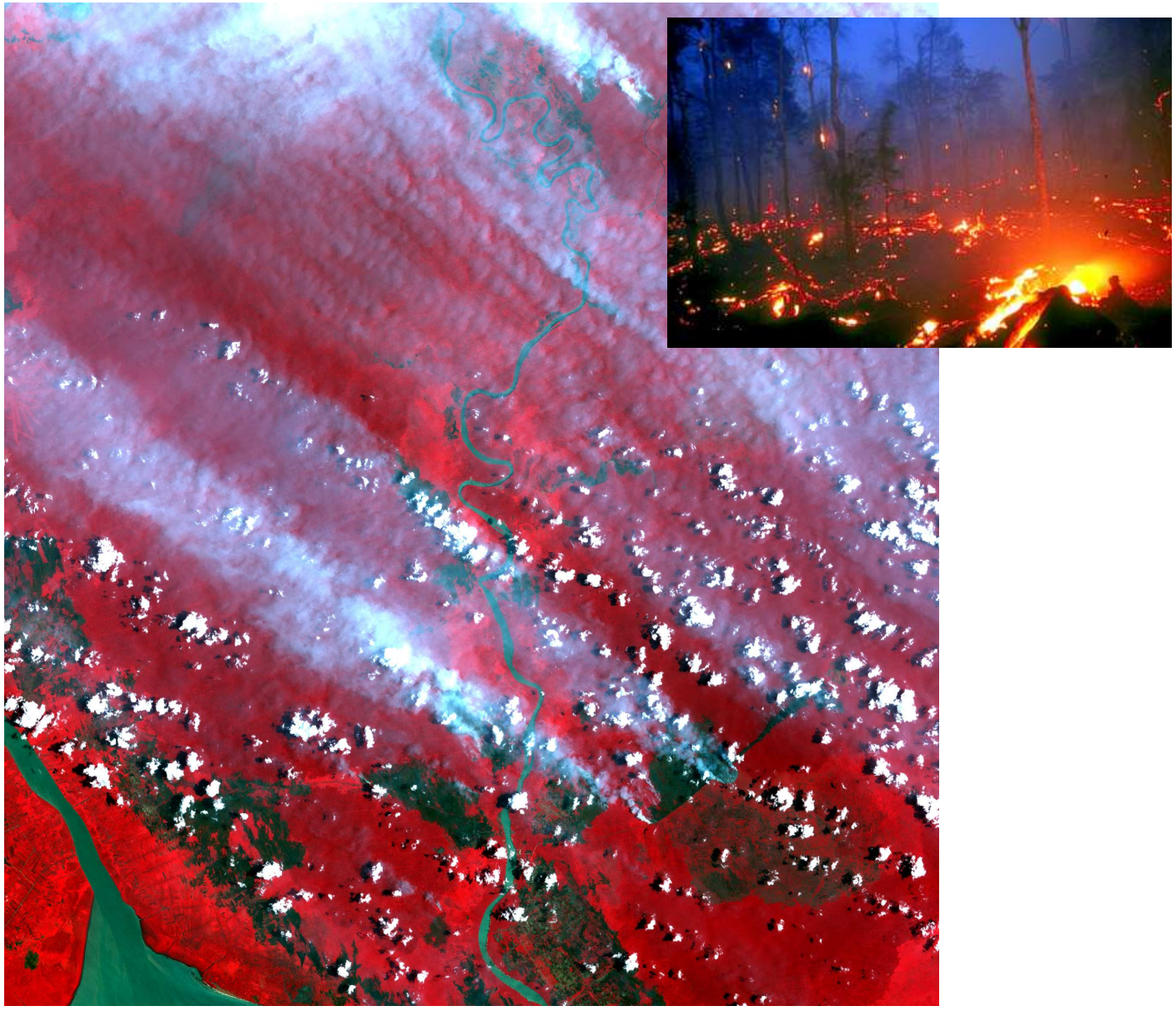
Can We Outlive Our Way of Life?

Forest Fire, Central Borneo (Kalimantan), Indonesia, Sept. 17, 2006

Tad Patzek, Civil & Environmental Engineering, U.C. Berkeley

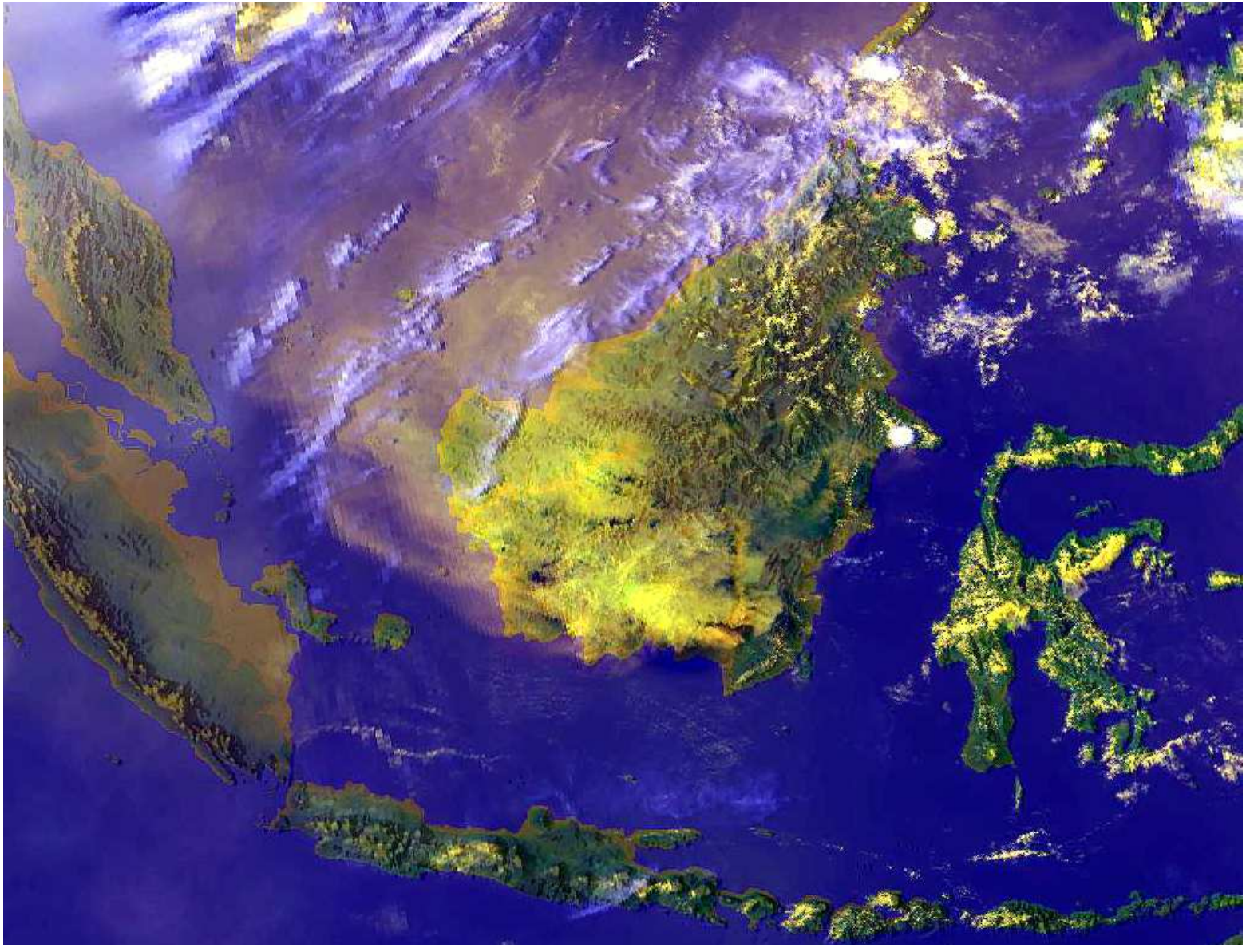
August 9, 2007, Redwood City, CA

Forest Fire, Central Borneo



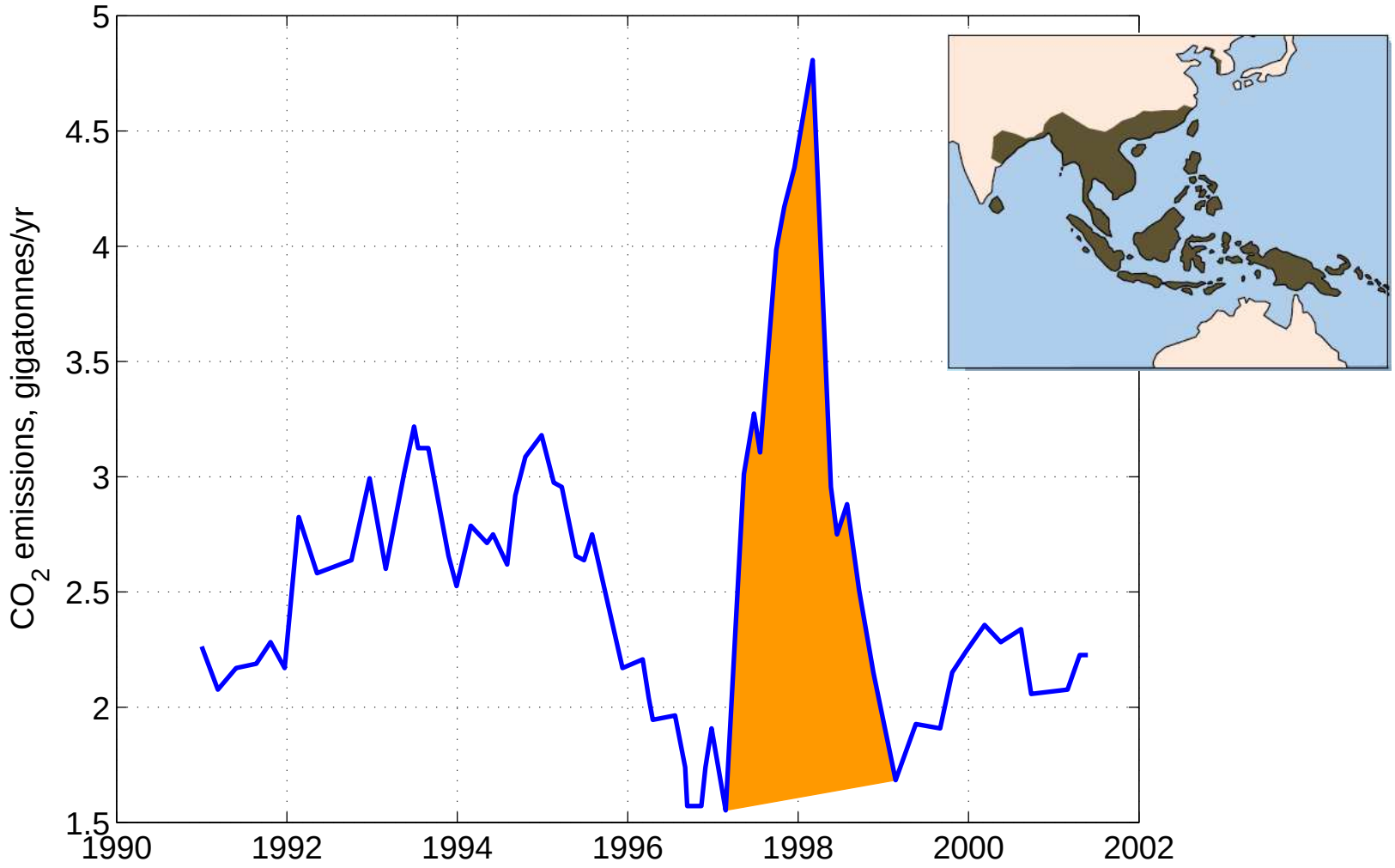
Red is forest. Sources: www.pandhitopanji-f.org/.../imagegallery.htm, ESA

Borneo Forest Fires



Huge fires on Borneo, Sept. 22, 1997, NOAA-14 Polar Orbiting Environmental Satellite (POES).

