Biofuels:
Challenges & Opportunities to Sustainability

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

"Transitioning to Sustainability through Research and Development"
***National Academy of Sciences*, October 17, 2007**

Readings from the RAEL Group at UC Berkeley

- Farrell, A. R., Plevin, R., Turner, B., Jones, A. R., O'Hare, M. and Kammen, D. M. "Ethanol can contriubte to energy and environmental goals", *Science*, **312,** 1748.

  The EBAMM model: http://rael.berkeley.edu

- Kammen, D. M. (2007) "Transportation's Next Big Thing is Already Here", May, *GreenBiz.com*, *Climate Wise*

- Jacobson, A. and Kammen, D. M. (2005) " Science and engineering research that values the planet", *The Bridge: Journal of the National Academy of Engineering*, **Winter,** 11 – 17

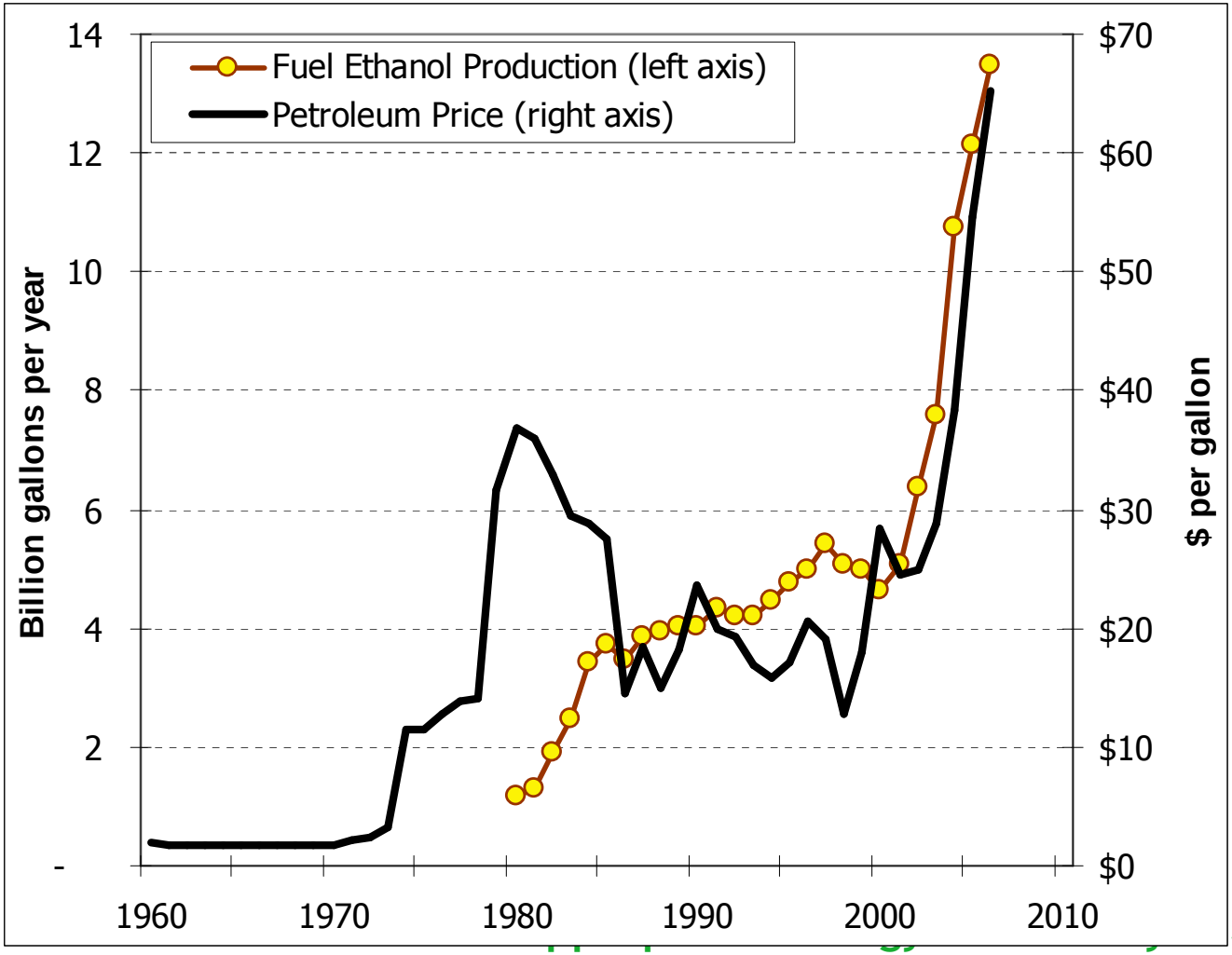
- **Low Carbon Fuel Standard for California**:

  A. R. Brandt, A. Eggert, A. E. Farrell, B. K. Haya, J. Hughes, B. Jenkins, A. D. Jones, D. M. Kammen, C. R. Knittel, M. Melaina, M. O'Hare, R. Plevin, D. Sperling (2007) ***A Low-Carbon Fuel Standard for California Part 2: Policy Analysis*** (Office of the Governor / Air Resources Board).

  S. R. Arons, A. R. Brandt, M. Delucchi, A. Eggert, A. E. Farrell, B. K. Haya, J. Hughes, B. Jenkins, A. D. Jones, D. M. Kammen, C. R. Knittel, D. M. Lemoine, E. W. Martin, M. Melaina, J. M. Ogden, R. Plevin, D. Sperling, B. T. Turner, R. B. Williams, and C. Yang (2007) ***A Low-Carbon Fuel Standard for California Part 1: Technical Analysis*** (Office of the Governor / Air Resources Board).

Today's Biofuel Industry

- Feedstocks are agricultural commodities
- Fuels are traditional substances
- Success depends on subsidies and mandates
- Small, but profitable and growing rapidly



Sources: US EIA, BP, RFA

Fundamental research goals for a sustainable biofuels industry

- **Lower costs and enhance economic opportunities**
  - Improve fuel properties
  - Decrease production costs
- **Reduce environmental effects**
  - Greenhouse gases, biodiversity, fertilizer runoff, land-use change
- **Promote social goals**
  - Rural livelihoods, oil import reduction, etc.

A joint focus is needed on

$\Rightarrow$ Social objectives and technological progress for biofuels which can reduce the need for arable land and increase sustainable economic opportunities

Feedstocks that use degraded land or no land require advanced technologies

- **Ligno-cellulosic fermentation**
- **Gasification &**
- **Fast Pyrolysis**
- **Algae**

Overview

- Feedstock-to-fuel choices have profound impacts far beyond the energy sector
- Carbon is a start, but *sustainable fuel* standards are needed

- Markets provide a key tool

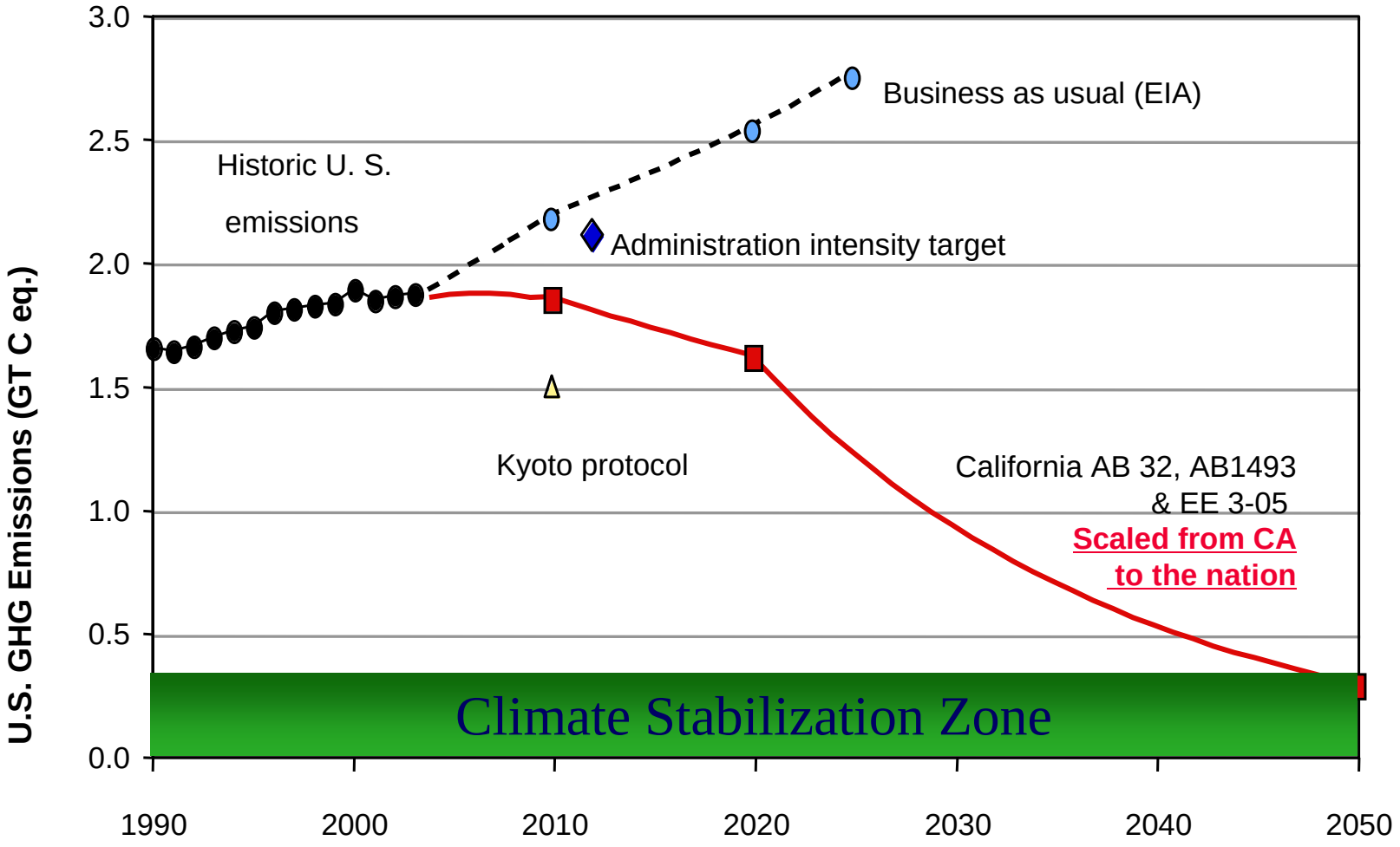
- The poor are the most at risk, but have much to gain if biofuels are made tools to achieve sustainable societies

- Biofuel research and demonstration must be integrated with policy development
- Biofuels link energy and globalization

Energy Biosciences Institute

University of California, Berkeley
Lawrence Berkeley National Laboratory
University of Illinois at Urbana-Champaign
BP (partner and $500 million funder)

