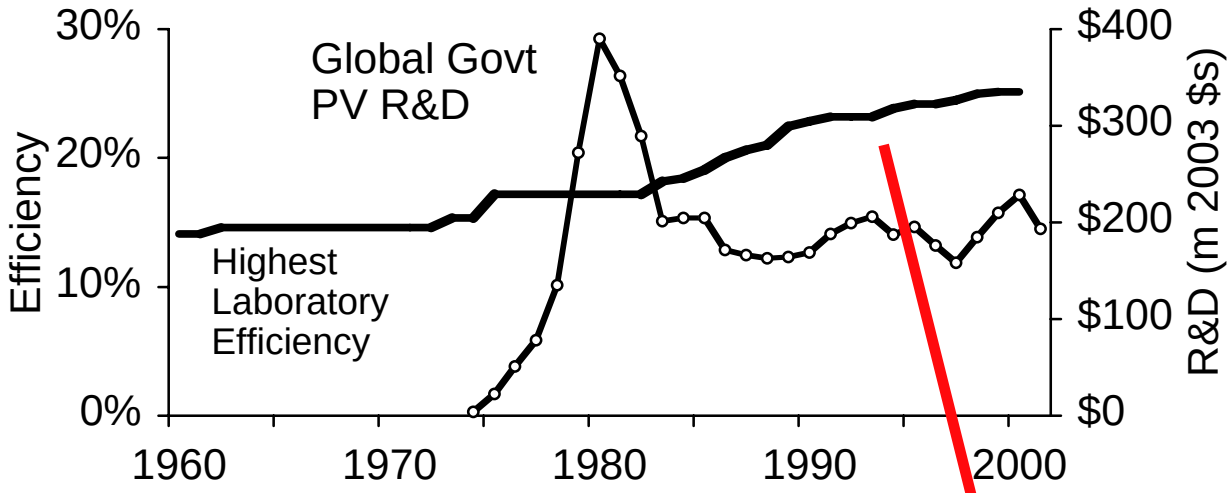




Kammen and Nemet (2005)
"Reversing the incredible shrinking energy R&D budget," *Issues in Science & Technology,* **Fall**, 84 – 88.