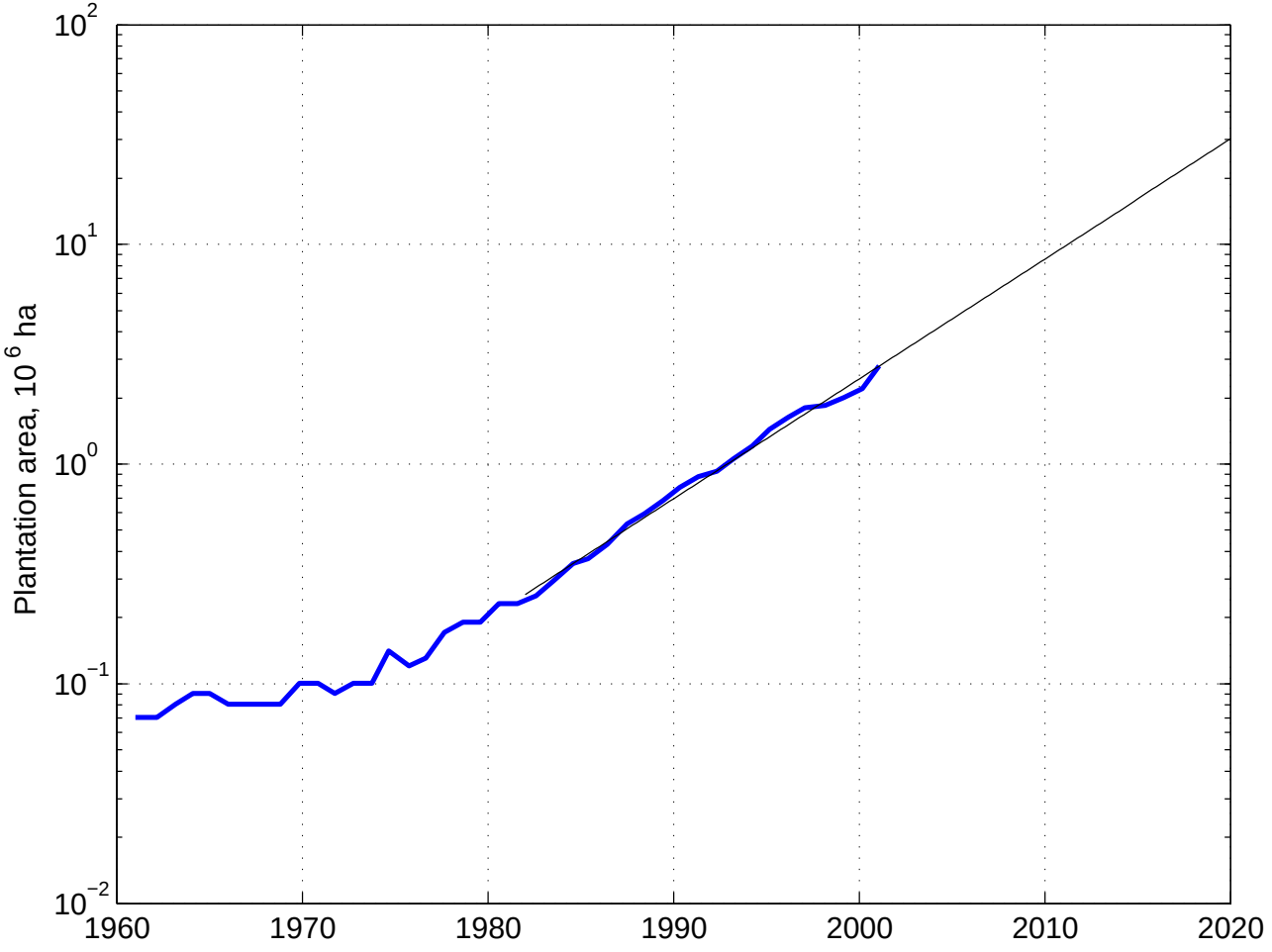
CO_2 From SE Asia Forest Fires



Source: D. SCHMIL AND D. BAKER, *The Wildfire Factor*, Nature, **420** 29, 2002

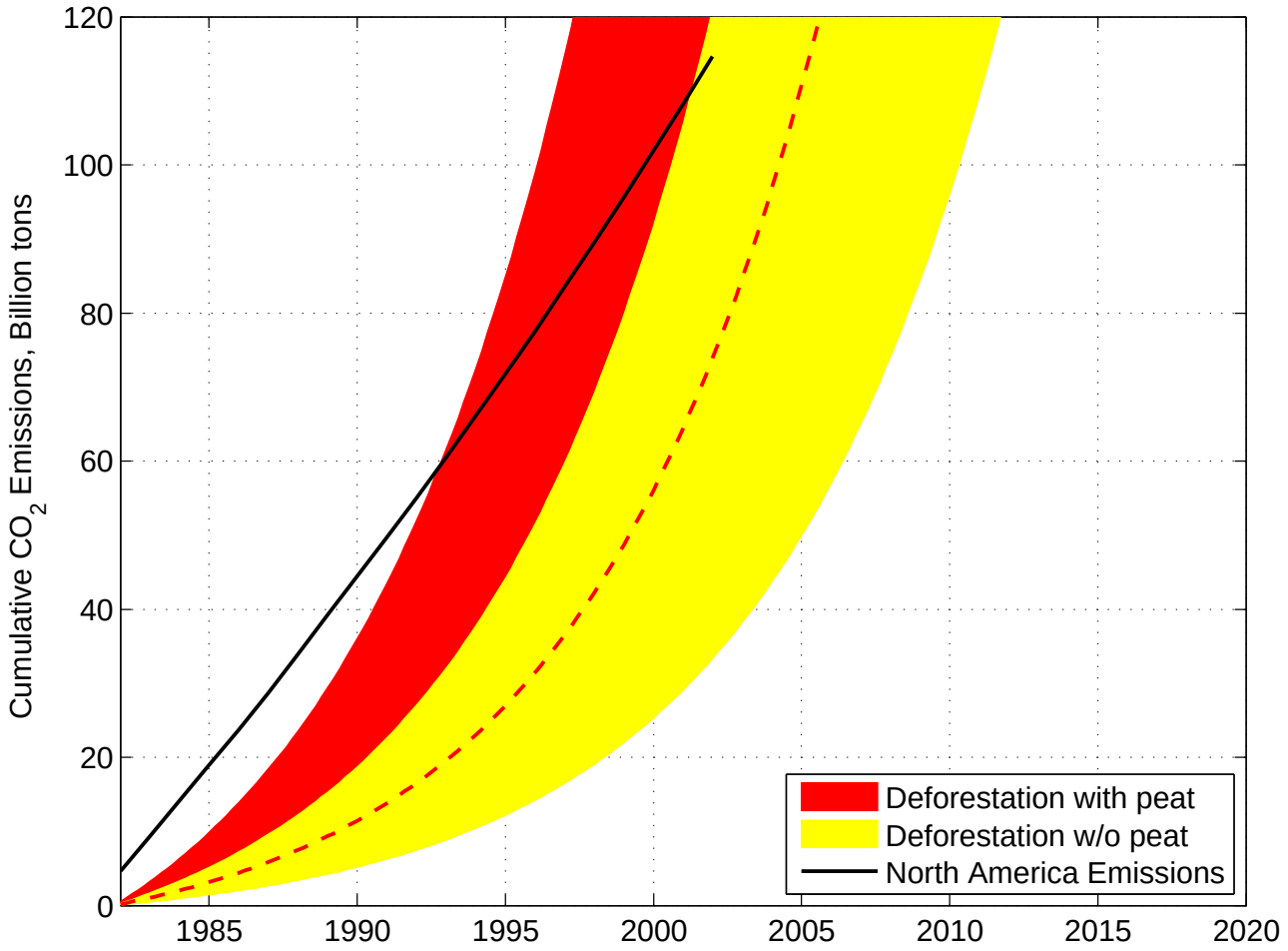
Borneo Forest Fires: Result

Indonesian Oil Palm Plantations



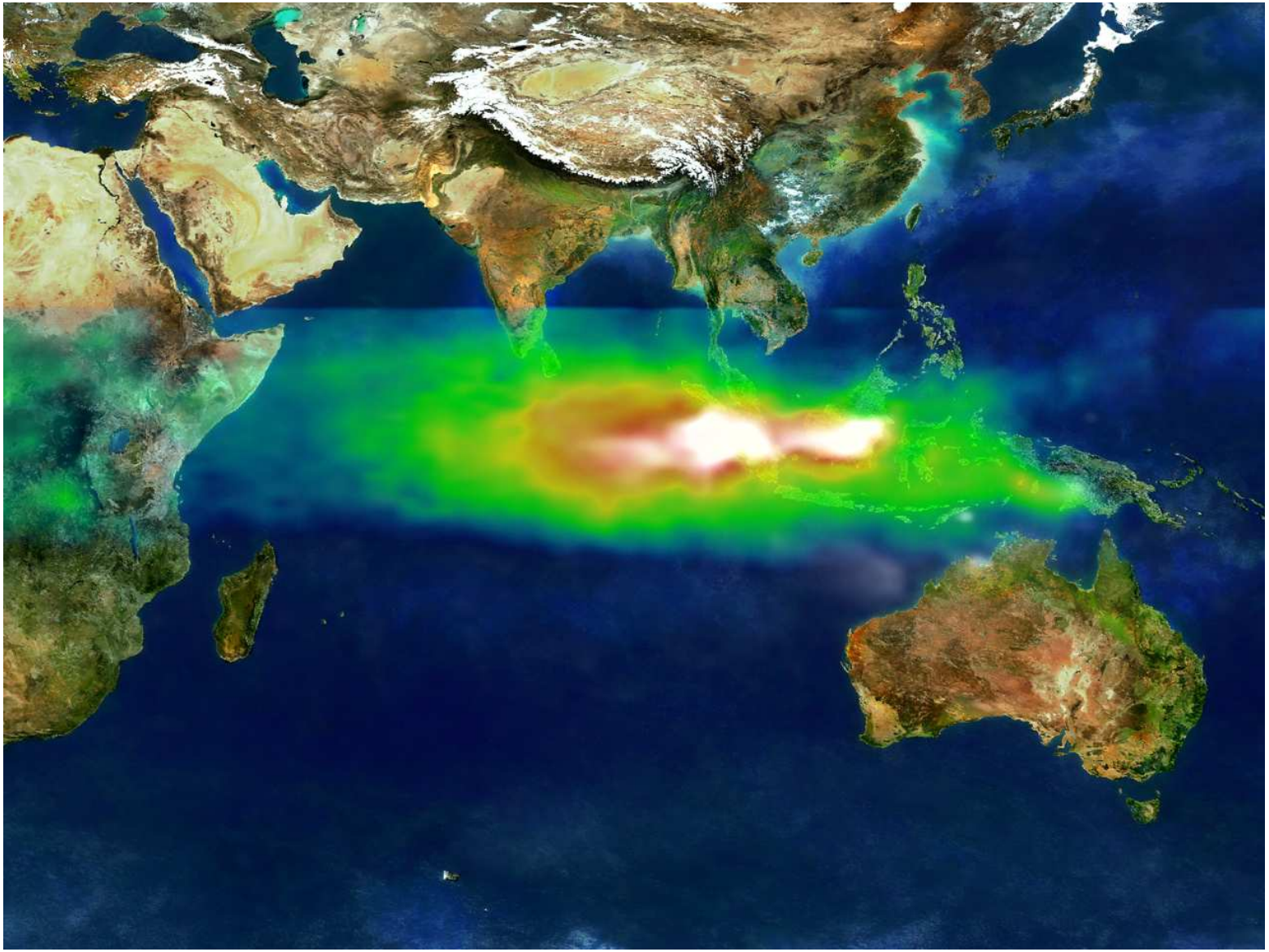
Source: Area of Indonesian oil palm plantations is from www.fao.org/forestry/index.jsp