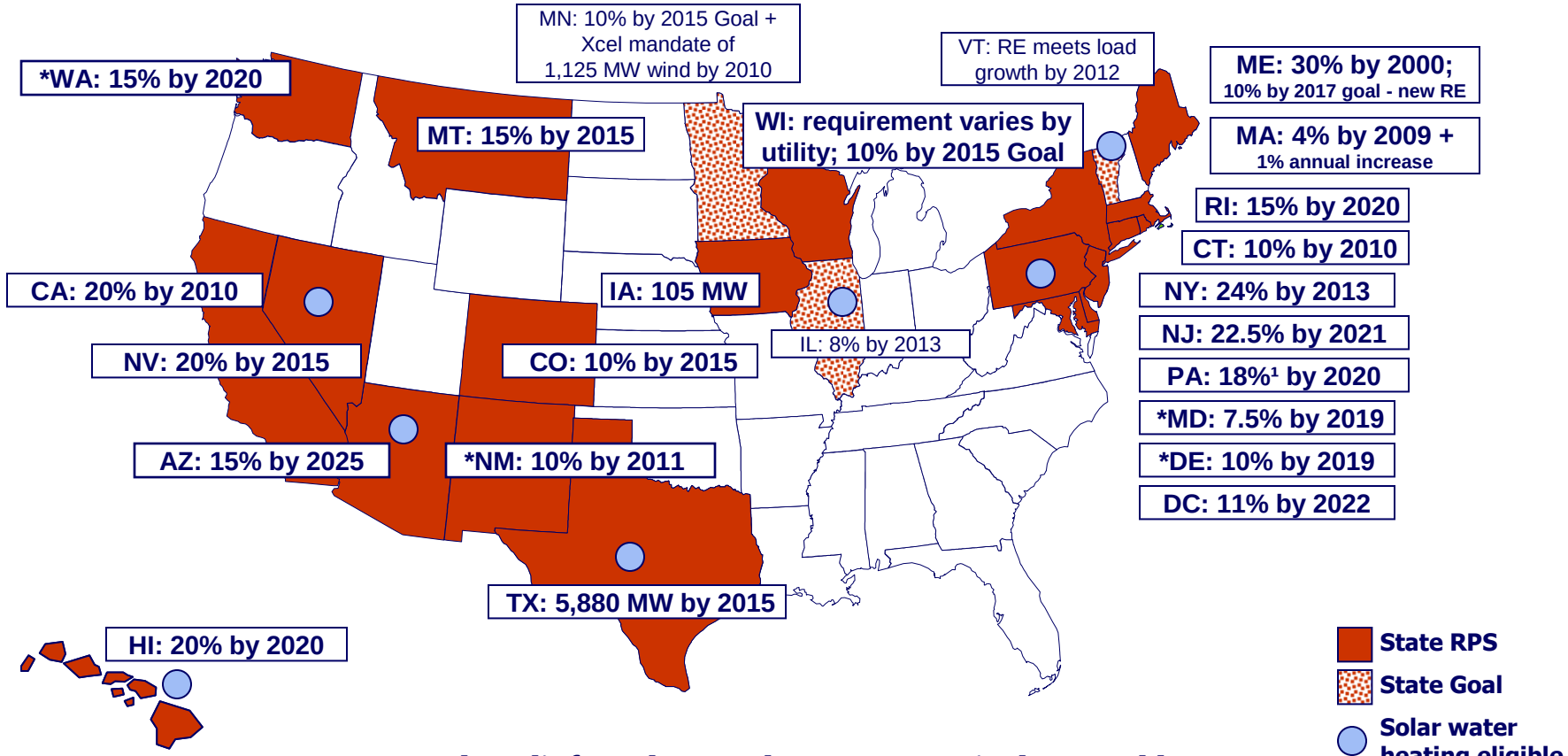
The California commitment - scaled to the nation



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

Renewable Energy Portfolio Standards

23 states + DC, and counting



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

PA: 8% Tier I (renewables)

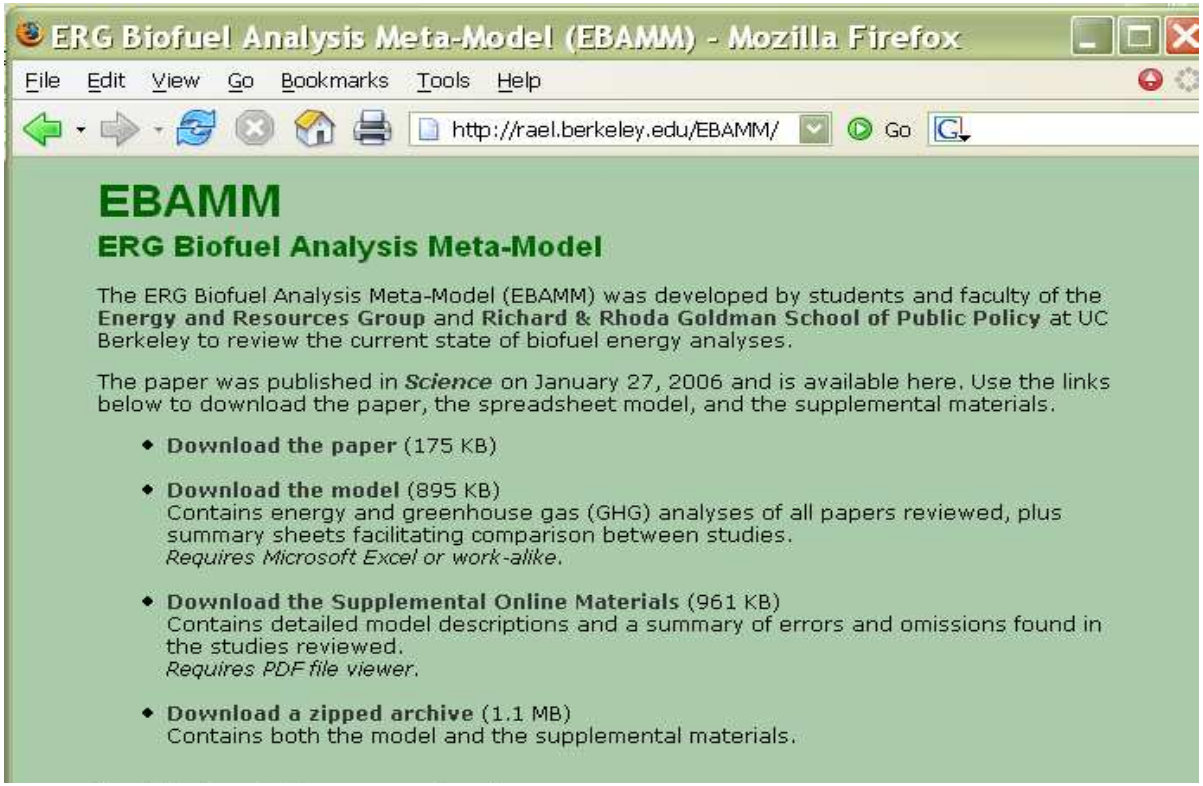
REPORTS

27 JANUARY 2006 VOL 311 SCIENCE www.sciencemag.org

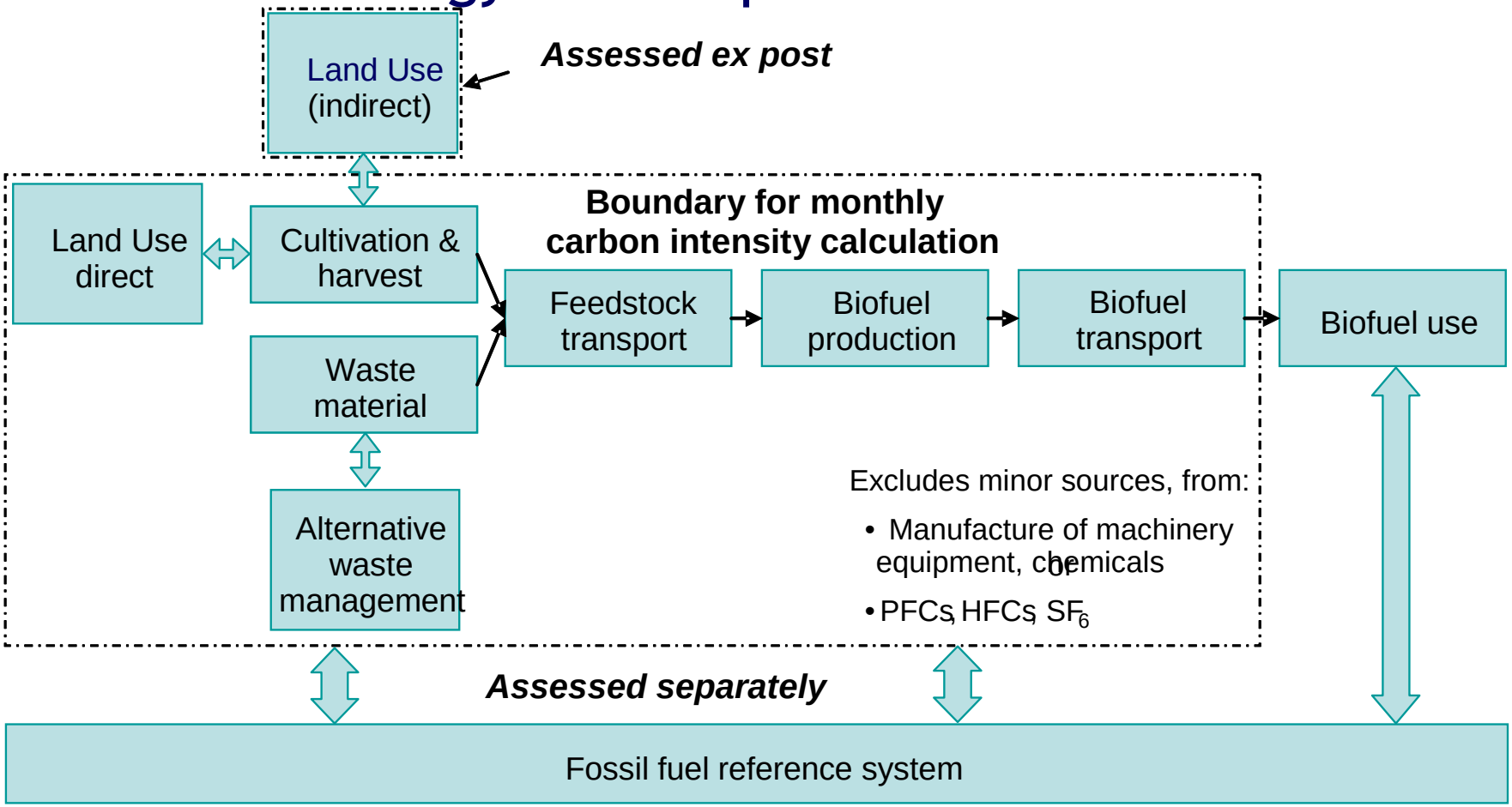
Ethanol Can Contribute to Energy and Environmental Goals

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



UK approach may become an internationally agreed methodology in compliance with WTO rules



