A Brief Tour of the Global Energy System

Prof. Robert Kopp

Rutgers SEBS Honors Seminar
February 29, 2012

Questions We'll Address:

- What is energy?
- What do we (as individuals, as a nation, as a planetary civilization) use energy for?
- What are the proximate sources of the energy we use?
- What are the ultimate sources of the energy we use? How does the human energy system fit into the natural energy system?
- How has human energy use changed over history?
- Is the present energy system sustainable? What are the major risks associated with it?
- What alternatives are there to the present energy system? What are the barriers to energy system transformation?
- What sorts of policies can overcome these barriers?

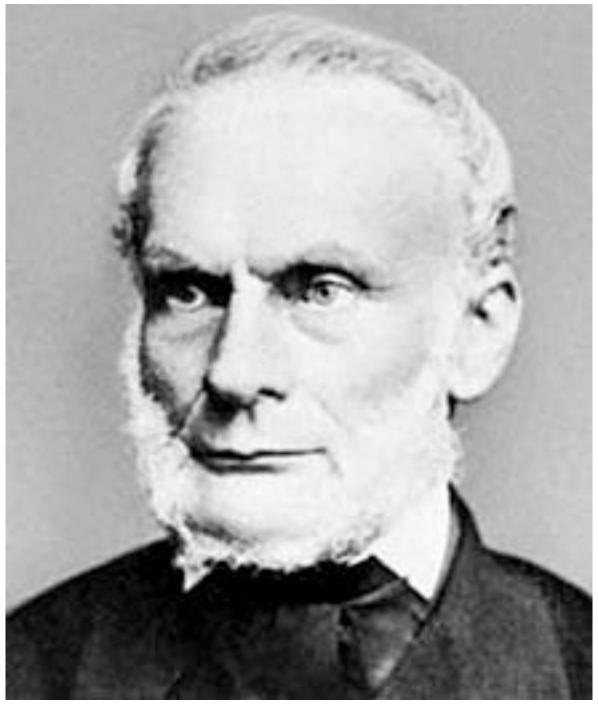
What is energy?

Turn to a partner, and come up with a definition of energy (in a physical sense) and 2-3 examples.

First Law of Thermodynamics

In a thermodynamic process, the increment in the internal energy of a system is equal to the difference between the increment of heat accumulated by the system and the increment of work done by it.

–Rudolf Clausius, 1850



Wikipedia

Equivalently: The work required to change the state of an otherwise isolated system depends solely upon the initial and final states involved and is independent of the method used to accomplish this change.

i.e.: The energy of any isolated system is constant.

Energy conversions

to \ from	**electro-magnetic**	**chemical**	**thermal**	**kinetic**	**electrical**	**nuclear**	**gravitational**
electro-magnetic		chemi- lu	thermal radiation	accelerating charge phosphor	electro-magnetic radiation electro- ence	gamma reactions nuclear bombs	
chemical	photo-synthesis photo-chemistry	chemical processing	boiling dissociation	dissociation by radiolysis	electrolysis	radiation catalysis ionization	
thermal	solar absorption	combustion	heat exchange	friction	resistance heating	fission fusion	
kinetic	radiometers	metabolism muscles	thermal expansion internal combustion	gears	electric motors electro-strictions	radioactivity nuclear bombs	falling objects
electrical	solar cells photo-electricity	fuel cells batteries	thermo-electricity thermionics	conventional generators		nuclear batteries	
nuclear	gama-neutron reactions						
gravitational				rising objects			

Smil, 2008

Energy conversions

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electro-magnetic		chemi- lu	thermal radiation	accelerating charge phosphor	electro-magnetic radiation electro- ence	gamma reactions nuclear bombs	
							falling objects
nuclear	gama-neutron reactions						
gravitational				rising objects			

Note that the First Law means that energy cannot be "consumed." Nonetheless, one frequently does talk about energy "consumption." Why?

Smil, 2008

Second Law of Thermodynamics

Clausius: *No process is possible whose sole result is the transfer of heat from a colder to a hotter body.*

Kelvin: *No process is possible in which the sole result is the absorption of heat from a reservoir and its complete conversion into work.*

Note that, classically, temperature is related to kinetic energy by

$$\frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_BT$$

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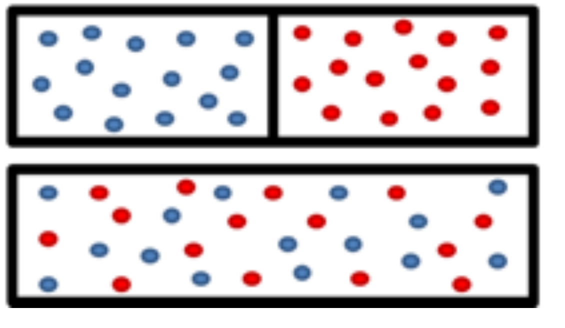
Equivalently: **In a closed system, entropy does not decrease.**

where entropy is defined as



$$S = -k_b \sum_i P_i \ln P_i$$

and *i* represents the different possible microstates of a system.

Second Law of Thermodynamics

Clausius: *No process is possible whose sole result is the* *transfer* …

Kelvin: … *lt is* *the abs*… *lete* *convers*…

Give an example of a system in a low entropy state and the same system in a high entropy state.

Equivalently: **In a closed system, entropy does not decrease.**

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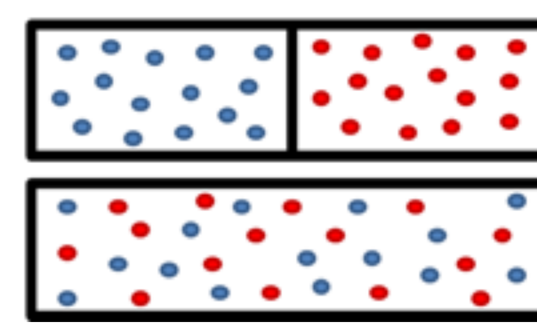
$$S = -k_b \sum_i P_i \ln P_i$$



and *i* represents the different possible microstates of a system.

Second Law of Thermodynamics

Exergy can be expressed as $B = E - TS$. Energy E is conserved, but entropy S increases, so B decreases.

So when we say "energy is consumed," what we really mean is **exergy** is consumed. Exergy has the same units as energy, but counts only energy associated with low-entropy states, which can be recovered to do work.

We're going to be sloppy and ignore this most of the time, by convention.

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sole result is
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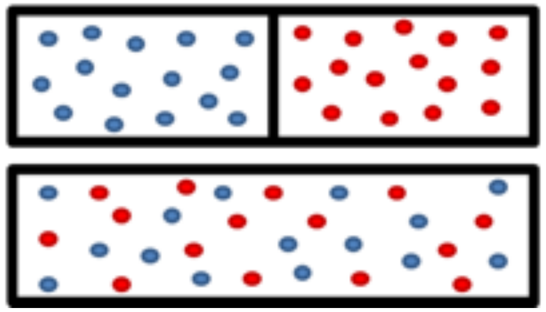
not decrease.



es of a system.

Key Units

Energy:

- 1 **Joule** = 1 kg m^2/s^2 (equal to the kinetic energy of 2 kg moving at 1 m/s)

Power:

- 1 **Watt** = 1 J/s

Energy:

- 1 **Watt•hour** = 1 Watt applied for 1 hour = 3600 J (so a 100 W lightbulb running for 1 hour uses 100 Wh energy)

A reminder on SI prefixes

- milli (m) = 10^{-3}
- kilo (k) = 10^{3}
- mega (M) = 10^{6}
- giga (G) = 10^{9}
- tera (T) = 10^{12}
- peta (P) = 10^{15}
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World annual primary exergy consumption = 474 EJ =132,000 TWh

World annual final exergy demand = 325 EJ = 91,000 TWh

Civilizational primary power supply =15 TW

Annual CO_2 emissions = 32 Gt CO_2 = 32 Pg CO_2

You may also encounter (with apologies)

Energy:

- 1 **calorie** = 4.184 J, the energy required to heat 1 g of water by 1°C [note that 1 food Calorie = 1 kcal]
- 1 **British Thermal Unit (BTU)** = energy required to heat 1 pound (454 g) of water by 1°F (0.56°C) = 252 cal = 1.055 kJ
- 1 **Quad** = 1 quadrillion BTU = 1.055 EJ (~293 TWh)
- 1 **tonne oil equivalent (toe)** = 41.9 GJ = 11.6 MWh

Key Electrical Units

Current:

- The **Ampere** (A) is a fundamental unit of the SI system; it is practically defined as the flow of 1 coulomb (C) of charge/second.

Electrical potential:

- 1 **Volt** (V) = 1 W/A = 1 J/C – so 1 A flowing down a 1 V potential gradient will acquire 1 J of energy per second

Resistance:

- The **Ohm** (Ω) is defined as 1 V/A. Power dissipated into heat is given by voltage x current or by current^2 x resistance

So: on a 120 V circuit (as in the U.S.), a 1,000 W device (e.g., a microwave) will draw a current of 8.3 A.

What do we use energy for?

Where does our energy come from?

In groups, share your personal energy consumption and create a list of the energy sources/fuels that are employed to fill this demand.

Then send a representative to the board to record the energy consumption of each of your group members.

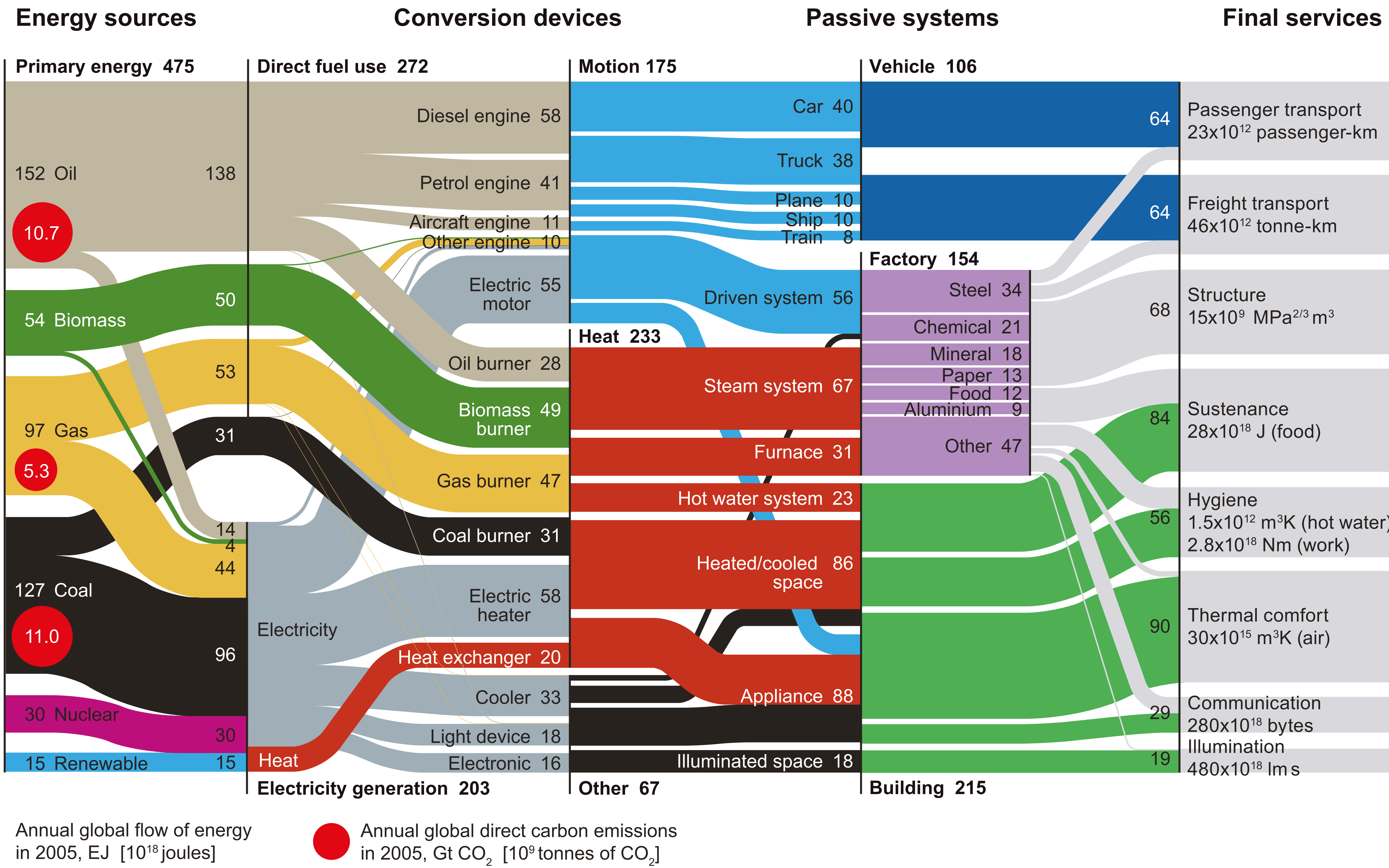


Fig. 2. From fuel to service: tracing the global flow of energy through society.

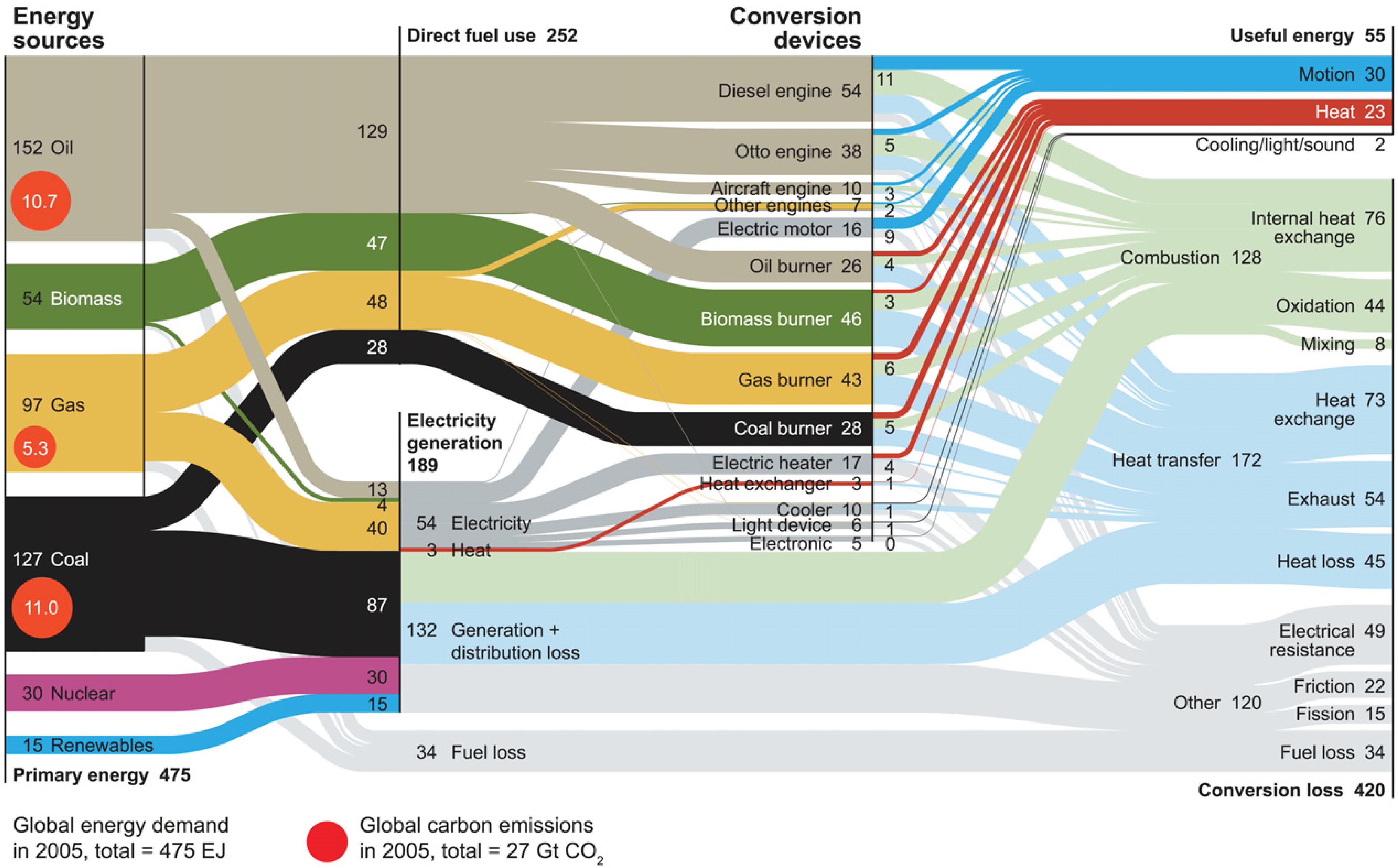
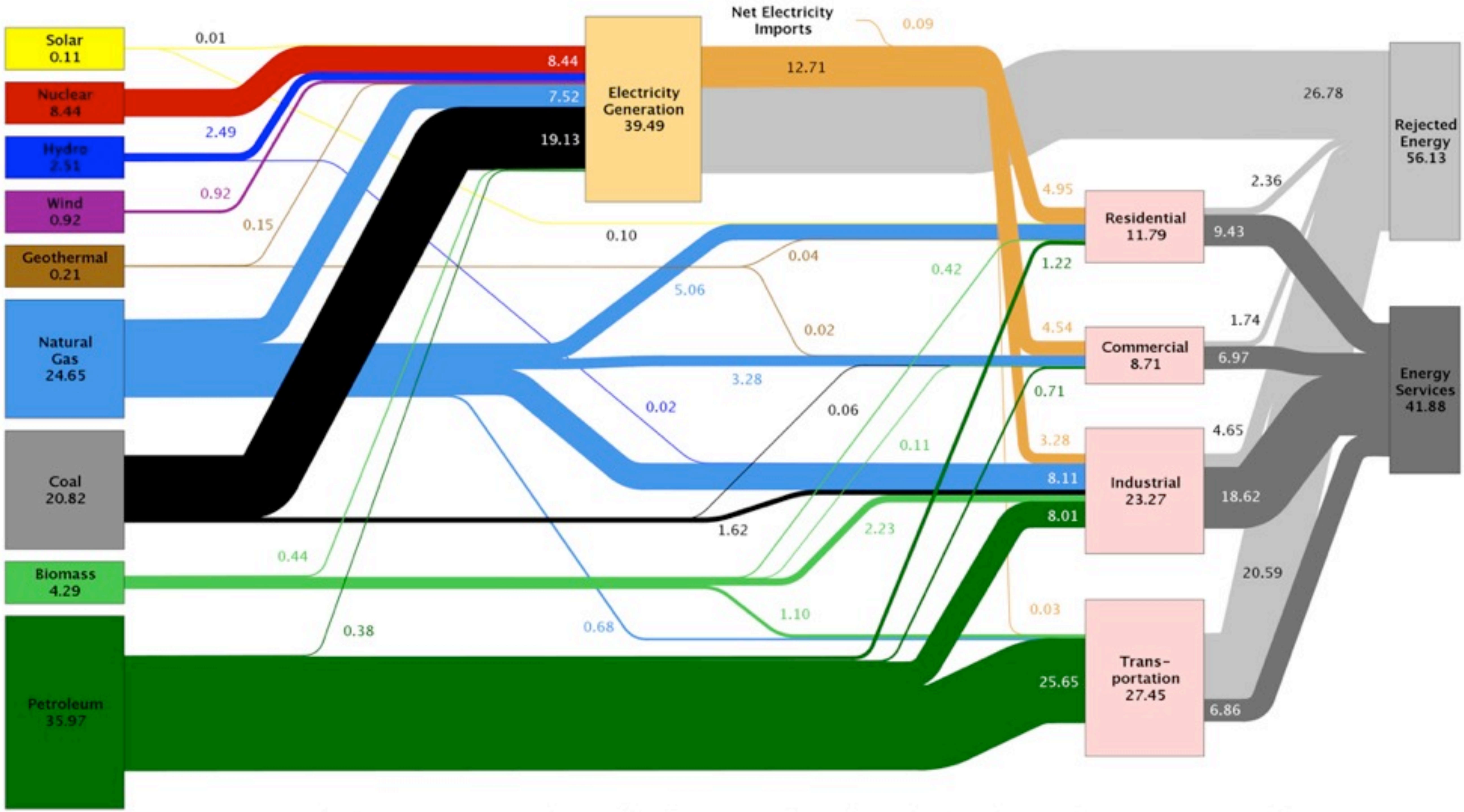


Fig. 3. The global map of energy conversion efficiency.

Estimated U.S. Energy Use in 2010: ~98.0 Quads

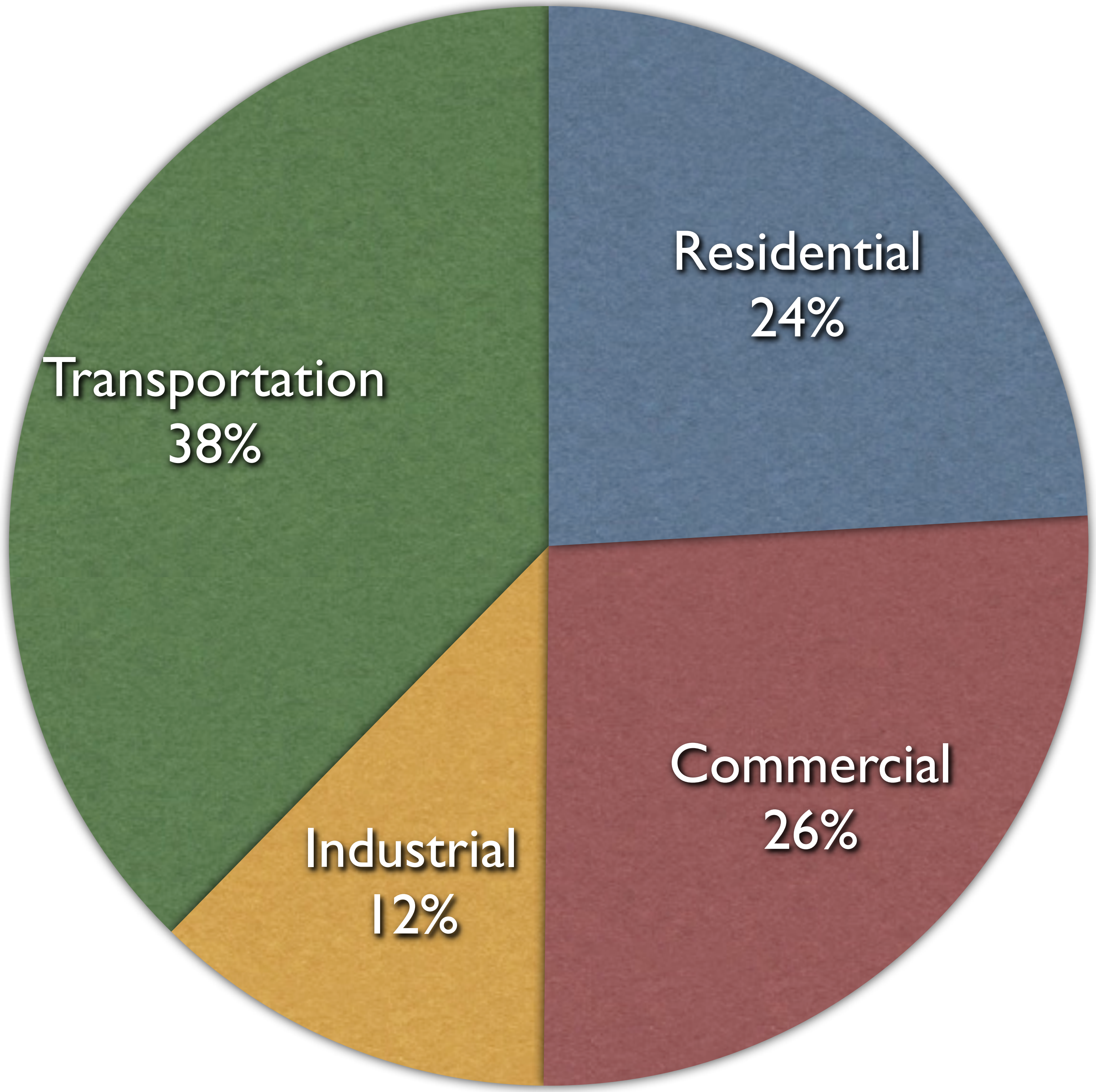
Lawrence Livermore National Laboratory



Source: LLNL 2011. Data is based on DOE/EIA-0384(2010), October 2011. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for hydro, wind, solar and geothermal in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." (see EIA report for explanation of change to geothermal in 2010). The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

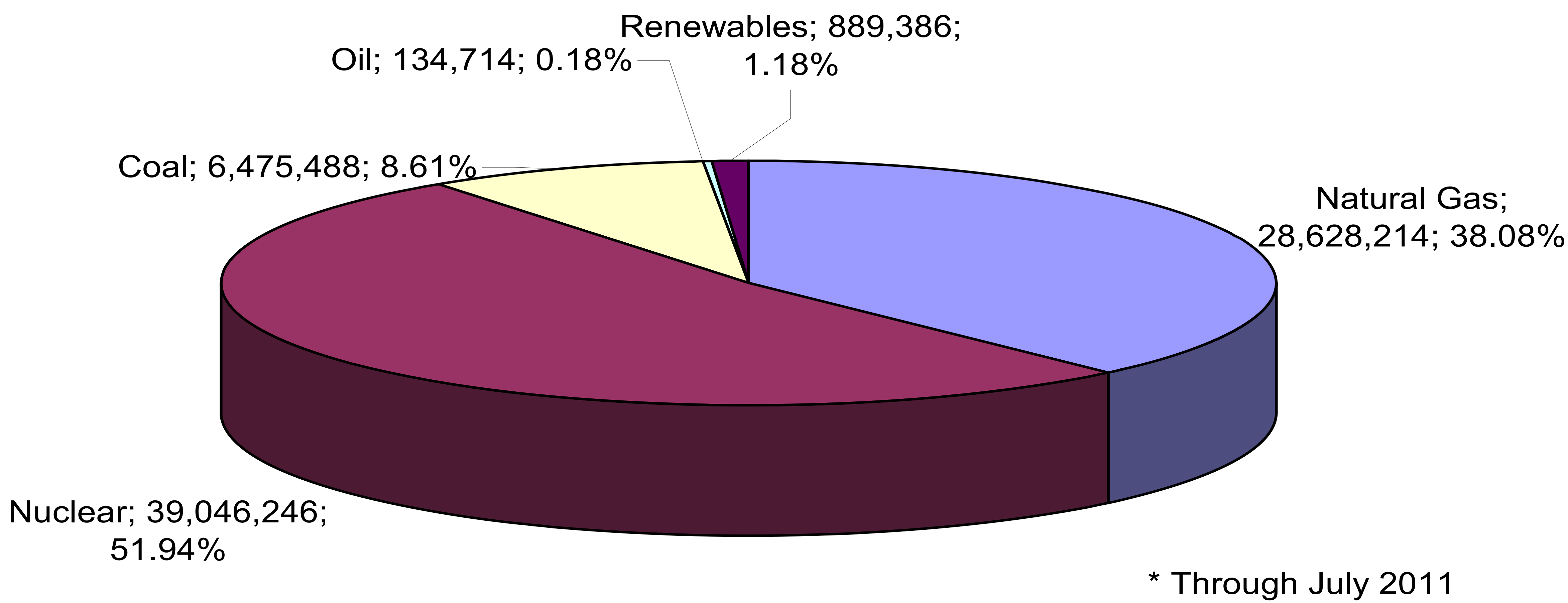
New Jersey Primary Energy Consumption in 2009

(Total = 701 TWh; 80,000 kWh/person)



Data from EIA

Figure 13. 2011 New Jersey Energy Generation by Fuel Type (MWh and %)



Where does our energy come from?

What physical processes led to the formation of the proximal energy sources we use today?

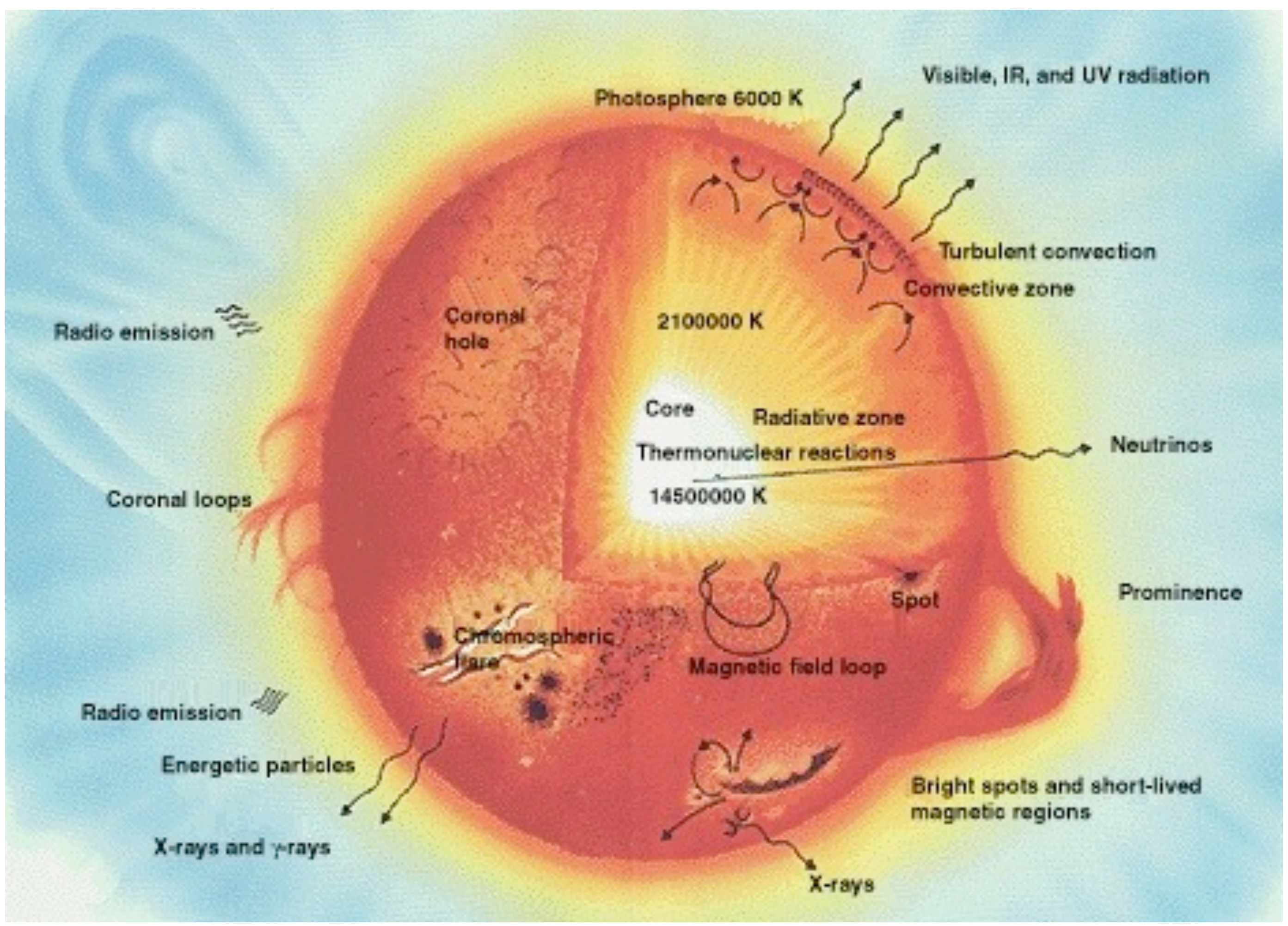
Each group will be assigned some energy sources. Briefly discuss where these sources came from, over the 4.6 billion year history of the solar system, then return to discuss with the class.