Cumulative CO_2 from Indonesia Fires



Indonesian oil palm plantations in forest areas, J. GERMER and J. SAUERBORN, ED&S, 2007. North American CO_2 emissions from Oakridge

Global Impact of Indonesia Fires



NASA's Earth Probe Total Ozone Mapping Spectrometer (TOMS), October 22, 1997

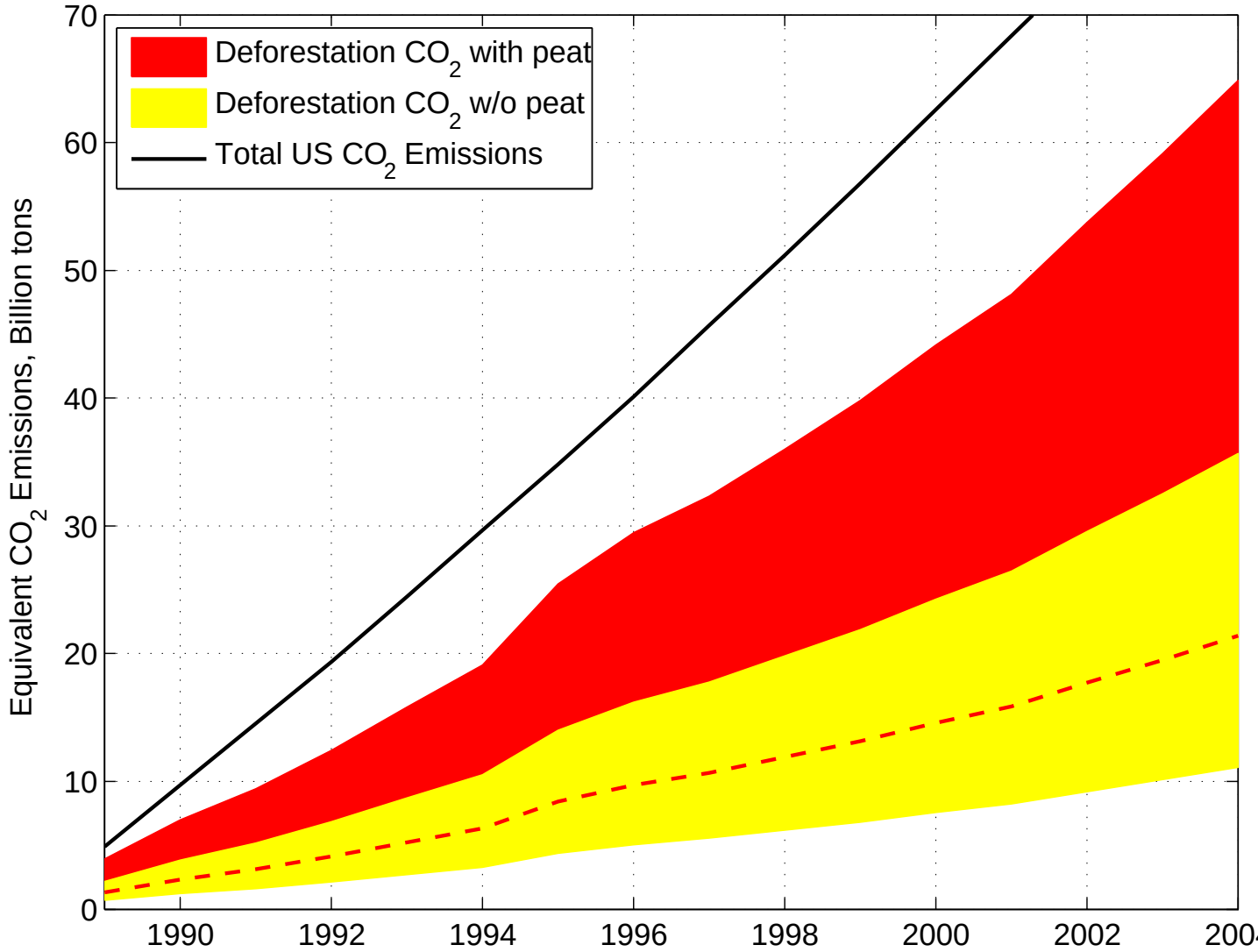
Amazon Deforestation

Source: Greenpeace: 4000 acres (Gleba do Pacoval area 60 miles SE of Santarem) illegally logged to clear land for soya plantations

Amazon Deforestation: Result

Source: Greenpeace: New soybean fields

Cumulative CO_2 from Amazon Fires



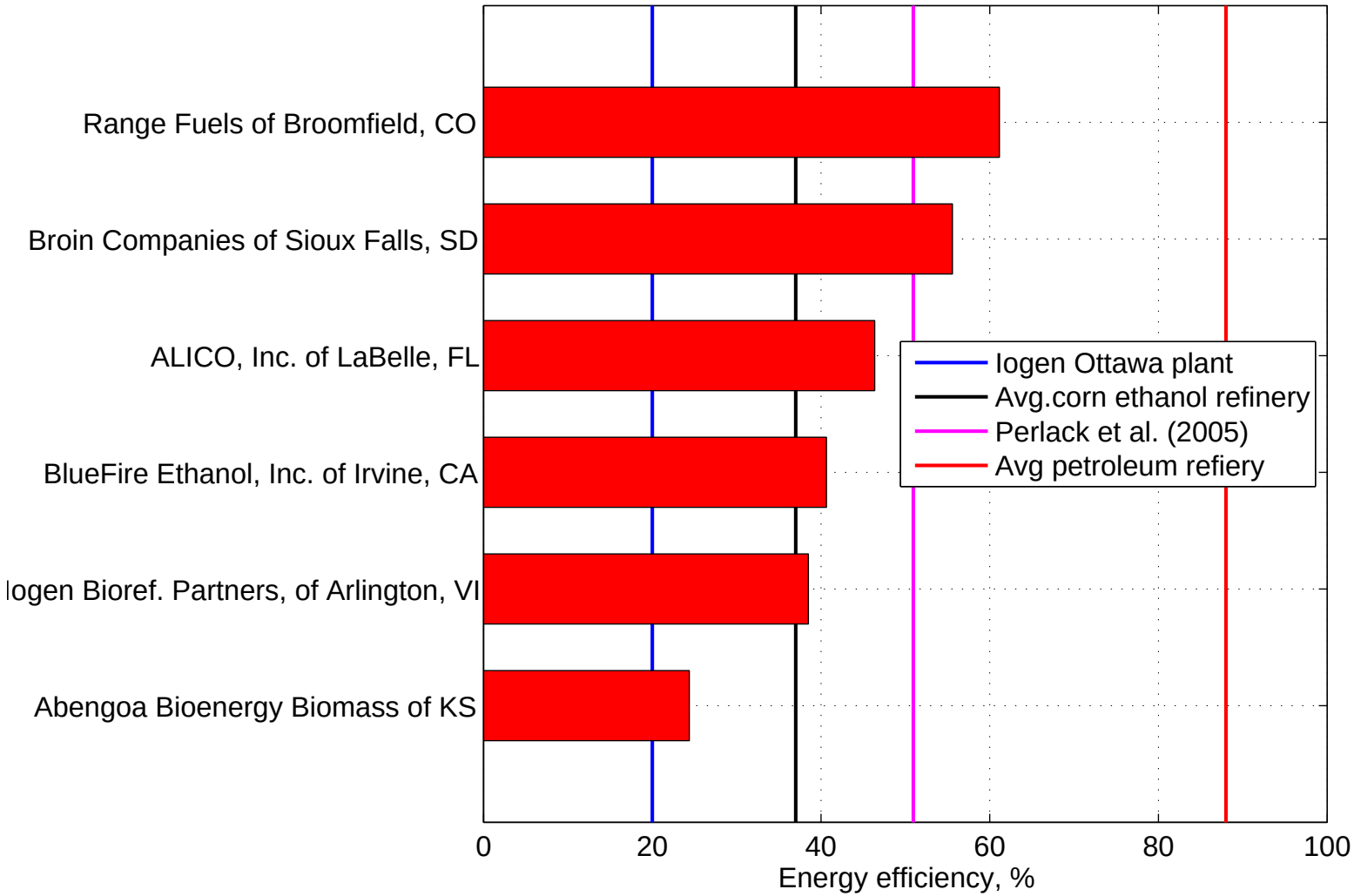
Sources: Brazilian National Institute for Space Research (INPE); ORNL; J. Germer and J. Sauerborn, ENVI102, Table 3

An Indefensible Proposition

Converting cellulosic biomass to ethanol involves a negative energy return - that is, the magnitude of energy required for biomass production and conversion is greater than the magnitude of energy displaced by the ethanol produced

- There is no scalable “cellulosic ethanol” technology, so there is no “energy return,” positive or negative
- Existing Iogen pilot plant is only 20%-efficient, very “negative”
- There are no large-scale “biowastes” or “biomass surplus” to make cellulosic ethanol

Cellulosic Ethanol Efficiency



Sources: Iogen, DOE, Patzek, 2007

Indefensible Assumptions

- Fossil fuels we use to produce anything are the only relevant limiting factor
- All other factors are limitless and irrelevant:
  - The Earth provides us with an infinite and instantaneous supply of pure air, fertile soil and clean water full of nutrients
  - She can regenerate all soil we destroy, and purify all water and air we pollute
  - Forever, she can feed 7–12 billion people, 1 billion cows, and all other non-human *living* consumers of plant and animal matter, . . .
  - . . . and – now – 1 billion cars and trucks (620 million produced since 1961)

A Defensible Proposition

- Every large ecosystem on Earth must approach a steady state characterized by zero net ecosystem productivity (NEP)
- When humans are not a natural part of an ecosystem, large-scale biomass harvesting by the humans leads to an eventual breakdown of that ecosystem
- Remedial actions (waste cleanup, erosion management, and applications of nutrients) are necessary to slow down – but never stop – the ecosystem deterioration
- All these actions require massive inputs of fossil energy and are unsustainable

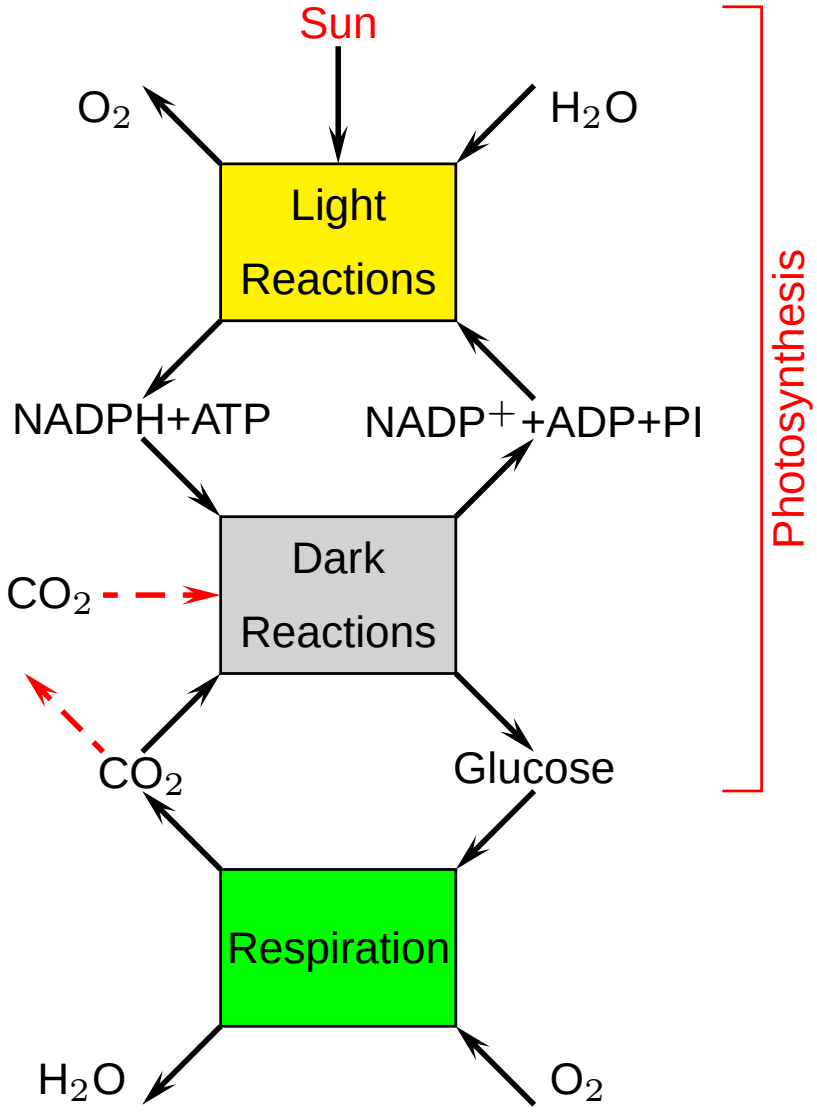
Background Terminology…

Ecosystems are characterized by:

- Gross Primary Production (*GPP*) = amount of CO_2 converted by plant photosynthesis to biomass
- Respiration = biomass plants, R_a, and animals, R_h, consume to live
- Net Primary Production, *NPP*

  $NPP = GPP - R_a$
- Net Ecosystem Production

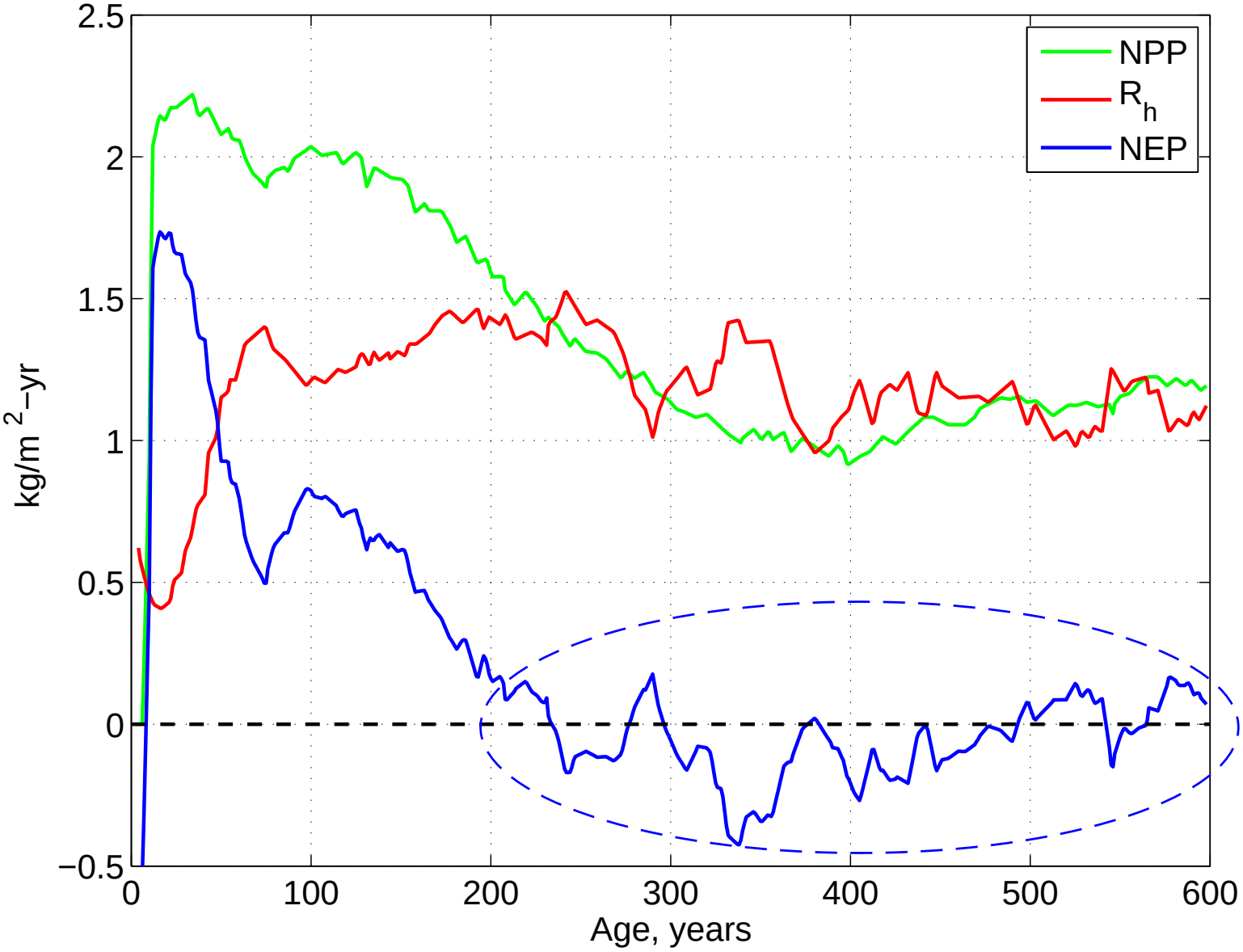
  $NEP = NPP - R_h - R_{\text{other}}$
- In natural ecosystems, $NEP \approx 0$
- Dry biomass$\times$HHV = Energy



Facts about Ecosystem Productivity

- Autotrophic respiration = $\sim$1/2 of photosynthesis (GPP)
- Heterotrophic respiration consumes up to 95% of the remainder
- On average, net ecosystem productivity (NEP) oscillates around zero
- Agricultural ecosystems must be heavily subsidized with ancient plant matter and minerals

Net Ecosystem Productivity $\rightarrow$ 0

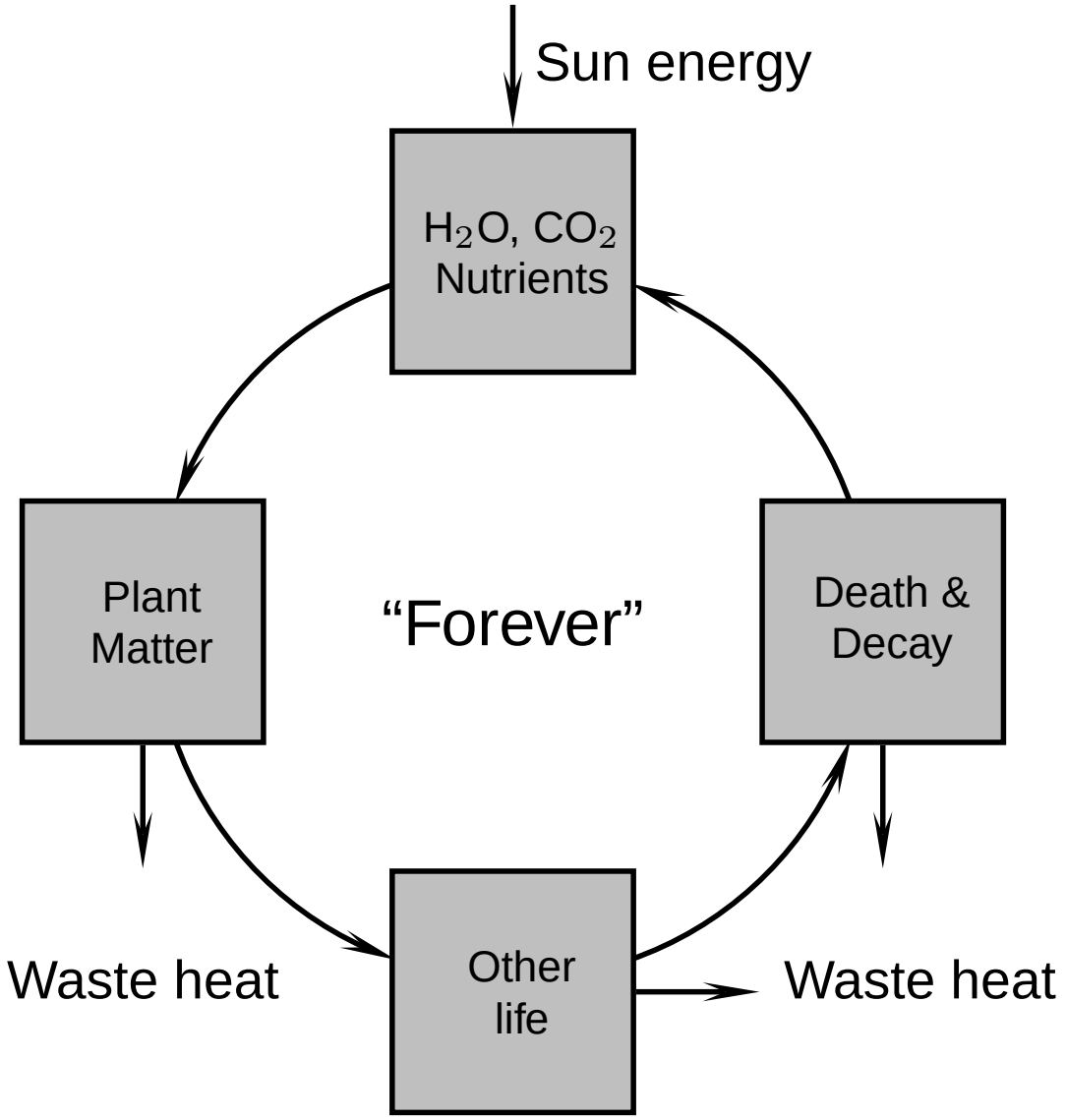


Source: SONGA & WOODCOCK (2003), simulation of H. J. Andrews Experimental Forest

Mass Stays on Earth, Heat Leaves

Source: Image Science & Analysis Laboratory, Johnson Space Center

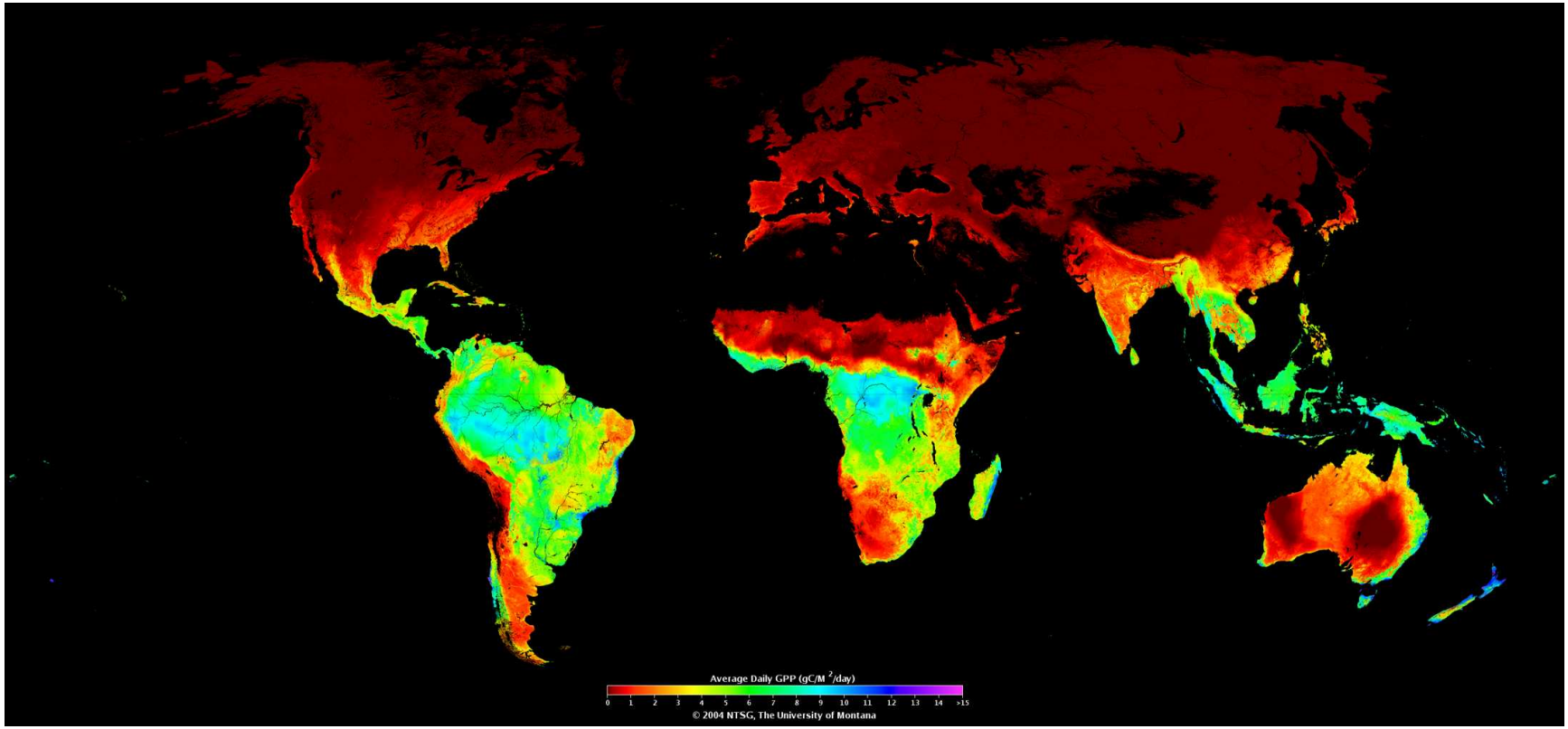
Ecological Cycles = No Waste!