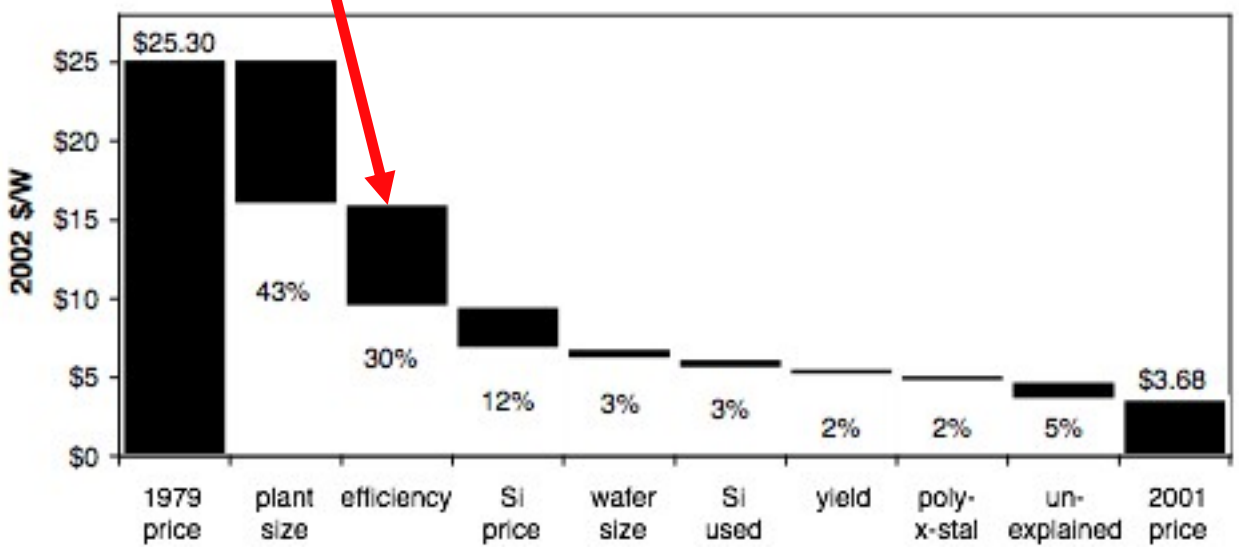
Quantifying the benefits of R&D

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)…

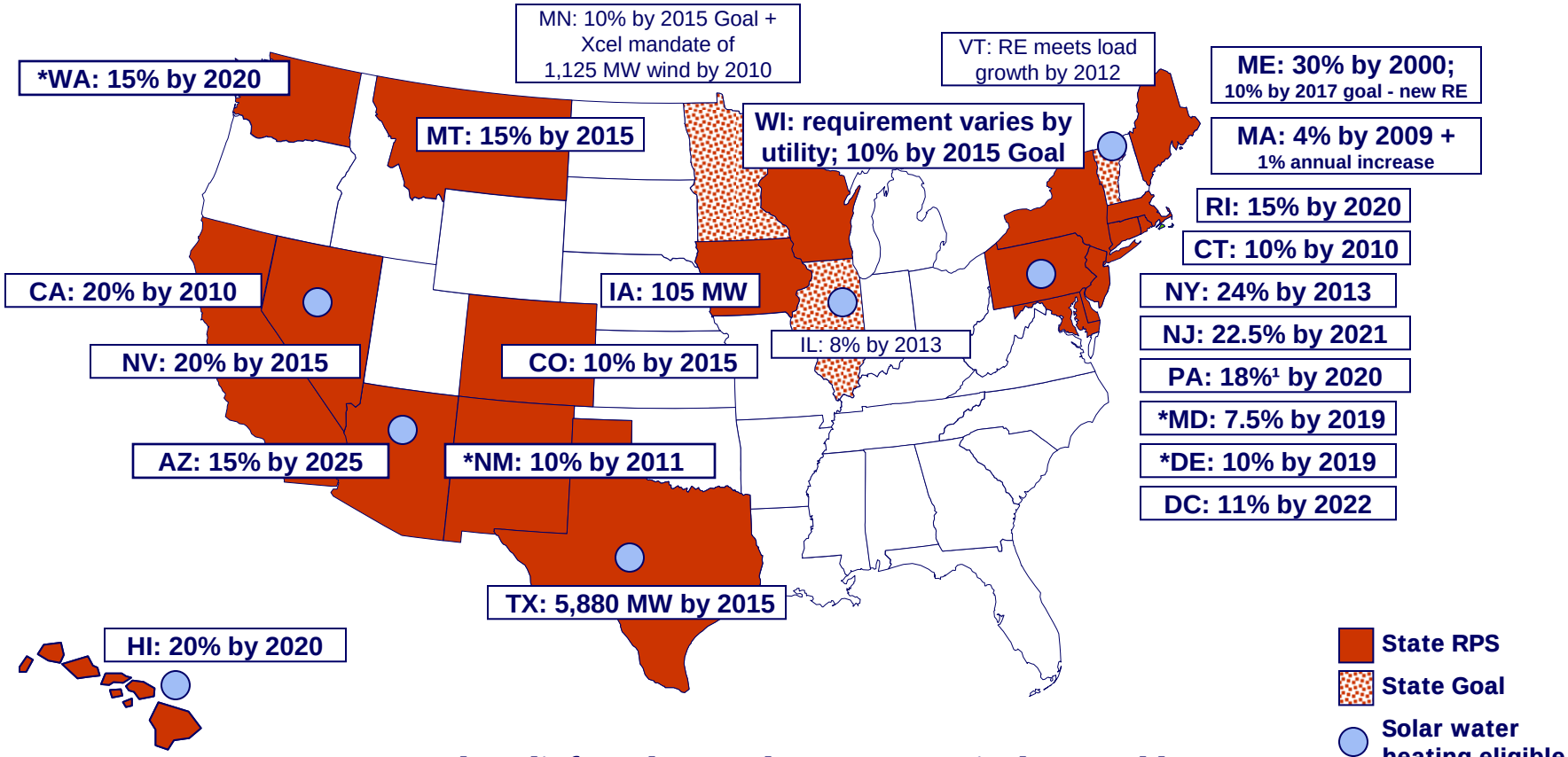
…efficiency improvements account for 30% of the cost reductions in PV over the past two decades.