Maximize the use of waste

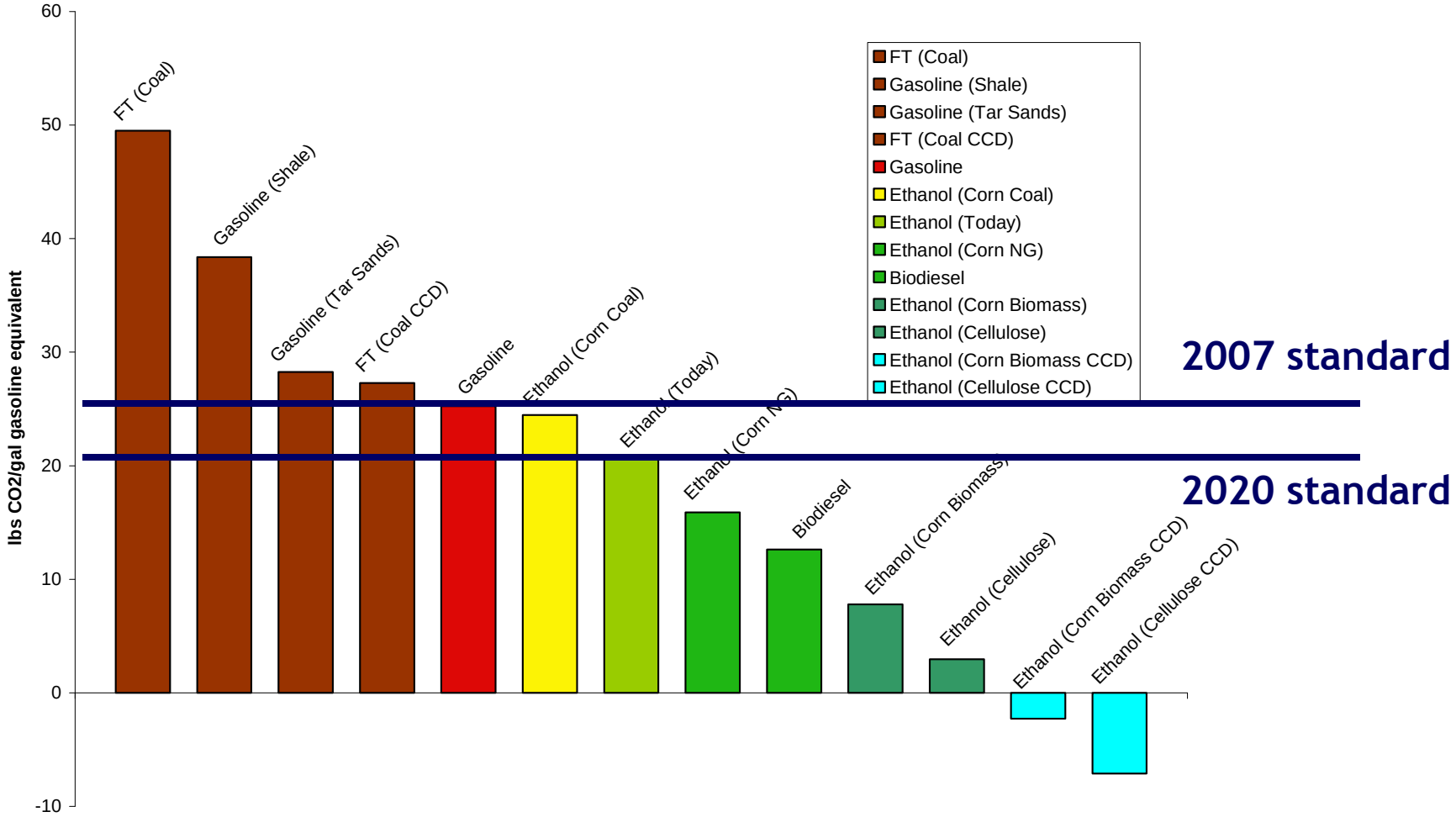
Standardize system boundaries

Recognize previous land use

Co-product allocation

Move to 'sustainable fuel' standard to benefit the poor and ecosystems

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



A promising crop: *Miscanthus X Giganticus*

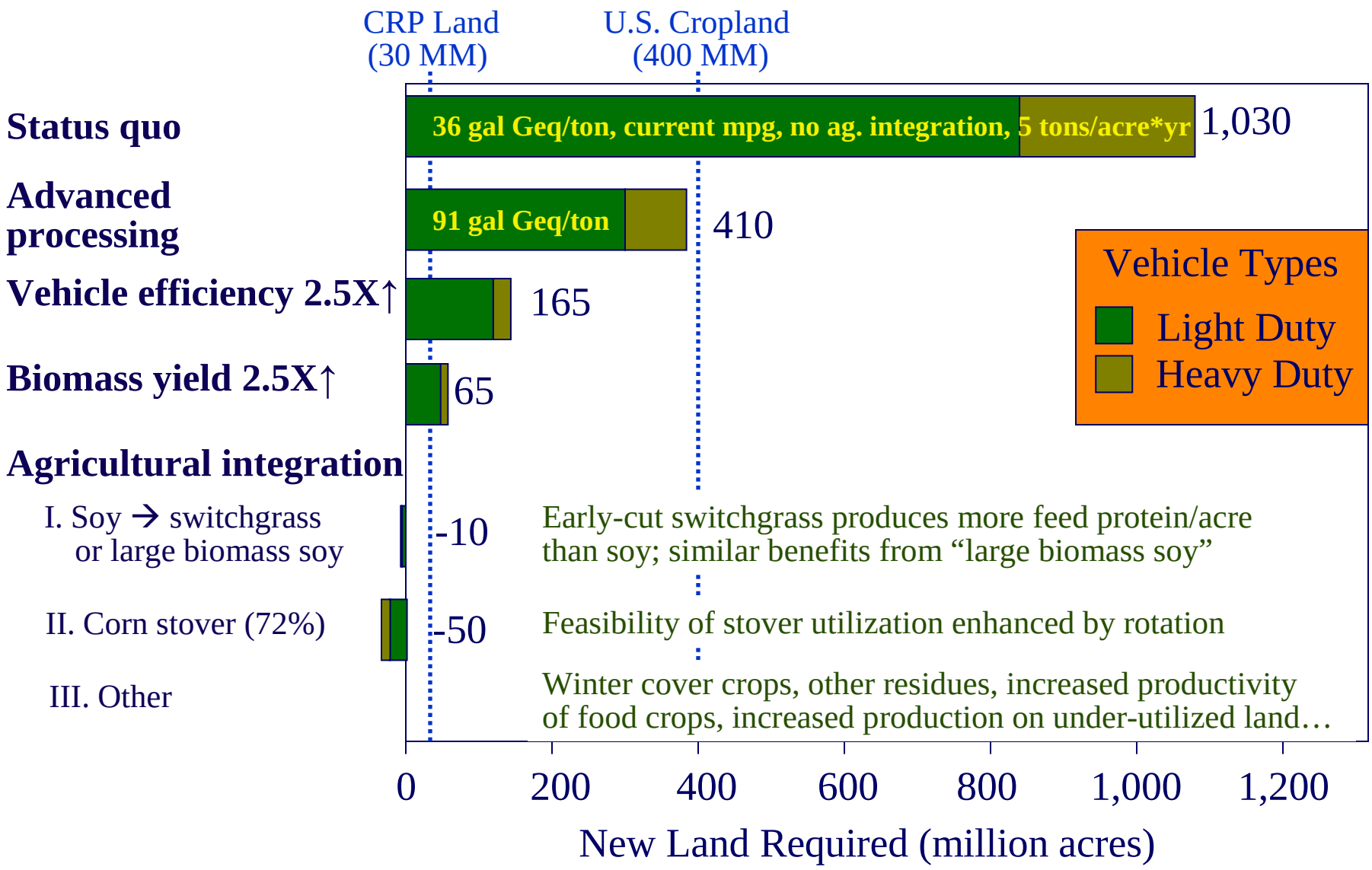
Top left: summer Miscanthus growth (sterile)

Top right: Miscanthus stands (UK)

Right: winter harvest of the C4 plant, Miscanthus after growing season and nutrients and water returned to the soil

Photo credits: S. Long (U. of Illinois/EBI)

Land Required to Satisfy Current U.S. Mobility Demand



U.S. mobility demand, the largest per capita in the world, could be met from land now used for agriculture while maintaining food production (L. Lynd)

Indirect land use causes large GHG emissions

(One, un-reviewed, example below)

U.S. corn farmer switches from corn/soy to corn/corn to supply a new ethanol plant

U.S. soy exports go down and world soy prices rise

Additional land in Brazil is put into soy production

Tailpipe GHG emission reductions (wrt gasoline)

Corn -0.6 ton / ac. yr.

Sugar -2 ton/ ac. yr.

Land use change GHG emissions

Rainforest: 100–400 ton / ac.

Grassland: 30–80 ton / ac.

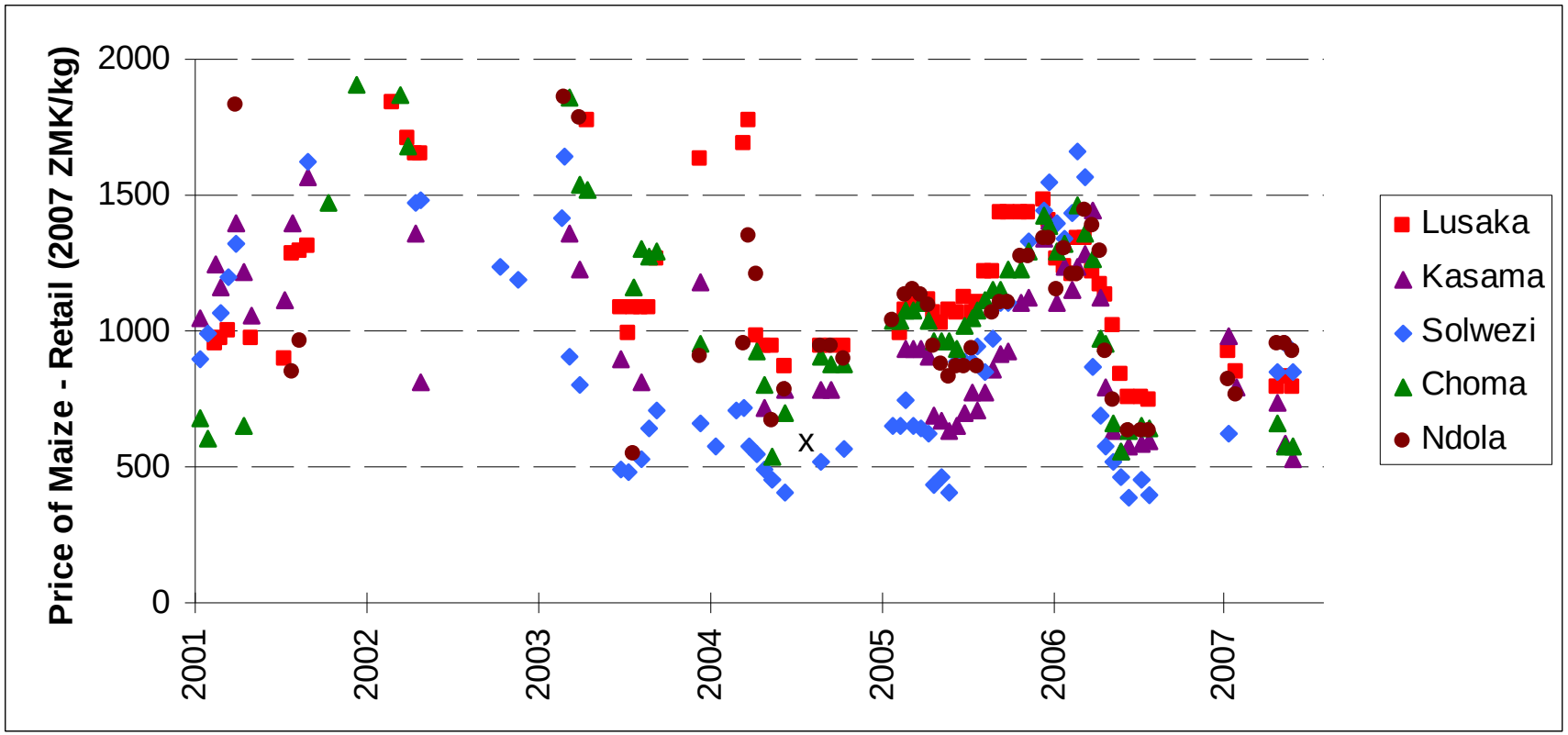
More Corn ethanol leads to *higher* atmospheric GHG concentrations for 38-100 years