Almost All Mass is Recycled. . .

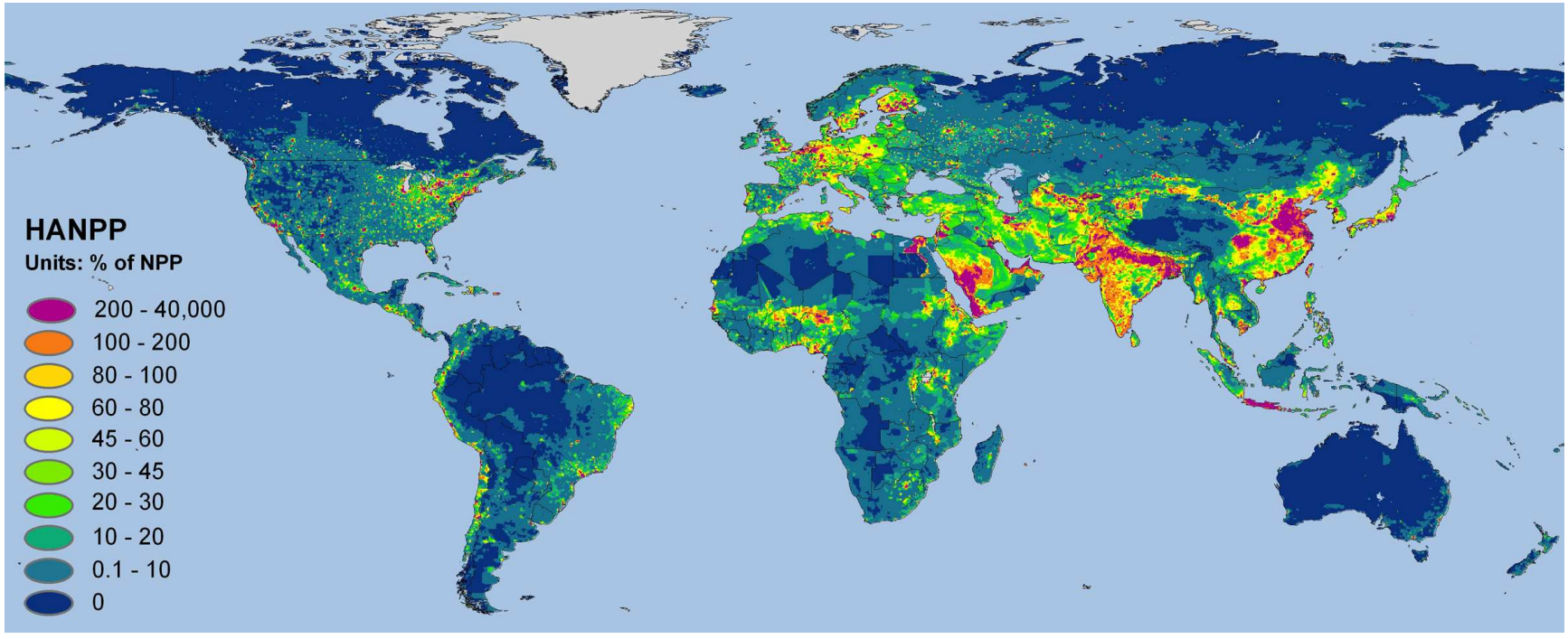
The recycling goes mostly above the ground

Global GPP and NPP are Known



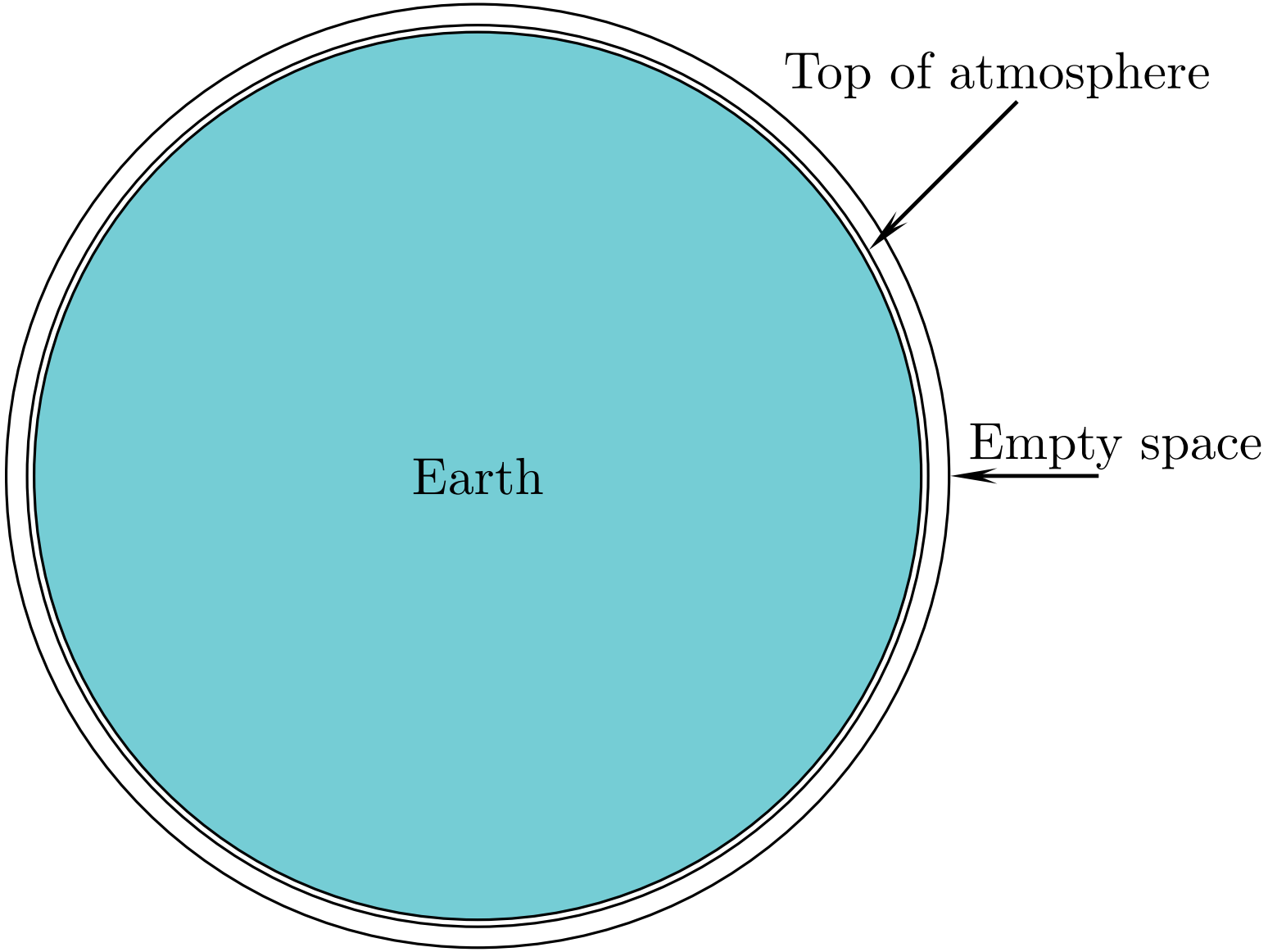
NASA produces a regular global estimate of gross primary productivity (GPP) and annual net primary productivity (NPP) of the entire terrestrial earth surface at 1-km spatial resolution, 150 million cells, each having GPP and NPP computed individually (MOD17A2/A3 User's Guide)
Image from Numerical Terradynamic Simulation Group, Missoula, Montana. Date: 12/27 – 12/31/2003

We Already Grab Most of NPP



Source: The Visible Earth, NASA images, 06-25-2004

Earth Has No Spare Capacity!



Drawn to Scale

An Indefensible Proposition

Ethanol produced from cellulosic biomass could make a large contribution to meeting mobility demand while honoring environmental and food production objectives

- As formulated this proposition contradicts a vast body of experimental and scientific evidence we have
- Mother Nature knows of no waste and has no spare capacity
- So-called “agricultural wastes” are our failure to close natural cycles, paid for with fossil fuels

Units in My Presentation. . .

- The fundamental unit of energy is 1 exa Joule (EJ)

1EJ = 1,000,000,000,000,000,000 J
is the amount of metabolized energy in food sufficient to sustain the entire U.S. population for one year @100 J/s-person = 100 W/person continuously