1. Solar
2. Wind
3. Hydro
4. Nuclear
5. Geothermal
6. Biomass
7. Coal, Natural Gas, and Petroleum

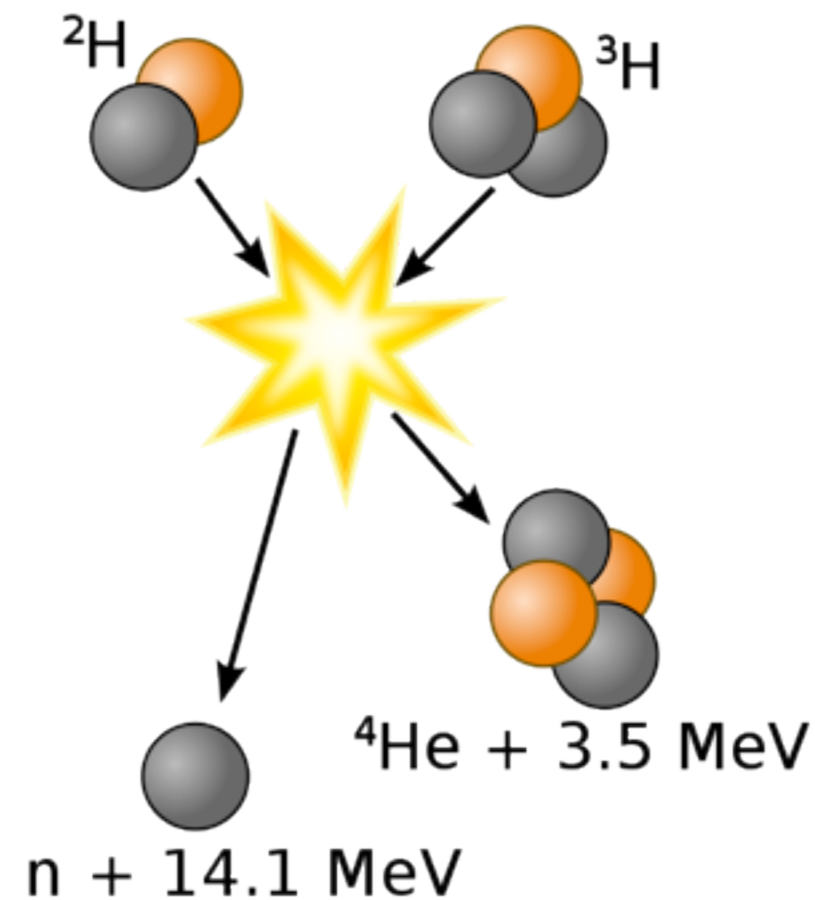
Solar Energy Flux

~1,360 W/m^2 (cross-section at Earth's orbit)
~174,000 TW total to Earth

- Conversion of nuclear energy (nuclear fusion)



Wikipedia



Energy balance of the Earth

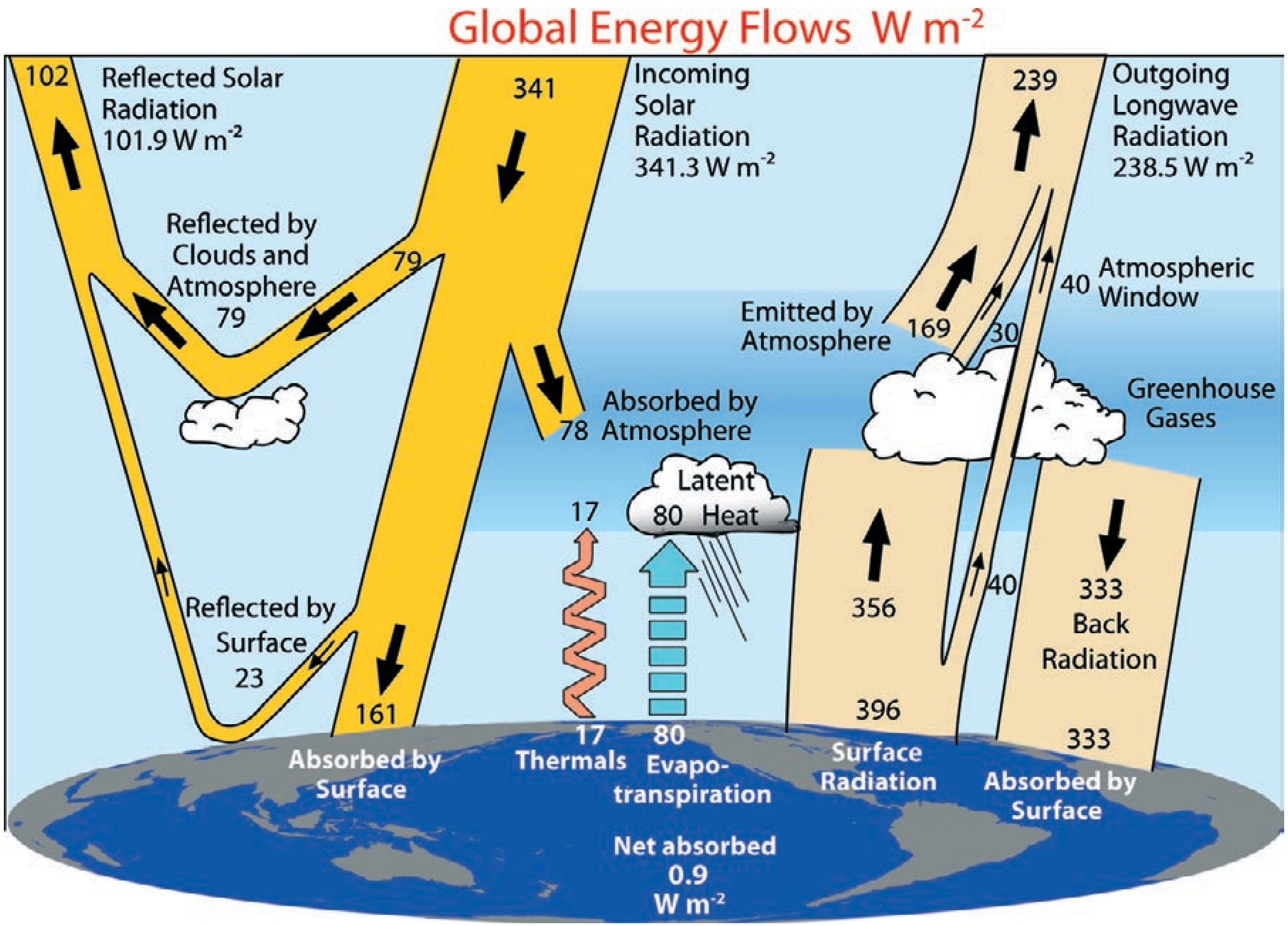


FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.

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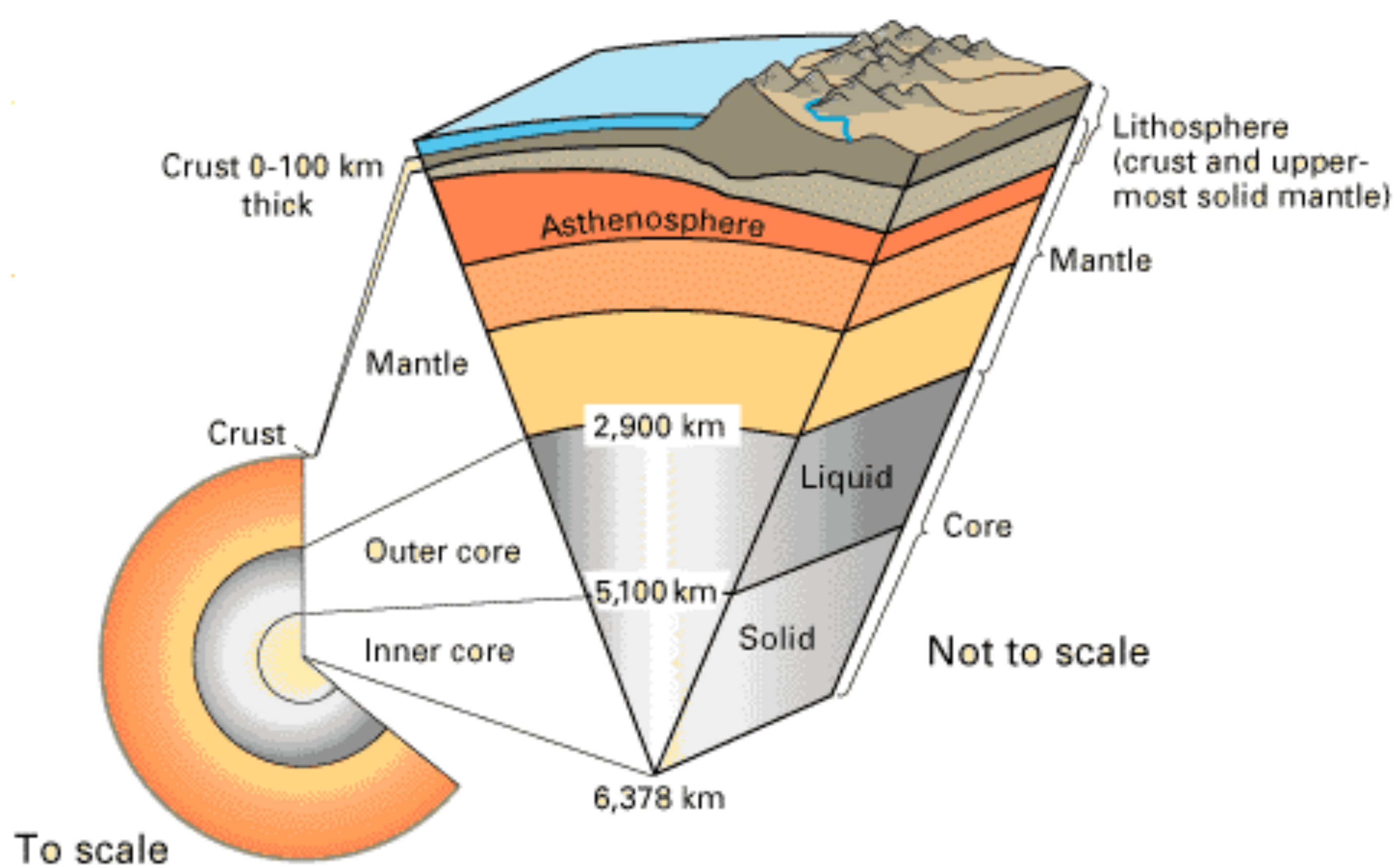
Trenberth et al., 2009

Geothermal Energy Flux

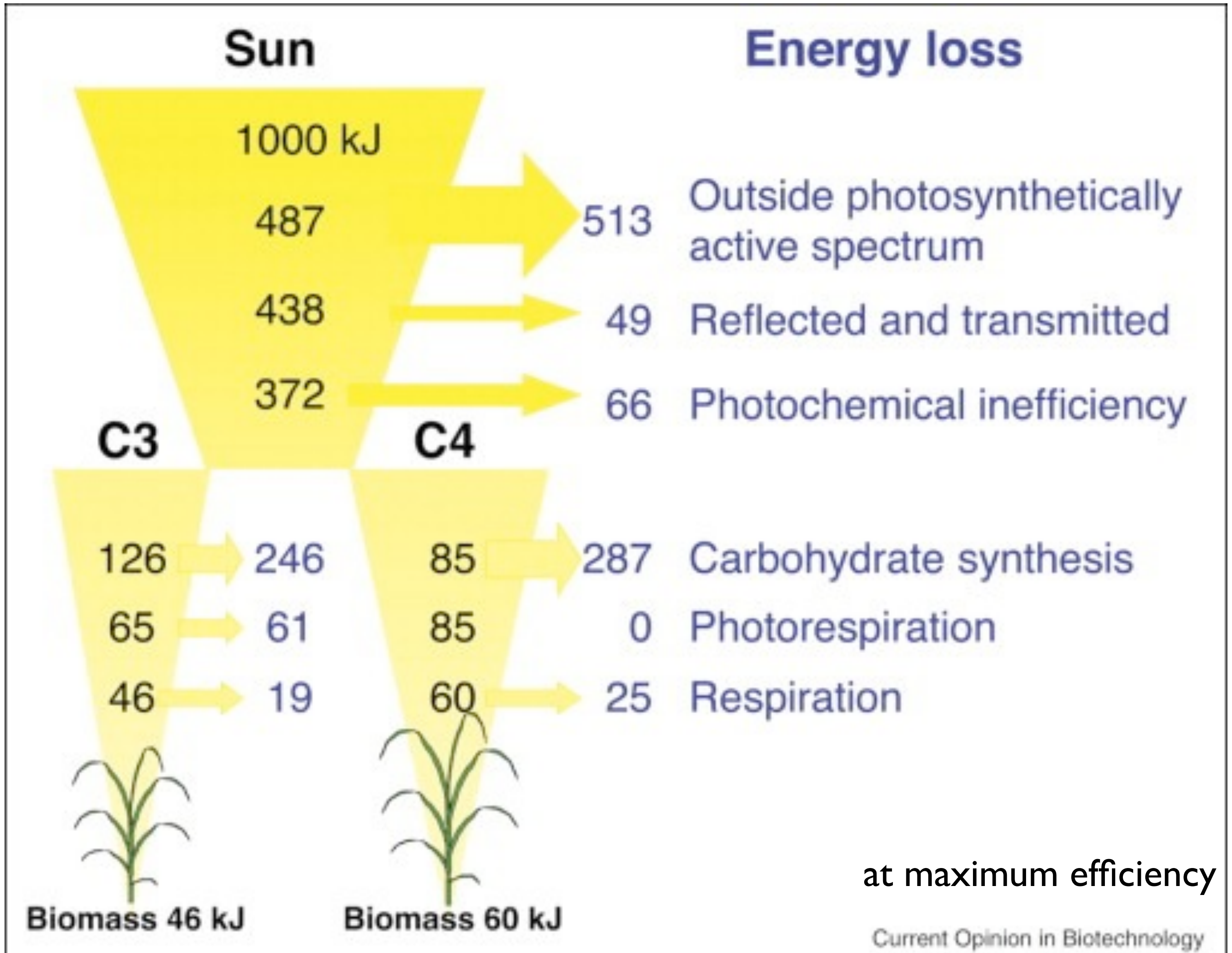
~65 mW/m^2 over continents
~100 mW/m^2 over oceans
44 TW total

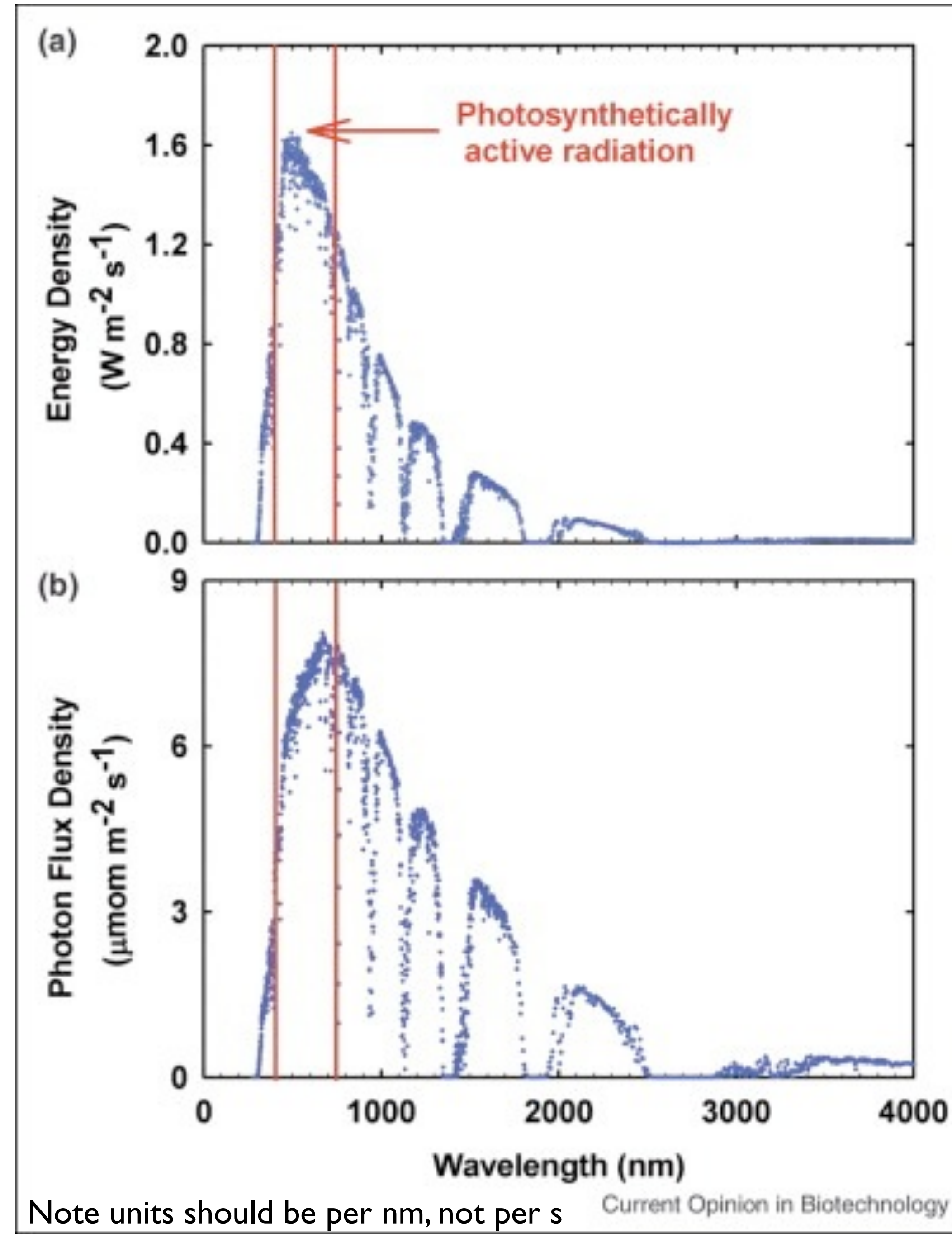


Wikipedia

- Conversion of gravitational energy (planetary accretion and differentiation)
- Conversion of nuclear energy (fission of radioactive nuclides)

Energy balance of photosynthesis





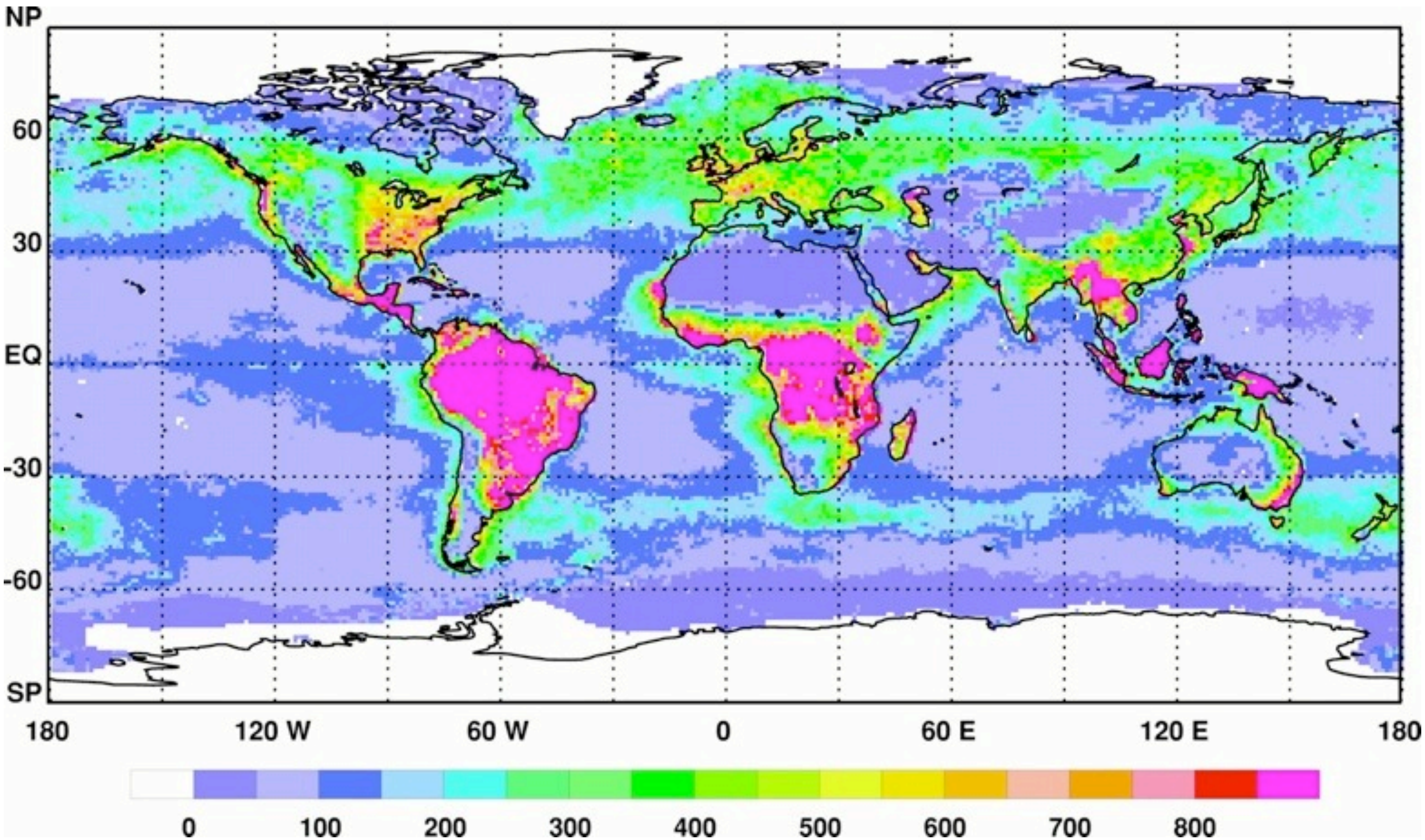
~4 kWh/kg biomass energy density

~2 kWh/kg C

Zhu et al., 2008

Global annual net primary productivity ($g\ C/m^2/y$) for the biosphere

Total = 105 Pg C/yr (~200,000 TWh/yr = ~23 TW),
of which ~0.1% is buried for the long term,
of which ~0.05% will turn into fossil fuels (very roughly)

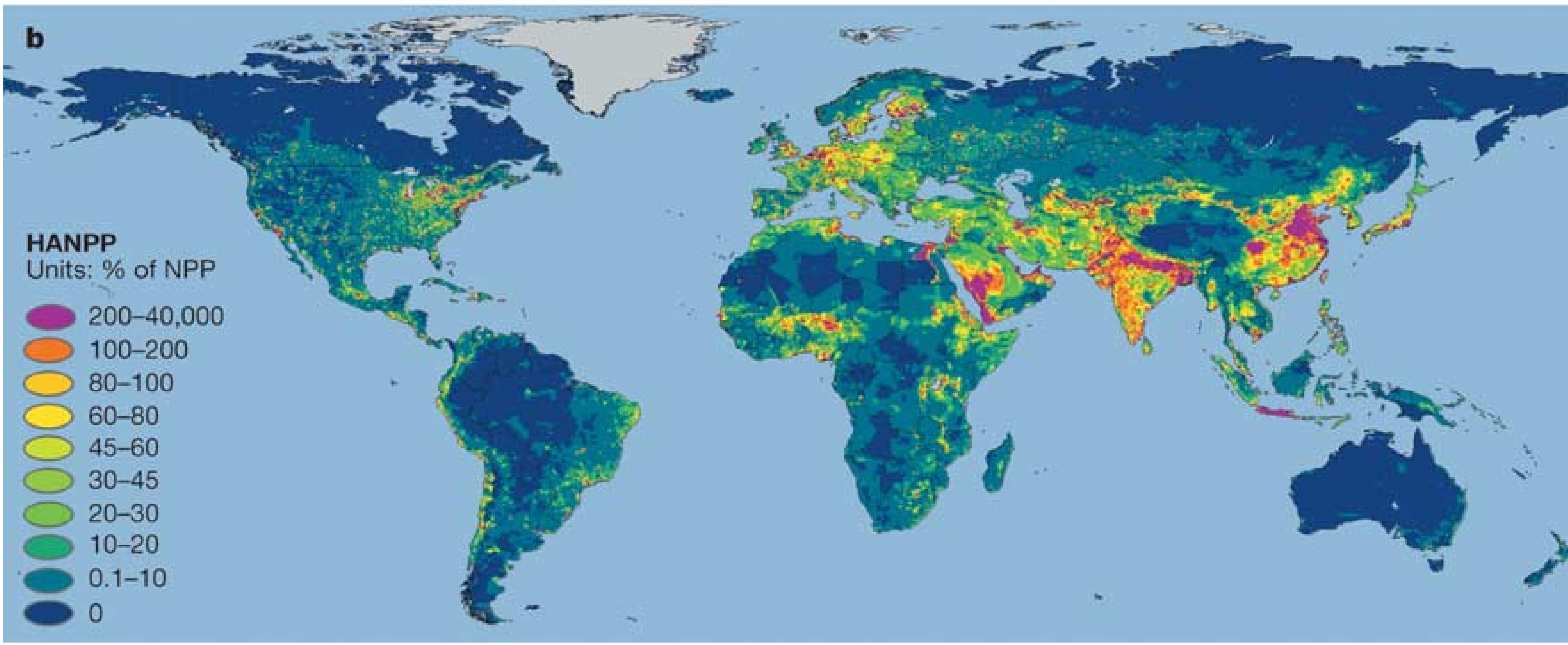


C B Field et al. Science 1998;281:237-240

Human appropriation of terrestrial NPP

Table 2 **Annual global HANPP estimates**

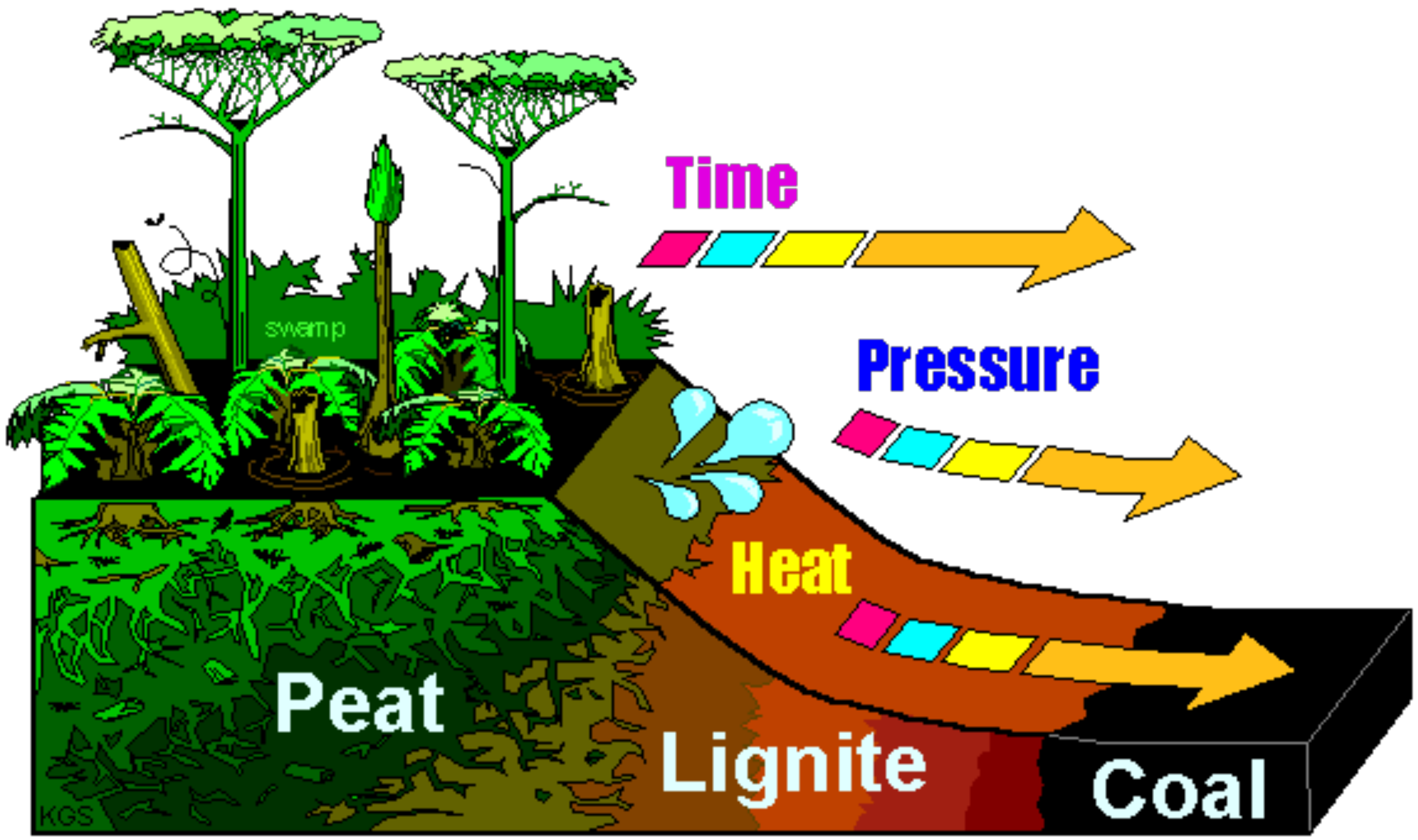
Product	Low estimate (Pg C)	Intermediate estimate (Pg C)	High estimate (Pg C)
Vegetal food	0.90	1.73	2.95
Meat	1.69	1.92	2.22
Milk	0.15	0.27	0.43
Eggs	0.09	0.17	0.26
Food (subtotal)	2.83	4.09	5.86
Paper	0.20	0.28	0.38
Fibre	0.32	0.36	0.42
Wood (fuel)	2.68	4.31	4.71
Wood (construction)	1.97	2.50	3.44
Wood and fibre (subtotal)	5.17	7.45	8.95
Total	8.00	11.54	14.81
% of annual NPP (56.8 Pg)	14.10	20.32	26.07



~20% total (~10 Pg C = ~20,000 TWh = ~2 TW)

Imhoff et al., 2004

Coal: fossil fuel from ancient swamps



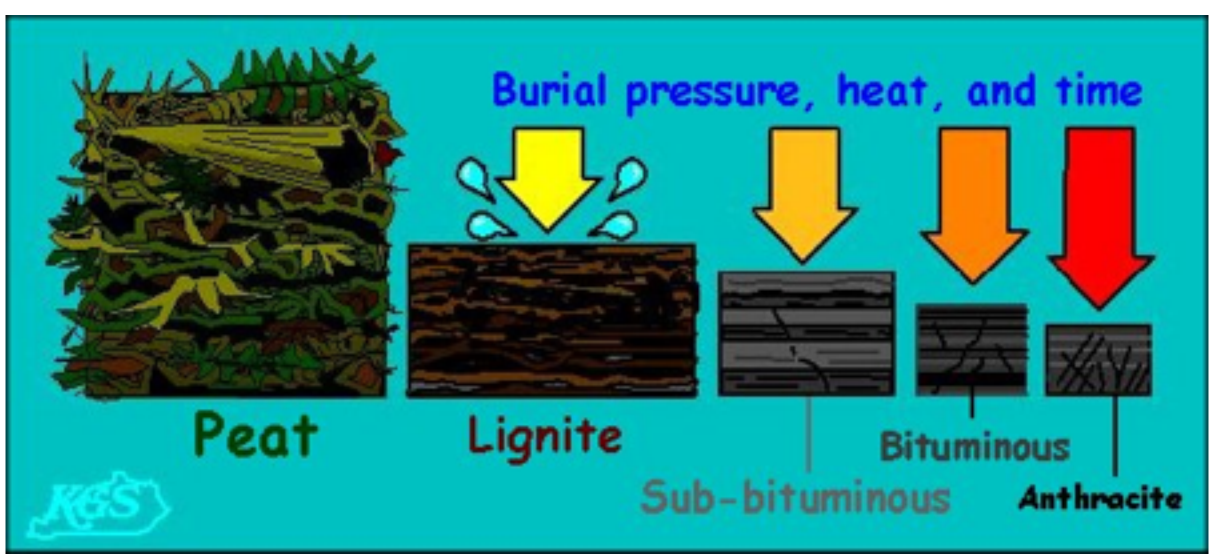
http://www.uky.edu/KGS/coal/coalform.htm

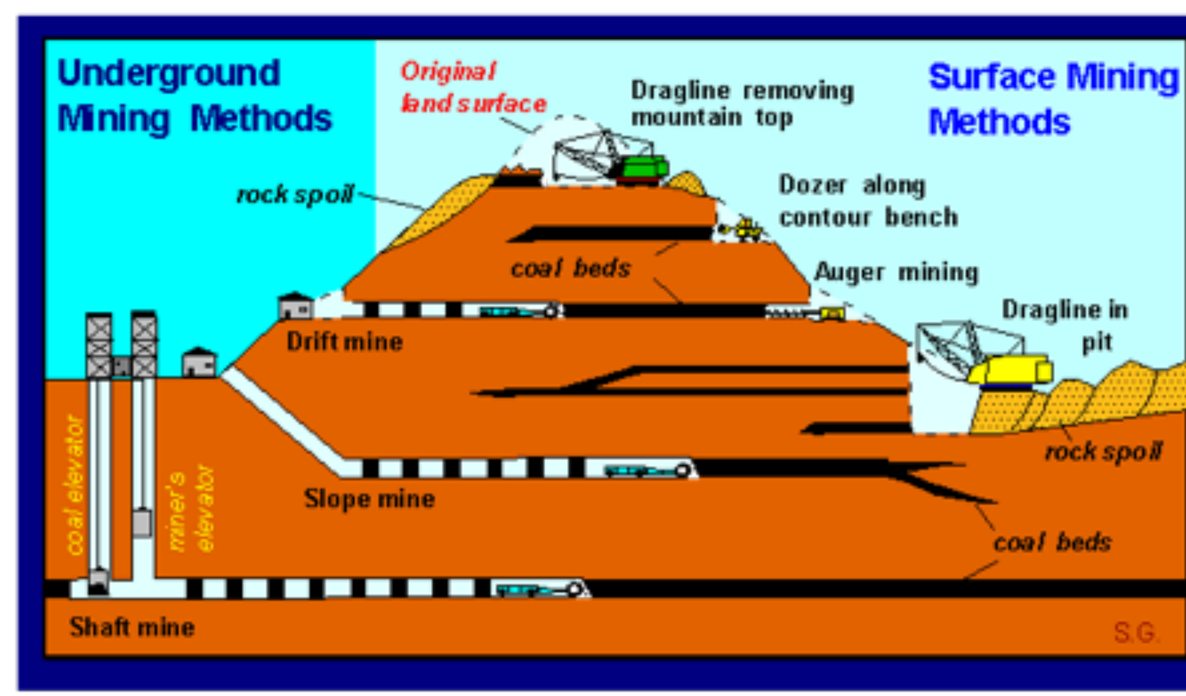
Proved recoverable lignite and coal reserves (WEC, 2010):