Source: Searchinger et al. 2007

CROP	Harvest-able Biomass (tons/ acre)	Ethanol (gal/t)	Million acres needed for 35 billion gallons of ethanol	% 2006 harvested US cropland needed
Corn grain	4	500	70	25.3
Corn stover	3	300	105	38.5
Corn Total	7	800	40	15.3
Prairie	2	200	210	75.1
Sorghum	2	200	210	75.1
Switch-grass	6	600	60	20.7
Miscanthus	17	1700	18	5.8
Tank Algae*	80+	600+	< 10	< 2

*assumes CO_2 input

Food Prices are Volatile Today – without biofuels (example: 5 Zambian markets)



Source: Zambia Ministry of Agriculture and Co-operatives, 2007.

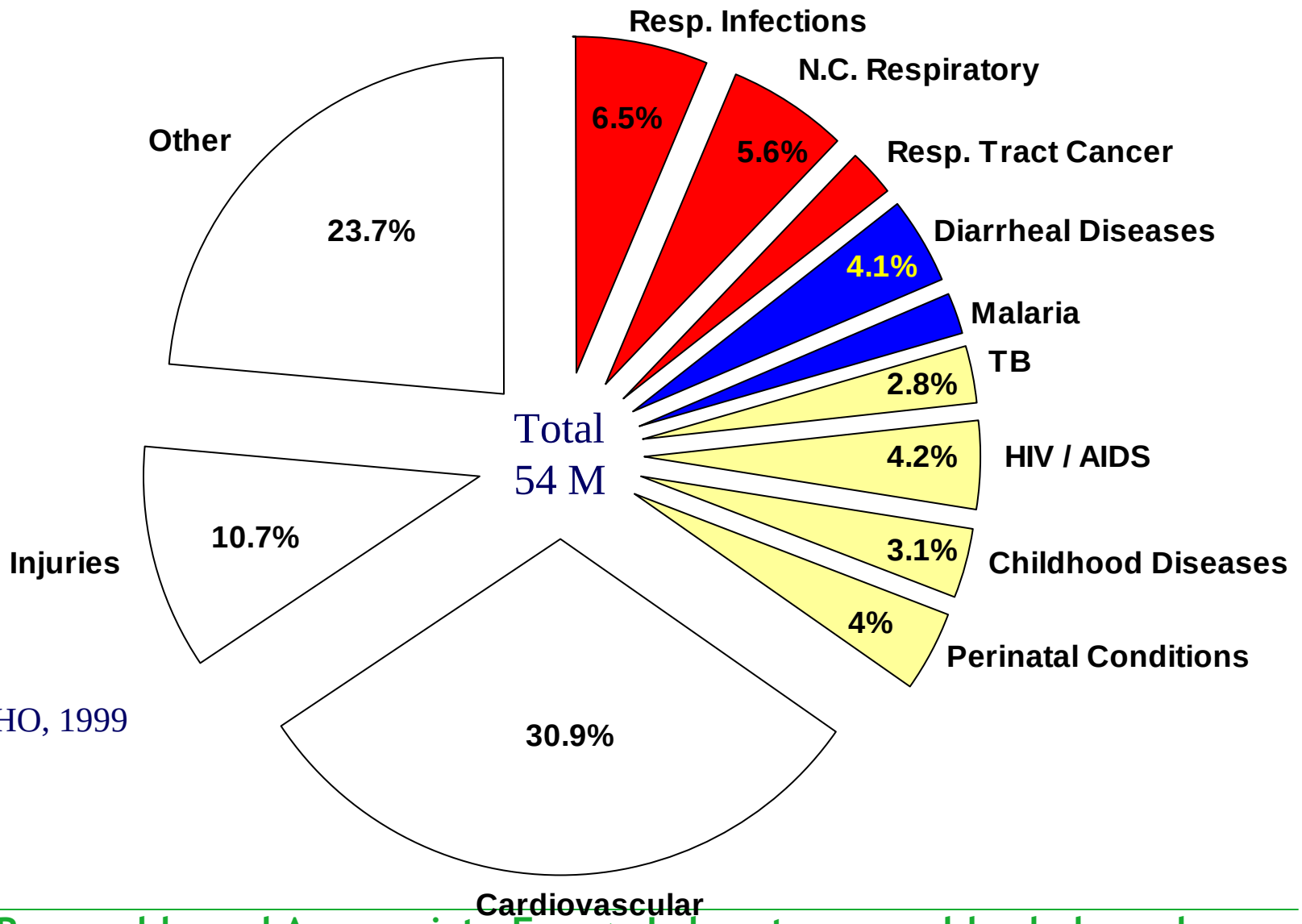
Zambia food prices are volatile due to pressures from climate and policy.

Forest Resources Under Stress

(Bailis, Ezzati and Kammen, *Science*, *2005)*

COOKSTOVE SMOKE is ubiquitous in Kenya, where wood, charcoal and other biomass fuels are used for cooking and heating. Particulates in smoke are a major contributor to respiratory disease, the leading cause of illness in developing nations.

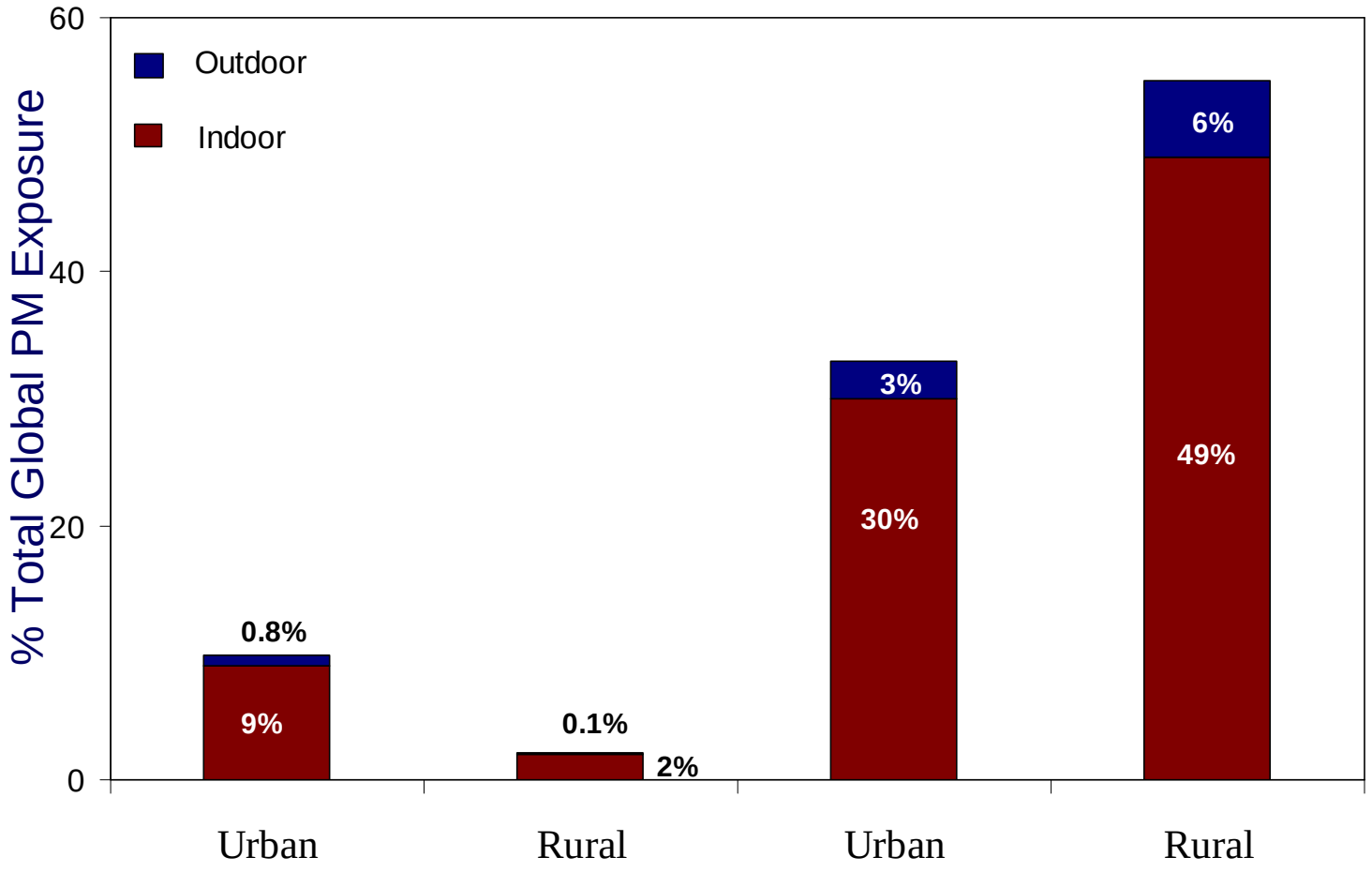
The Global Distribution of Disease (Mortality)