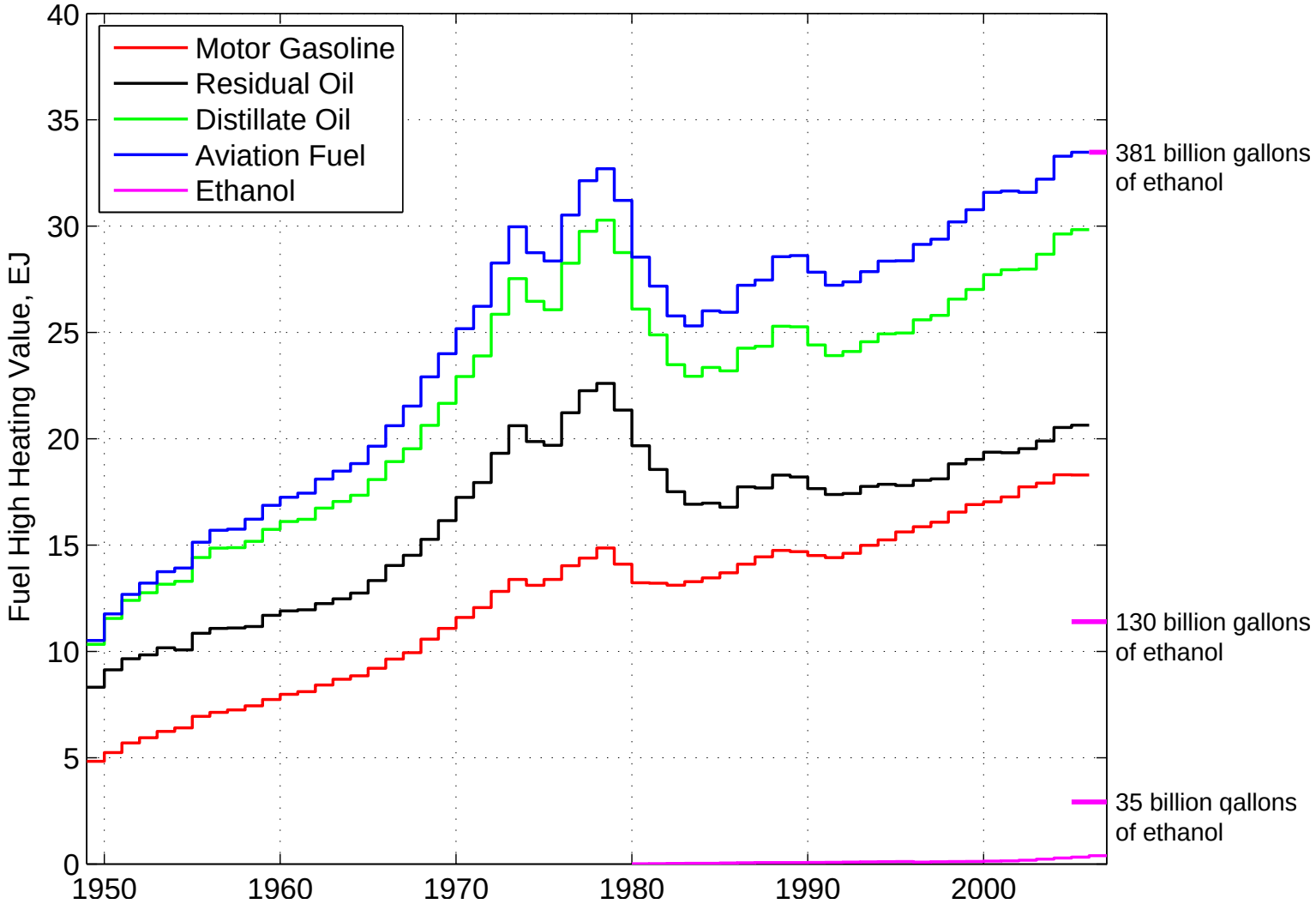
- Currently the U.S. uses 105 EJ/year; one hundred and five times more than we need to live
- If we were to metabolize this amount of energy, we would be 15 m long sperm whales, each weighing 40 tonnes. There are $\sim$360,000 sperm whales worldwide and 850 times more Americans

Homo Colossus Americanus…

1 Statistical American = 1 Sperm Whale

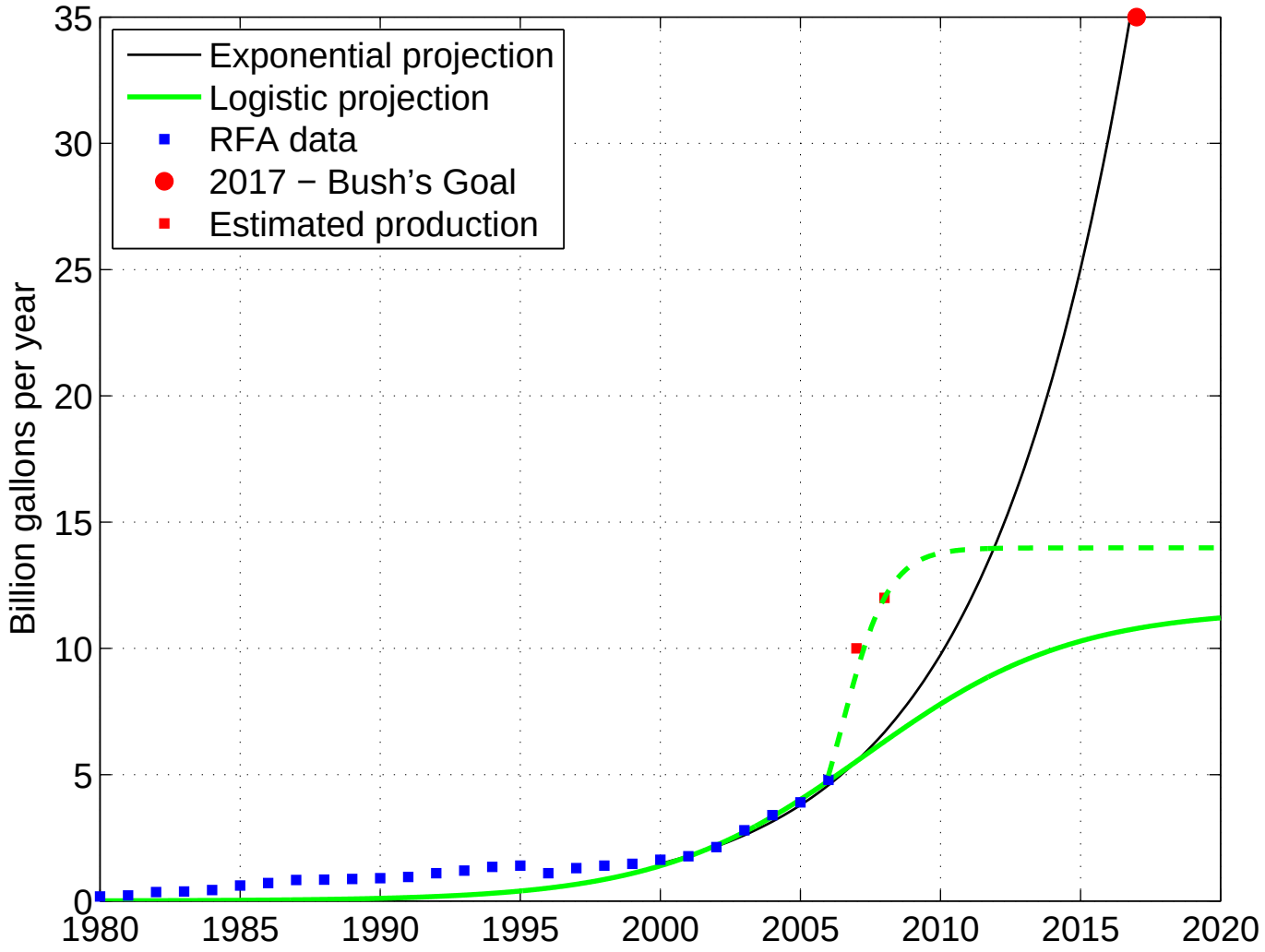
EUGENE ODUM, *Ecological Vignettes*, 1998

Transportation Fuels in US



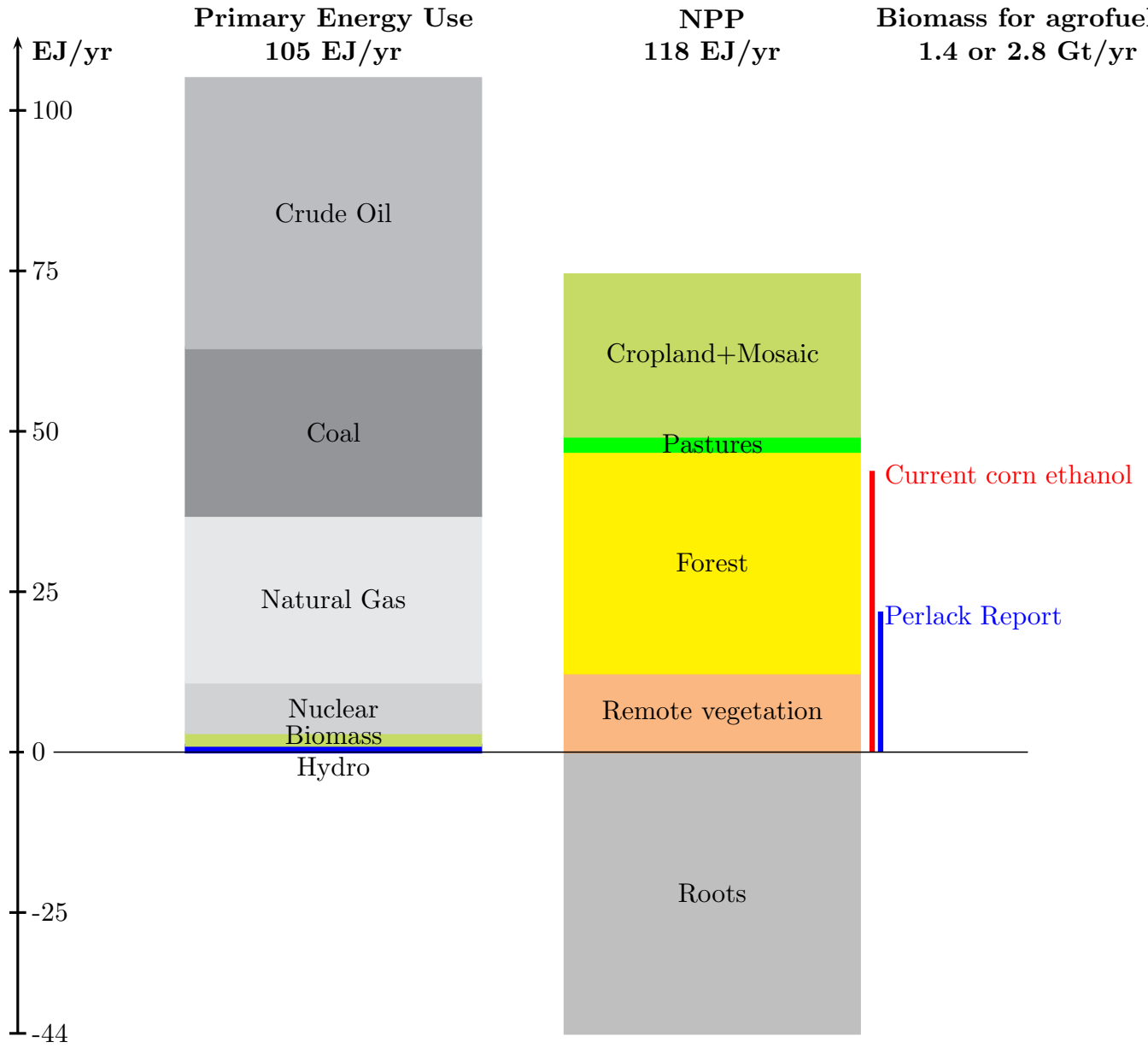
Sources: US DOE EIA, Patzek (2004)