860 Gt globally
240 Gt USA

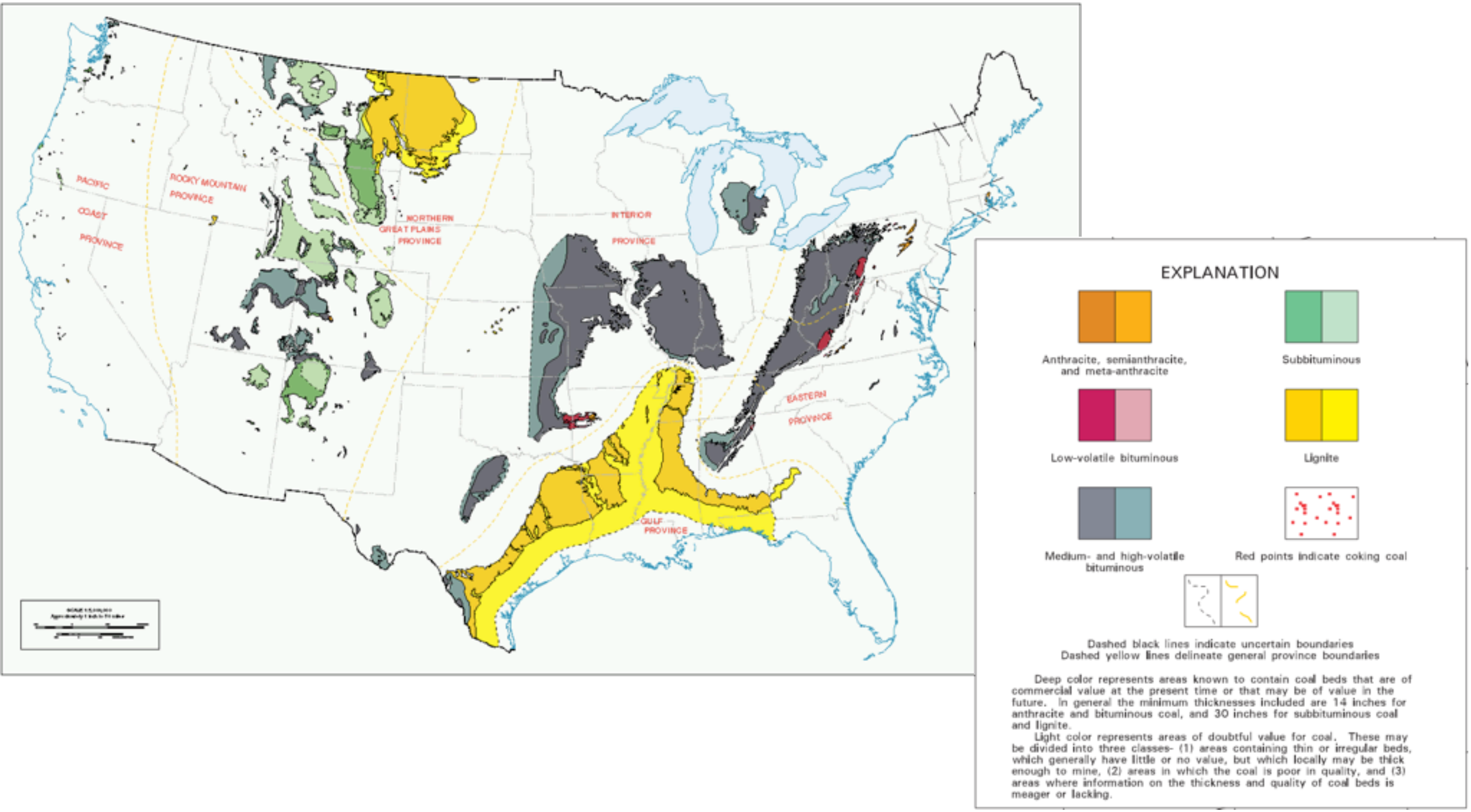
Equivalent to ~8 y terrestrial NPP, ~8 ky of terrestrial NPP burial

Lignite is 60-75% C
Anthracite > 91.5% C



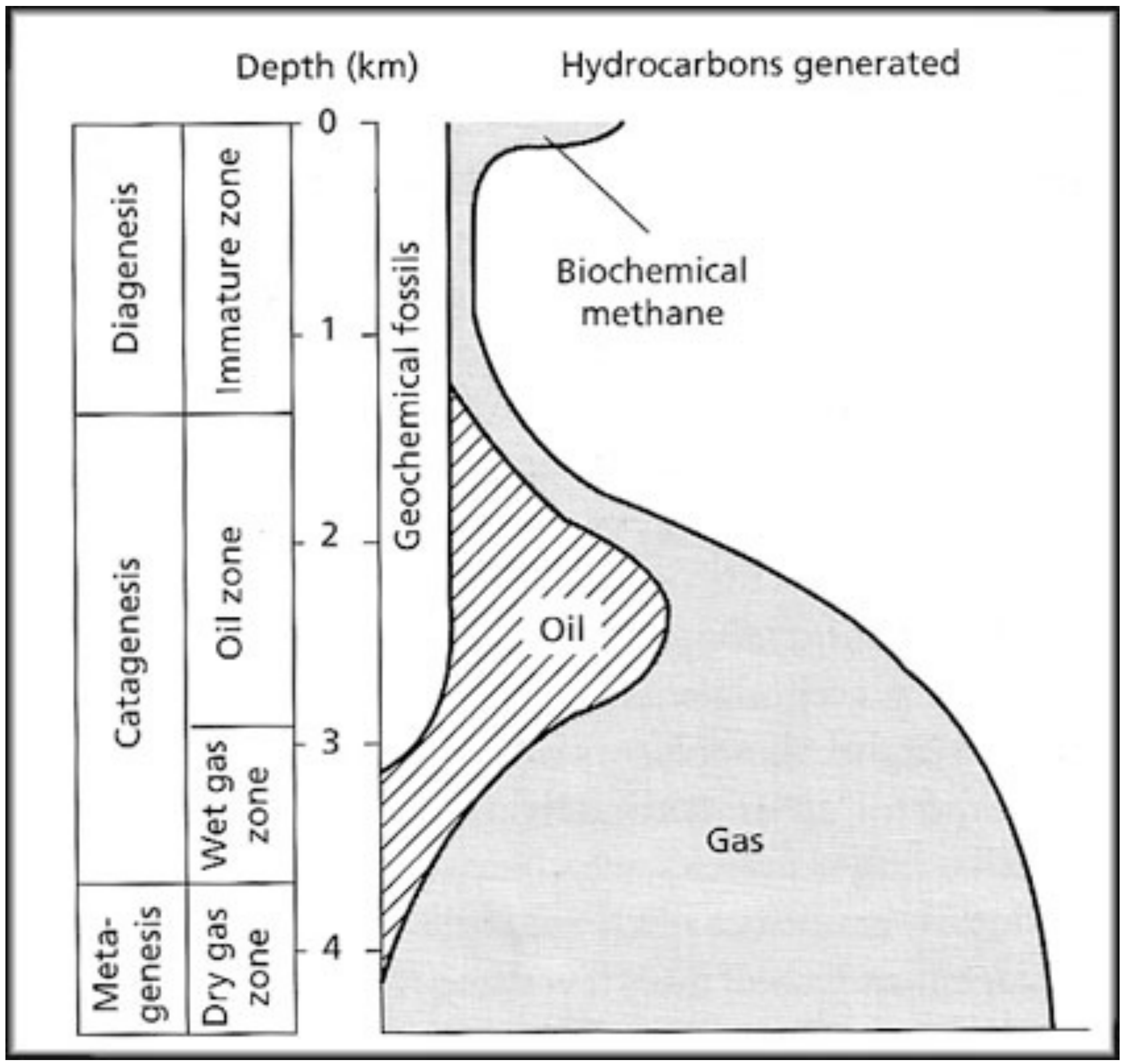


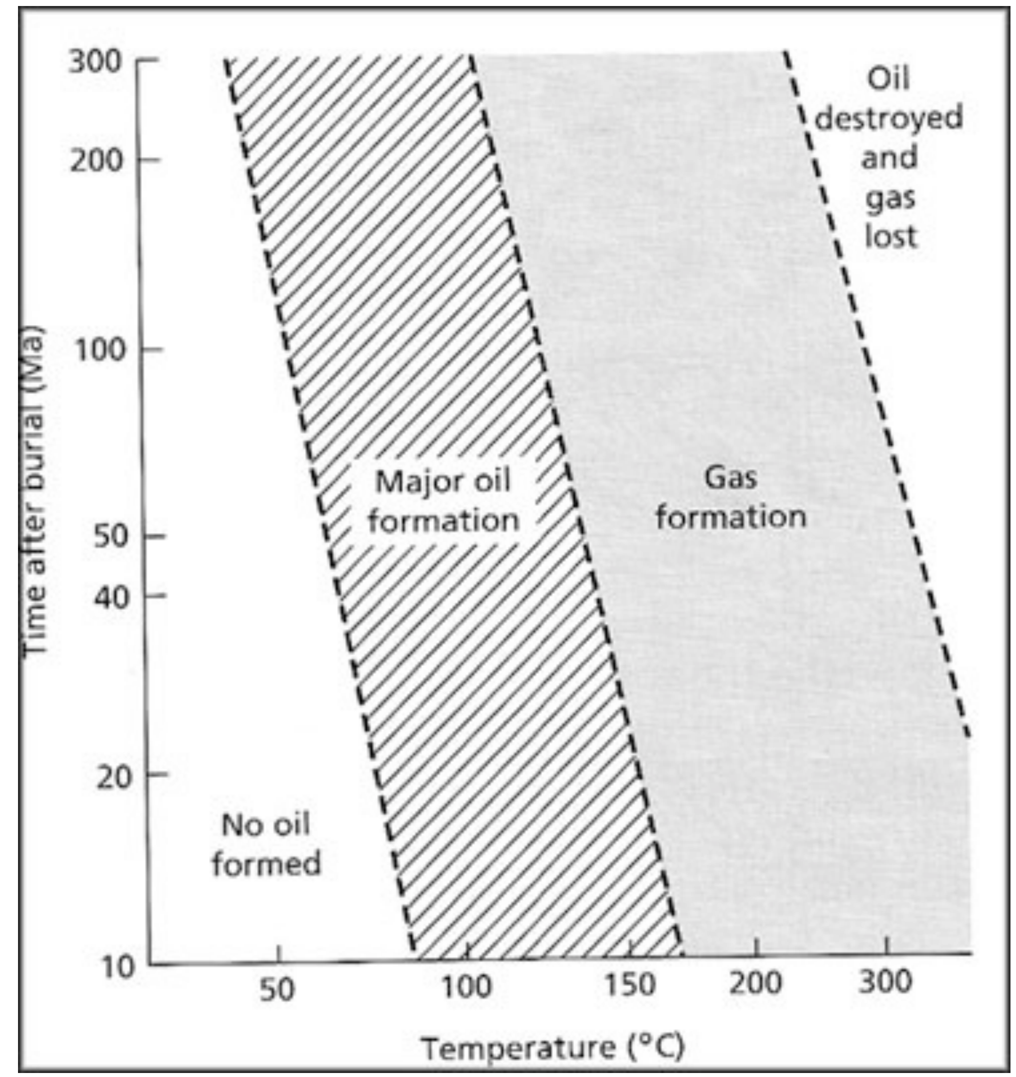
US coal reserves



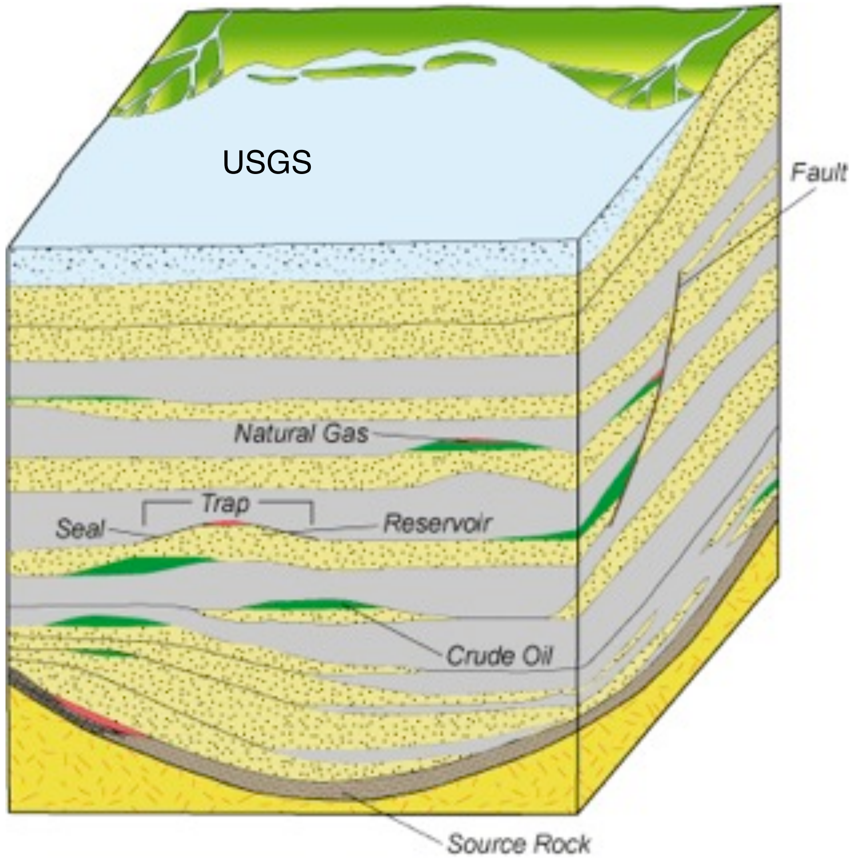
USGS OF 96-92

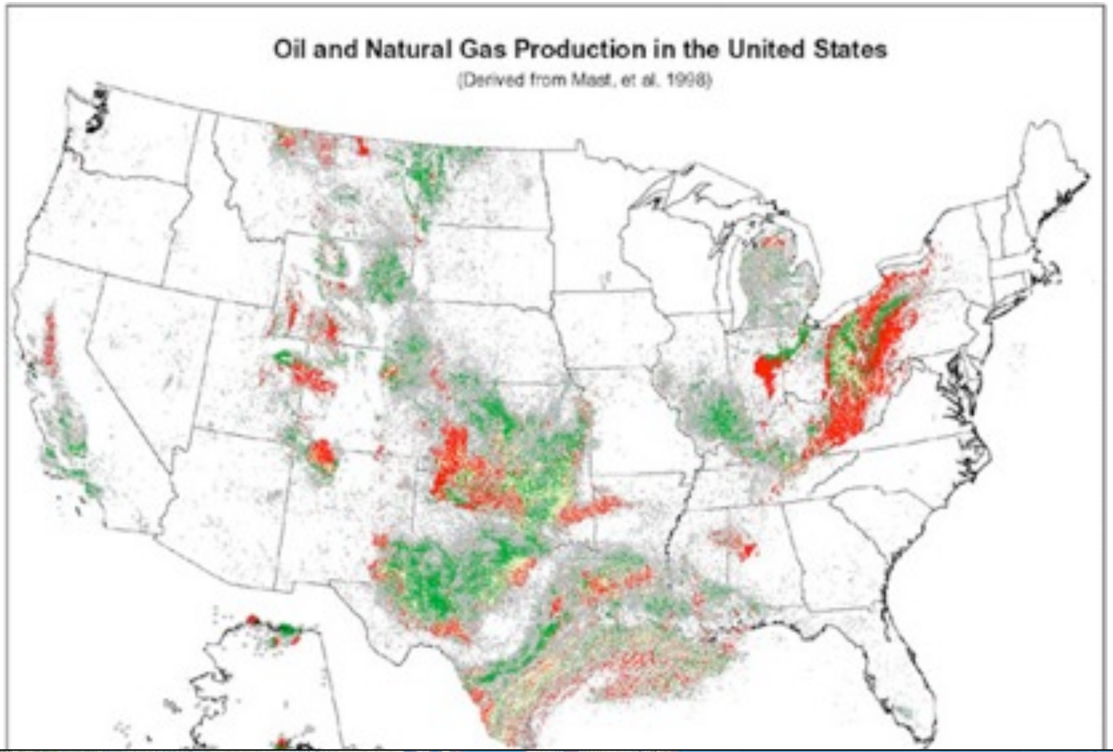
Petroleum and natural gas: fossil fuels from ancient oceans





Tucker (2001)





Proved recoverable conventional oil reserves (WEC, 2010): 163 Gt globally, 3 Gt USA

Prospective oil shale resource in Canada: 105 Gt

Proved recoverable conventional natural gas reserves (WEC, 2010): 148 Gt globally, 6 Gt USA

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

How does our energy use fit into natural energy flows?

Human primary power demand: 15 TW

- Fossil fuel use: 12 TW
- Human appropriation of net primary productivity: 2 TW

Solar flux to surface: 184 W/m^2 = 94,000 TW

Geothermal flux: 44 TW

Net primary productivity: 23 TW

- Buried net primary productivity: ~23 GW
  - *that ultimately turns into fossil fuels: ~10 MW*

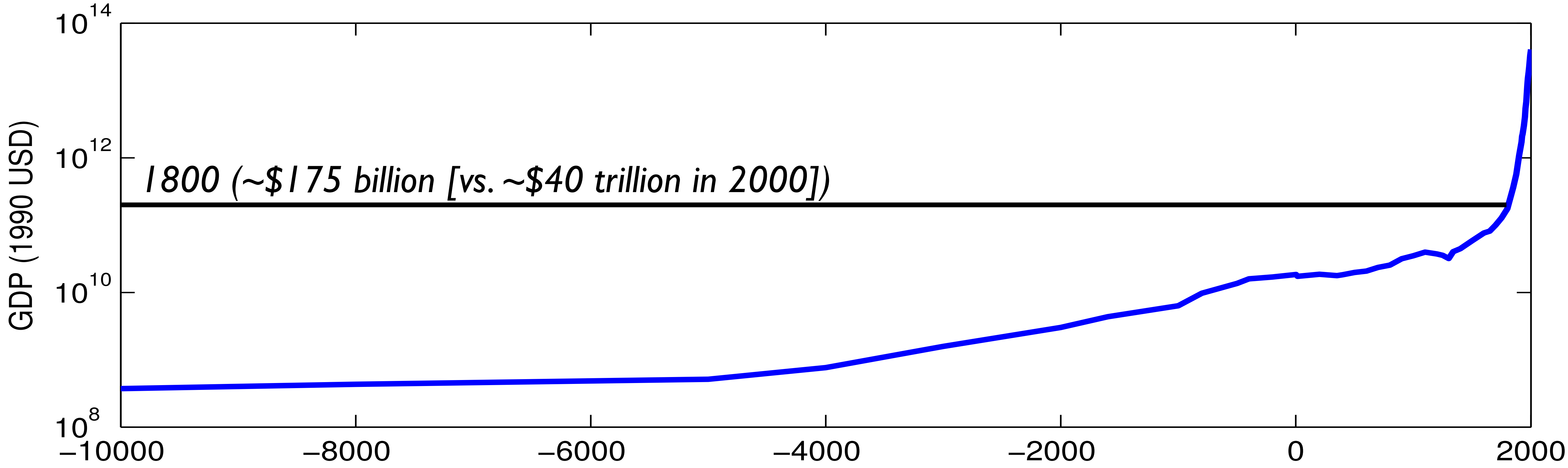
How has this changed over time?

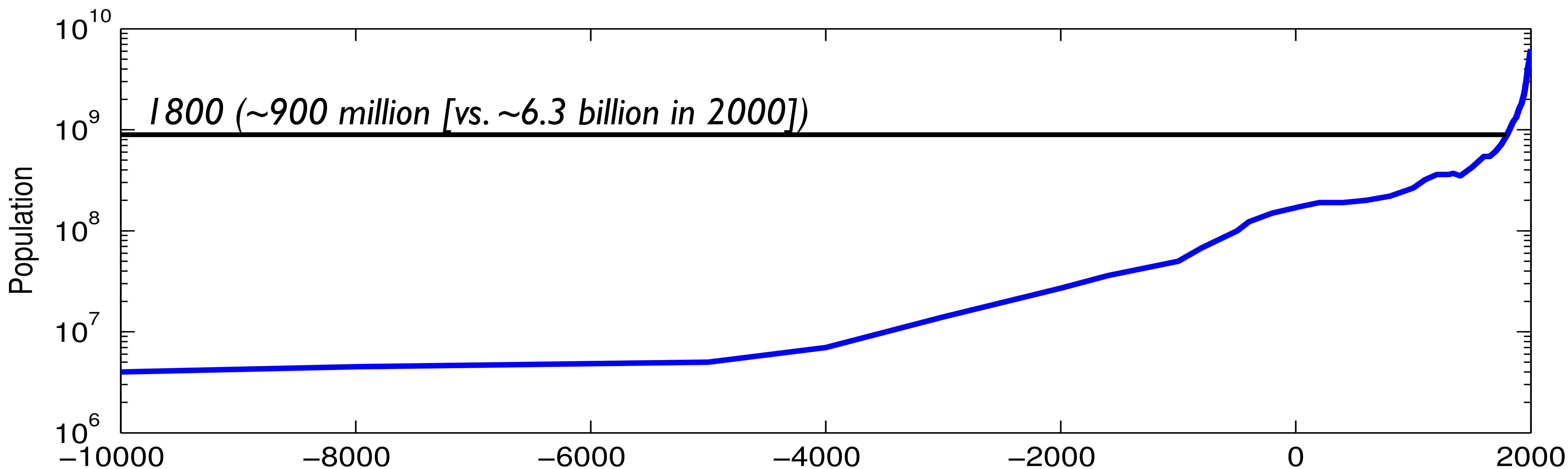
Think about your personal energy consumption, and about the energy sources that underlie it.

In 1800, at the start of the Industrial Revolution, the world had a population of ~900 million and a GDP of ~$200 billion (compared to ~7 billion and ~$63 trillion today).

How much energy do you have at your disposal today compared to the average person of 1800? Write down your estimate.

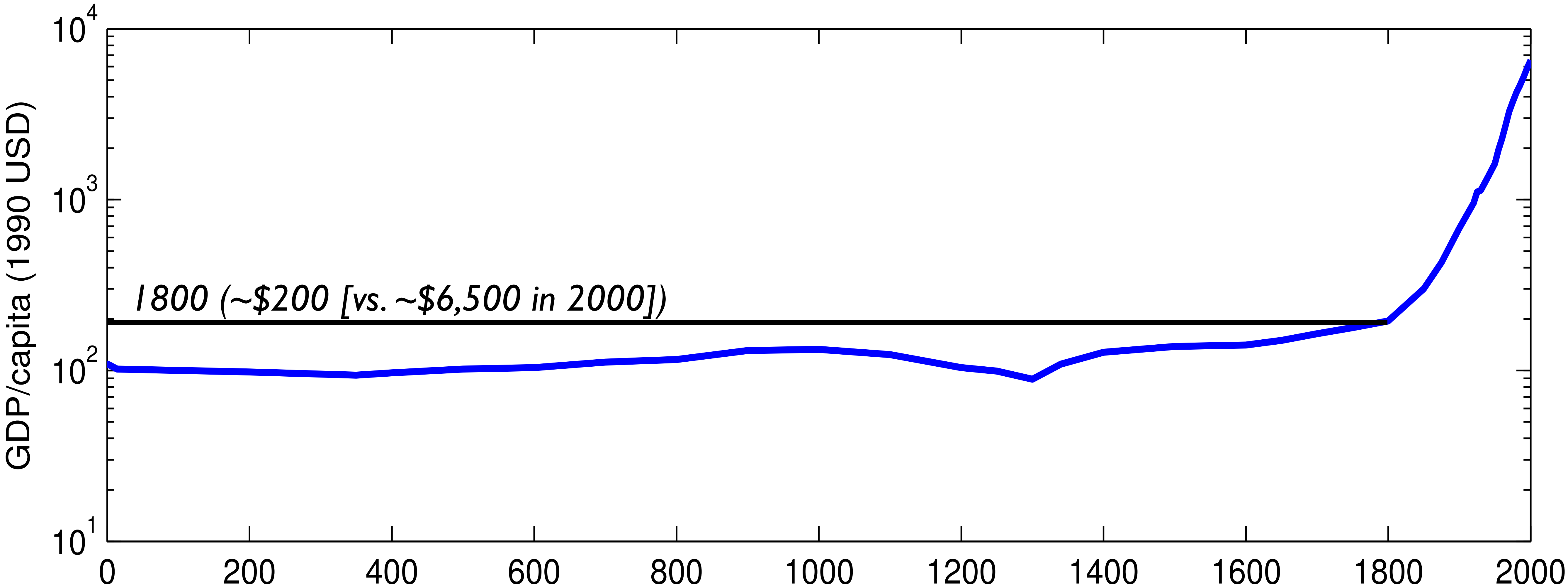
World GDP and Population





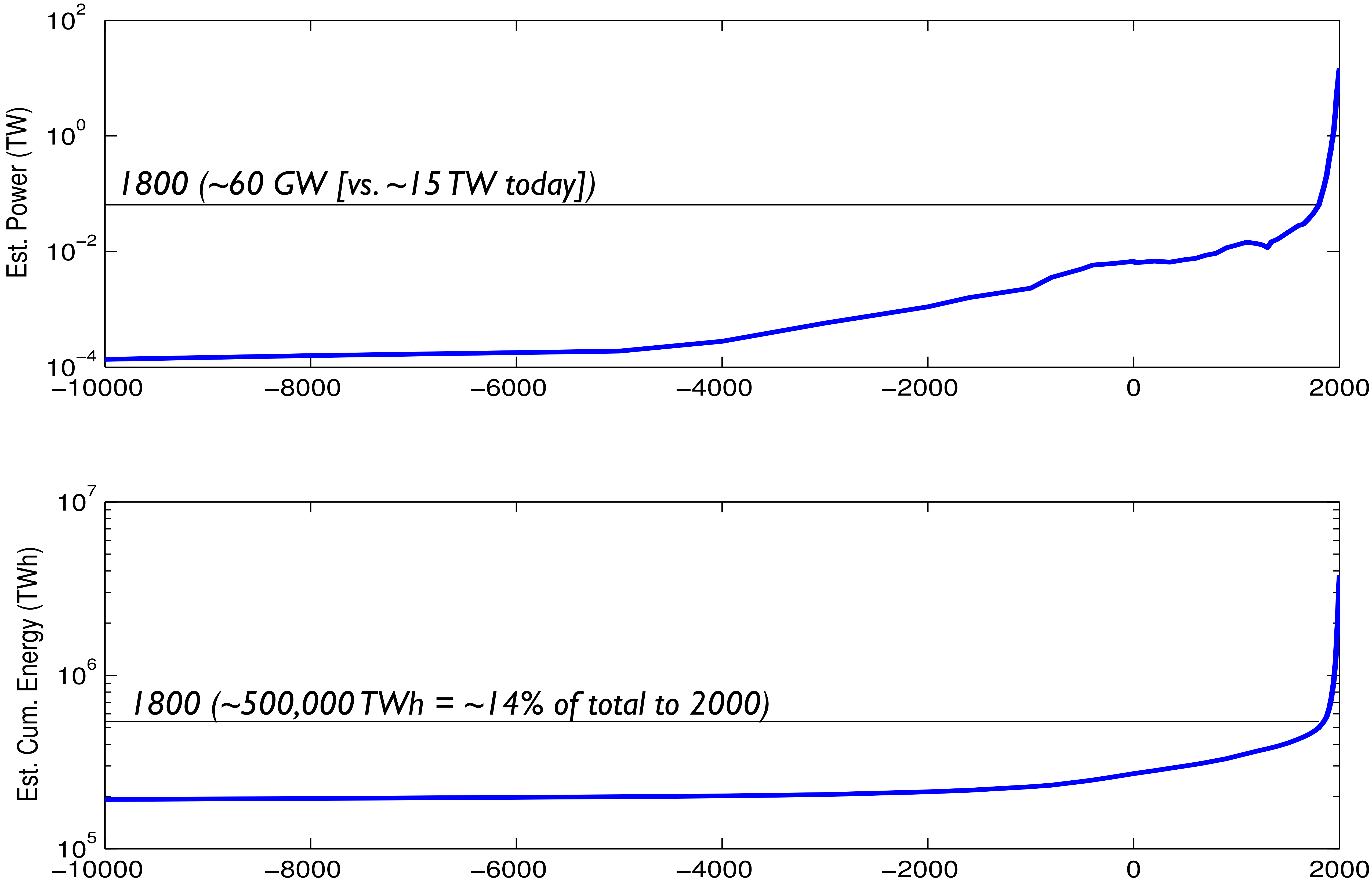
Delong (1998)

World GDP Per Capita



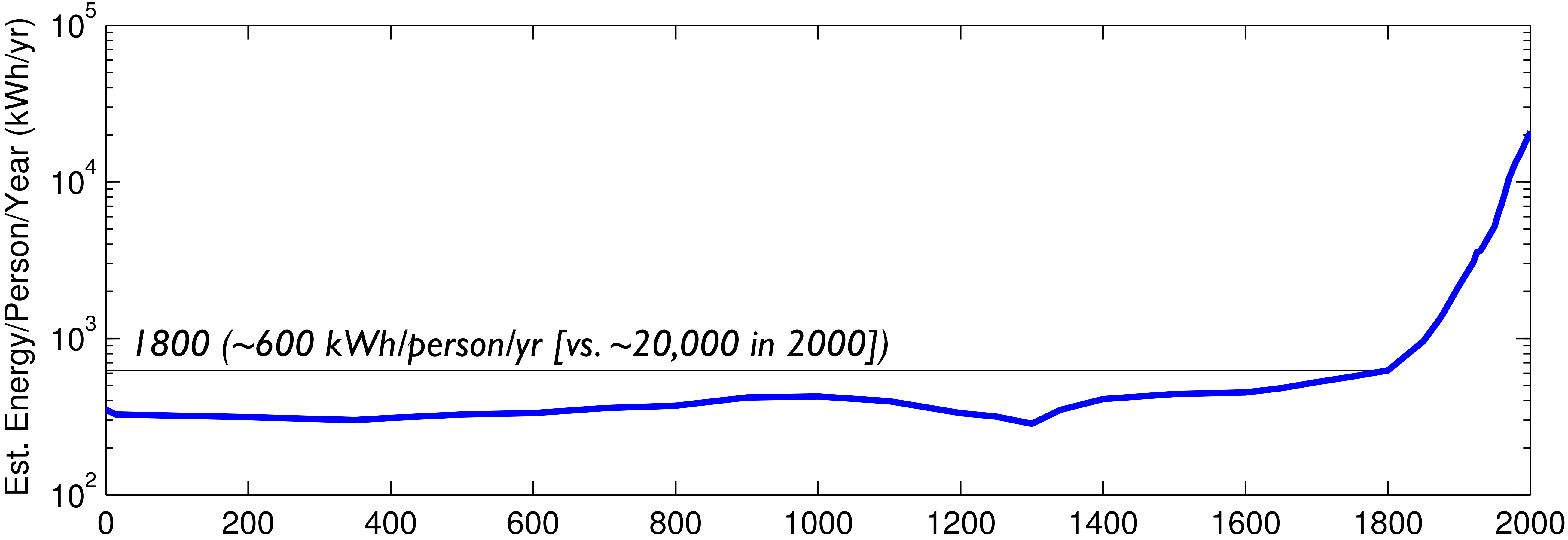
Delong (1998)

Est. Global Energy



assuming constant energy intensity (~0.4 Wh/$)

Est. Global Energy Per Capita



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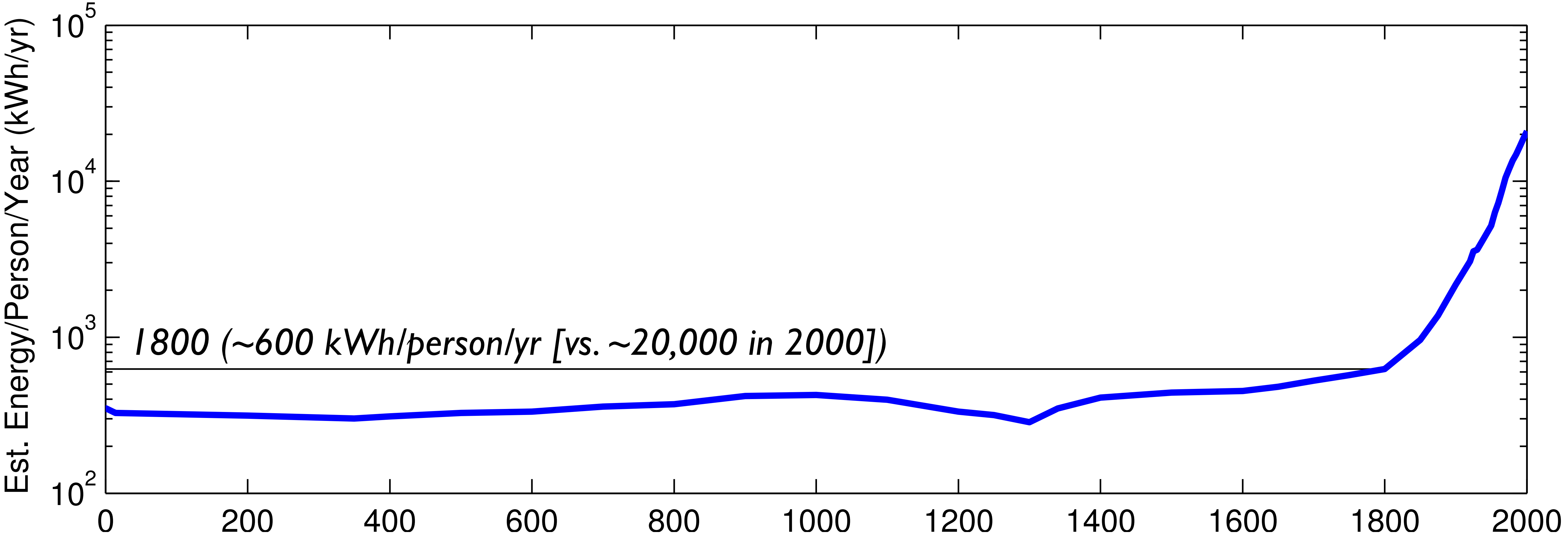
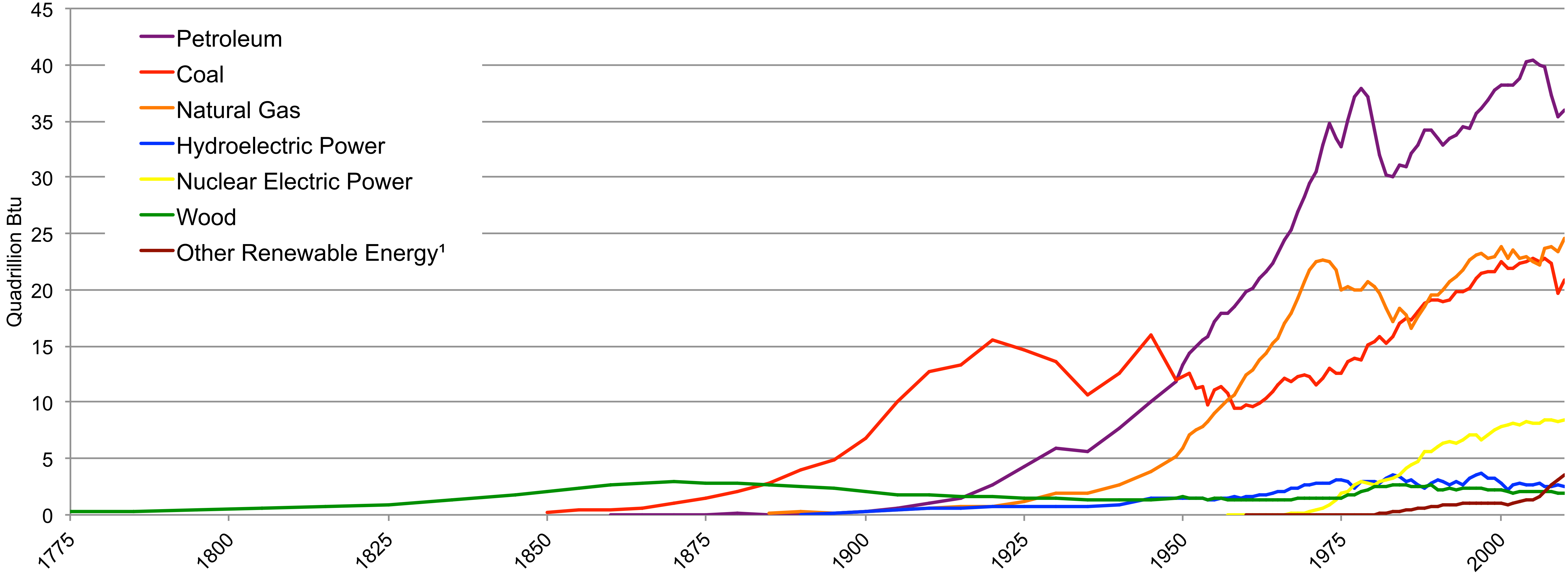