source: WHO, 1999

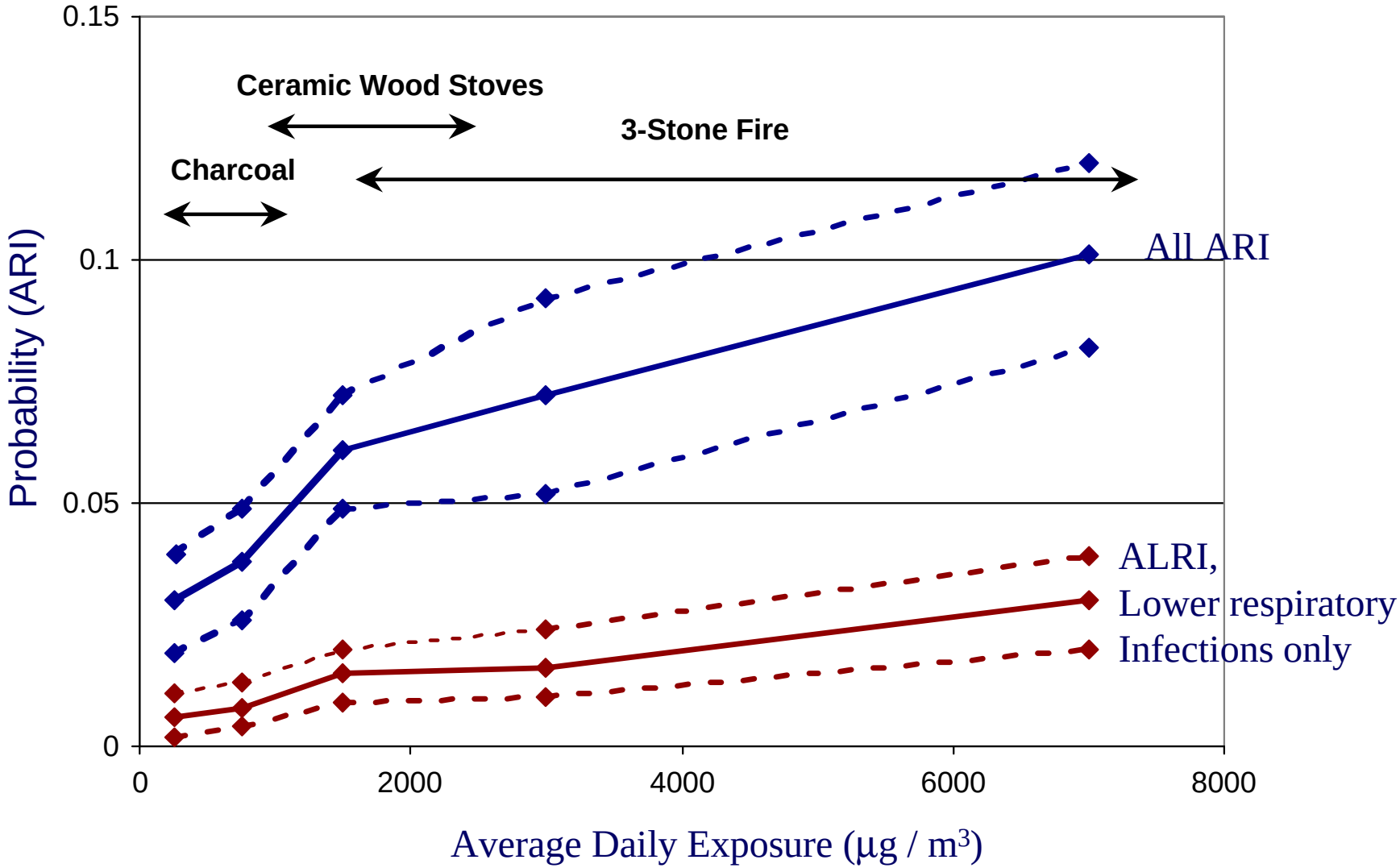
Global Exposure to Air Pollution

Exposure = Population • Time • Pollution



Smith, 1988

Illness Reduction Observed in Kenya
(ARI = acute respiratory infection)



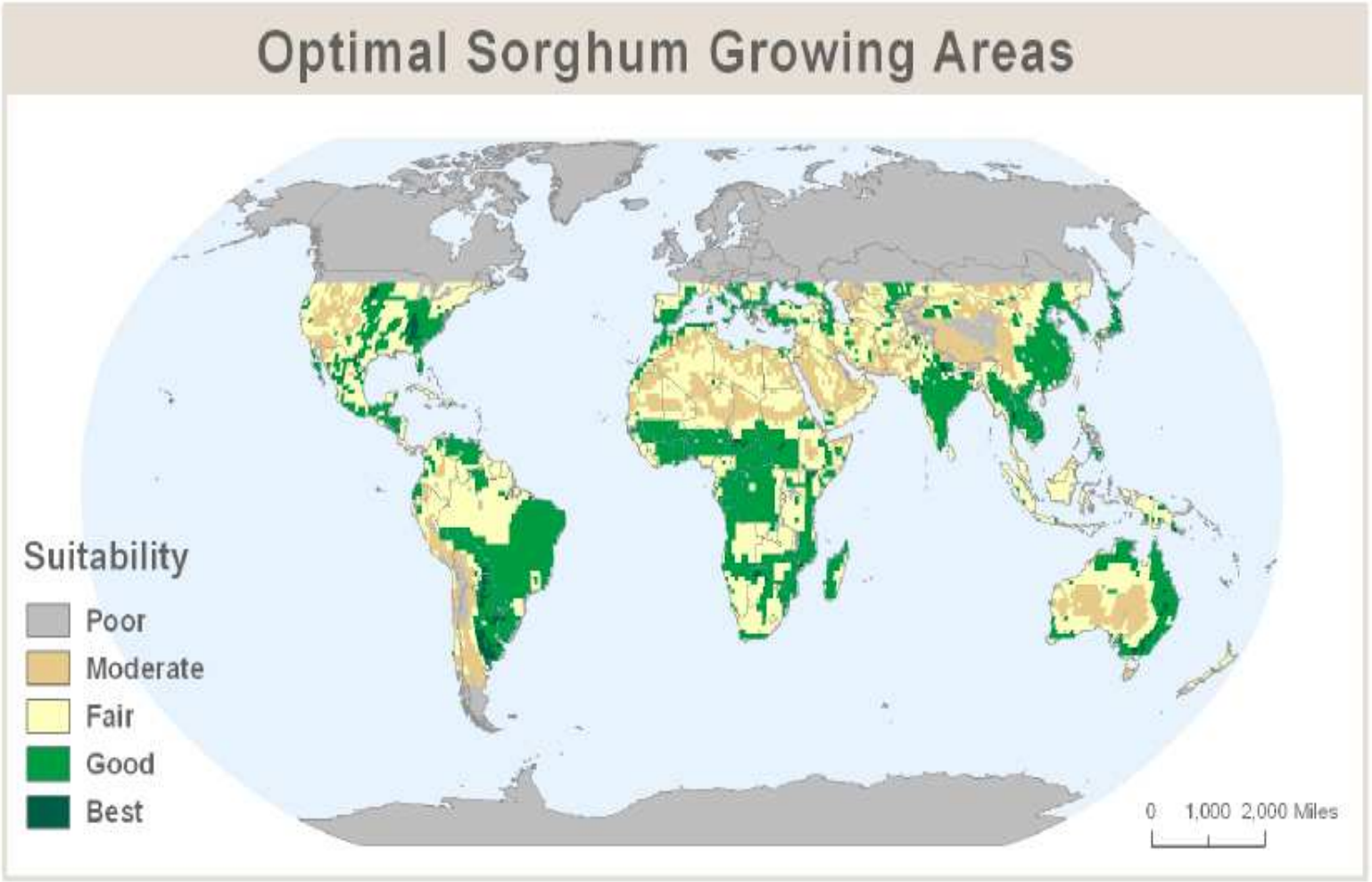
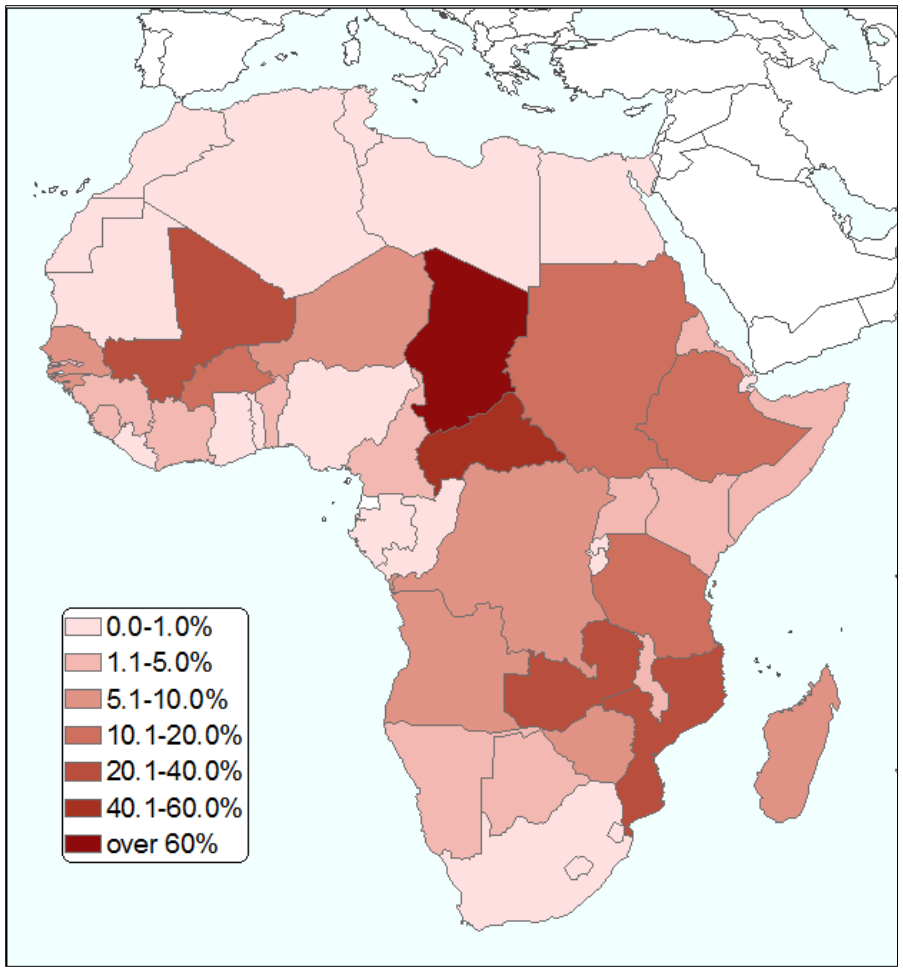


Figure 1. Optimal sorghum growing areas are based on solar radiation, minimum, maximum, and monthly temperature, annual precipitation, and soil texture. Produced by the UC-Berkeley Geospatial Imaging and Informatics Facility (GIIF) as an early demonstration of the data methods available for this study.