35 Billion Gallons of Ethanol



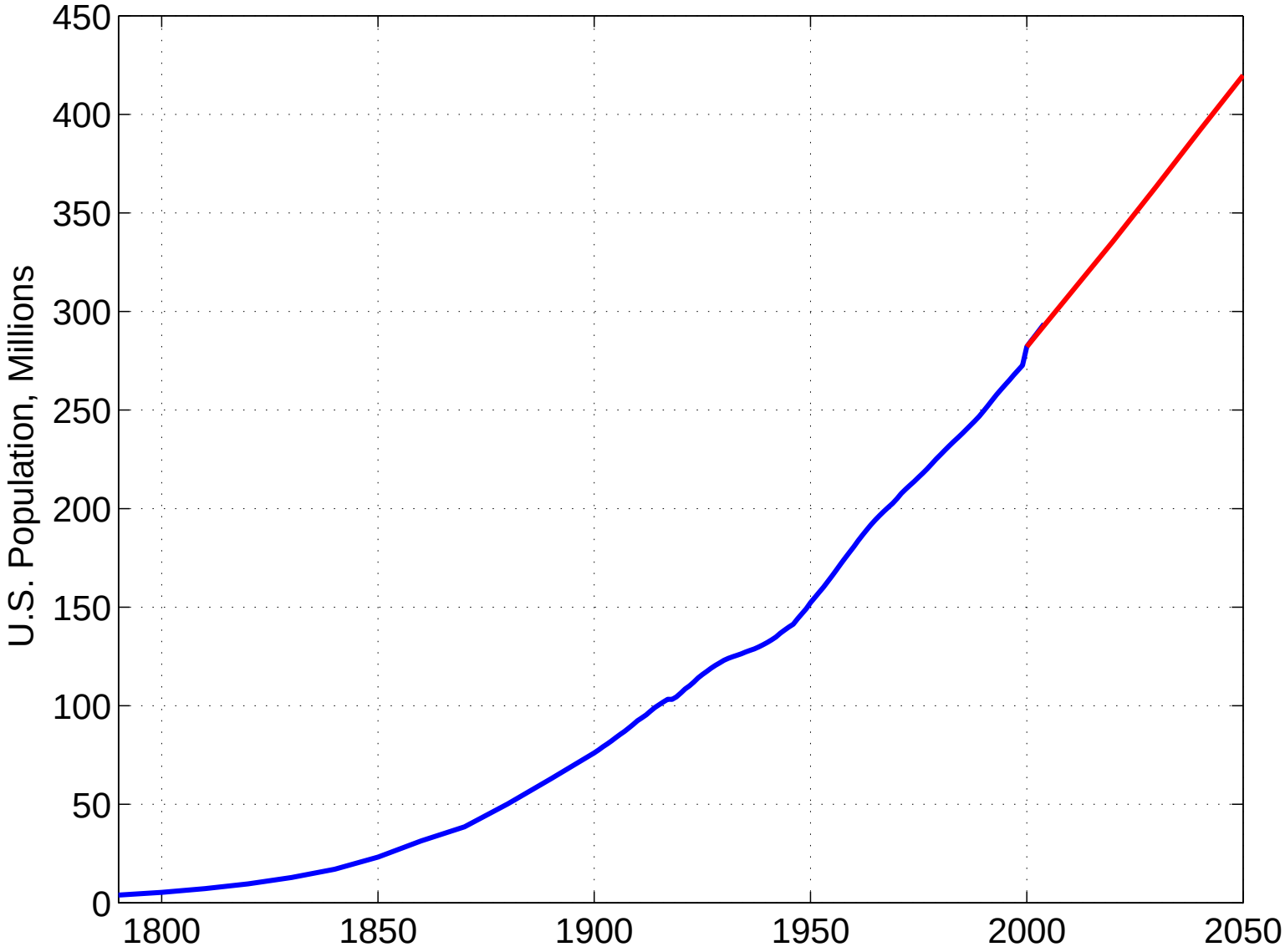
Sources: US DOE EIA, RFA, Patzek (2007)

130 Billion Gallons of Ethanol



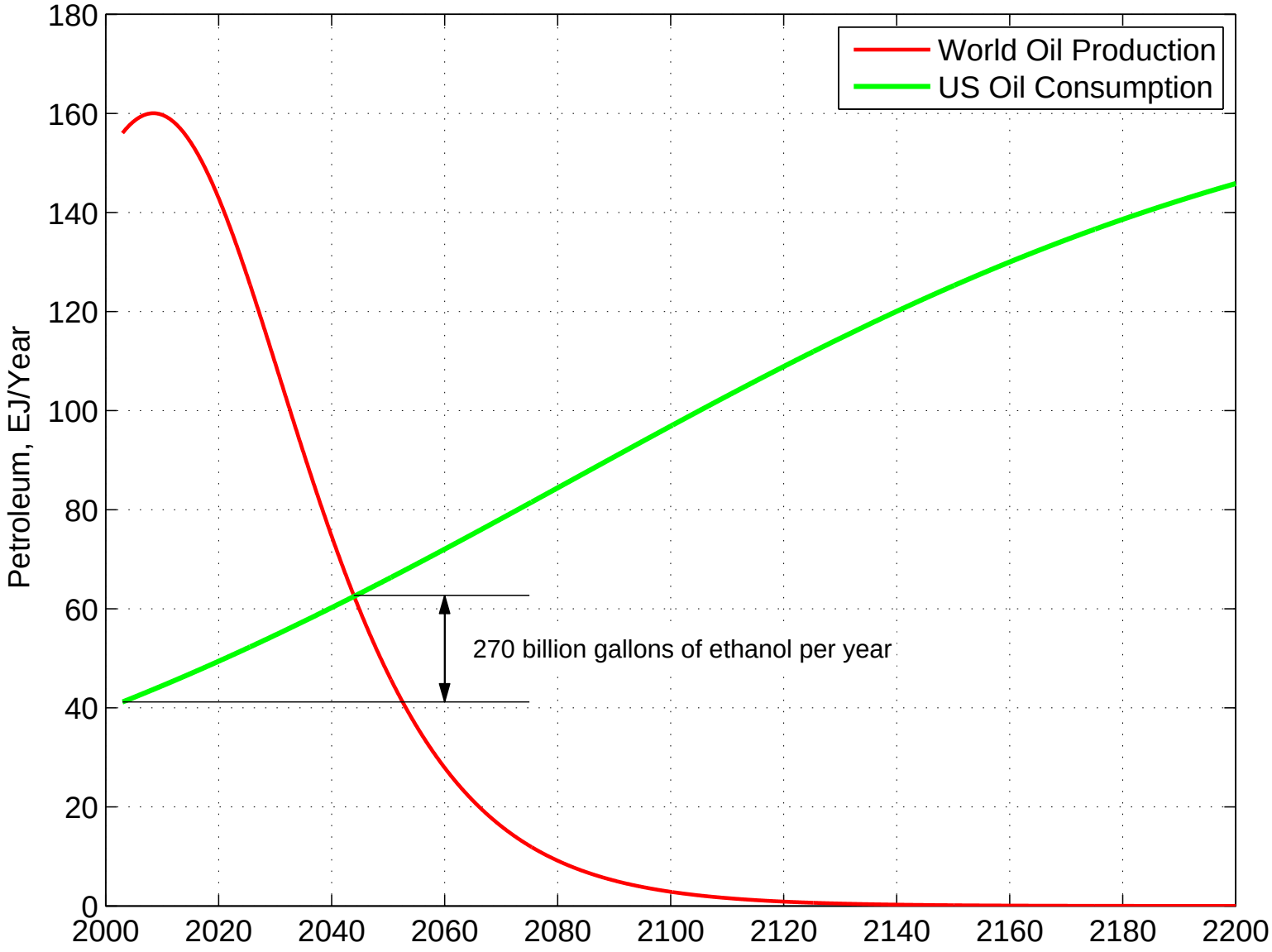
Sources: NASA MODIS; NTSG Missoula, Montana; Patzek, 2007

US Population Projections



Source: www.census.gov/popest/states/tables/NST-EST2004-01.xls

Projected US Energy Use

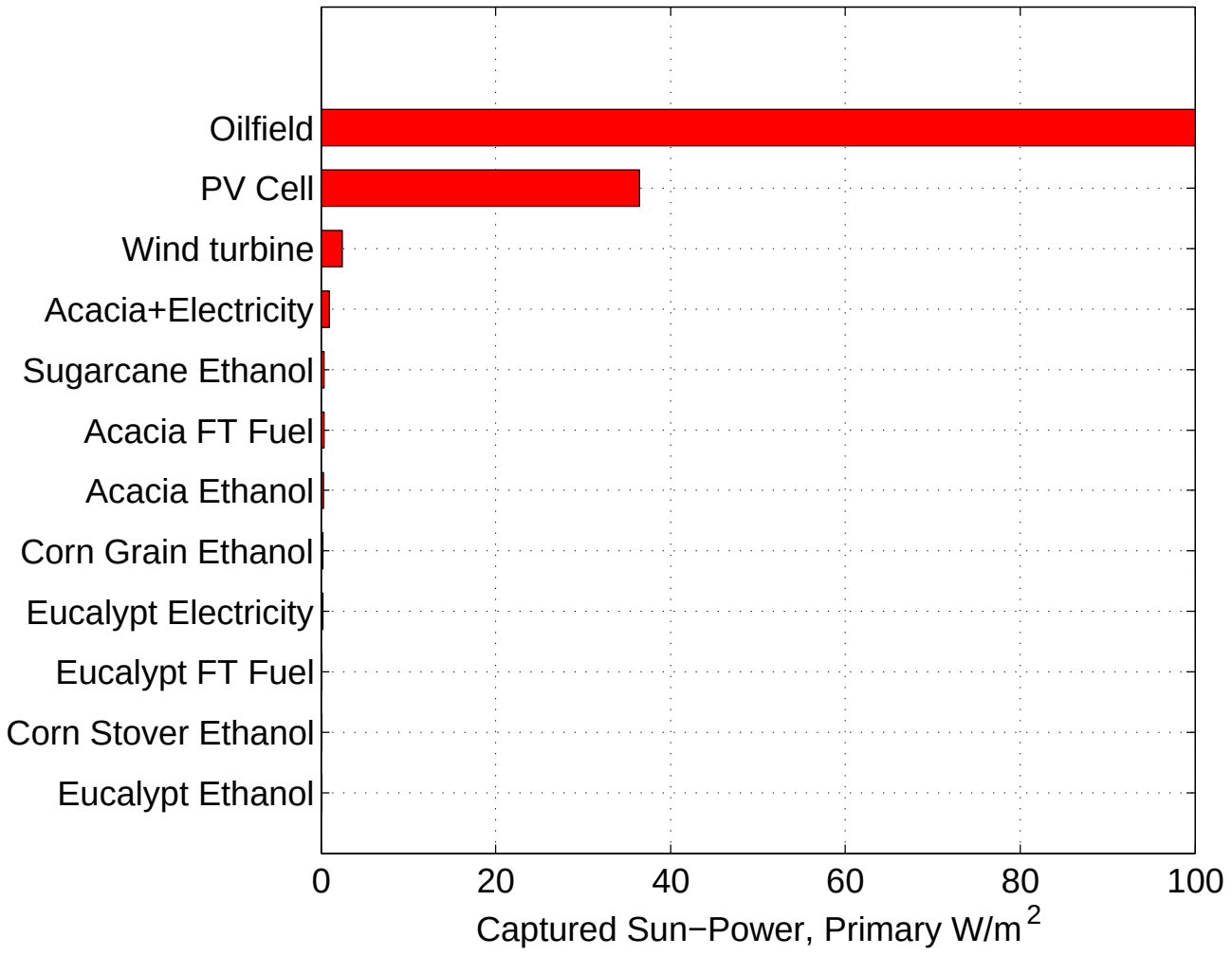


Capture of Solar Power…

Brief Explanation

Primary Power From the Sun. . .