The average American today has about ~100,000 TWh/yr at his/her disposal. By this calculation, that's equivalent to ~170 people of 1800.

assuming constant energy intensity (~0.4 Wh/$)

U.S. Primary Energy Consumption Estimates by Source, 1775-2010

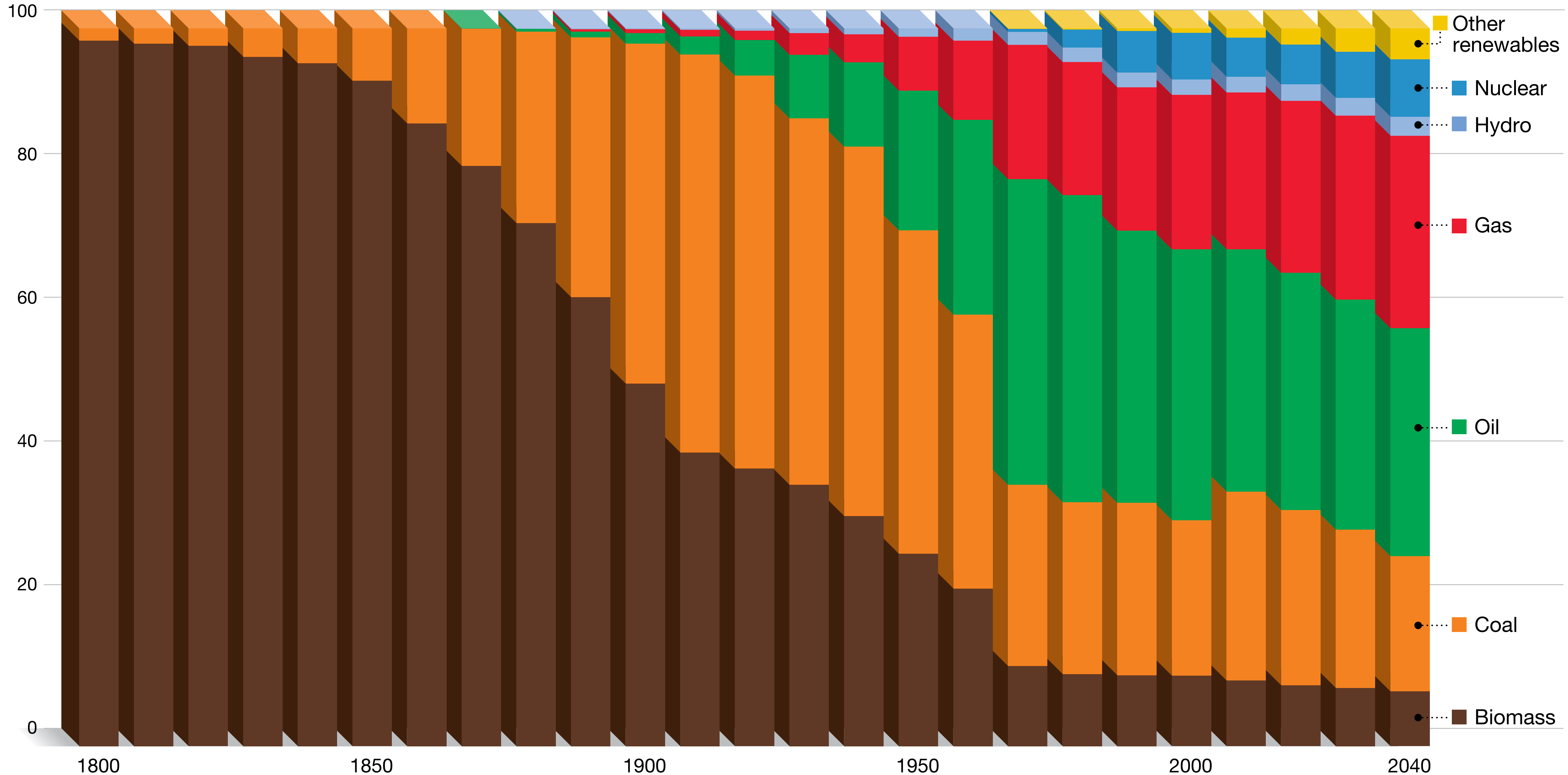


Source: U.S. Energy Information Administration Annual Energy Review, Tables 1.3, 10.1, and E1.

¹ Geothermal, solar/PV, wind, waste, and biofuels.

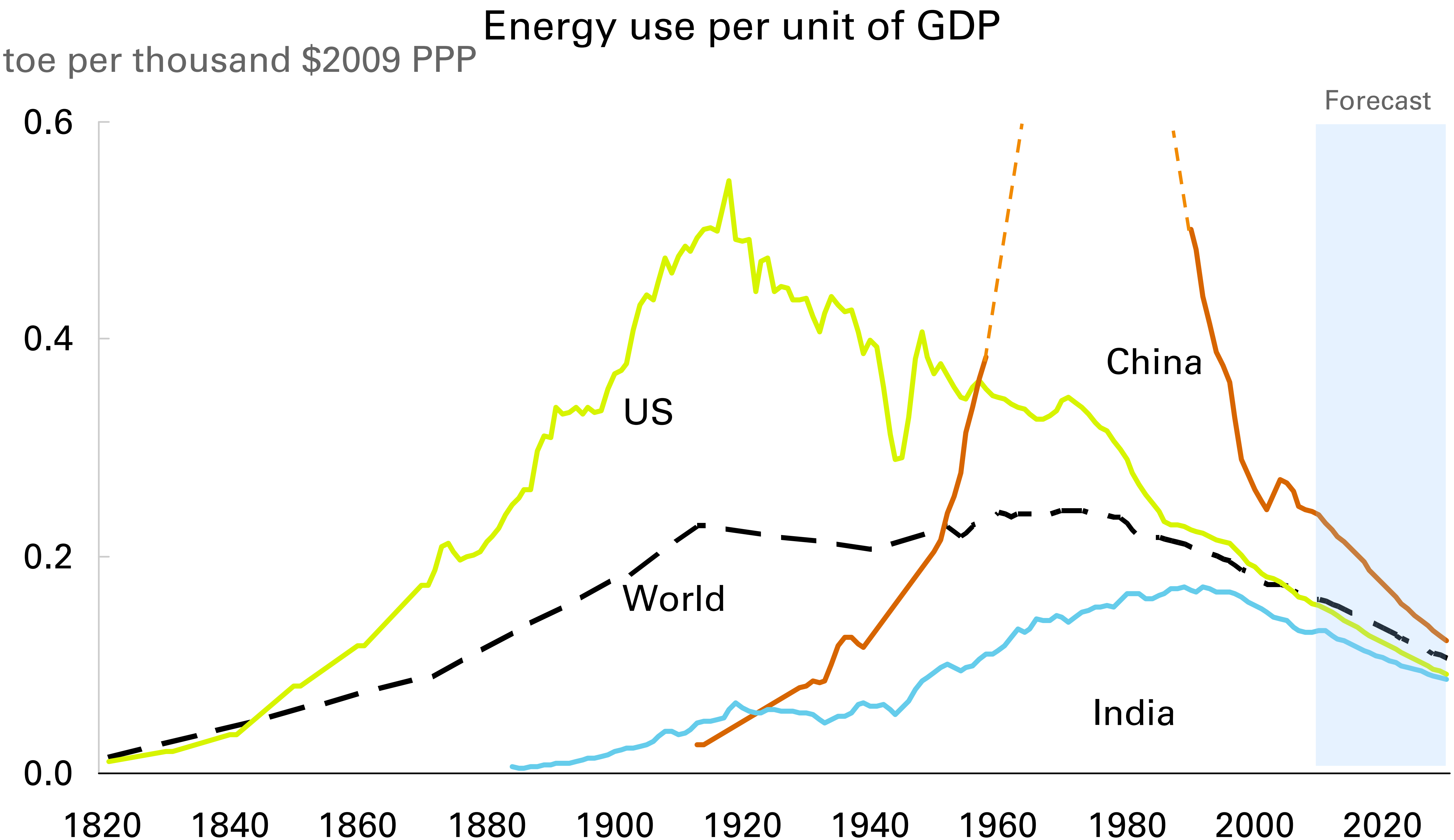
Global fuel mix by decade

Percent

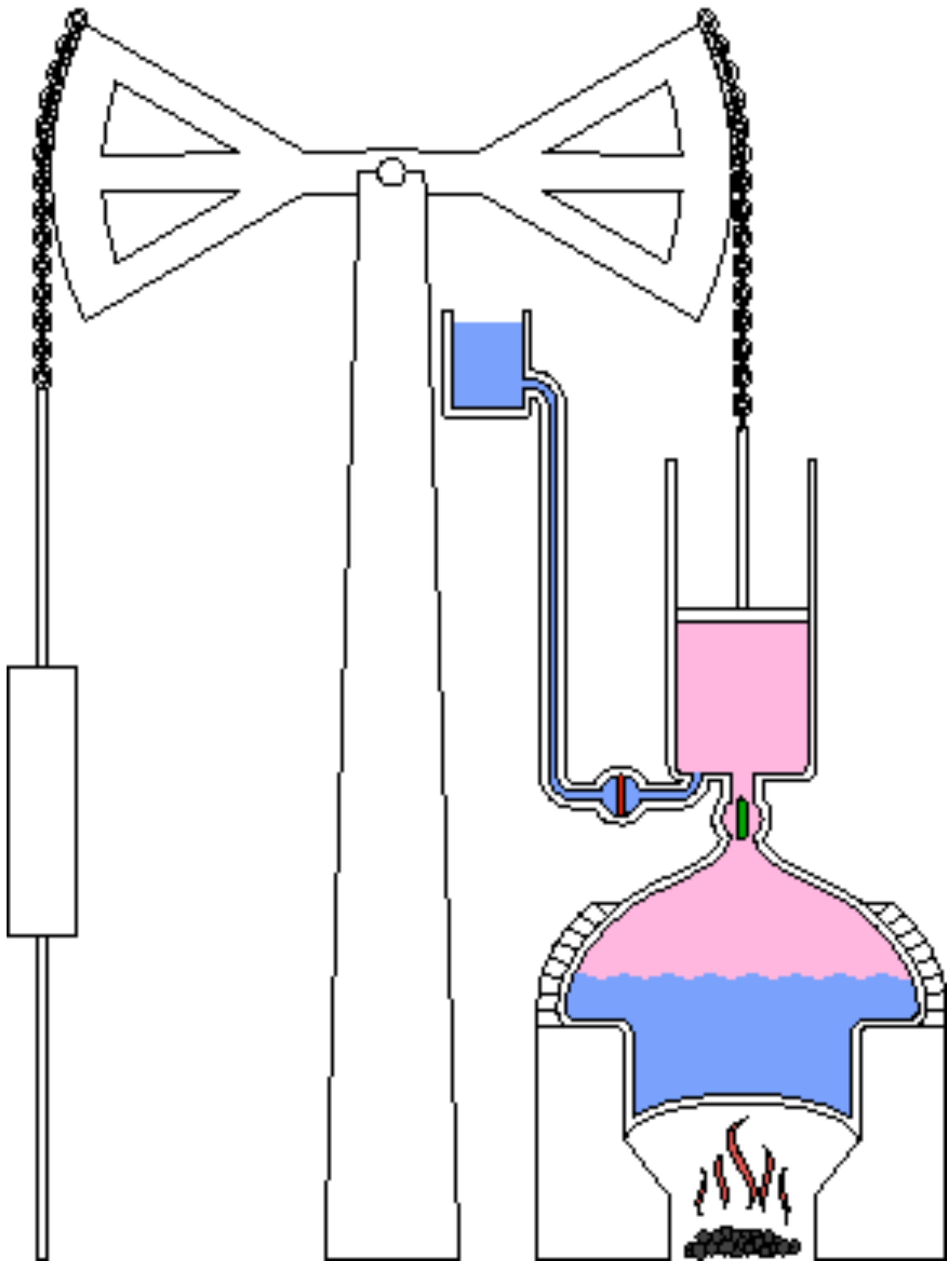


Source: Smil, Energy Transitions (1800-1960)

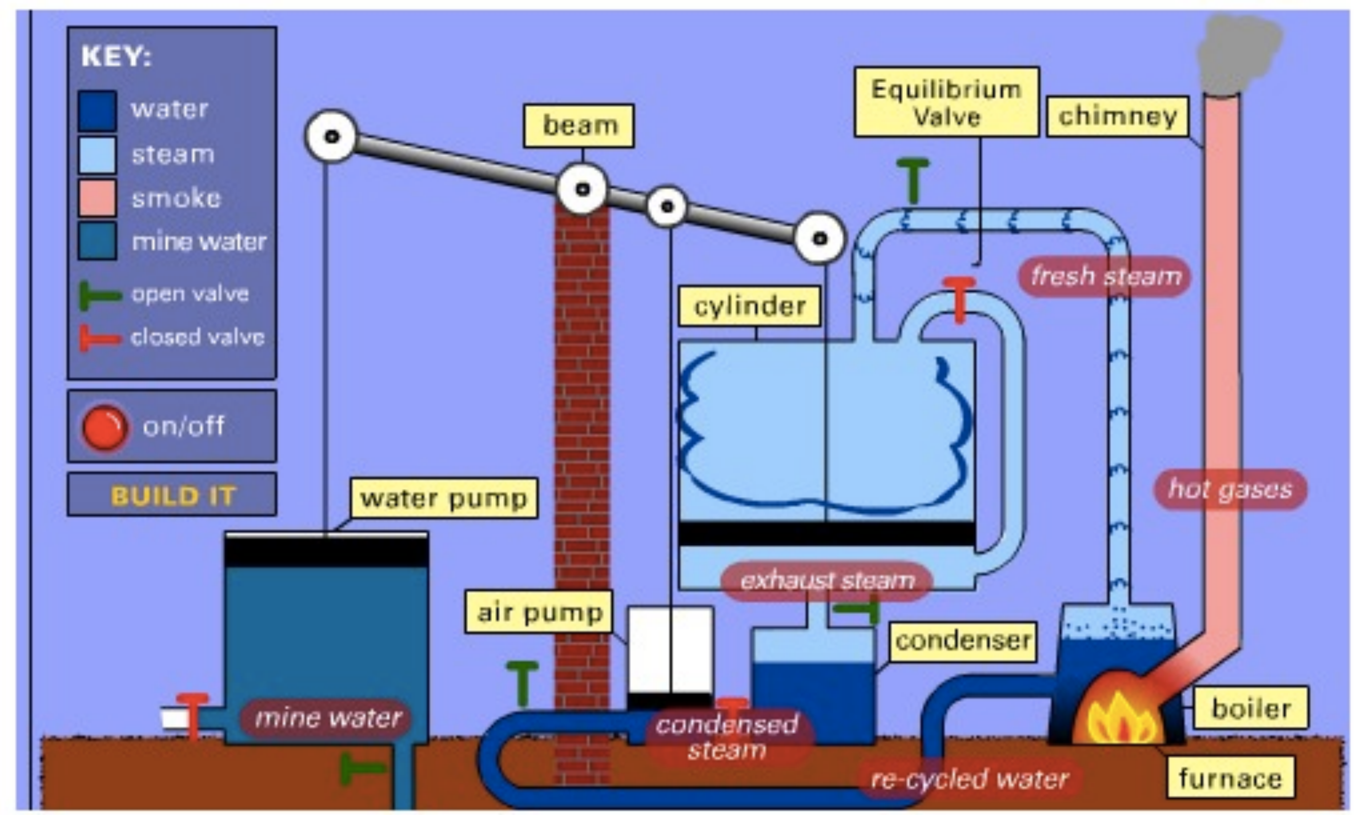
Historical trends and patterns of development...



Newcomen steam engine (1712)



Watt steam engine (1775)

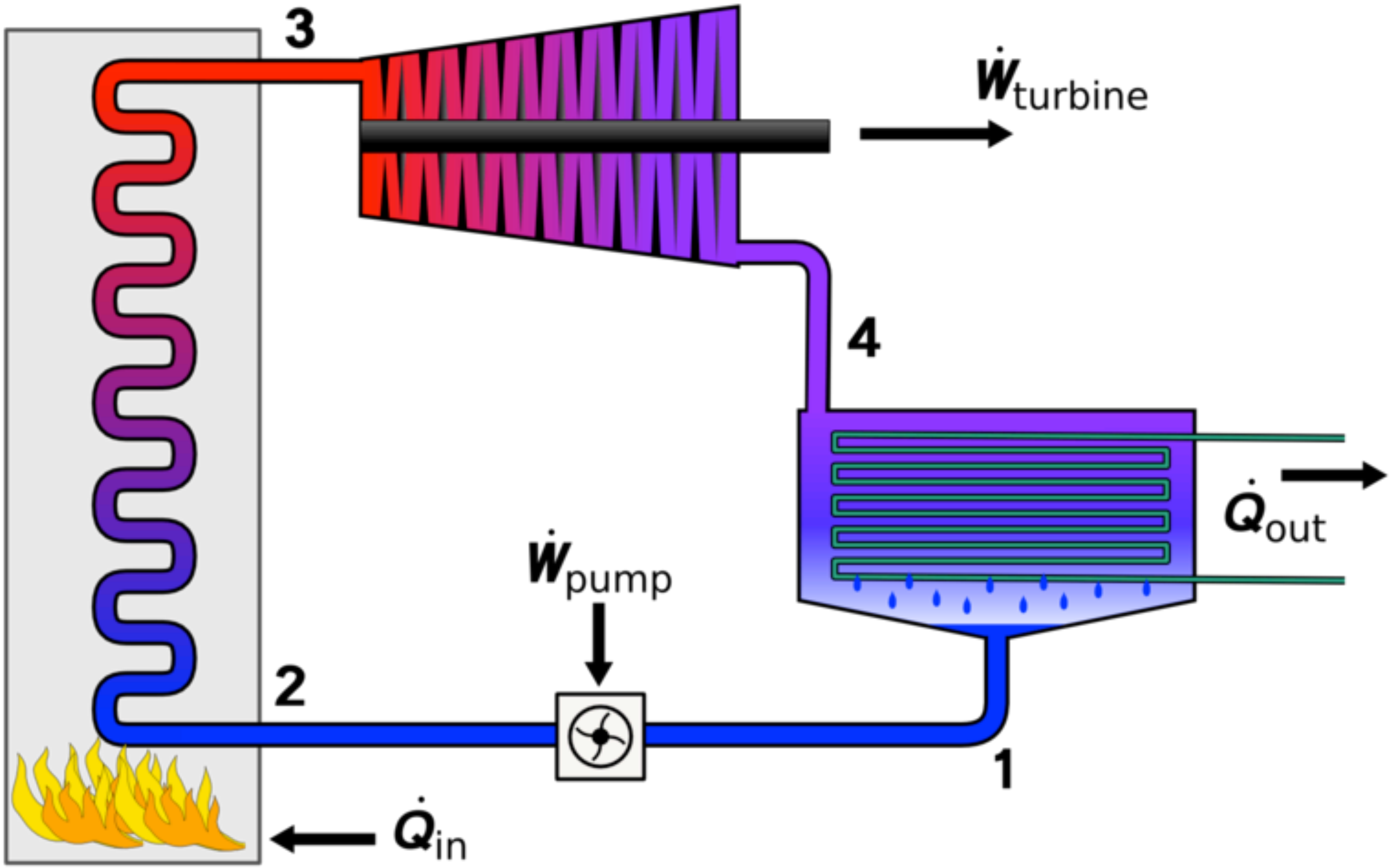


Wikipedia

BBC

Rankine Cycle

(underlies modern thermoelectric plants)



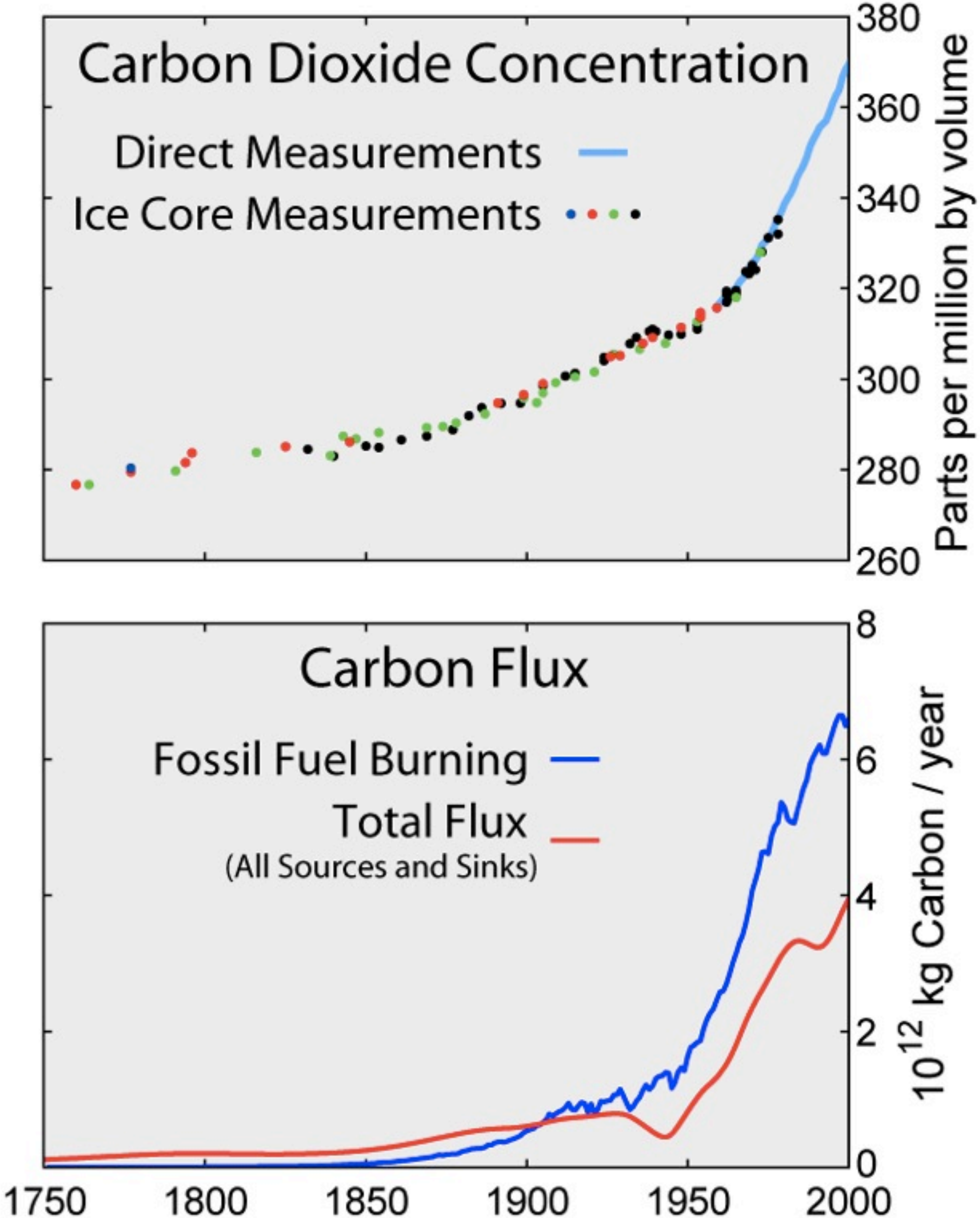
1820-1872

Wikipedia

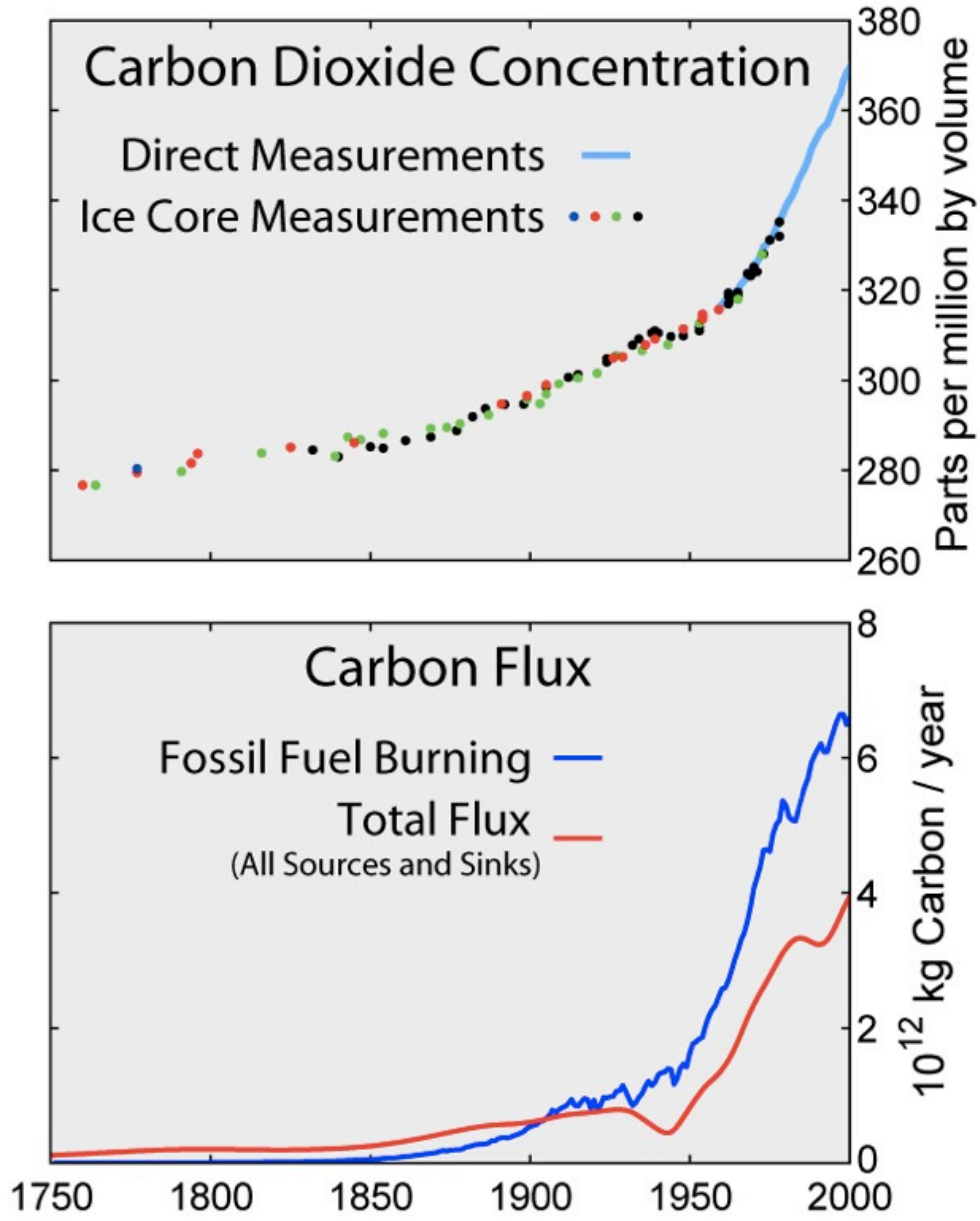
Is the current energy system sustainable? What are the major associated risks?

Brainstorm some possible limits to and potential risks associated with the current global energy system.

Big Risk: Climate Change

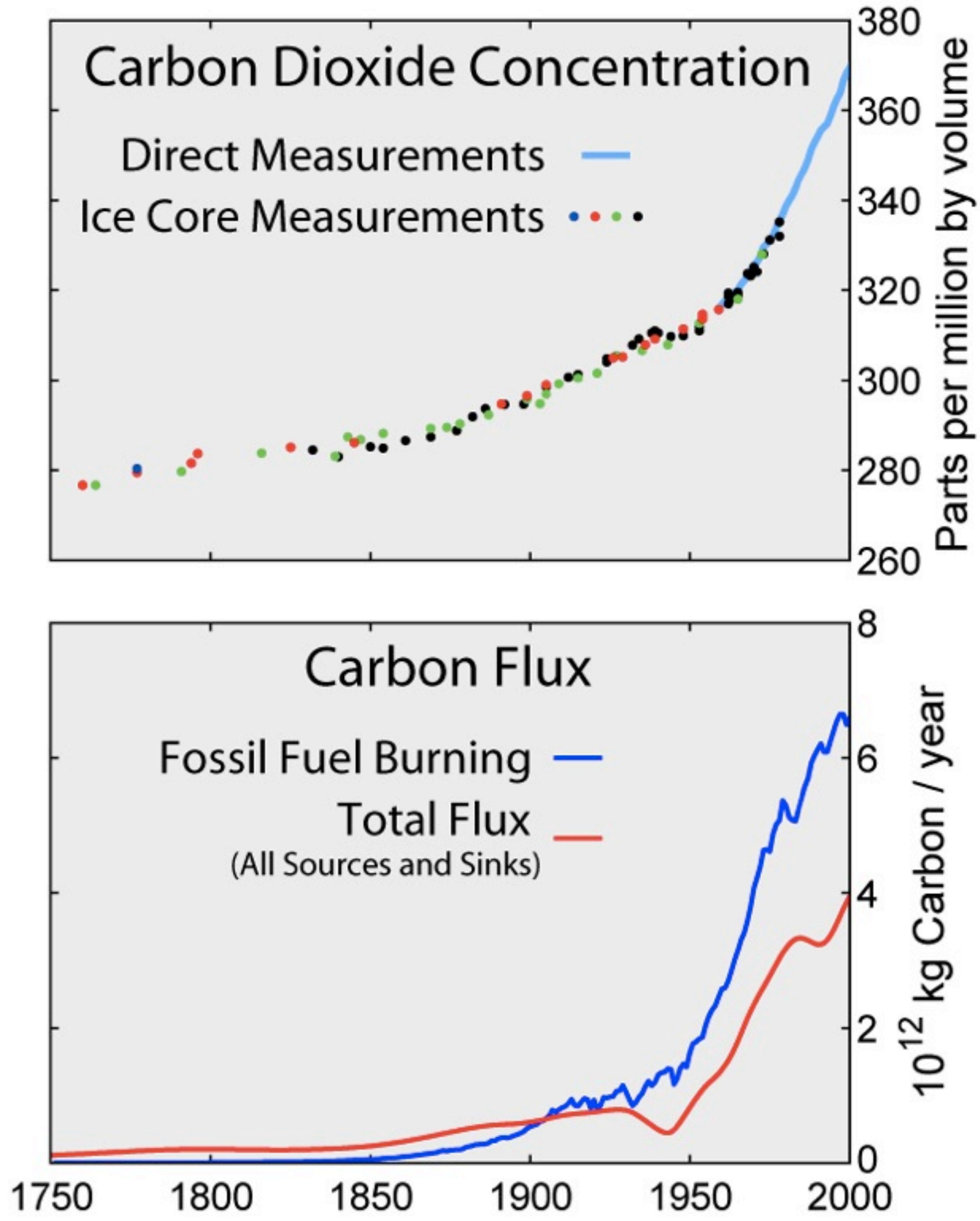


GlobalWarmingArt.com



Carbon Dioxide Concentration
Direct Measurements
Ice Core Measurements
Parts per million by volume
380
360
340
320
300
280
260
Carbon Flux
Fossil Fuel Burning
Total Flux
(All Sources and Sinks)
10^{12} kg Carbon / year
8
6
4
2
0
1750
1800
1850
1900
1950
2000