William Collins, LBNL

Ethanol can Displace Gasoline Consumption in Africa

- Using only post-harvest crop losses as inputs (up to 50 percent of yields), biofuels can play a significant role
- Implications for poverty alleviation, job creation, urban health, and foreign currency savings
- Metrics for ecological and cultural sustainability must be part of the planning process



Source: FAO/IIASA 2002, EIA 2007, ICRISAT 2007

UNIVERSITY OF CALIFORNIA
BERKELEY

REPORT OF THE
RENEWABLE AND APPROPRIATE ENERGY
LABORATORY

Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?

by

Daniel M. Kammen
Kamal Kapadia
Matthias Fripp

of the
Energy and Resources Group &
the Goldman School of Public Policy

APRIL 13, 2004

Study reviews:

- 13 studies of job creation

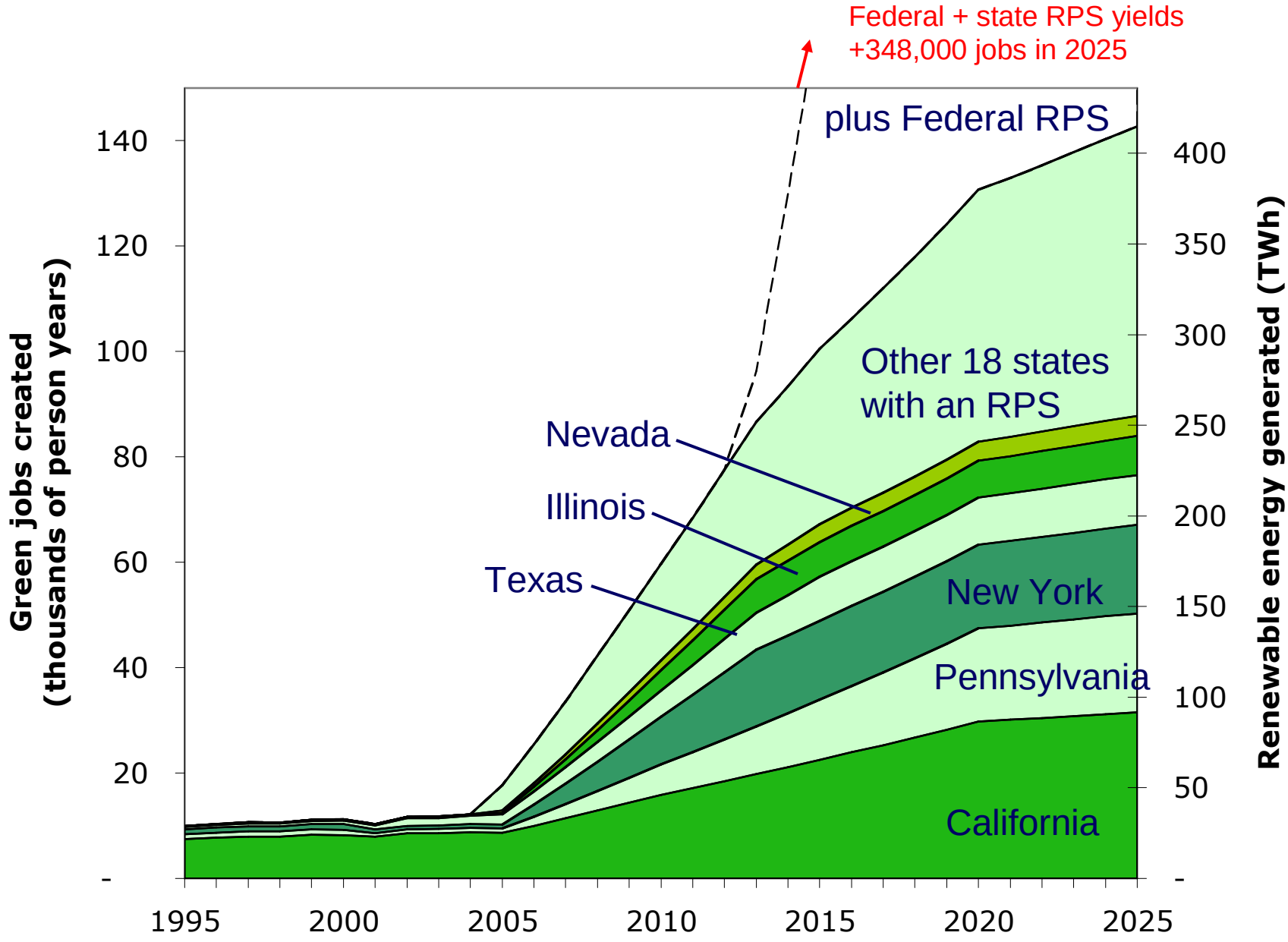
- 3 - 5 *times* More jobs per dollar invested in the renewables sector than in fossil fuels

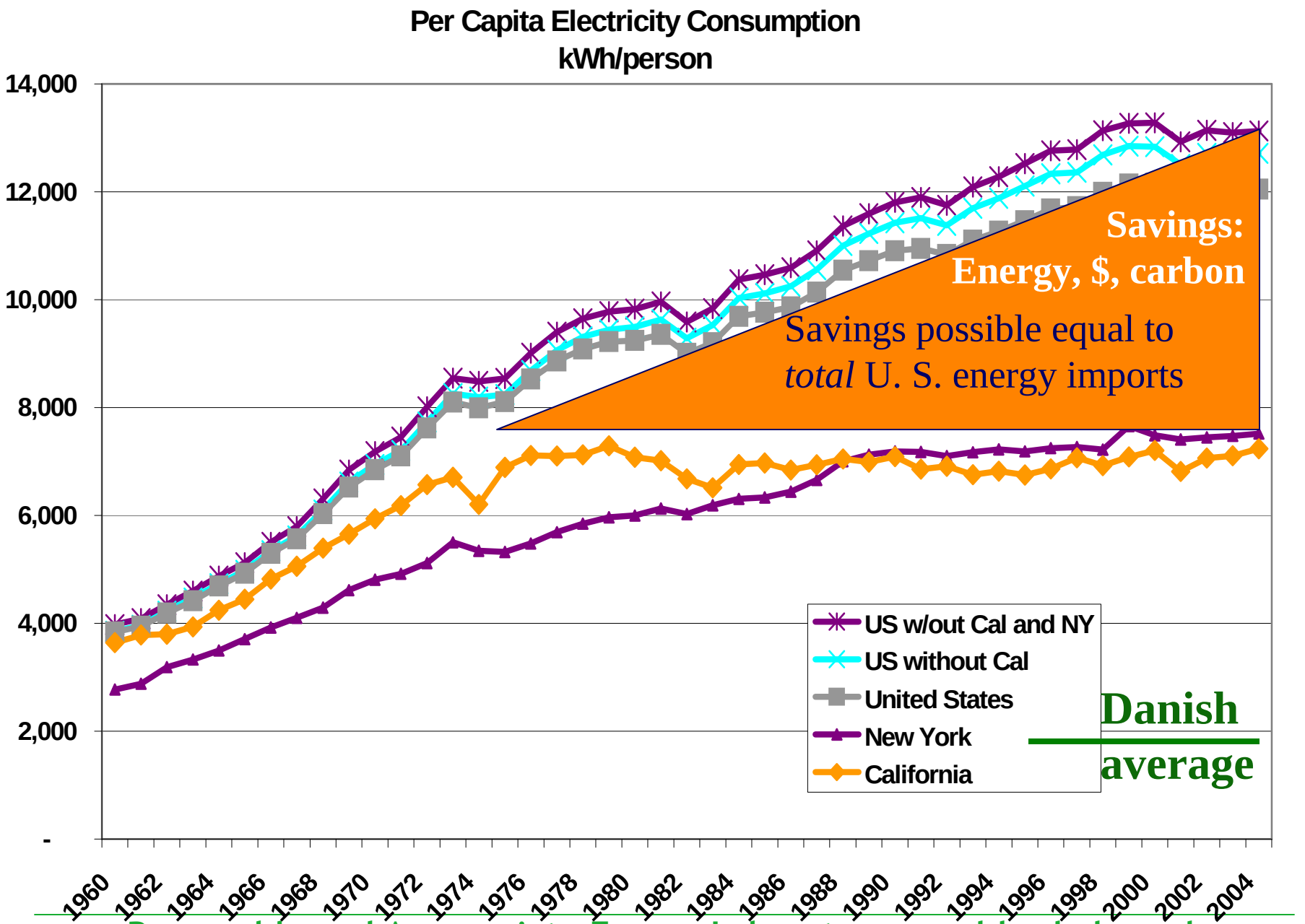
Look-up table for simple estimating: Jobs per MW

Energy Technology	Source of Estimate	Average Employment Over Life of Facility (jobs/MWa)		
		Construction, Manufacturing, Installation	O&M and fuel processing	Total Employment
PV 1	REPP, 2001	6.21	1.20	7.41
PV 2	Greenpeace, 2001	5.76	4.80	10.56
Wind 1	REPP, 2001	0.43	0.27	0.71
Wind 2	EWEA/Greenpeace, 2003	2.51	0.27	2.79
Biomass Š high estimate	REPP, 2001	0.40	2.44	2.84
Biomass Š low estimate	REPP, 2001	0.40	0.38	0.78
Coal	REPP, 2001	0.27	0.74	1.01
Gas	Kammen, from REPP, 2001; CALPIRG, 2003; BLS, 2004	0.25	0.70	0.95

Kapadia, Fripp and Kammen (2004)
"Putting renewables to work"

Green Collar Job Creation




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
Savings possible equal to
total U. S. energy imports
US w/out Cal and NY
US without Cal
United States
New York
California
Danish
average

Solar Energy for Many Applications

Moscone Center, SF: 675,000 W

Residential Solar: 1000 - 4000 Watts/home

CA Solar Initiative/Million Solar Roofs:

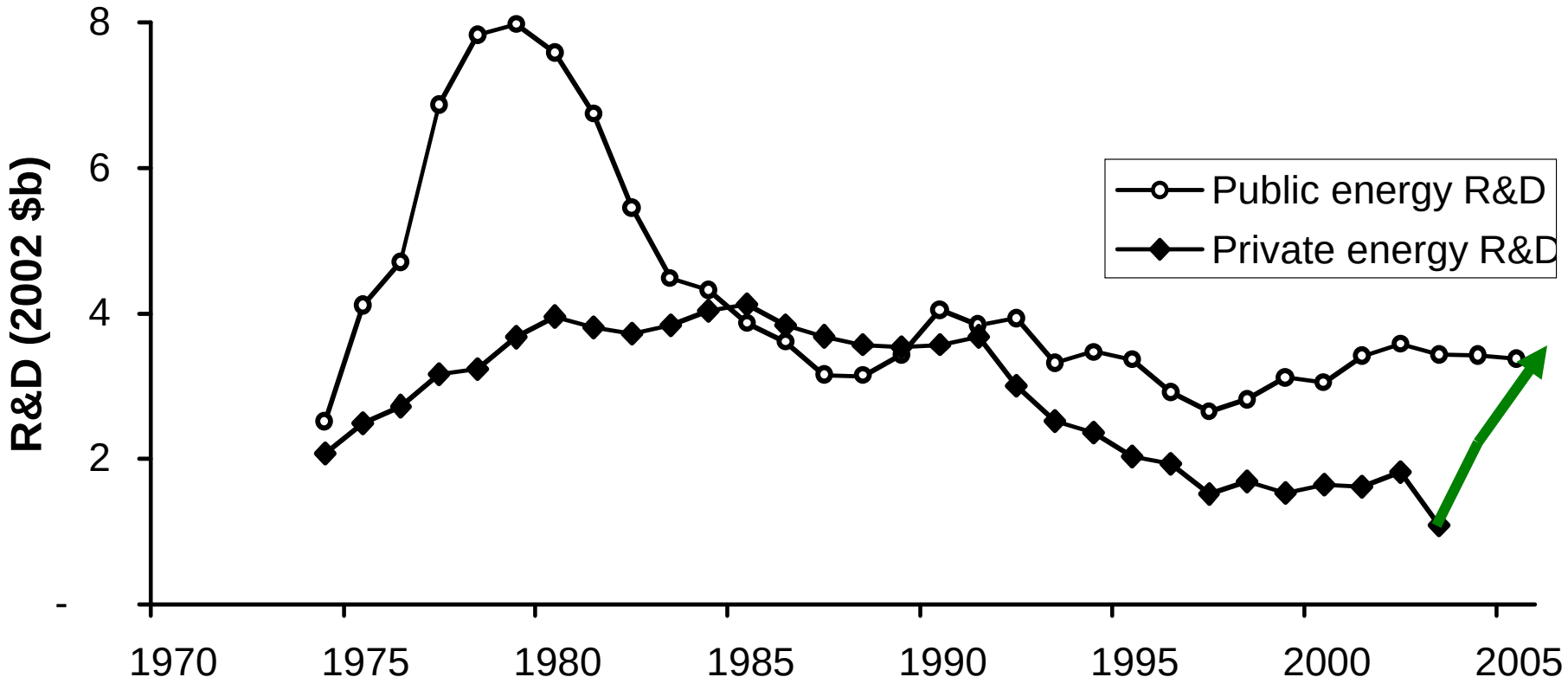
3,000 - 10,000 MW of solar to be built

Kenyan PV market: Average system: 18W

Largest penetration rate of any nation

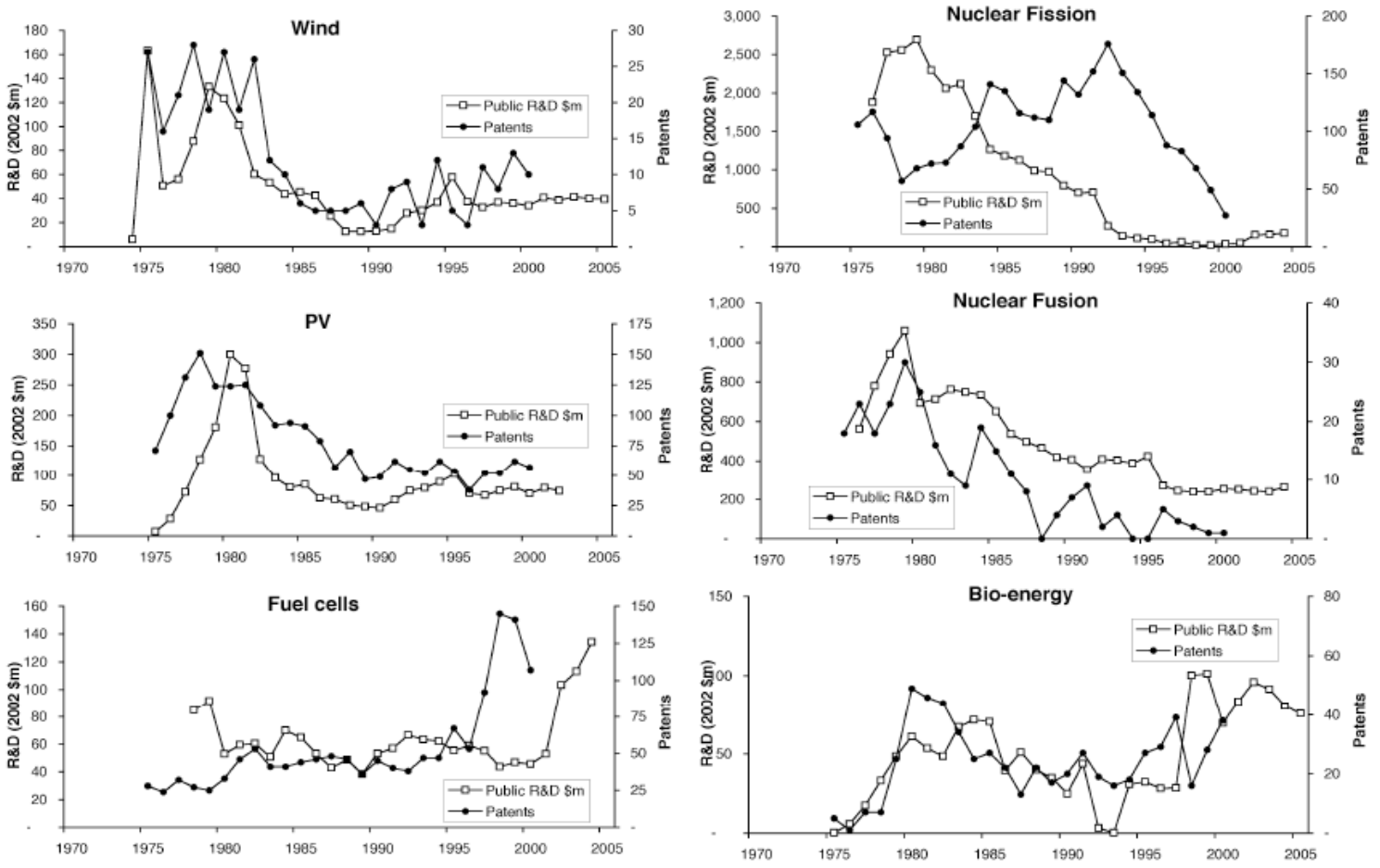
	California	Japan
2005 Annual PV Installations	50 MW	290 MW
Average Cost for Residential System	$8.8/Wac	$7.4/Wac
Average Cost Reduction from 99-04	5.2%/year	8.9%/year

United States' Public and Private Sector Energy Research and Development Spending



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

Patents and R&D Funding Correlated

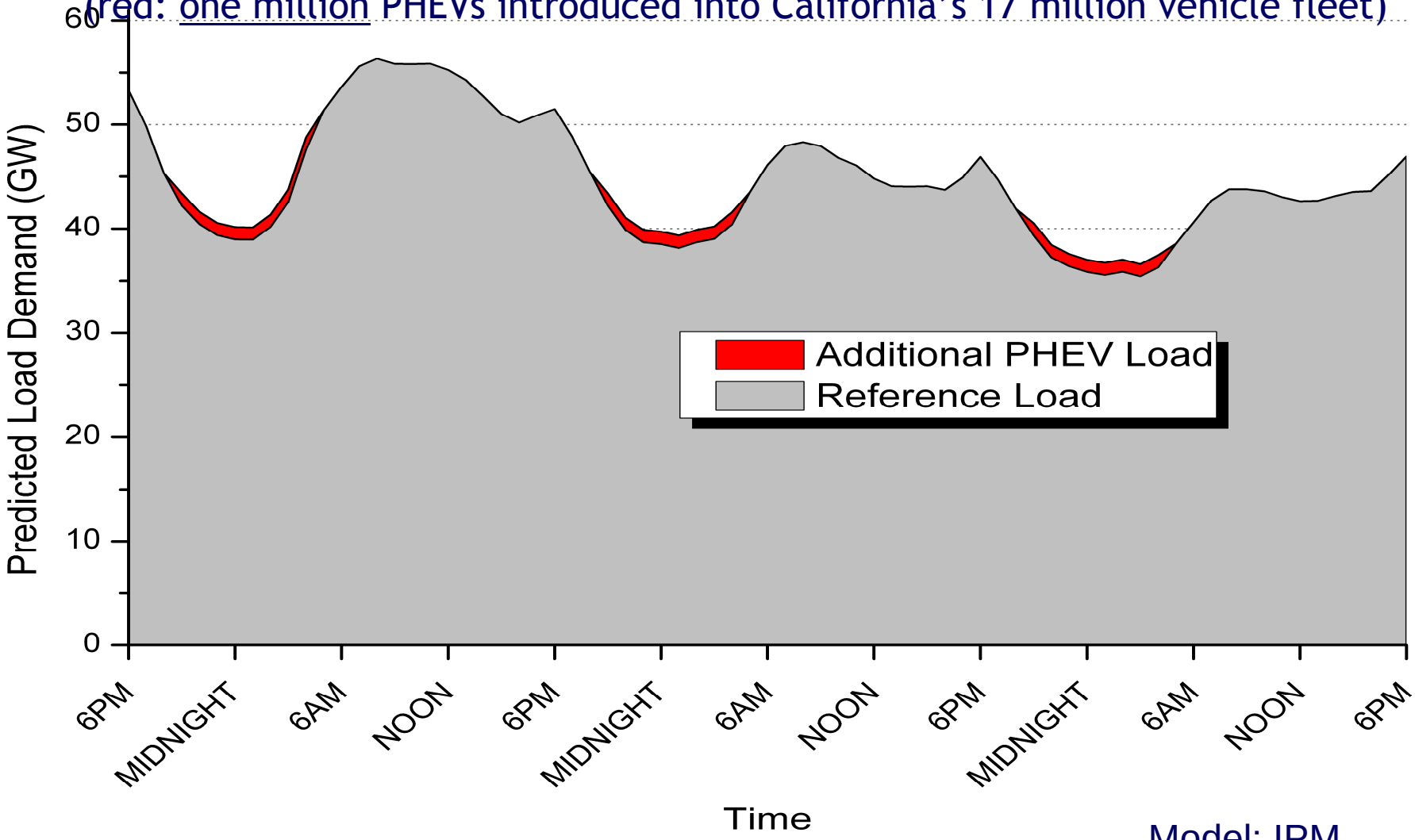


Kammen and Nemet (2005)
"Reversing the incredible shrinking energy R&D budget," *Issues in Science & Technology*, **Fall**, 84 – 88.
And Nemet, dissertation, 2007

Plug In Partners / e.g. CalCars.org

Plug-in Hybrid (PHEV) Off-Peak Electricity Demand

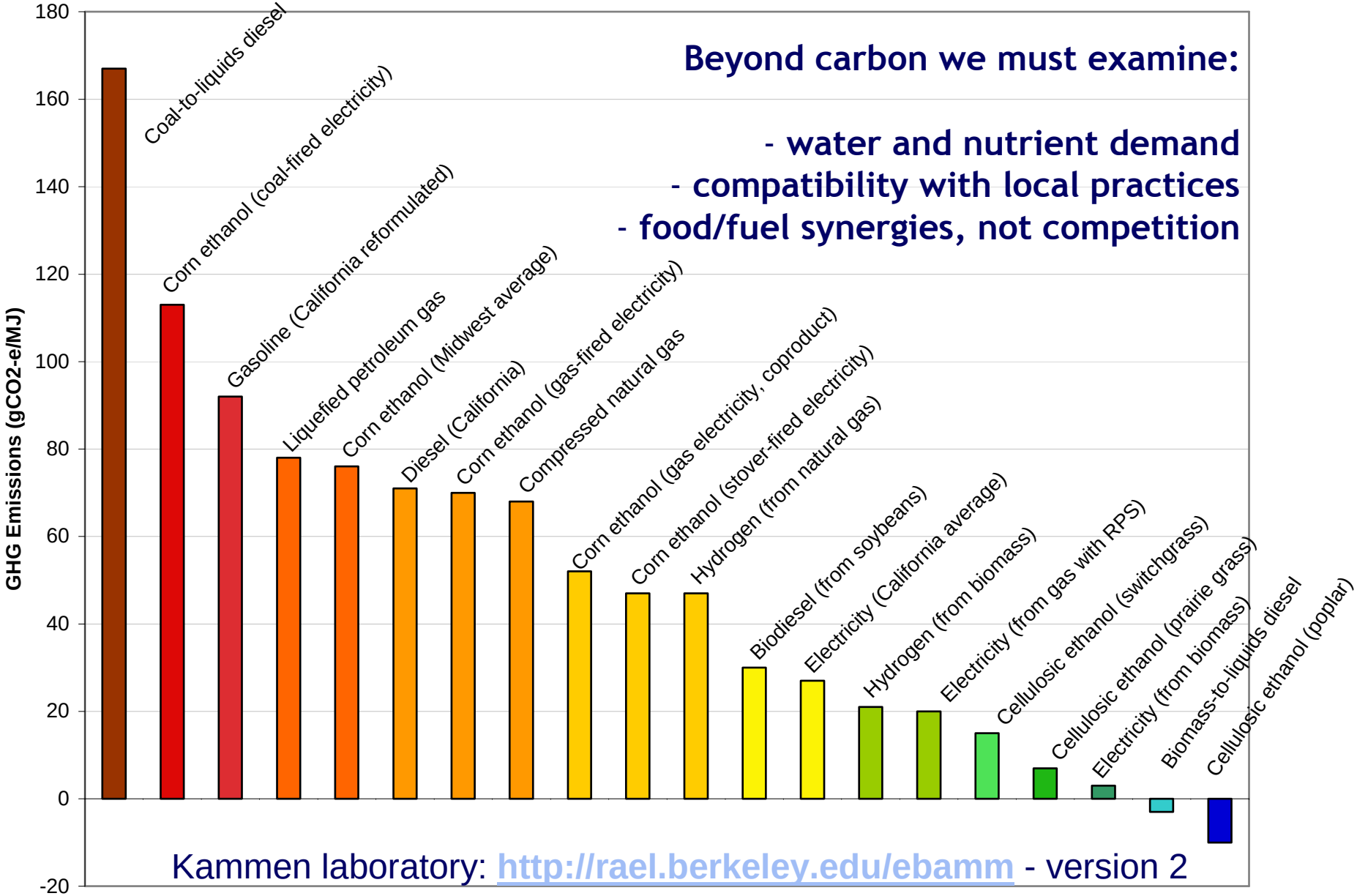
(red: one million PHEVs introduced into California's 17 million vehicle fleet)