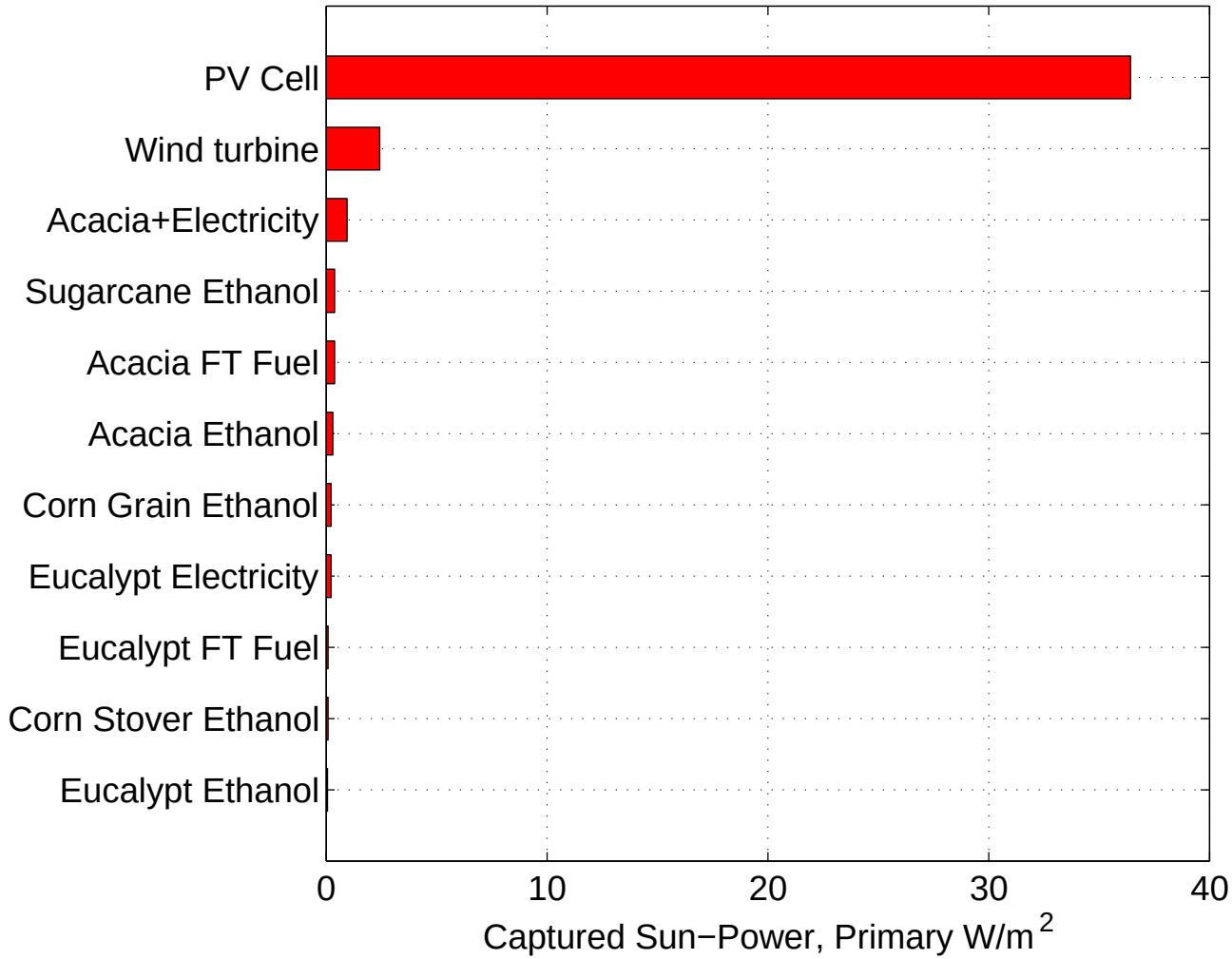
Oil field will be depleted in 30-100 years



Source: T. W. PATZEK & D. PIMENTEL, CRPS **23**(6), 2004, **24**(5-6), 2005

Exclude Oil. . .

Solar cells are up 70 - 630 times more efficient than biofuels



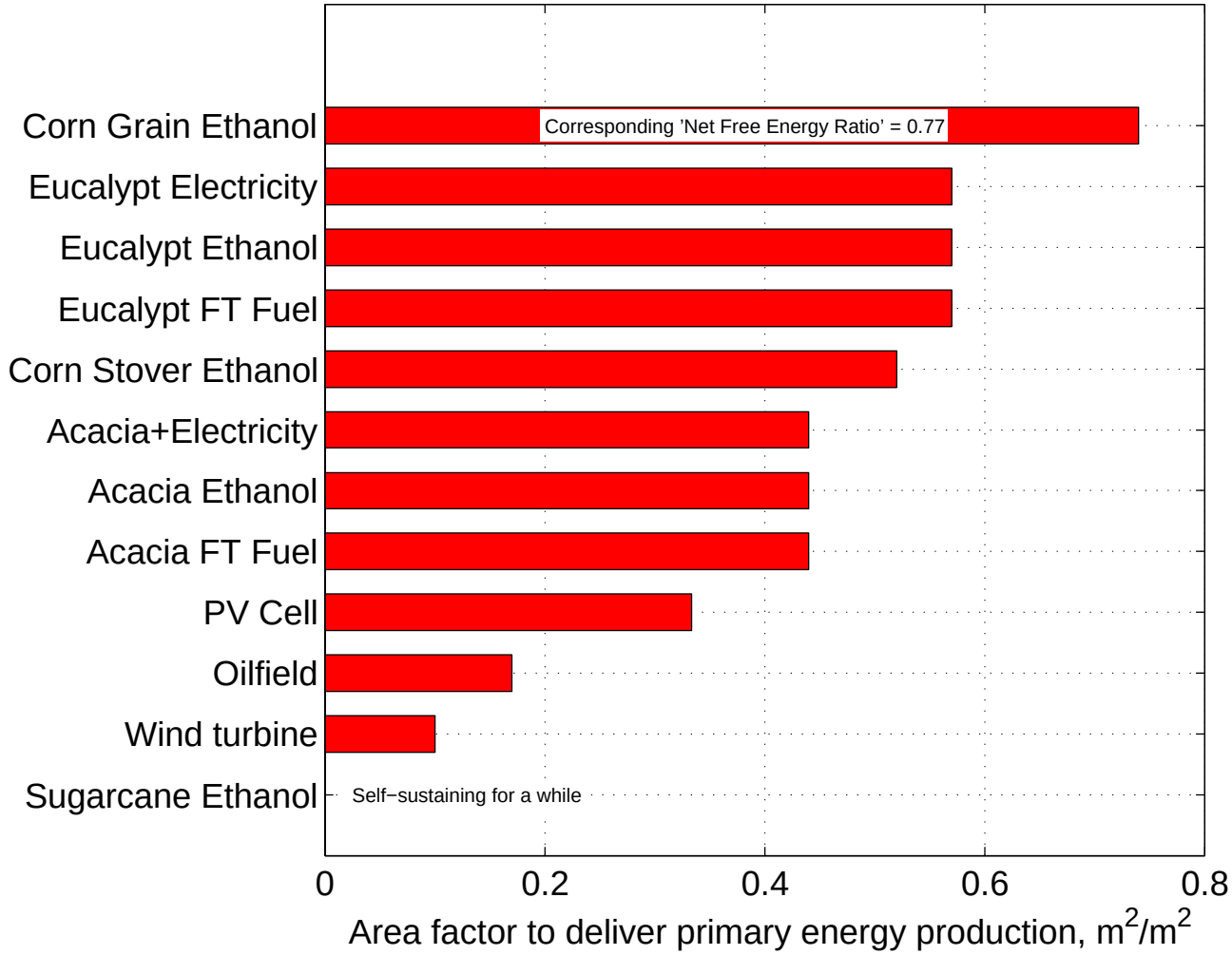
Source: T. W. PATZEK & D. PIMENTEL, CRPS **23**(6), 2004, **24**(5-6), 2005

Land Area to Drive a Car…

- Assume driving 15,000 miles/year @40 mpg in a Toyota Prius hybrid
- Alternatively, drive an all-electric car that is 2.5 times more efficient than the Prius
- Account for average energy costs of producing gasoline from crude oil (17%) and biofuels from biomass as in the slides above
- Assume energy costs of manufacturing and deploying PV panels and wind turbines, 33% and 10% of their 30-year production

Extra Area to Deliver Energy...

Additional Land Area Needed to Cover Energy Production Costs



Source: T. W. PATZEK & D. PIMENTEL, CRPS **23**(6), 2004, **24**(5-6), 2005

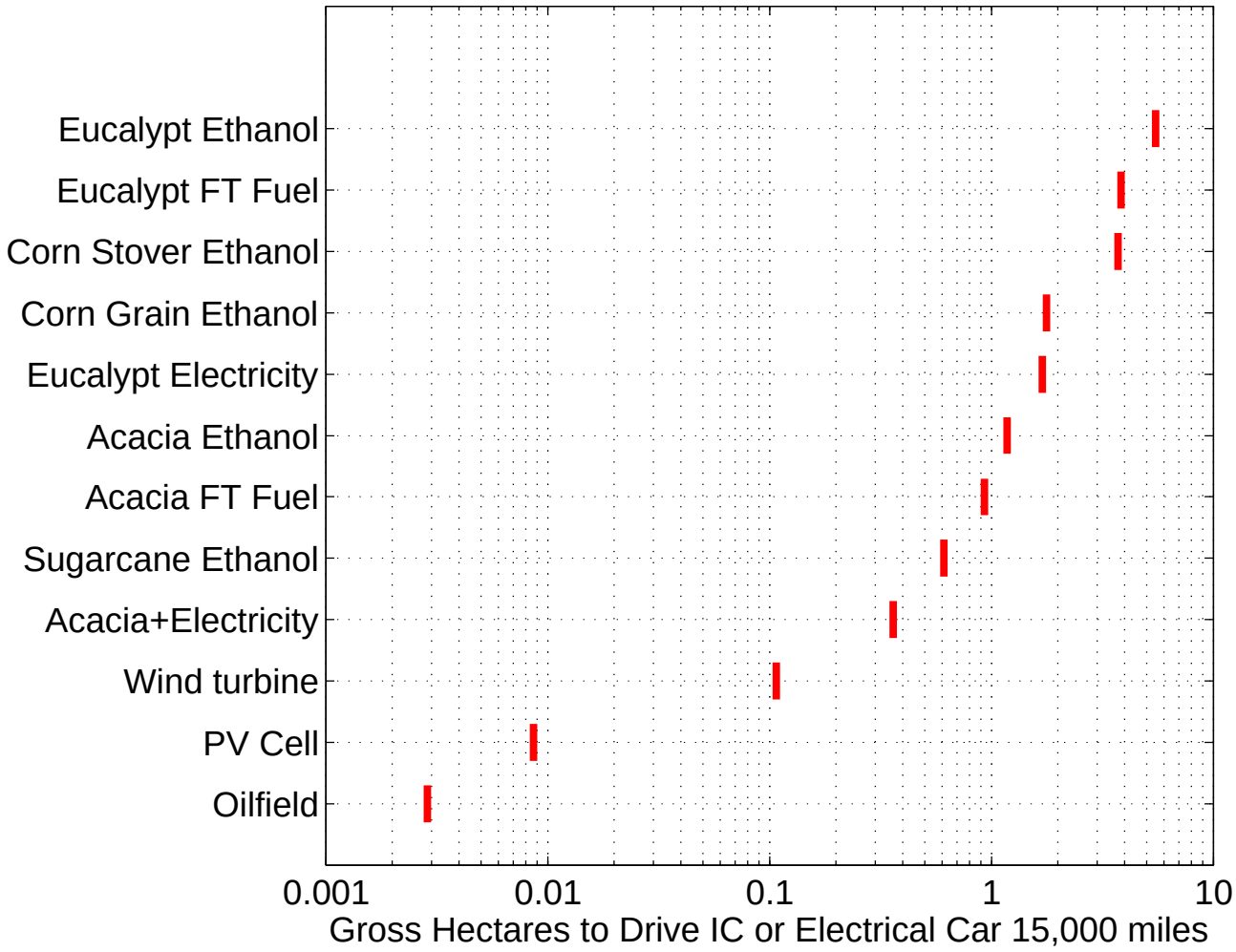
Areas Relative to Oilfield...

Oil field area to drive the Prius is 330 square feet (30 m^2)

Technology	Net Ratio	Gross Ratio
Oilfield	1.0	1.0
PV Cell	2.7	3.0
Wind turbine	40	37
Acacia+Electricity	102	125
Sugarcane Ethanol	250	214
Acacia FT Fuel	263	324
Acacia Ethanol	333	410
Eucalypt Electricity	417	593
Corn Grain Ethanol	442	620
Corn Stover Ethanol	1000	1299
Eucalypt FT Fuel	1000	1342
Eucalypt Ethanol	1429	1917

Gross Acres to Drive a Car…

Solar cells and 85%-efficient electrical car are clear winners



Source: T. W. PATZEK & D. PIMENTEL, CRPS **23**(6), 2004, **24**(5-6), 2005

Conclusions

Thirty million hectares (75 million acres) covered with:

Corn = 16 million Priuses from grain + 8 million Priuses from stover – for a while

Sugarcane = 47 million Priuses – for a while

Solar cells = 3000 million electric cars

Wind turbines = 270 million electric cars

We need to invest is solar cell and electricity storage technologies, *not* in biofuels