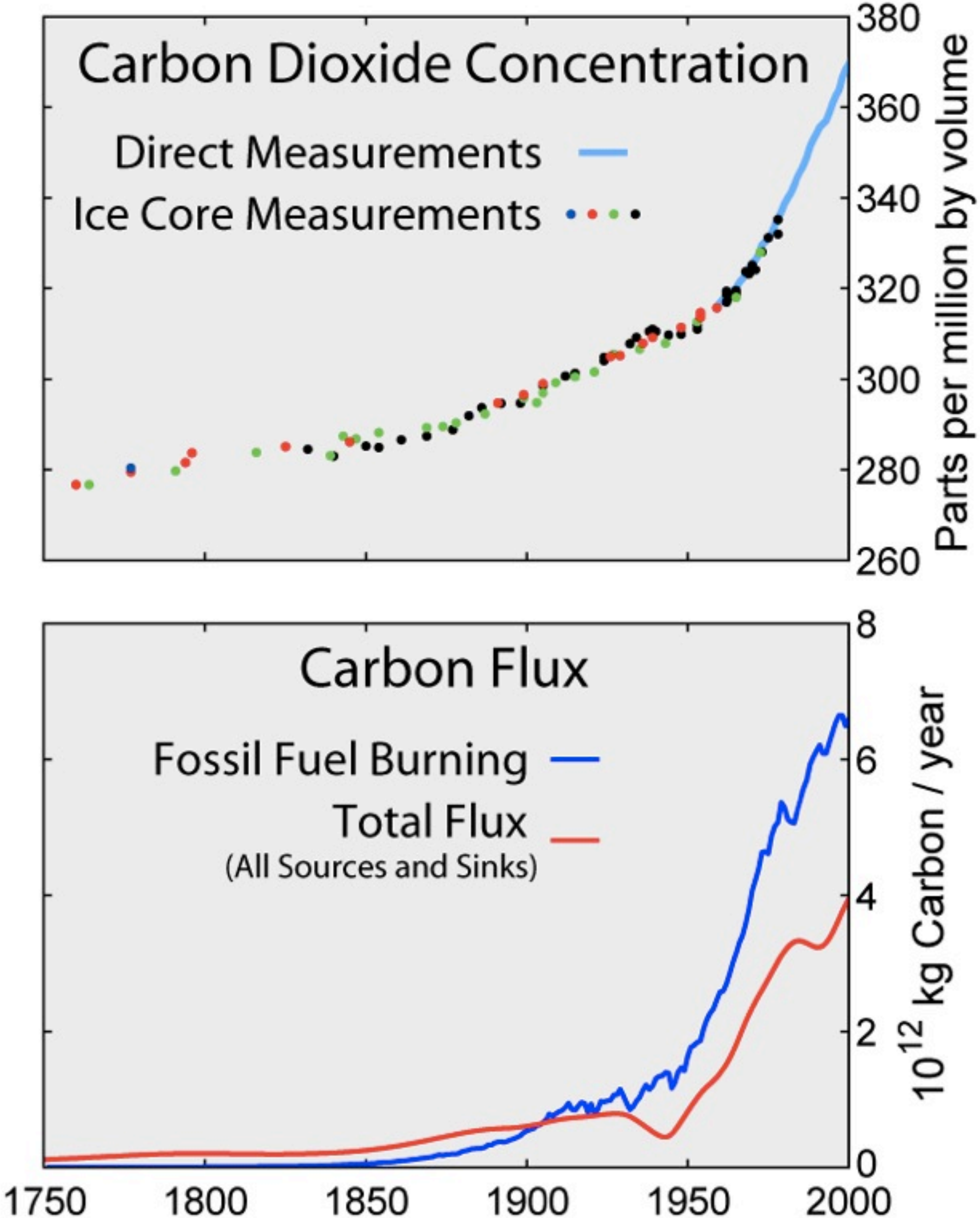
Since 1750:



Since 1750:

- ~110 ppm increase in atmospheric CO_2

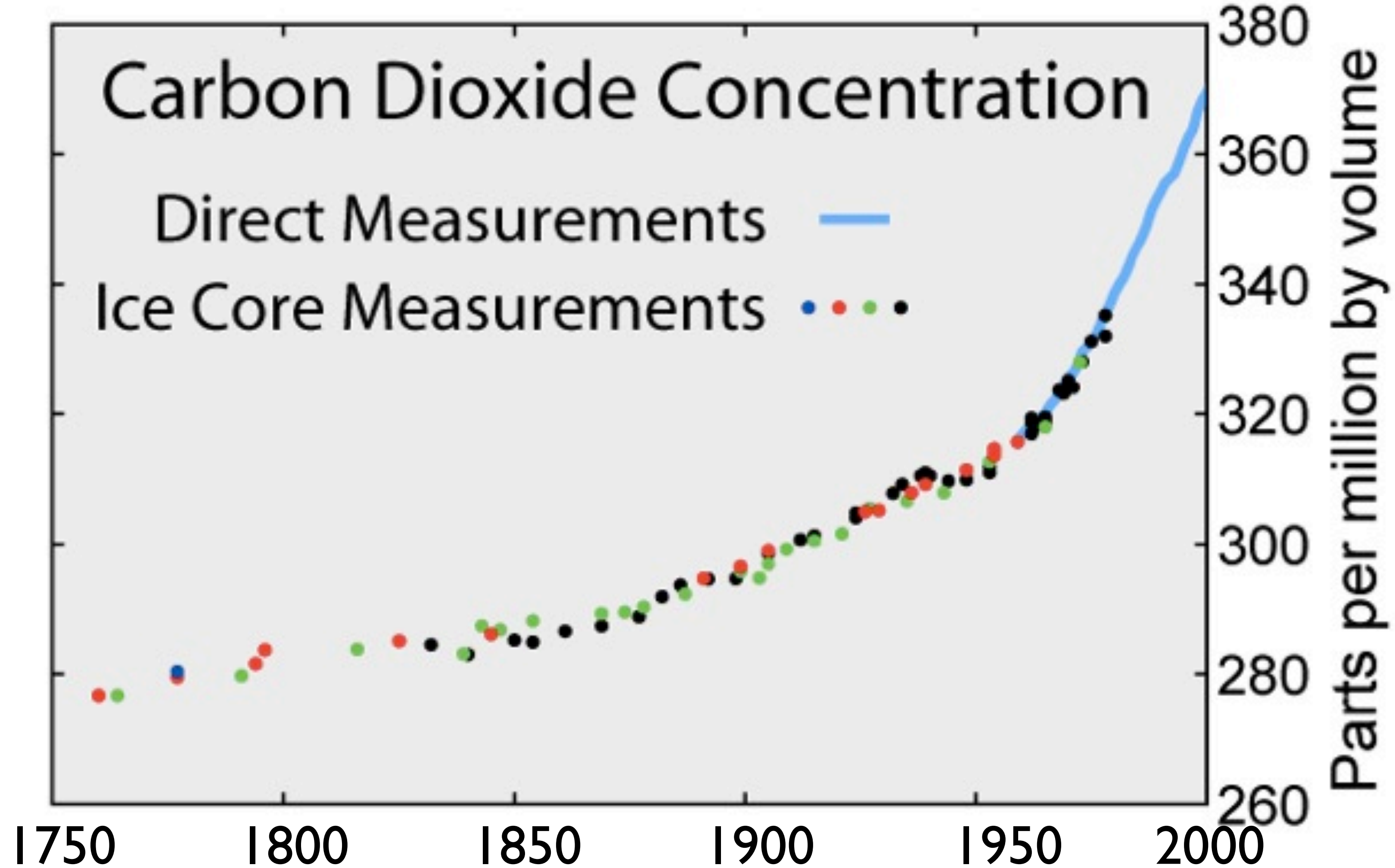
GlobalWarmingArt.com



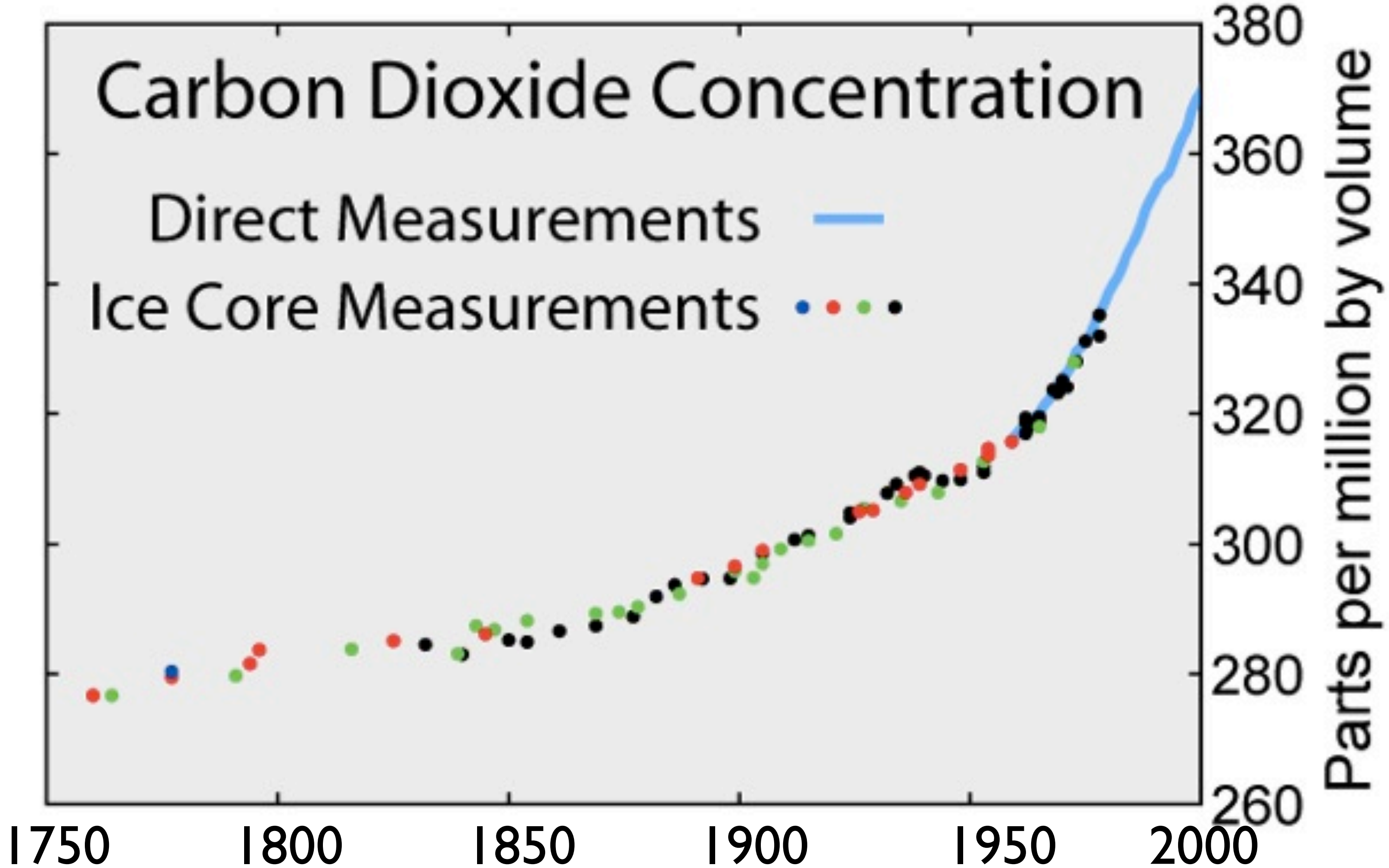
Since 1750:

- ~110 ppm increase in atmospheric CO_2

- ~1.1 trillion tonnes CO_2 emitted from fossil fuels and cement production



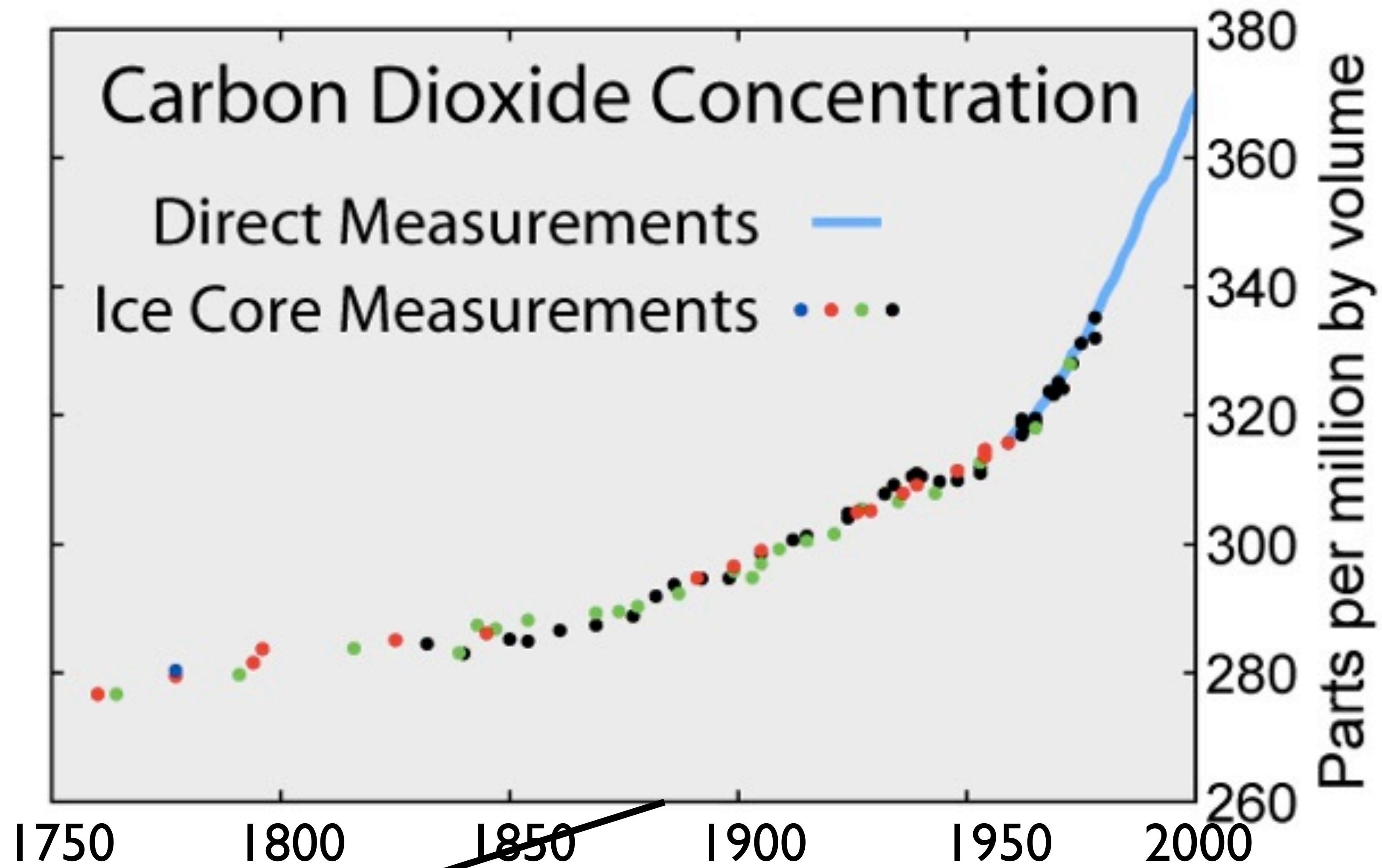
GlobalWarmingArt.com

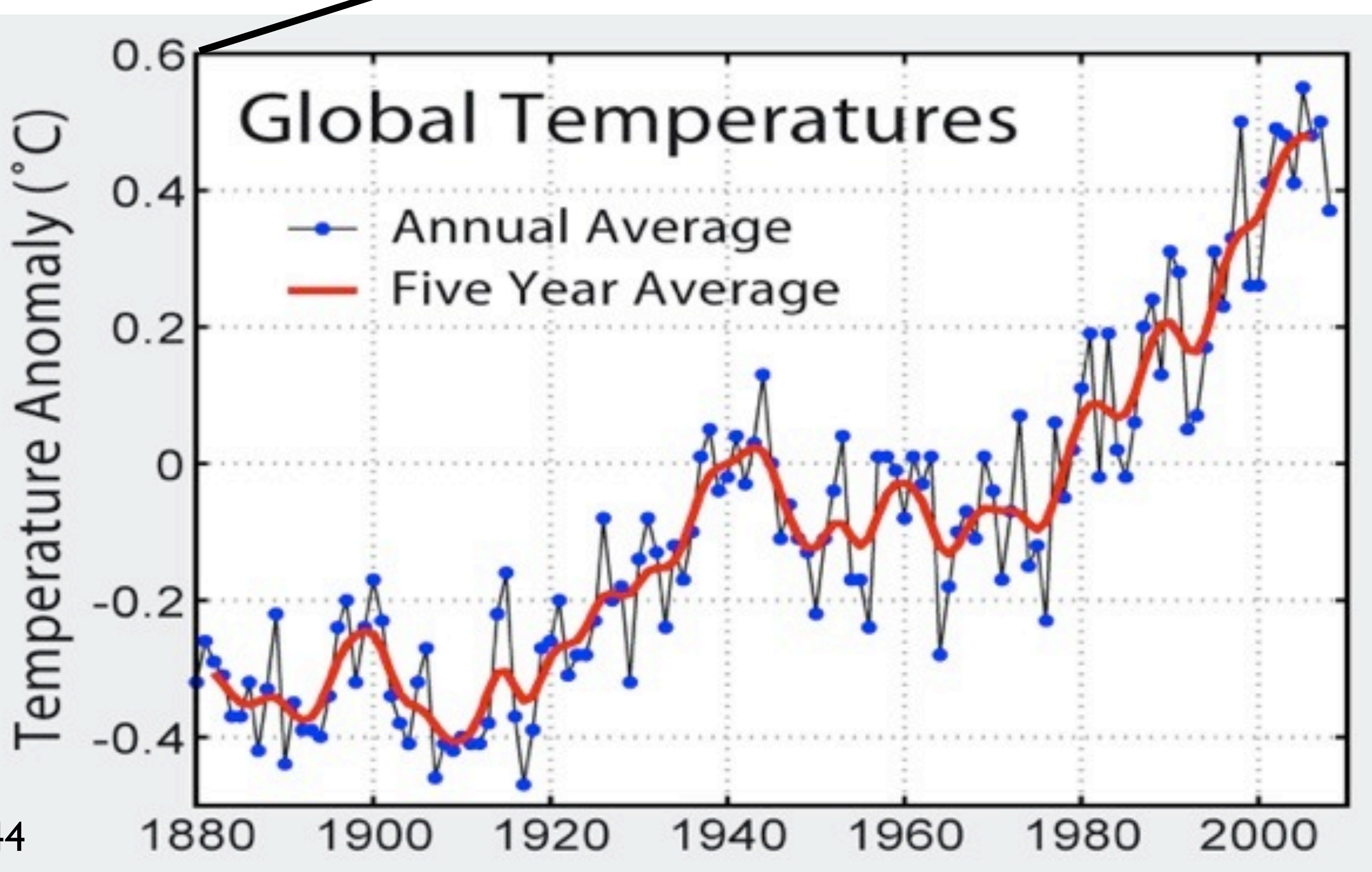


Since 1880:

- ~100 ppm increase in atmospheric CO_2

GlobalWarmingArt.com





Since 1880:

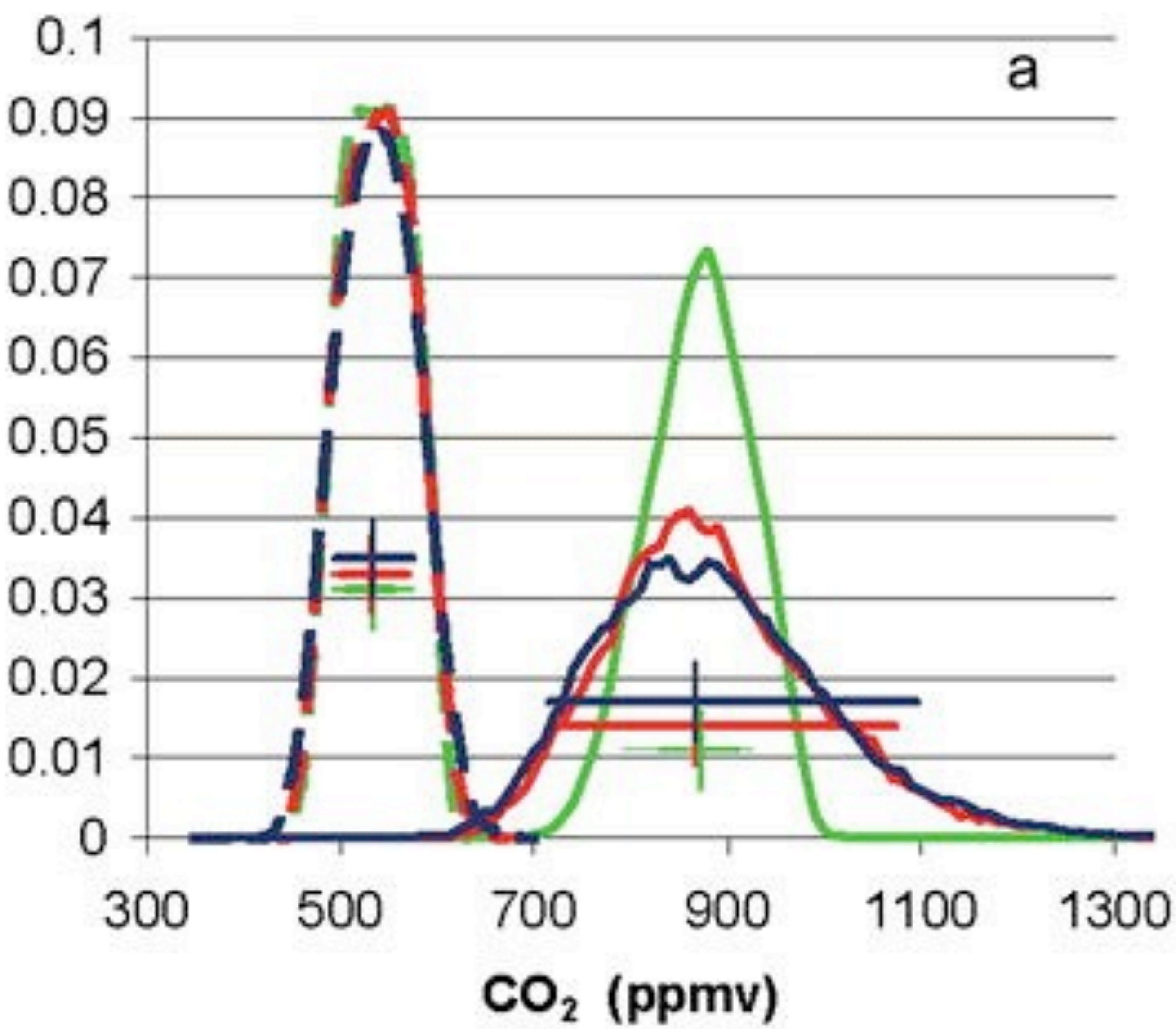
- ~100 ppm increase in atmospheric CO_2
- ~0.8°C increase in mean global temperature

GlobalWarmingArt.com

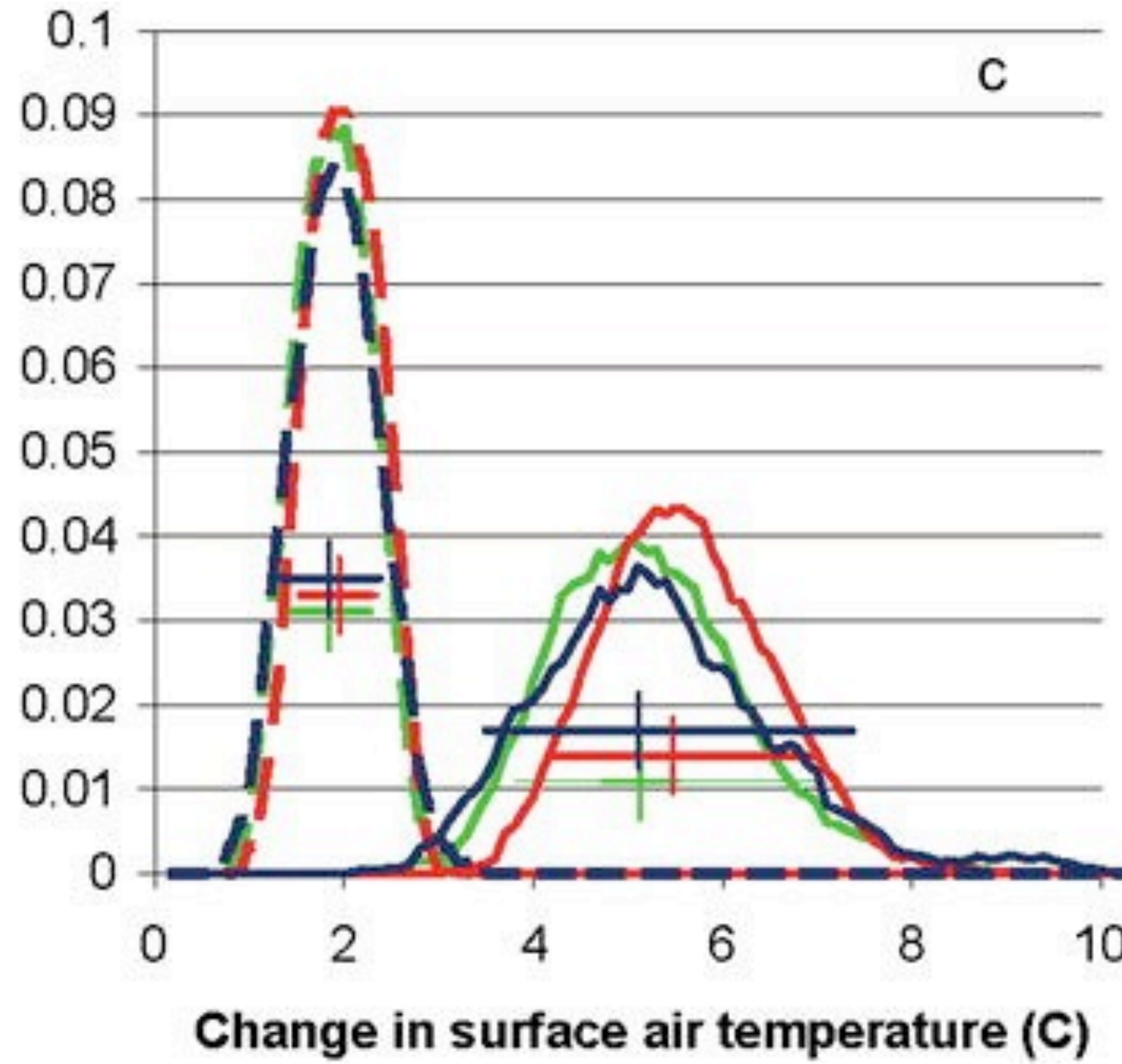
MIT IGSM projections for 2041-2050 and 2091-2100

(“Business-as-usual” no policy case)

CO_2



Surface Temperature



Red: Emissions Uncertainty

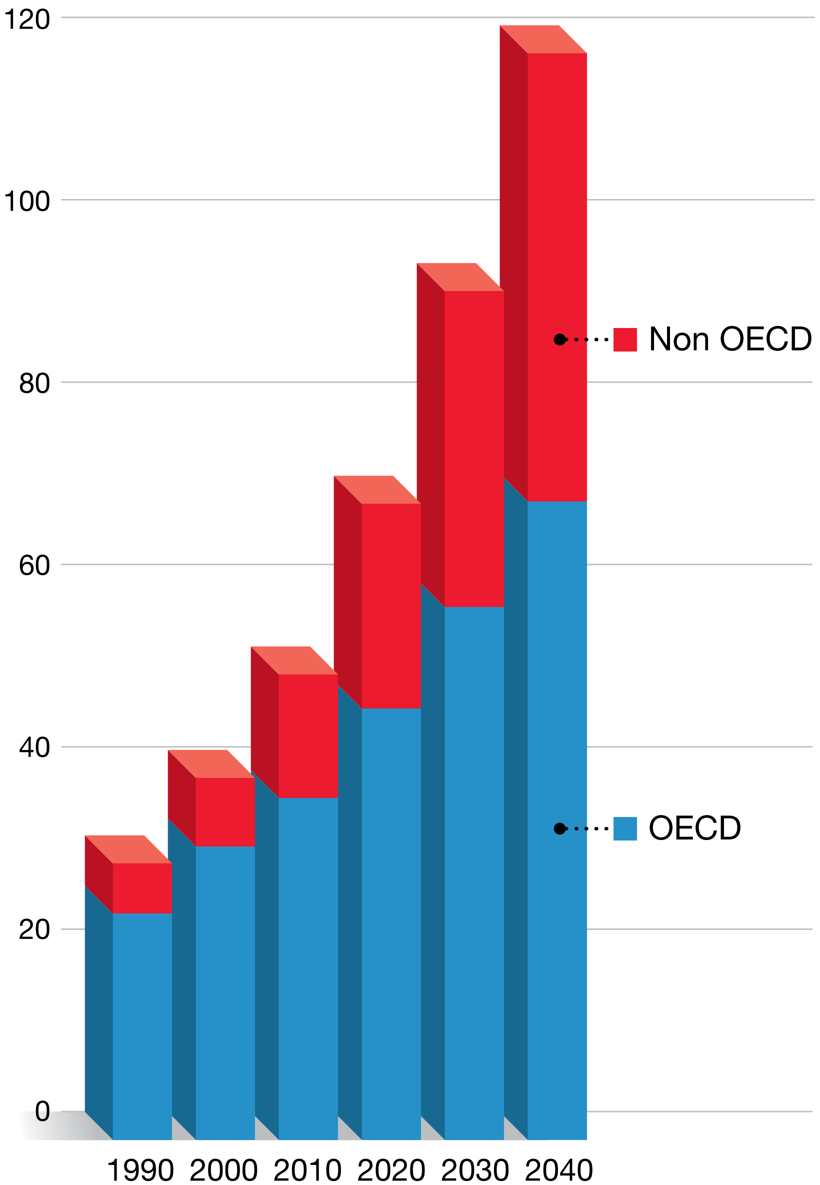
Green: Climate and Carbon Cycle Uncertainty

Blue: Combined Uncertainty

Sokolov et al. (2009)