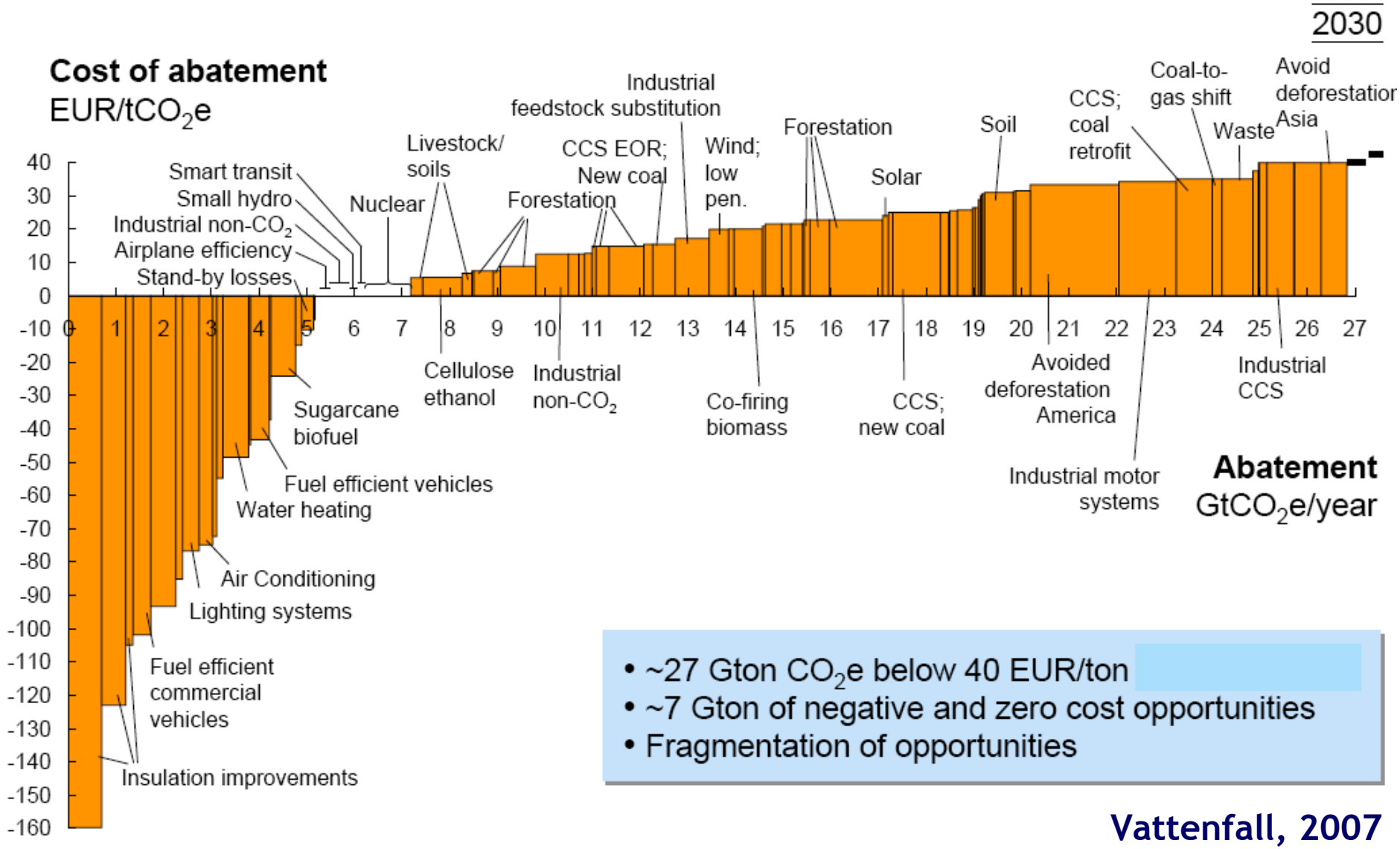
Model: IPM

- Additional load from PHEVs is small
- PHEVs could be charged mostly via base-load filling during evenings and nights, when electricity costs are low

From a Low Carbon Fuel Standard to a Sustainable Fuel Standard



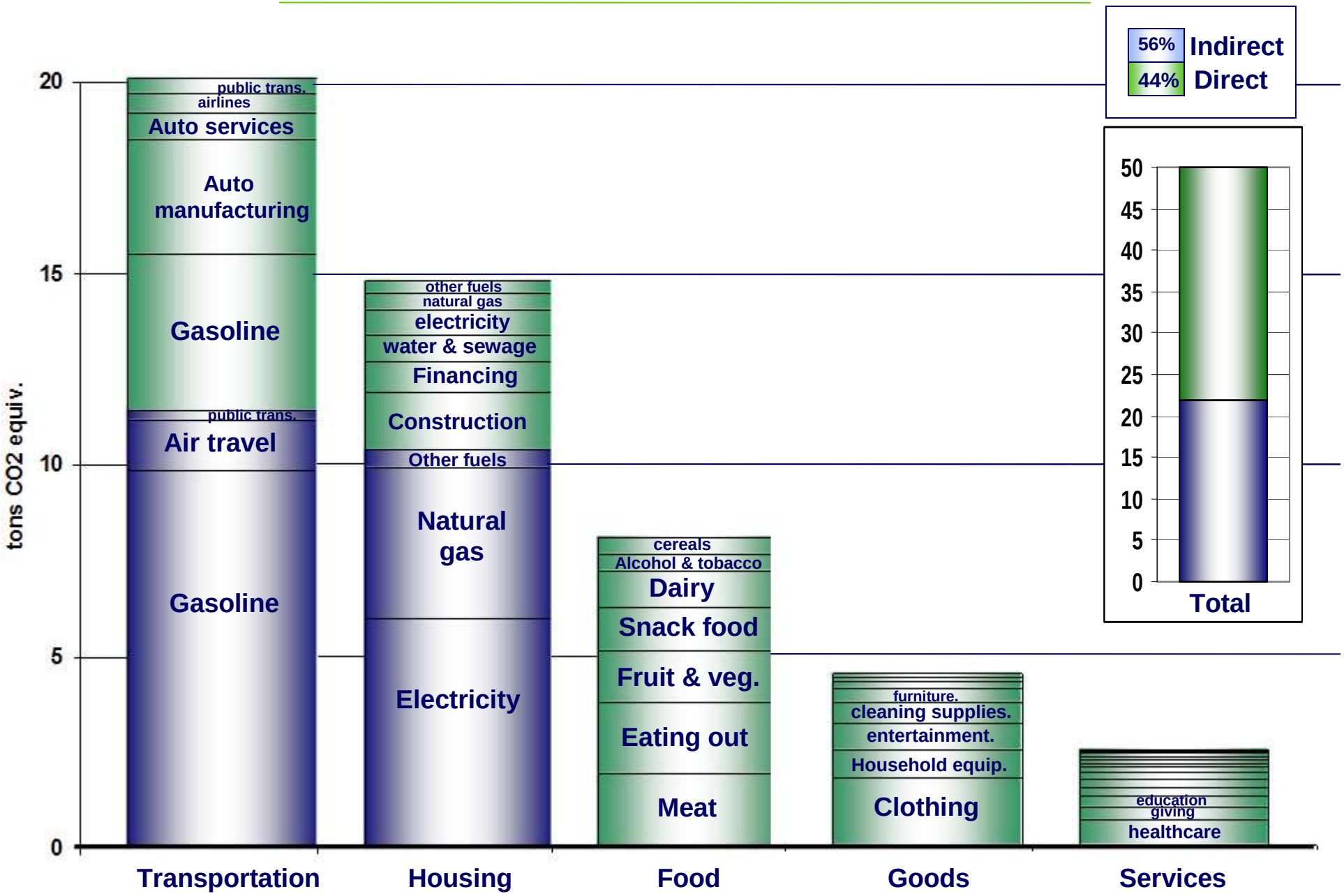
Global CO_2 Abatement Opportunities



- ~27 Gton CO_2e below 40 EUR/ton
- ~7 Gton of negative and zero cost opportunities
- Fragmentation of opportunities

Vattenfall, 2007

Summary of GHG Emissions for Typical U.S. Household
(LEAPS Results) 50 Metric tons of CO_2 equivalent gases



Recommendations

- **Program I:**

  A research program to assess environmental effects in both developed and developing nations

  - Greenhouse gases, water intensity (grey and pure) biodiversity, fertilizer runoff, land-use change

- **Program 2:**

  Planning methods to assess costs and to enhance economic opportunities

  - Recommendation: develop methodology for

    sustainable fuel standard(s)

    - An integration of GIS data and life-cycle analysis is the likely framework
    - Provide a framework for policy decisions around food-fuel conflicts and opportunities for enhanced equity*

- **Promote social goals and integration of these two research and advising programs is needed.**

Recommendations/expanded

- A national cellulosic biofuel research strategy is needed, and must not only include, but integrate, (*at least)* the DoE, EPA, USAID, and, centrally, the DoA and the Department of State.

- Low-carbon standards for biofuels are a beginning, but *sustainable biofuel* standards that include water, nitrogen and other fertilizer applications *and* cultural sustainability and development, are needed.

- Biofuels bring energy and globalization issues into direct interaction; this presents a major international challenge because bioenergy intensification *without* a broader low-carbon framework is likely to be harmful.