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

Renewable Energy Portfolio Standards

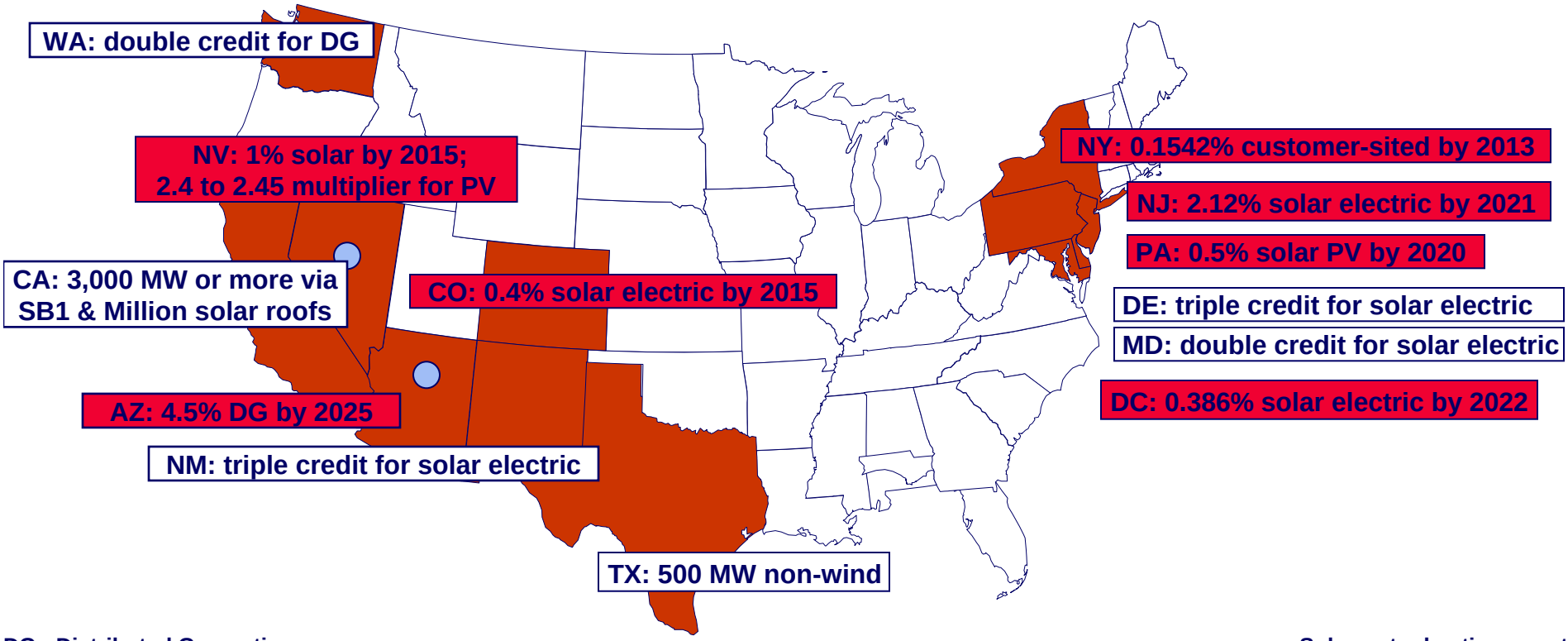
23 states + DC, and counting



*** 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

Opportunities for Action

- Raise our expectations, and investments, in clean energy
  - We now must have 'one California' per year … for decades
- Recognize the sectoral differences between transportation and stationary power and the linkages
- Examine the range of options under a Low Carbon Fuel Standard (LCFS)
- Plan beyond the important first step of the LCFS to a Sustainable Fuels research program

Extra Materials - addendums

Continued example for gasoline

	Input	Energy		CI	% change
Default	Gasoline	96.3%		92.7	
Worst	Ethanol	3.7%	Midwest corn dry mill (Et2)	114.0	
Common			**Weighted Total**	**93.5**	**+1.6%**
Opt-in 1	Gasoline	96.3%		92.7	
Good	Ethanol	3.7%	CA corn NG dry mill wet DDGS (Et74)	51.5	
Practice			**Weighted Total**	**91.1**	**-1%**
Opt-in 2	Gasoline	96.3%		92.7	
Best	Ethanol	3.7%	MW corn stover dry mill wet DDGS (Et6)	23.6	
Practice			**Weighted Total**	**90.0**	**-2.1%**
Opt-in 3	Gasoline	93.3%		92.7	
E10 and	Ethanol	6.7%	MW corn stover dry mill wet DDGS	23.6	