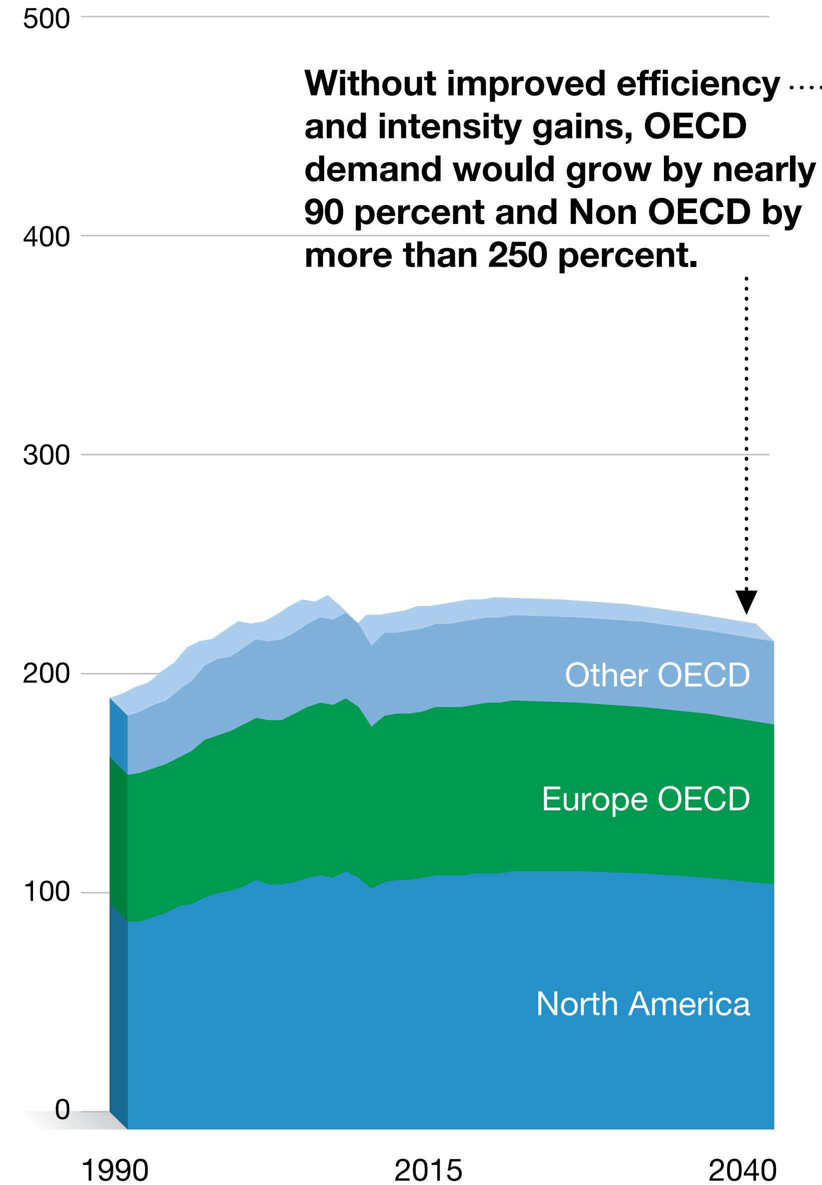
Global GDP by region

Trillions of 2005 dollars



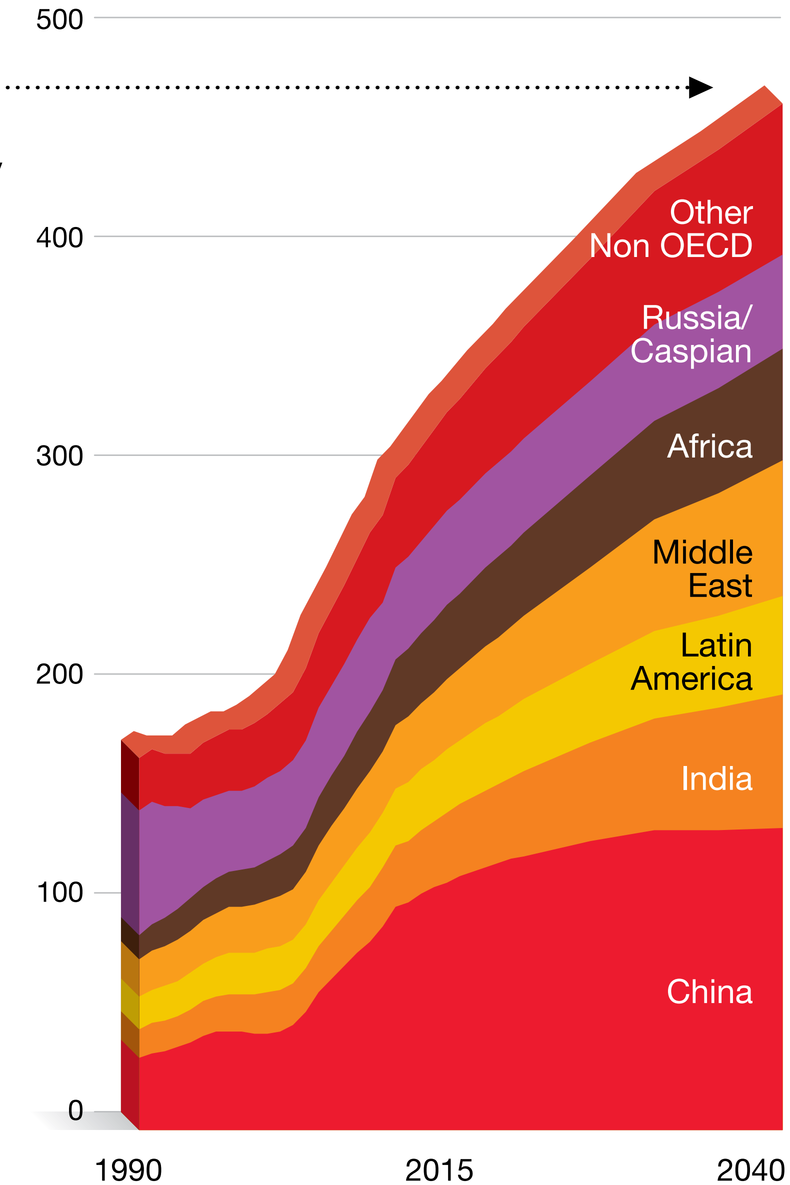
OECD energy demand

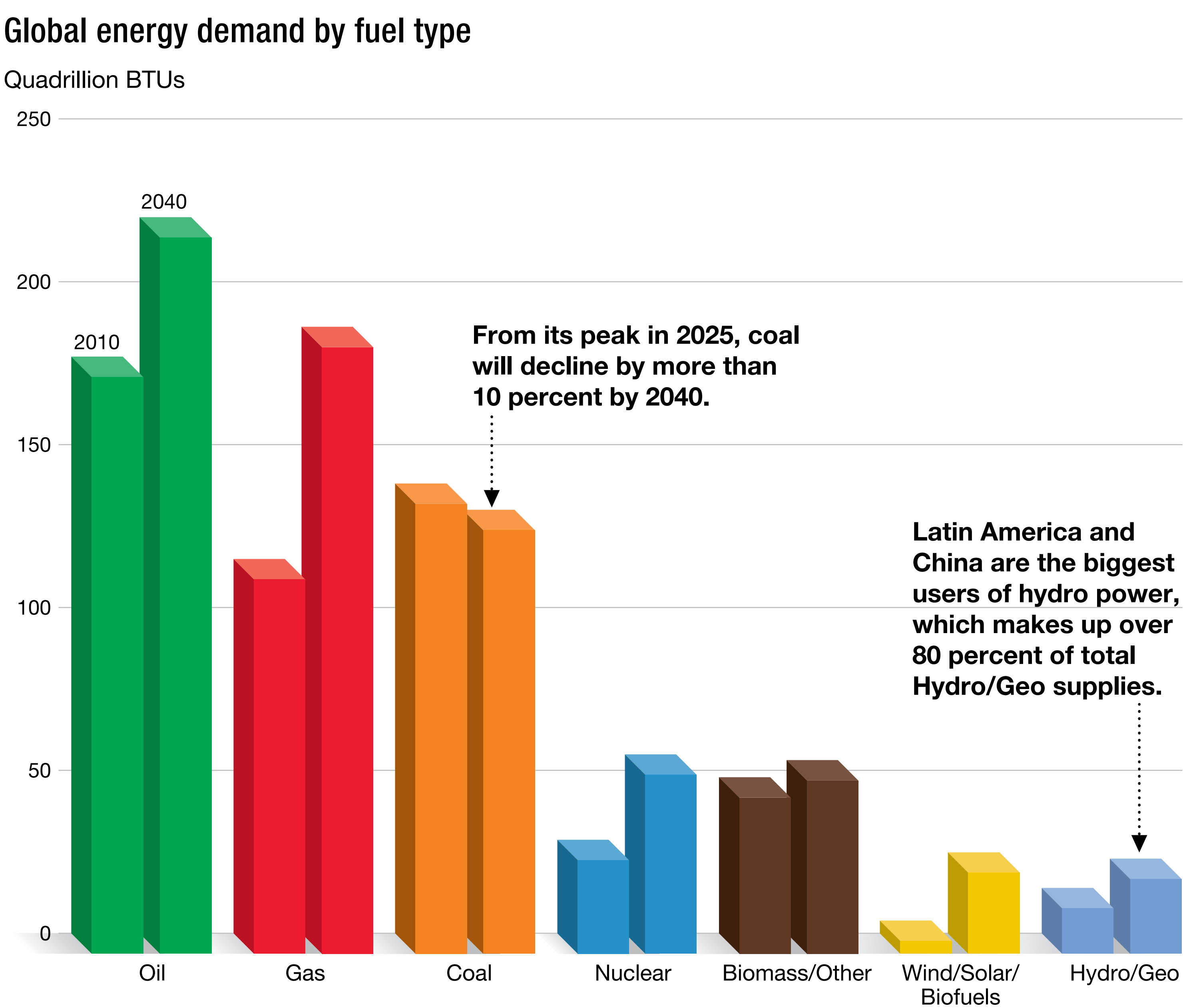
Quadrillion BTUs

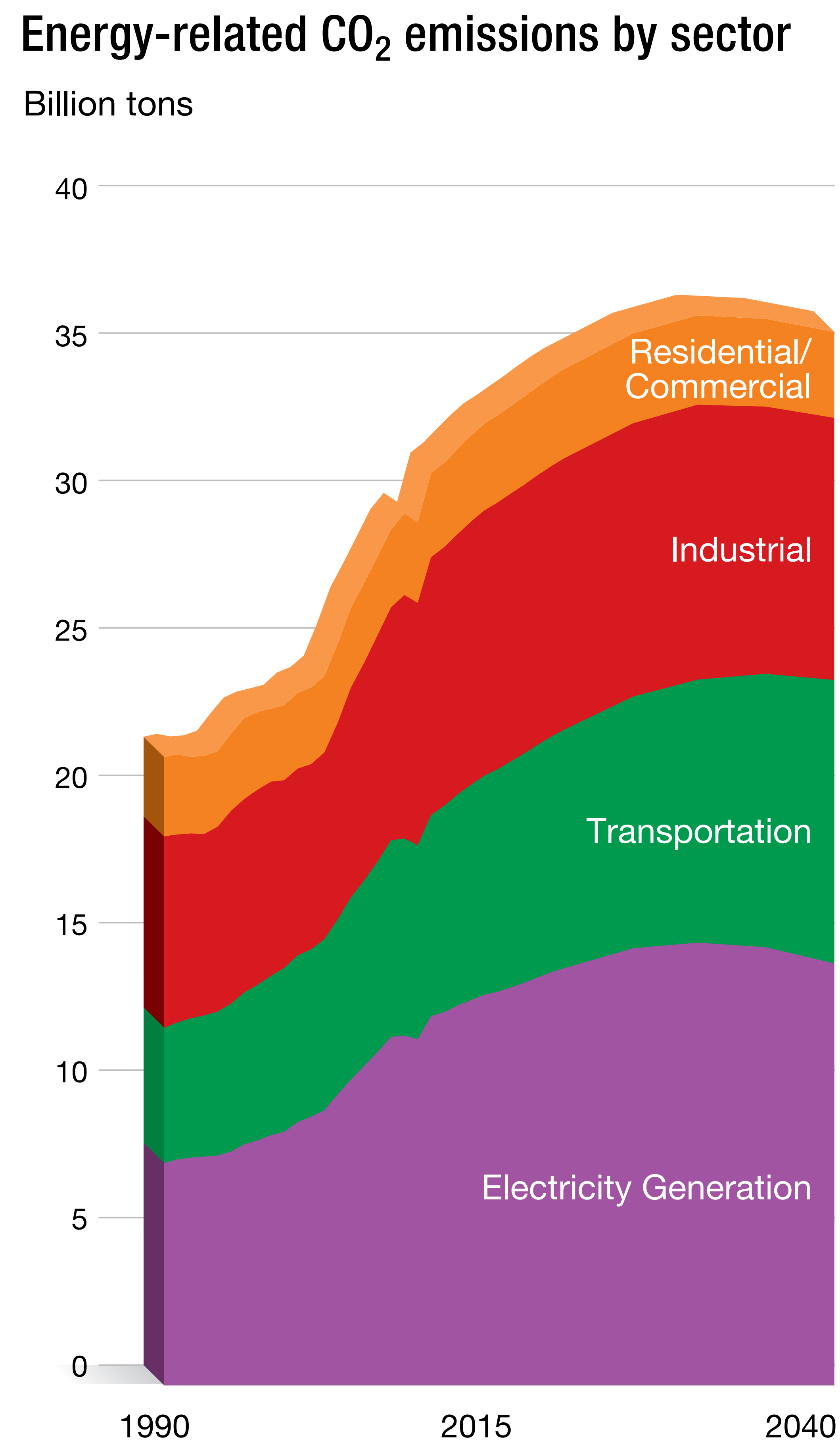


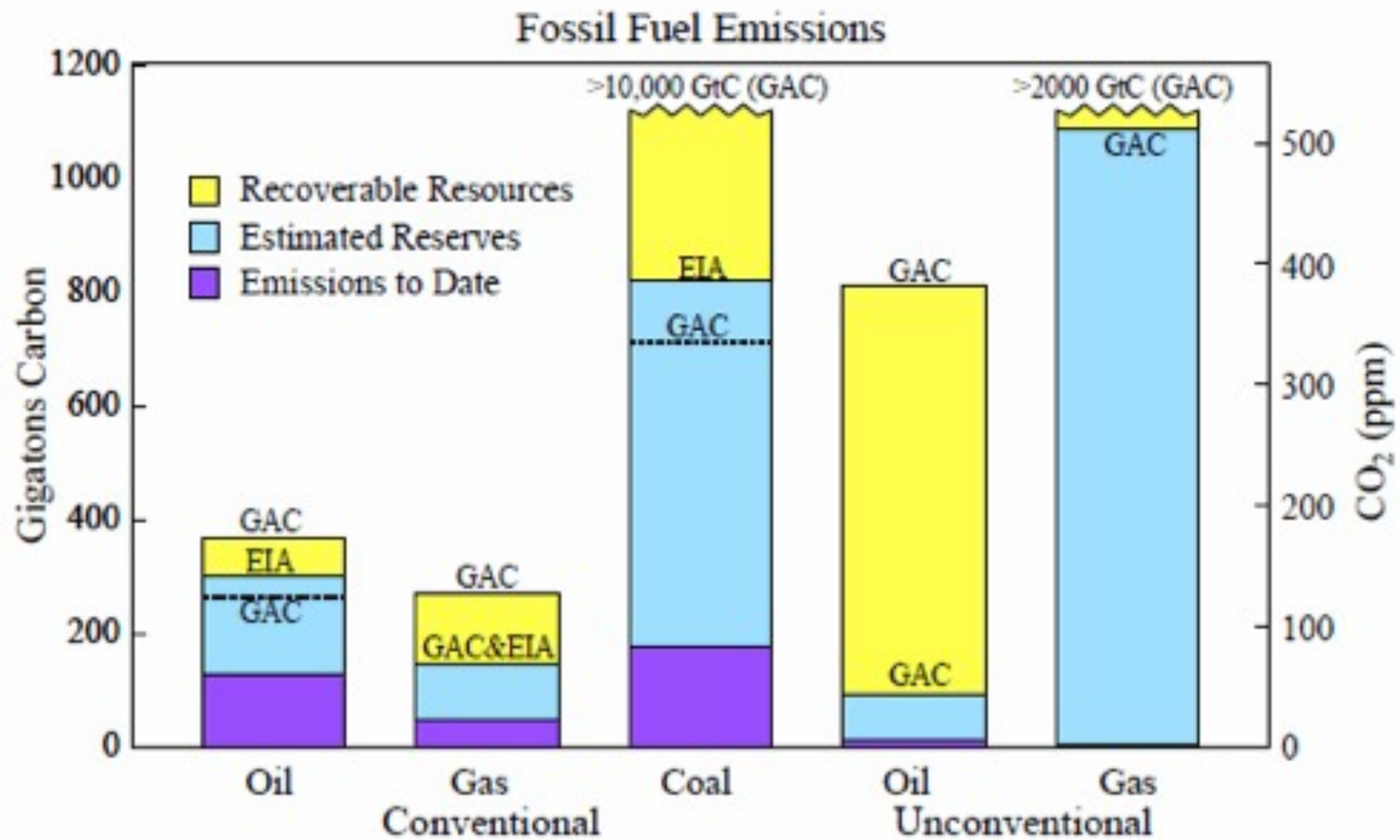
Non OECD energy demand

Quadrillion BTUs

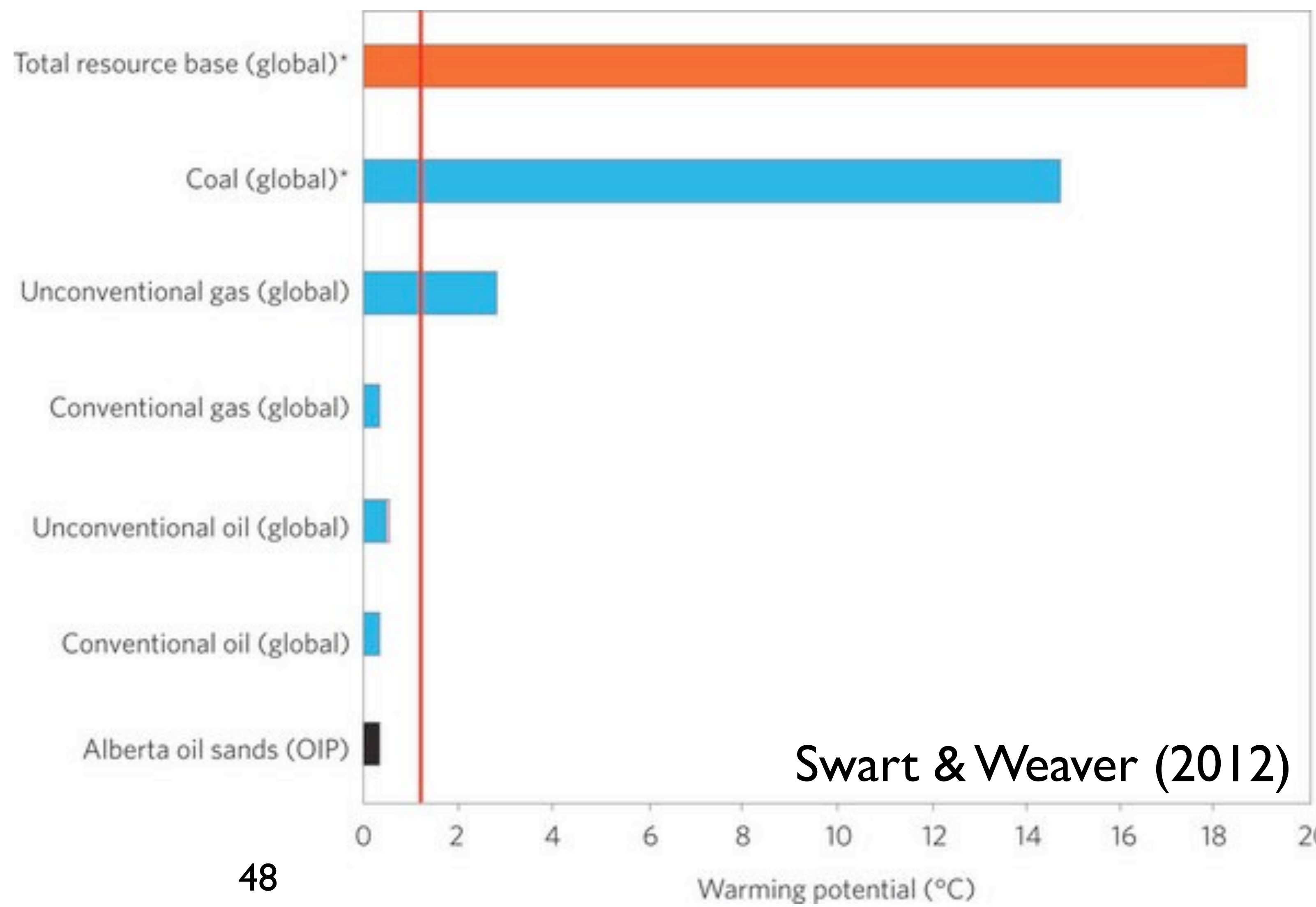



Global energy demand by fuel type
Quadrillion BTUs
250
200
150
100
50
0
2010
2040
From its peak in 2025, coal will decline by more than 10 percent by 2040.
Latin America and China are the biggest users of hydro power, which makes up over 80 percent of total Hydro/Geo supplies.
Oil
Gas
Coal
Nuclear
Biomass/Other
Wind/Solar/Biofuels
Hydro/Geo


Energy-related CO_2 emissions by sector
Billion tons
40
35
30
25
20
15
10
5
0
Residential/Commercial
Industrial
Transportation
Electricity Generation
1990
2015
2040



Hansen (2012)



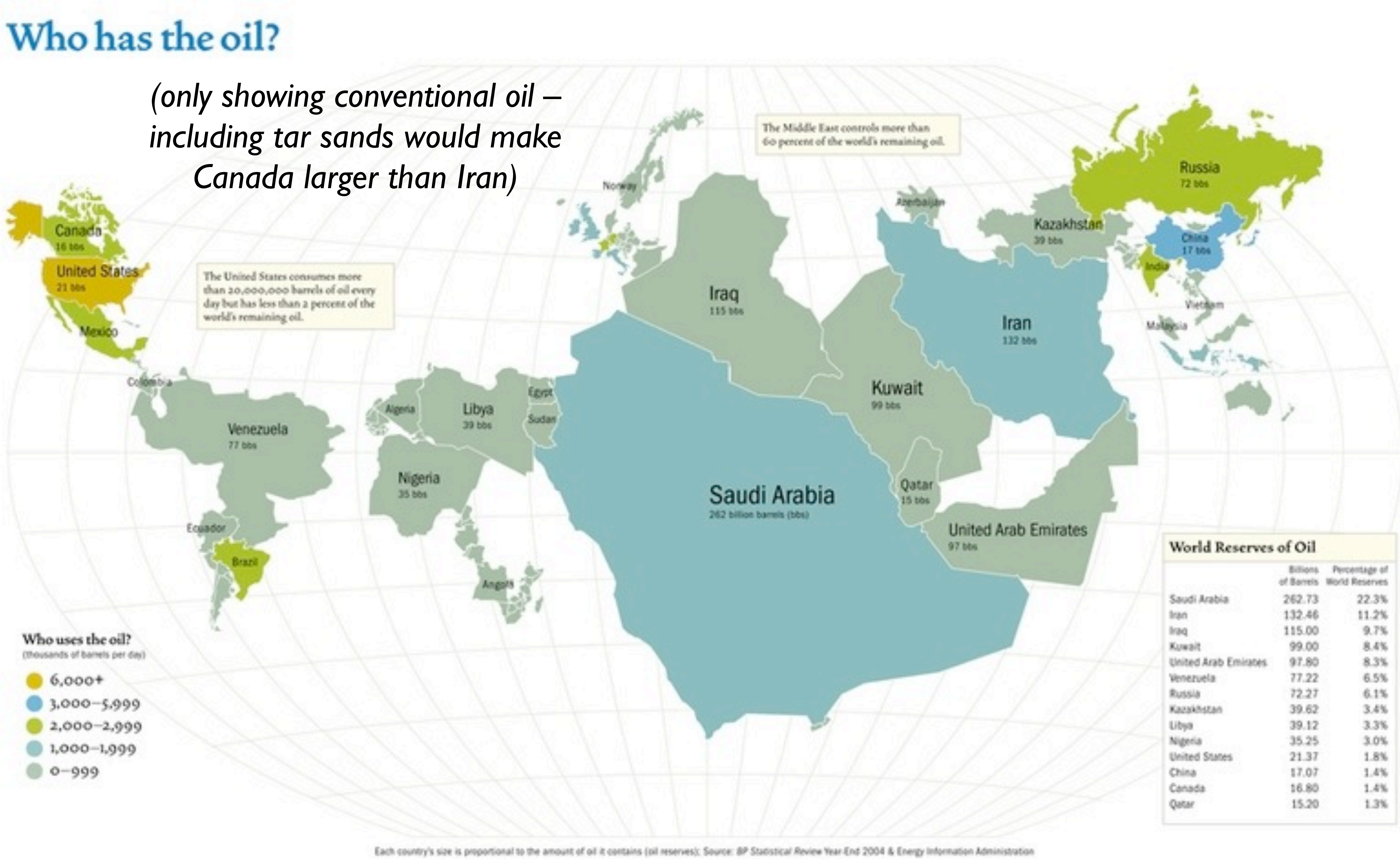
Swart & Weaver (2012)

(oil-in-place includes difficult to produce resources)

Shorter Term Risk: Energy Security

Other problem...

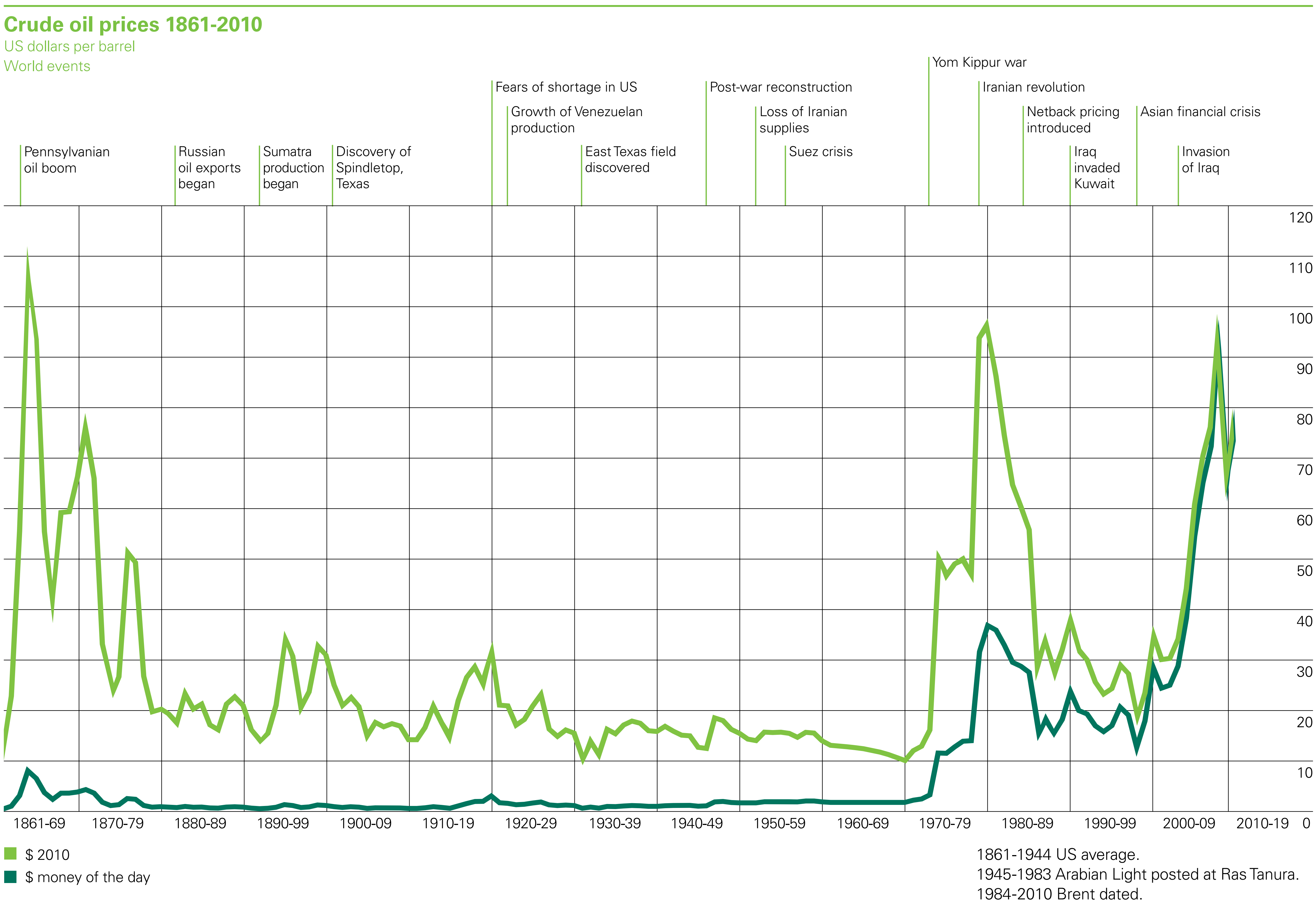
(only showing conventional oil – including tar sands would make Canada larger than Iran)



World Reserves of Oil

	Billions of Barrels	Percentage of World Reserves
Saudi Arabia	262.73	22.3%
Iran	132.46	11.2%
Iraq	115.00	9.7%
Kuwait	99.00	8.4%
United Arab Emirates	97.80	8.3%
Venezuela	77.22	6.5%
Russia	72.27	6.1%
Kazakhstan	39.62	3.4%
Libya	39.12	3.3%
Nigeria	35.25	3.0%
United States	21.37	1.8%
China	17.07	1.4%
Canada	16.80	1.4%
Qatar	15.20	1.3%

Other problem...



BP (2011)

Though net imports are declining:

Figure 11. Total energy production and consumption, 1980-2035
(quadrillion Btu)

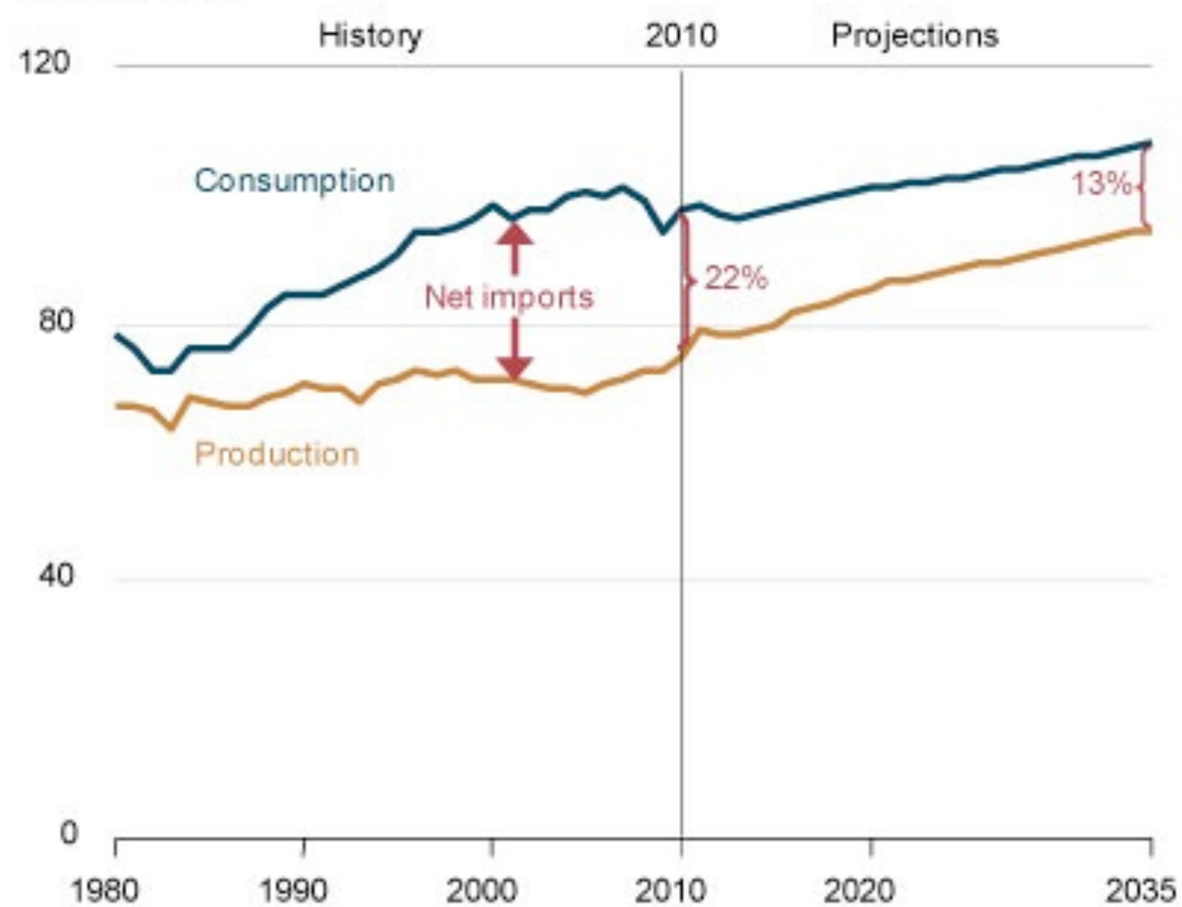
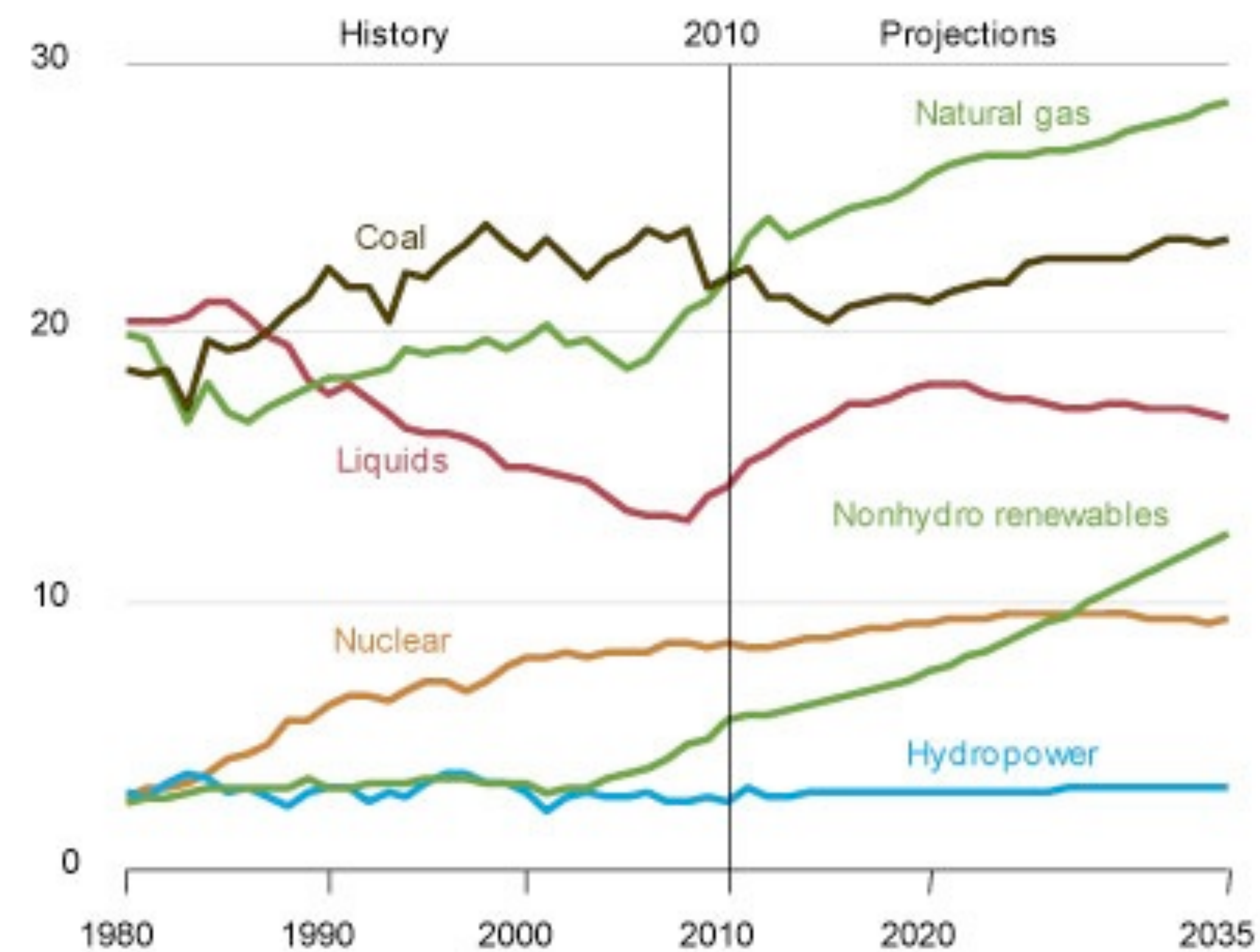
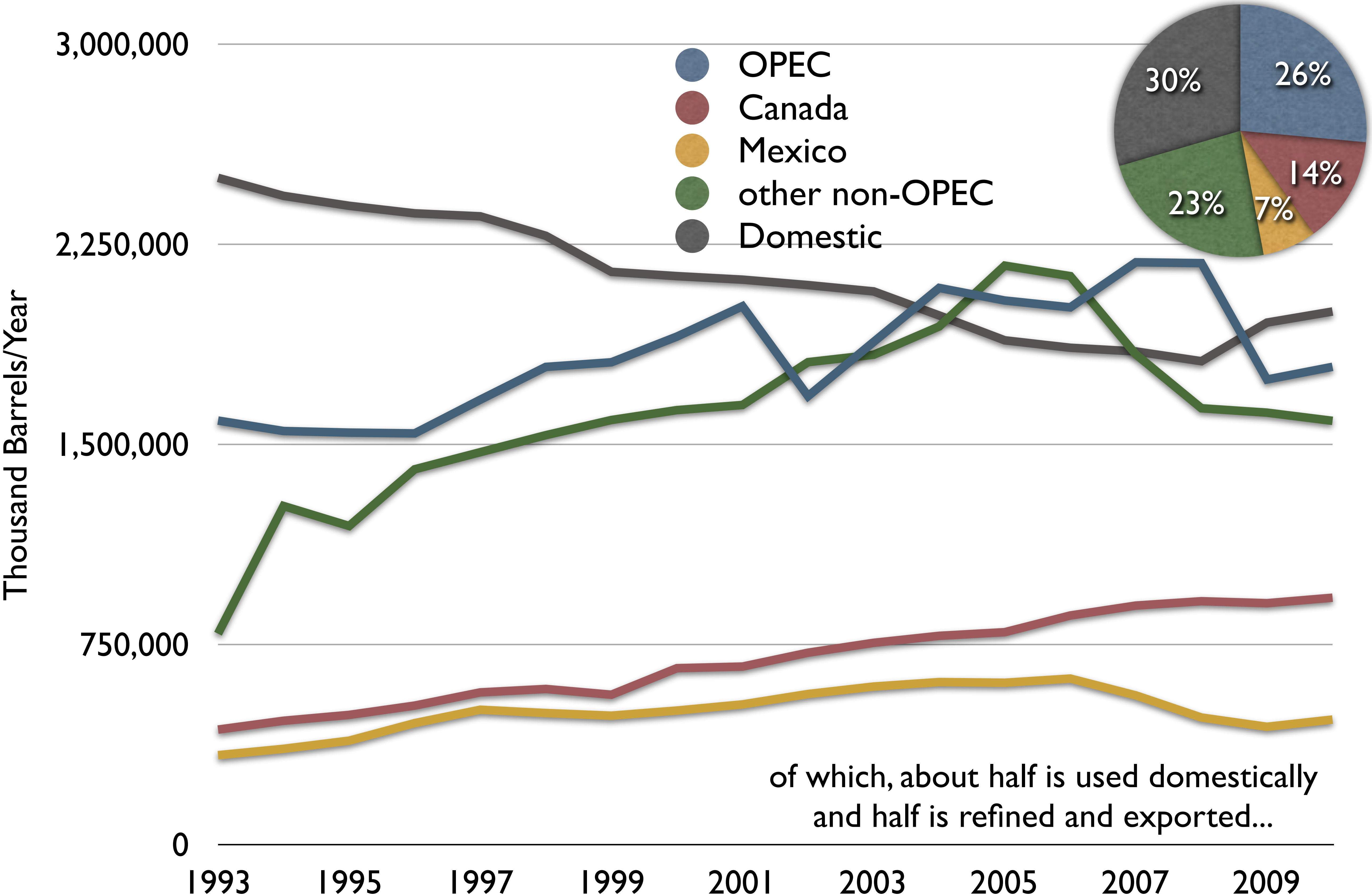


Figure 12. Energy production by fuel, 1980-2035
(quadrillion Btu)



EIA (2012)

Where does our crude oil come from today?



of which, about half is used domestically and half is refined and exported...

EIA (2012)

What demand-side alternatives are there? What are the barriers?

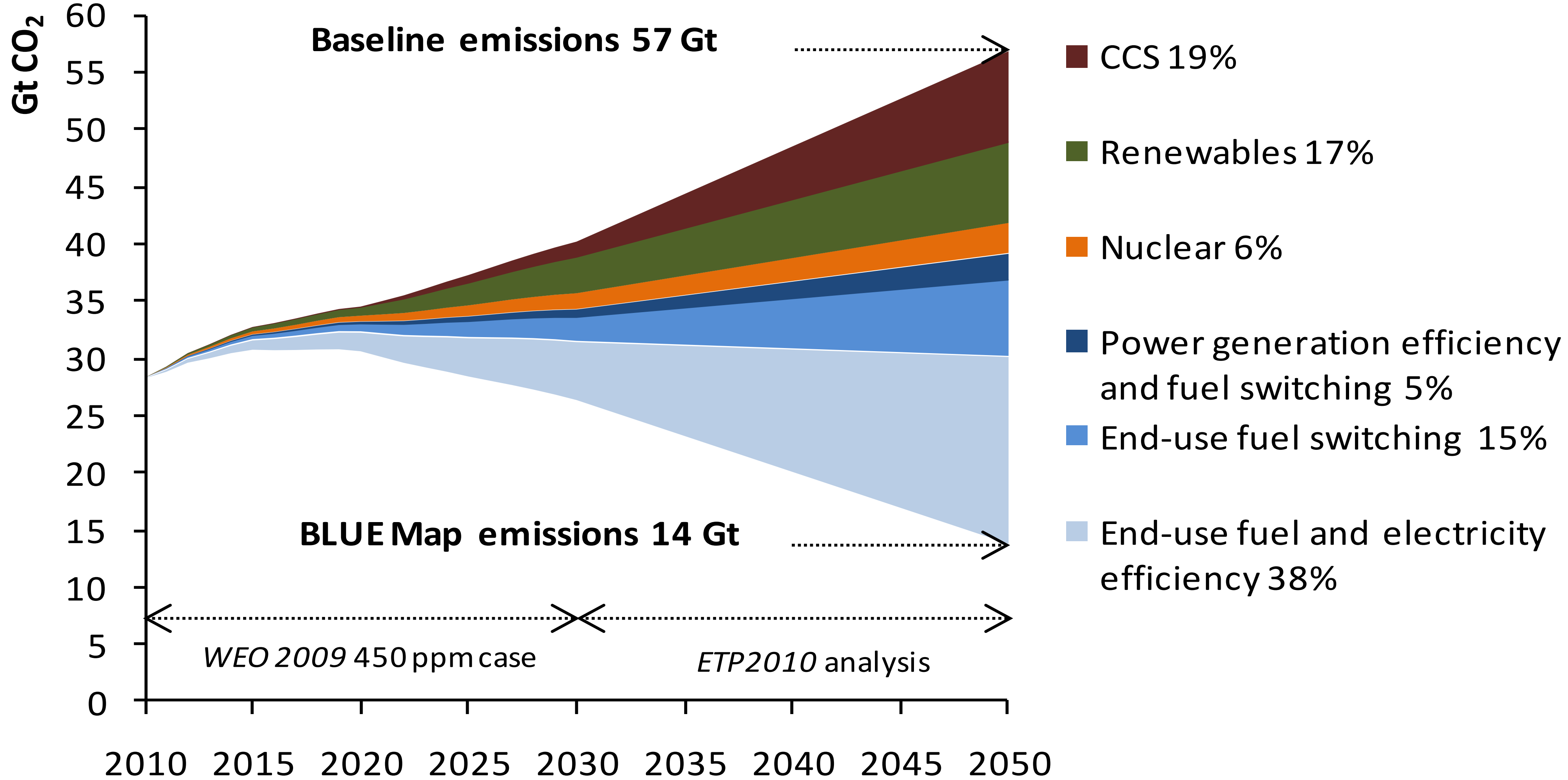
Consider the readings and your personal energy audit.

In your groups, consider ways of reducing energy consumption. Which would seem to be most effective? For ones that can be adopted at an individual level, what is preventing you from adopting them? For ones that require societal action, what do you think the barriers are?

What supply-side alternatives are there? What are the barriers?

In your groups, discuss what alternative, low-carbon energy supply options are there. What are some barriers to their deployment?

Key technologies for reducing global CO_2 emissions under the BLUE Map scenario



A wide range of technologies will be necessary to reduce energy-related CO_2 emissions substantially.

Energy Efficiency

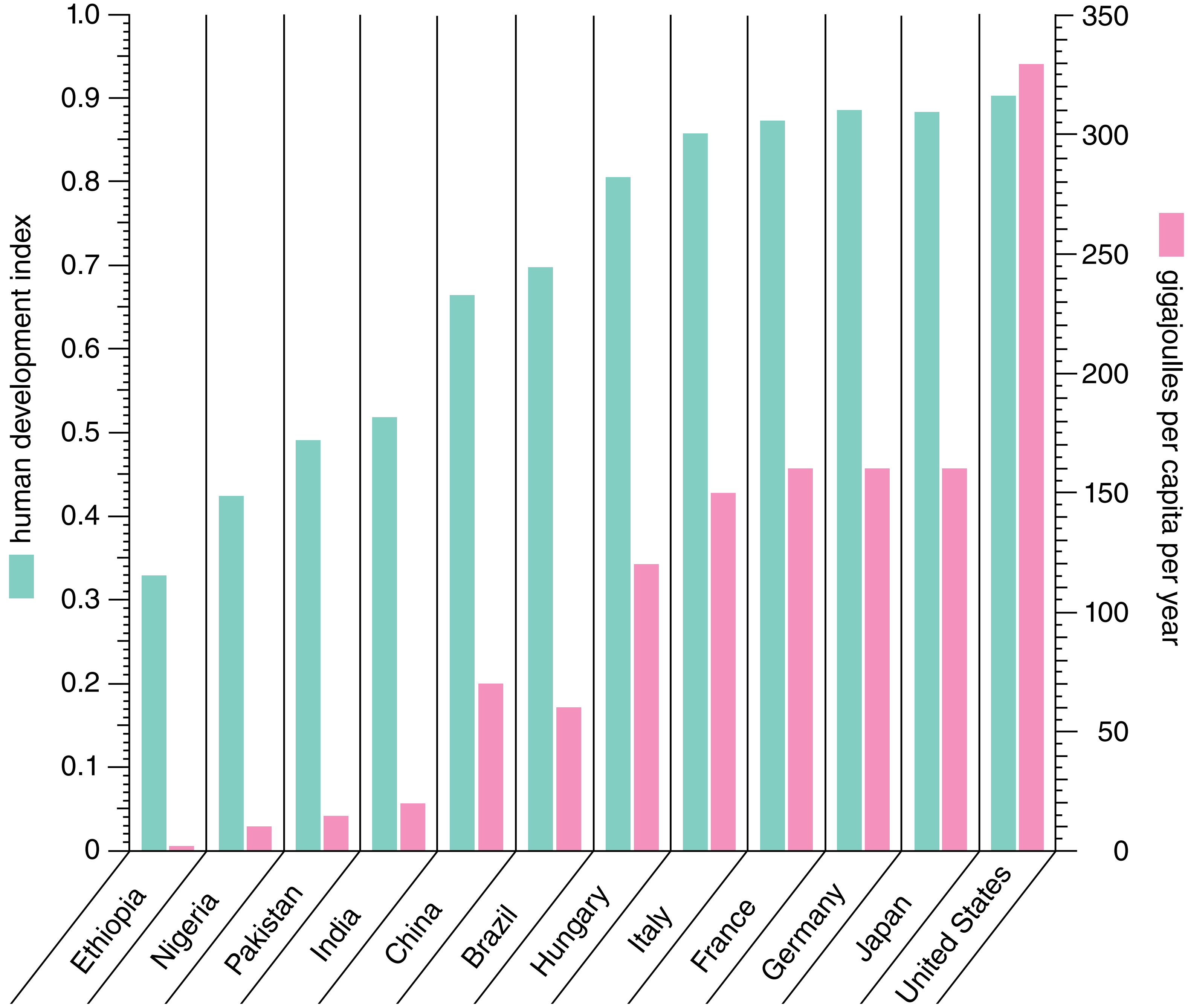
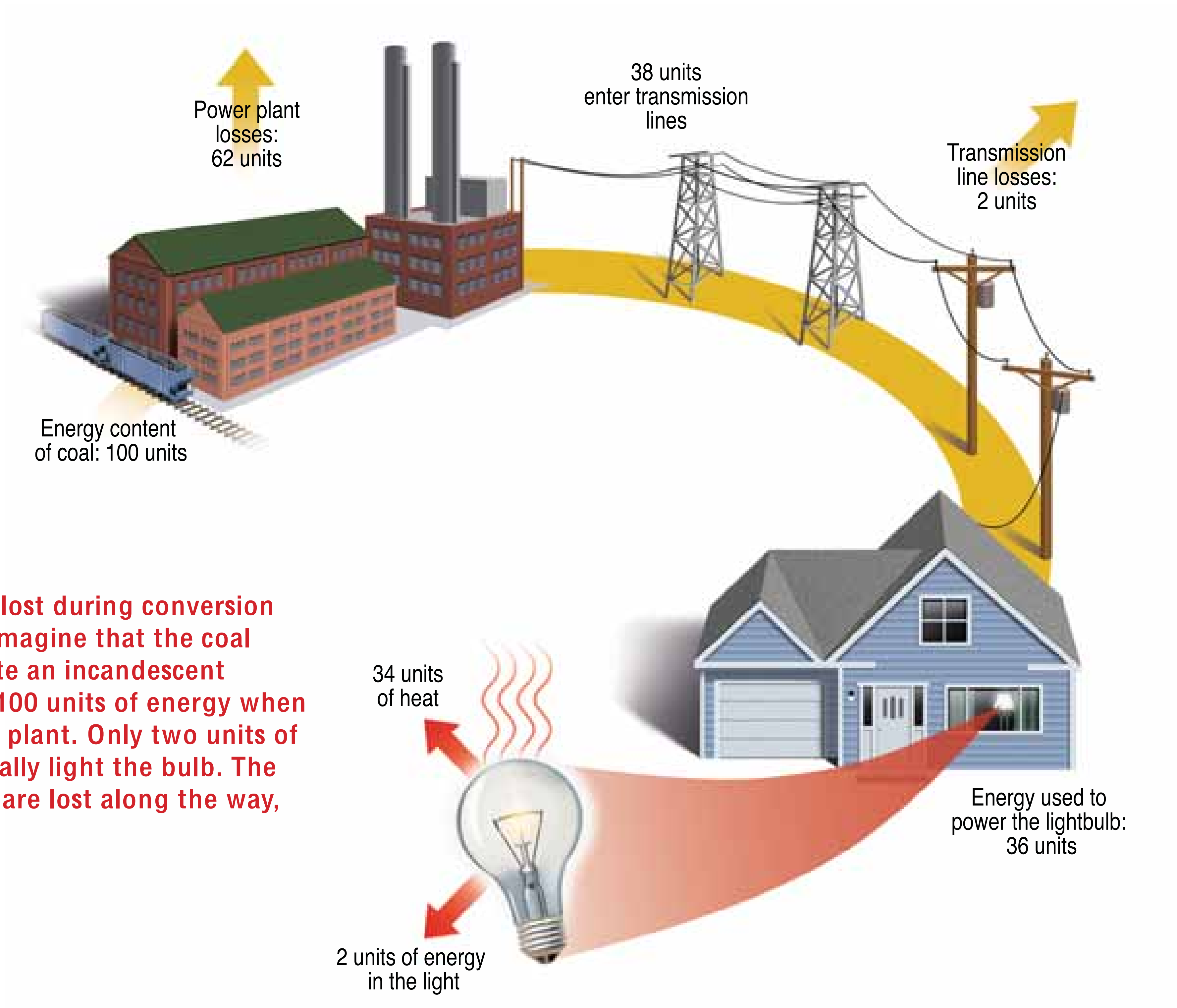


Figure 2. At very low and low per capita consumption levels, higher use of energy is clearly tied to rising index of human development, but once energy per capita reaches about 150 gigajoules per year, the correlation breaks down. More is not better.

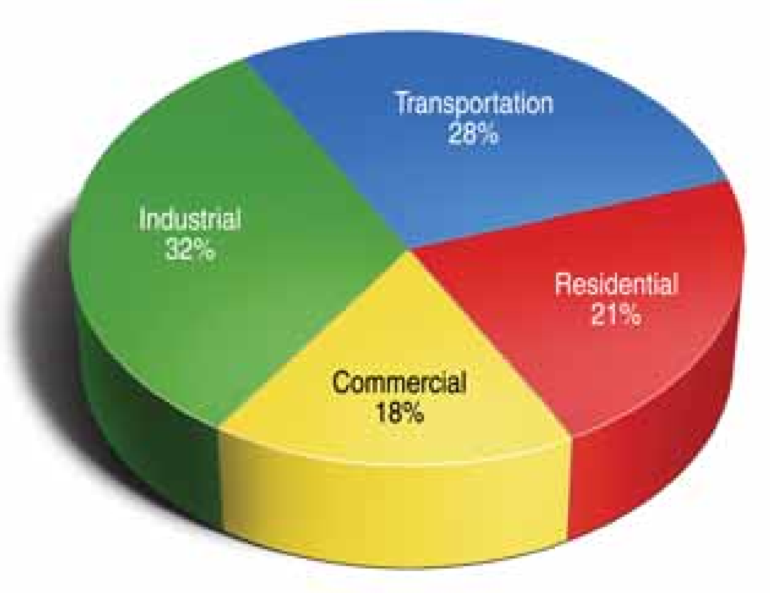
Smil, 2011



Example of energy lost during conversion and transmission. Imagine that the coal needed to illuminate an incandescent lightbulb contains 100 units of energy when it enters the power plant. Only two units of that energy eventually light the bulb. The remaining 98 units are lost along the way, primarily as heat.

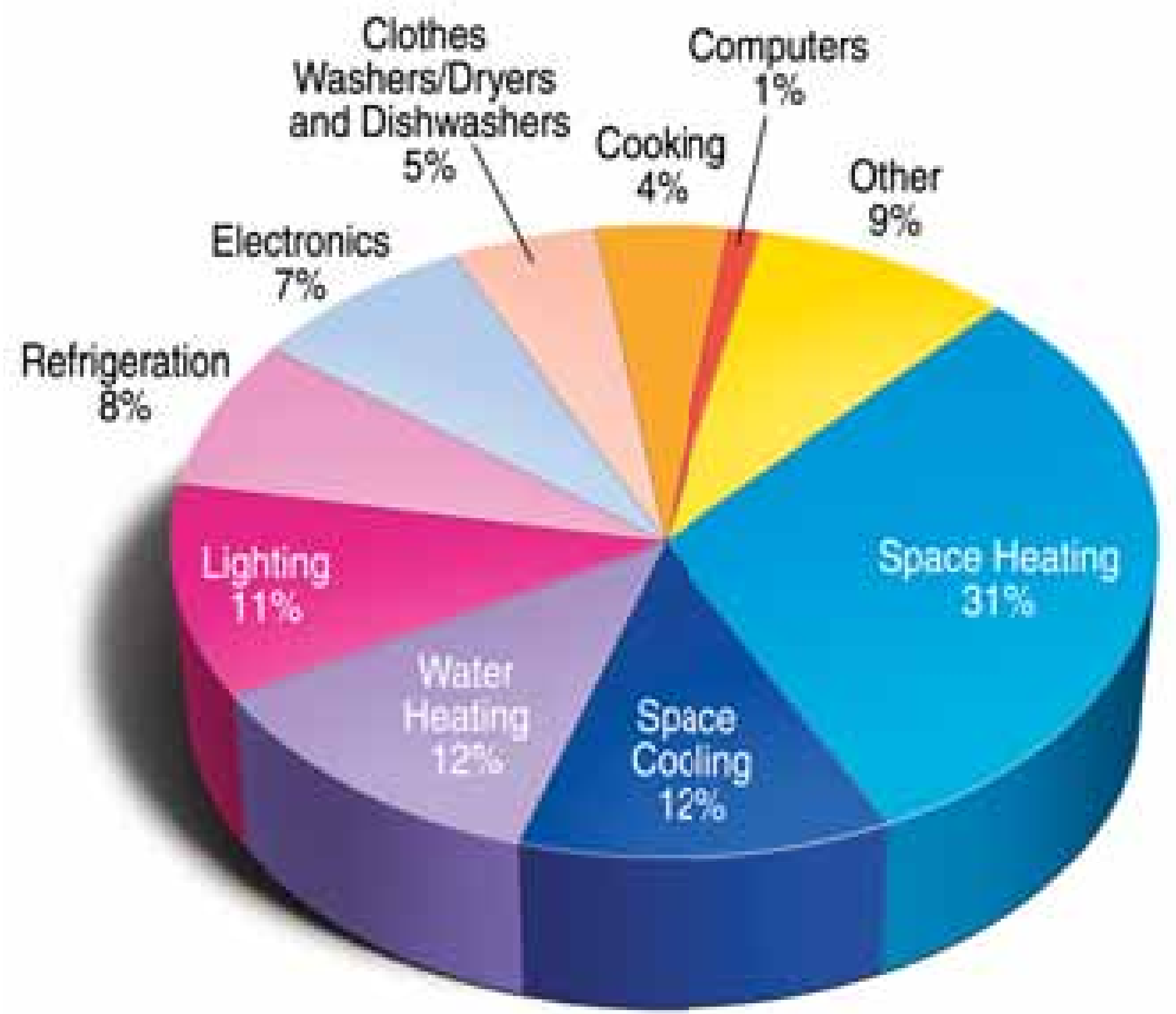
NAS 2008

So what's it used for?



Percentage of energy consumed by each economic sector in the United States in 2006.*

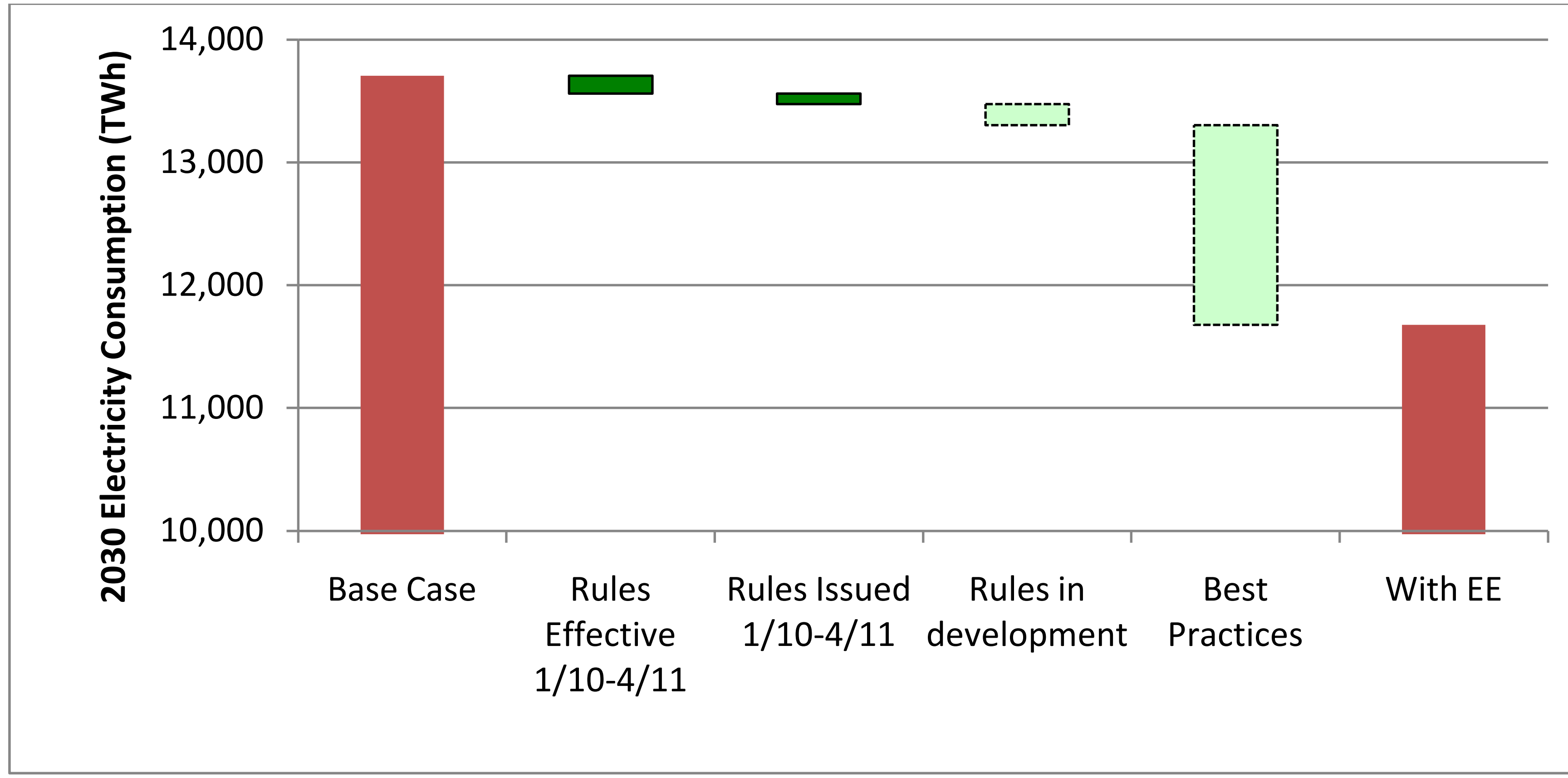
* Percentages do not sum to 100% due to independent rounding.

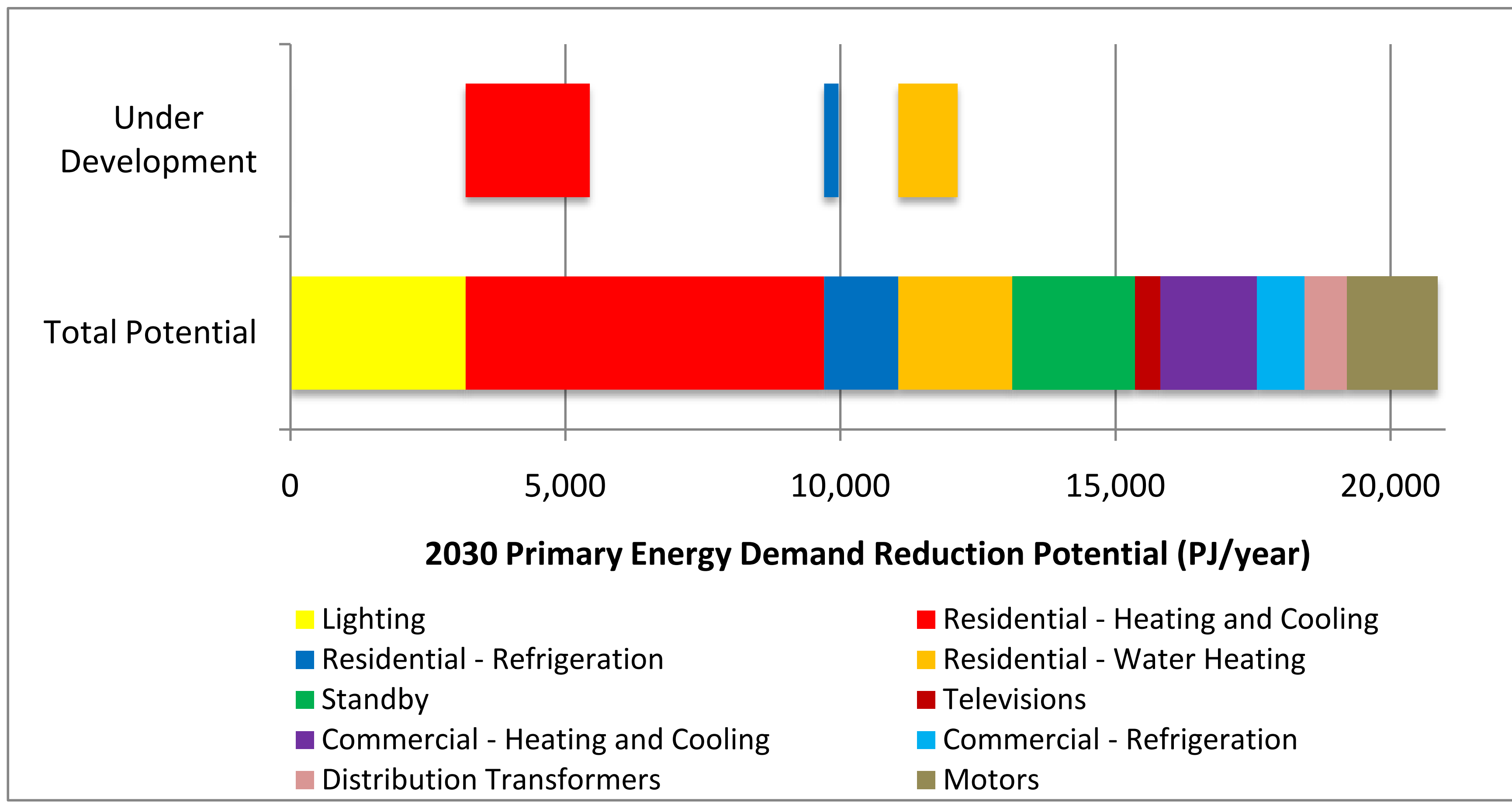


Energy usage in the U.S. residential sector in 2006.

NAS 2008

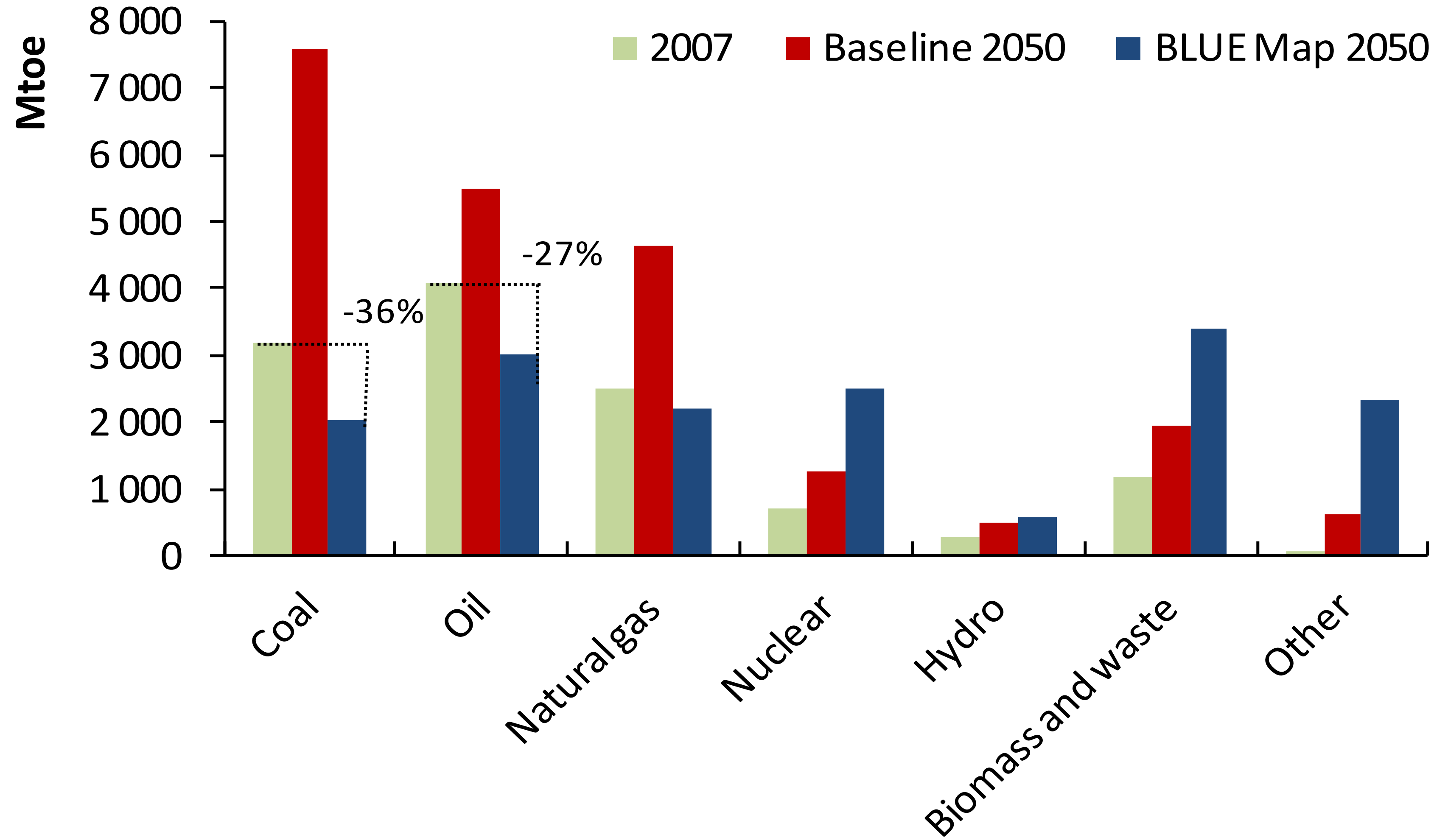
Appliance efficient potential in SEAD partners from best practice adoption





SUPEREFFICIENT.ORG

Primary energy demand by fuel and by scenario



By 2050, coal, oil and gas demand are all lower than today under the BLUE Map scenario.

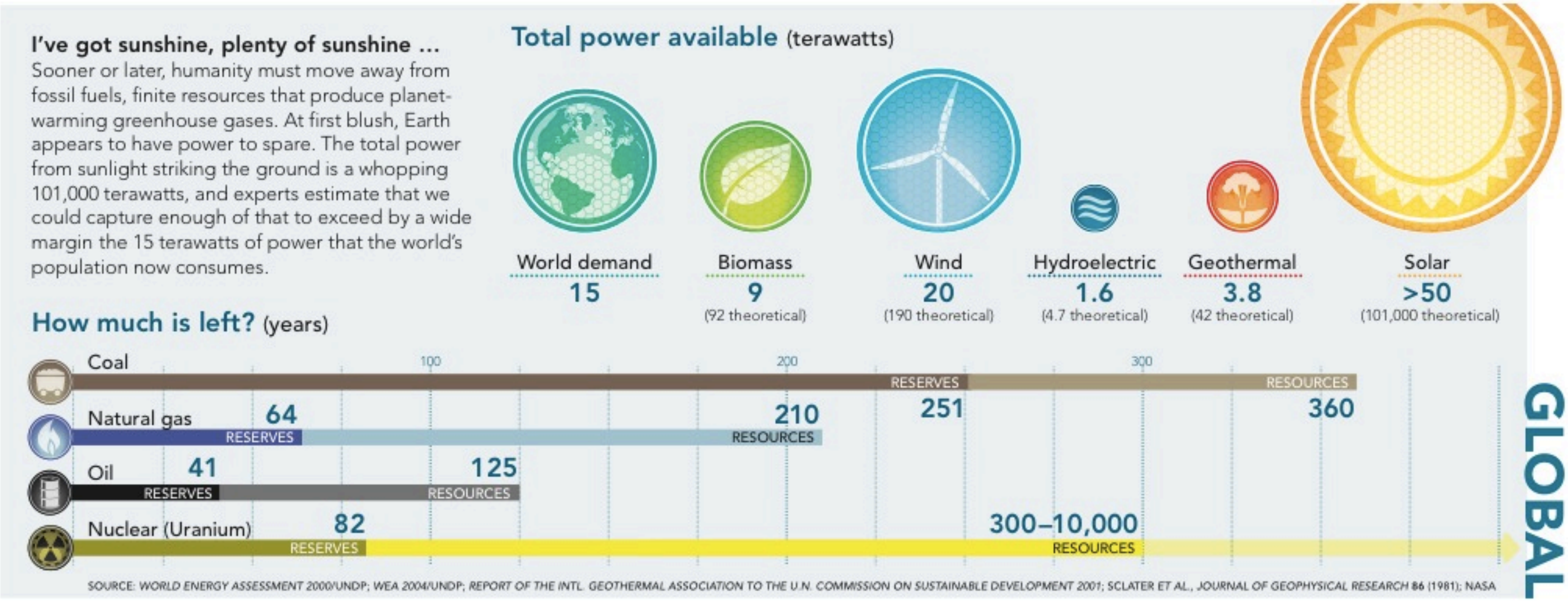
1Mtoe = 11.6 TWh

RECALL: How does our energy use fit into natural energy flows?

Human primary power demand: 15 TW
- Fossil fuel use: 12 TW
- Human appropriation of net primary productivity: 2 TW

Solar flux to surface: 184 W/m^2 = 94,000 TW
Geothermal flux: 44 TW
Net primary productivity: 23 TW
- Buried net primary productivity: ~23 GW
  - *that ultimately turns into fossil fuels: ~10 MW*

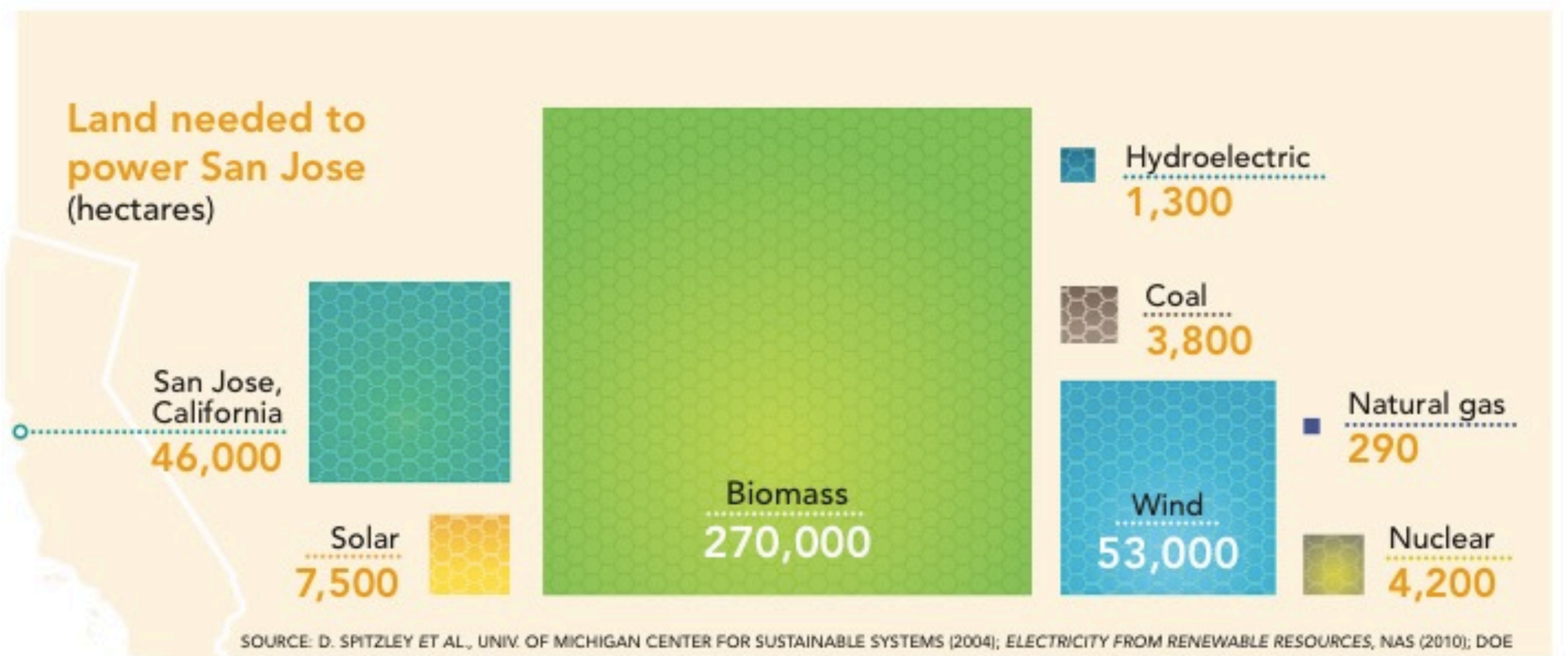
Resource availability



At 184 W/m^2 and 30% efficiency, how much area would it take to produce 15 TW from solar?

Cho (2010), *Science*

Challenge: Power density



San Jose Power Consumption = 740 MW

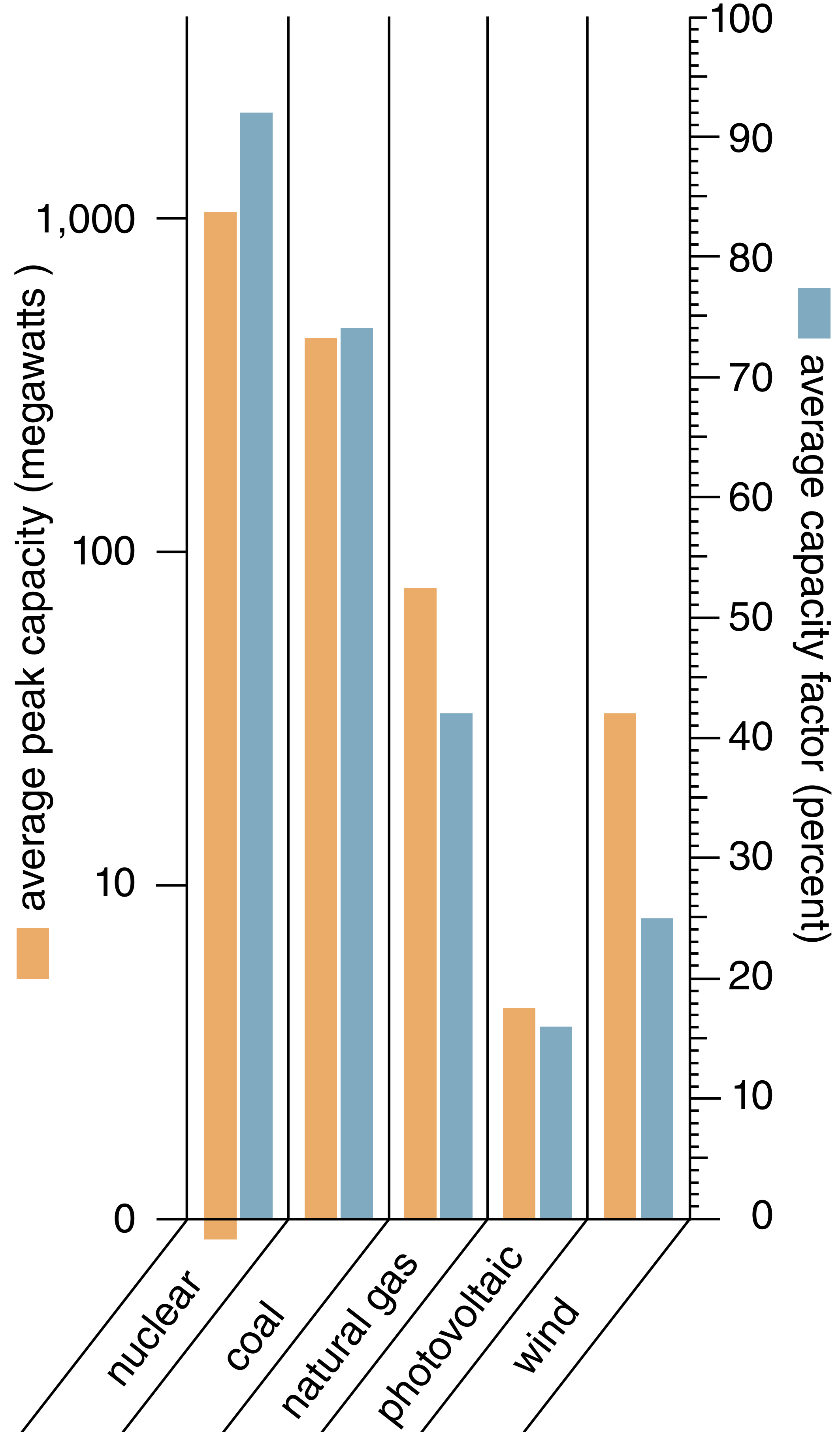
1 hectare = 10,000 m^2

multiply by ~20,000 to get area to power world

Cho (2010), *Science*

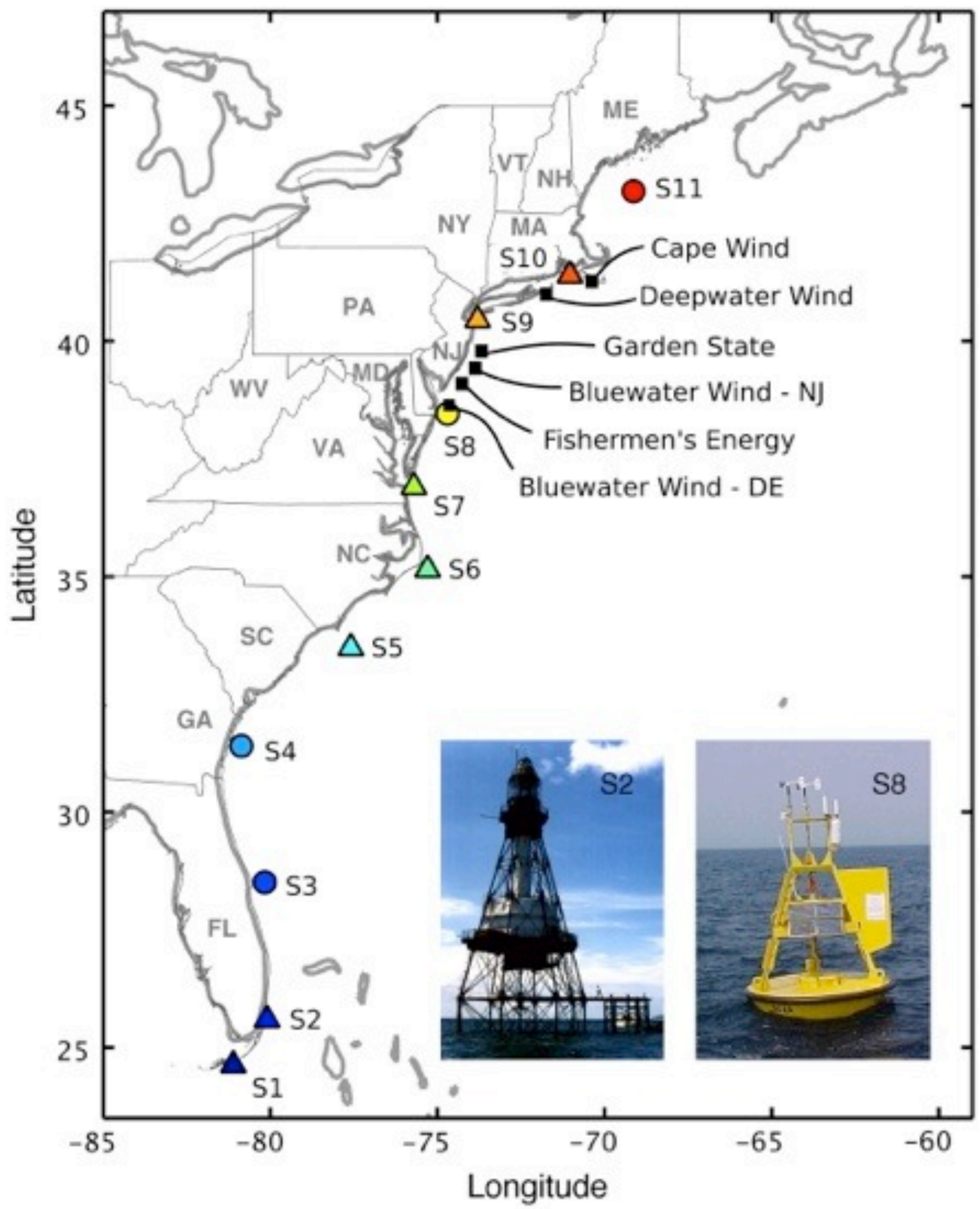
Challenges: Intermittency and Scalability

Solutions for intermittency: backup, grid design, storage



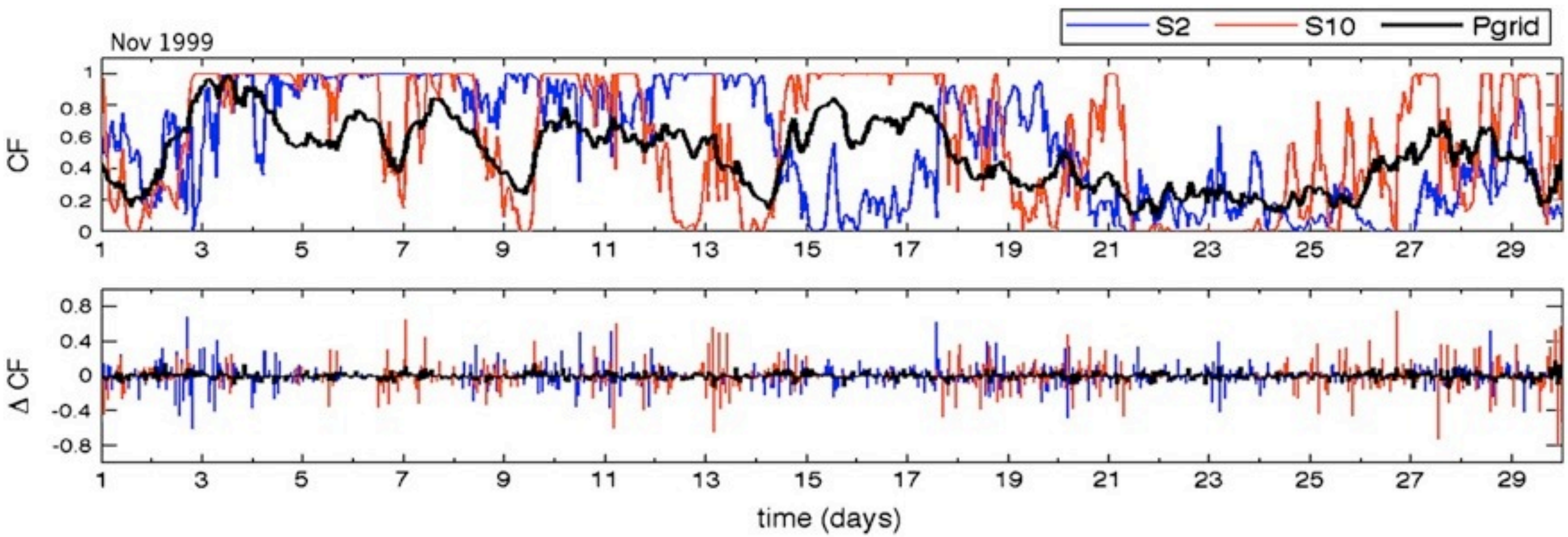
Smil, 2011

Proposed offshore wind projects off the U.S. coast (black squares and names).



Kempton W et al. PNAS 2010;107:7240-7245

(Top) One month of power, expressed as CF, from two isolated wind parks (blue and orange lines) compared with power from the Atlantic Transmission Grid (Pgrid, thick black line).

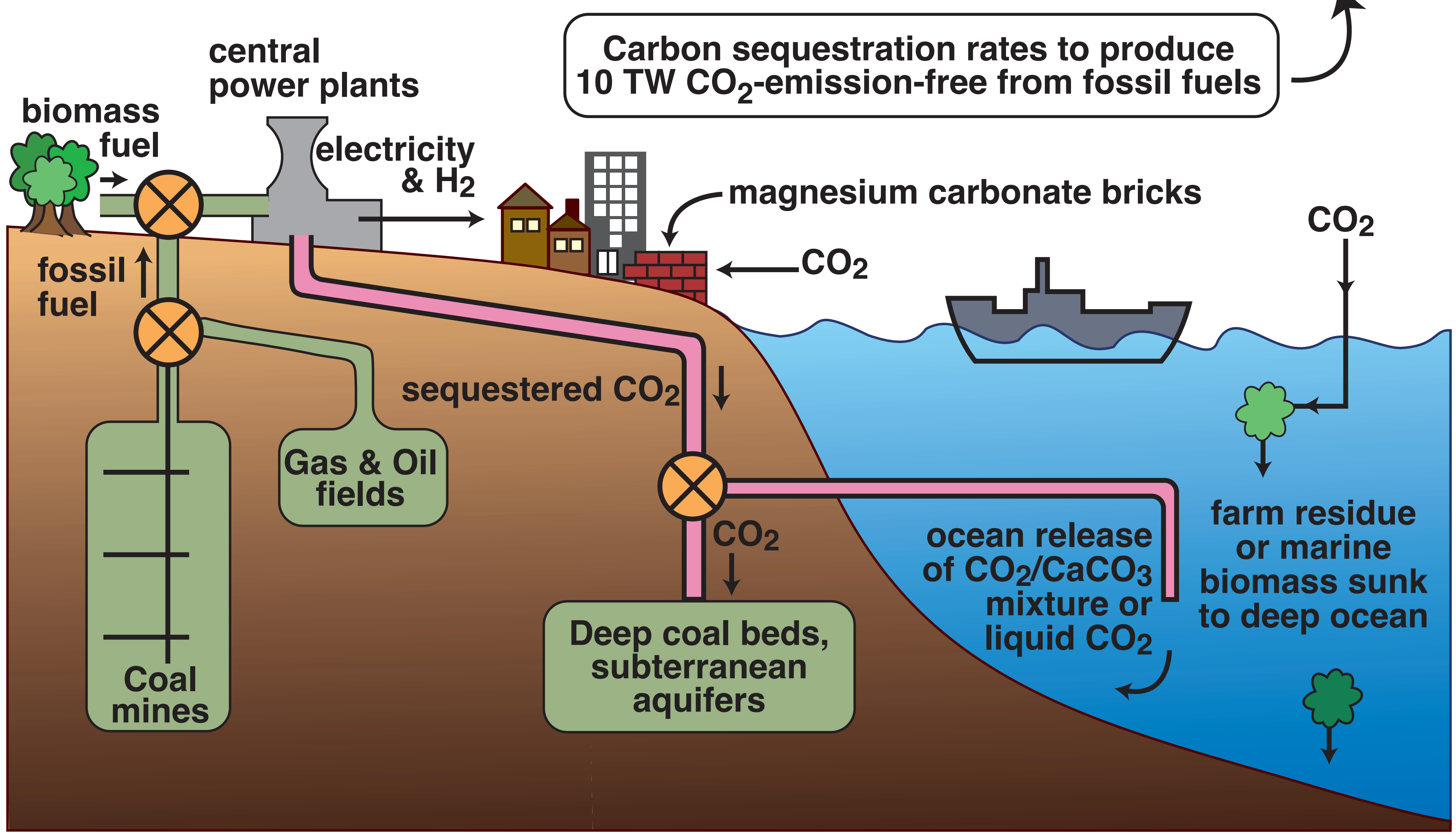


Kempton W et al. PNAS 2010;107:7240-7245

Carbon capture and storage

B

Fossil fuel	Energy content [TW-yr]	Carbon content [GTC]	(E_{fuel}/C) [TW-yr/GtC]	(E/C) [TW-yr/GtC]	Sequestration rate [GtC/yr]
Gas	1200	570	2.1	1.9 - 1.6	5 - 6
Oil	1200	750	1.6	1.4 - 1.2	7 - 8
Coal	4800	3690	1.3	1.2 - 1.0	9 - 10



Hoffert et al., 2002

Carbon capture and storage

B

Fossil fuel	Energy content [TW-yr]	Carbon content [GTC]	(E_{fuel}/C) [TW-yr/GtC]	(E/C) [TW-yr/GtC]	Sequestration rate [GtC/yr]
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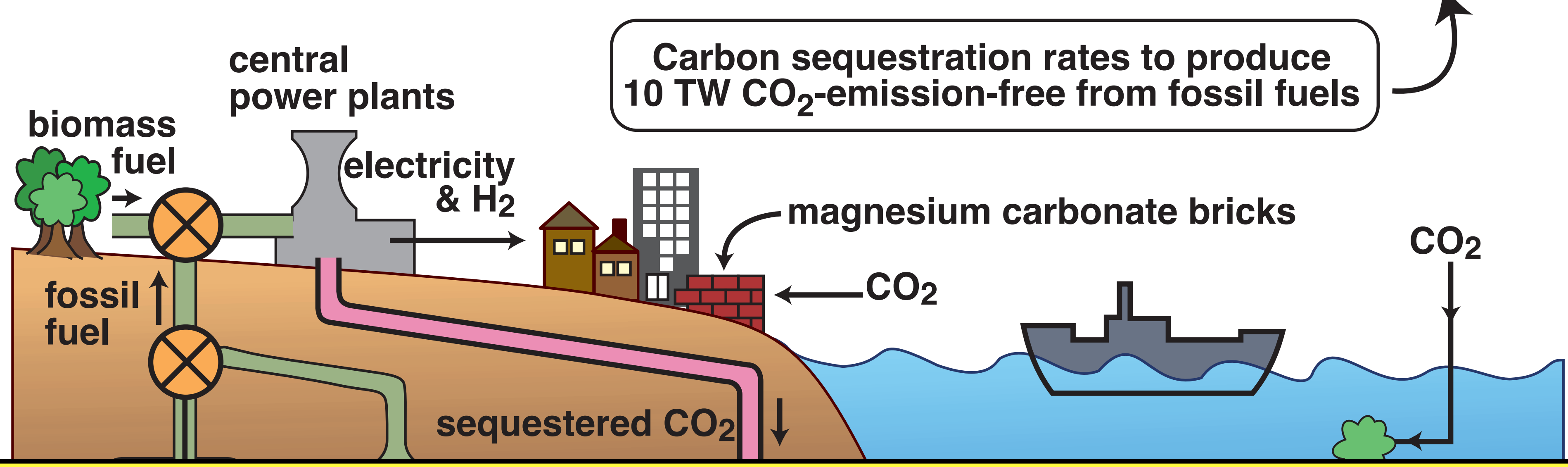
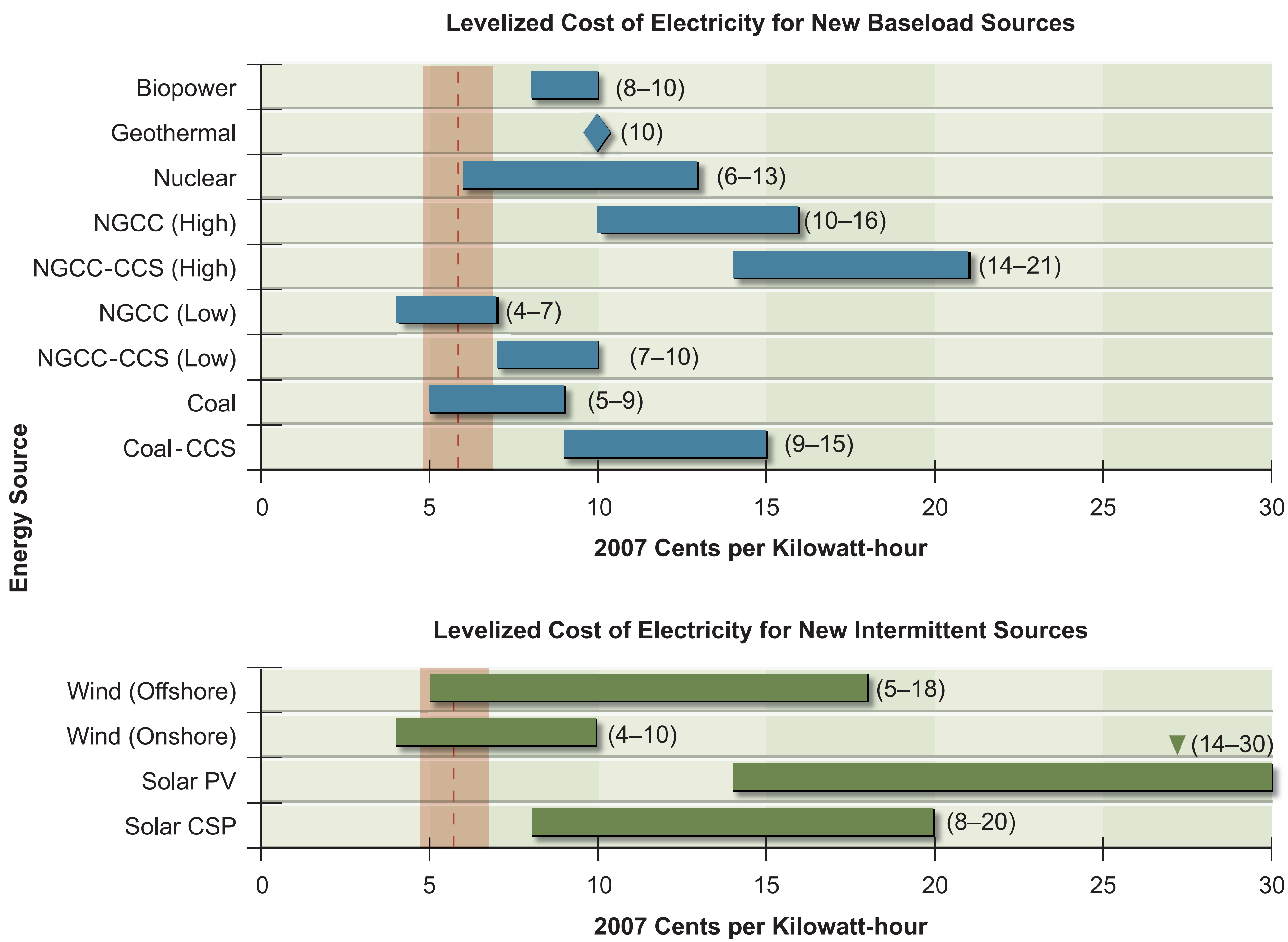


Note that this requires creation of an infrastructure comparable in scale to that of the fossil fuel industry.

Hoffert et al., 2002

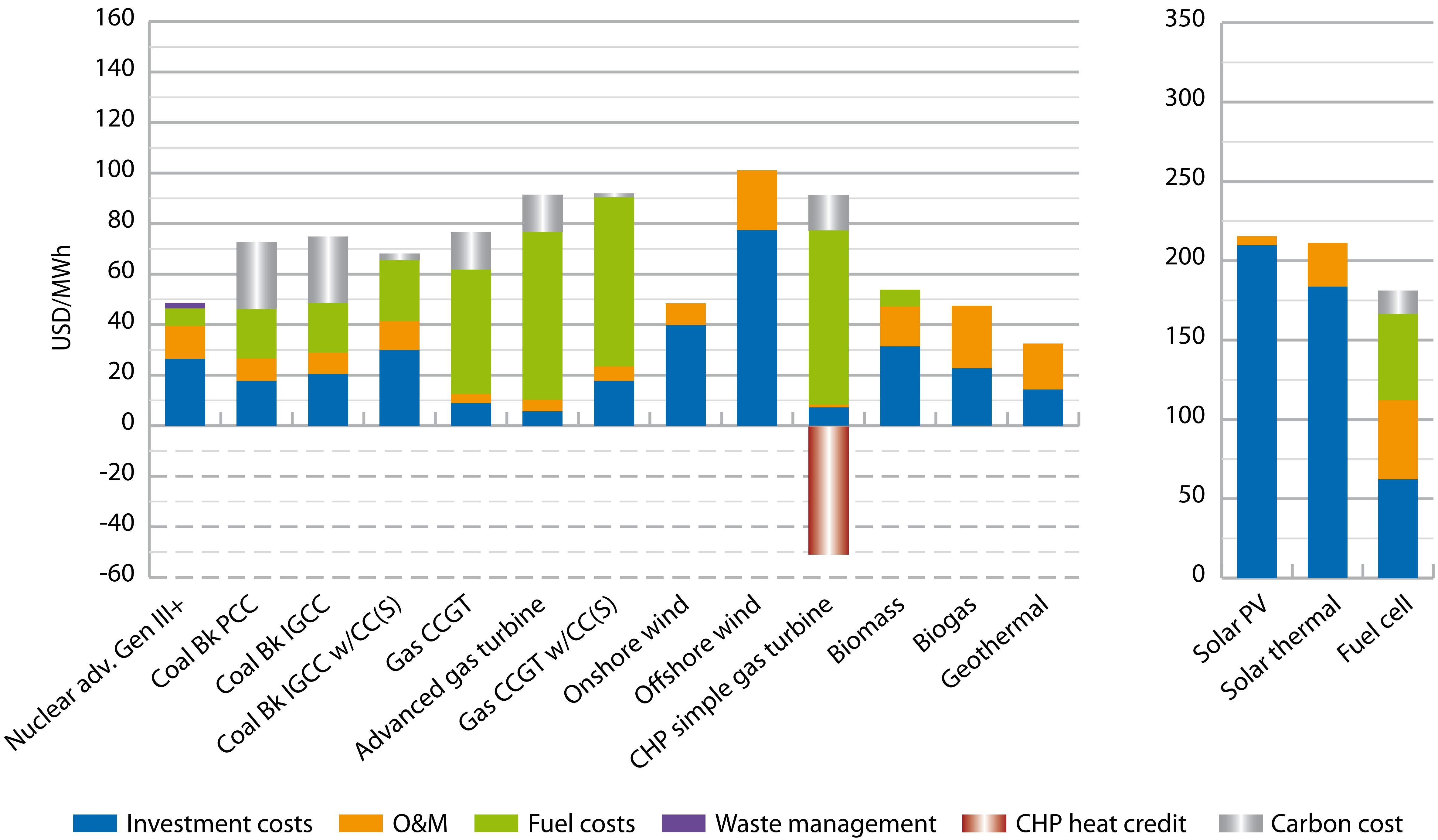
Challenge: Cost



NAS, 2009

Figure 4.16a: United States – levelised costs of electricity

(at 5% discount rate)



IEA (2010)

assuming carbon cost of $30/tonne

Scale can drive down costs for newer technologies

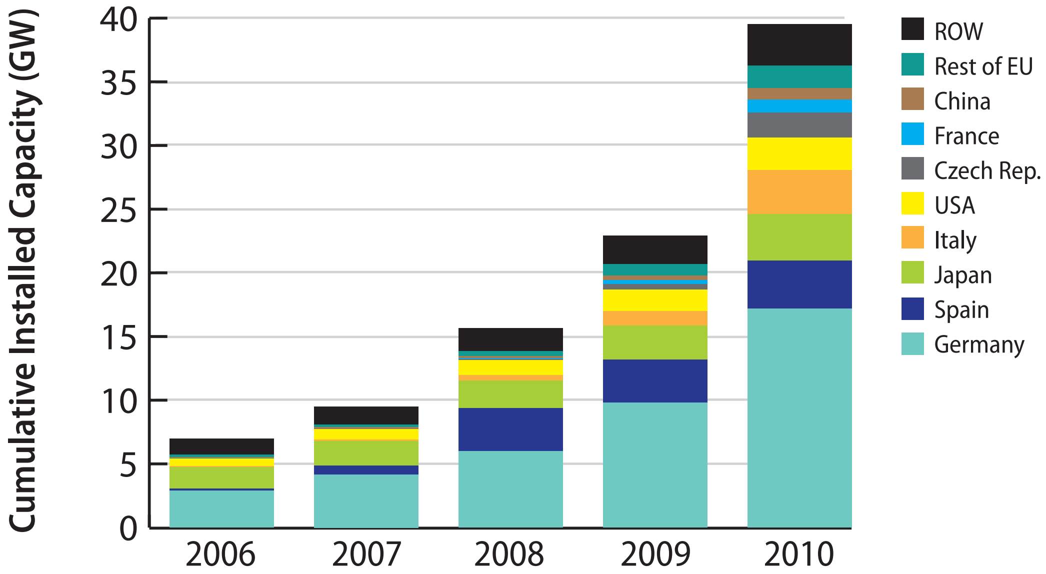


Figure 1.2 Cumulative installed PV capacity in the top eight countries (EPIA 2011)

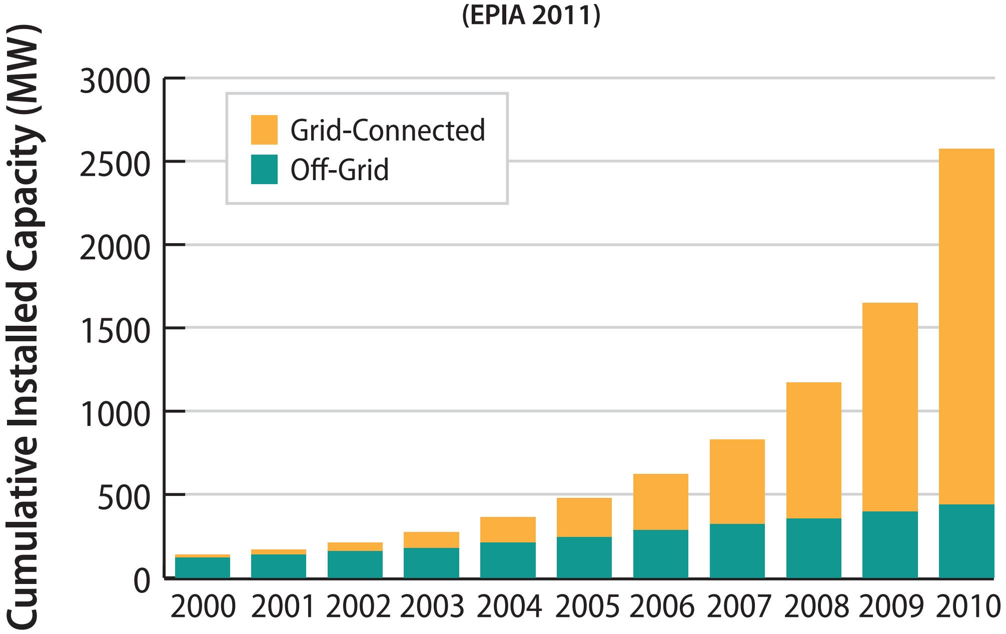


Figure 1.5 U.S. cumulative installed PV capacity, by interconnection status (Sherwood 2011)

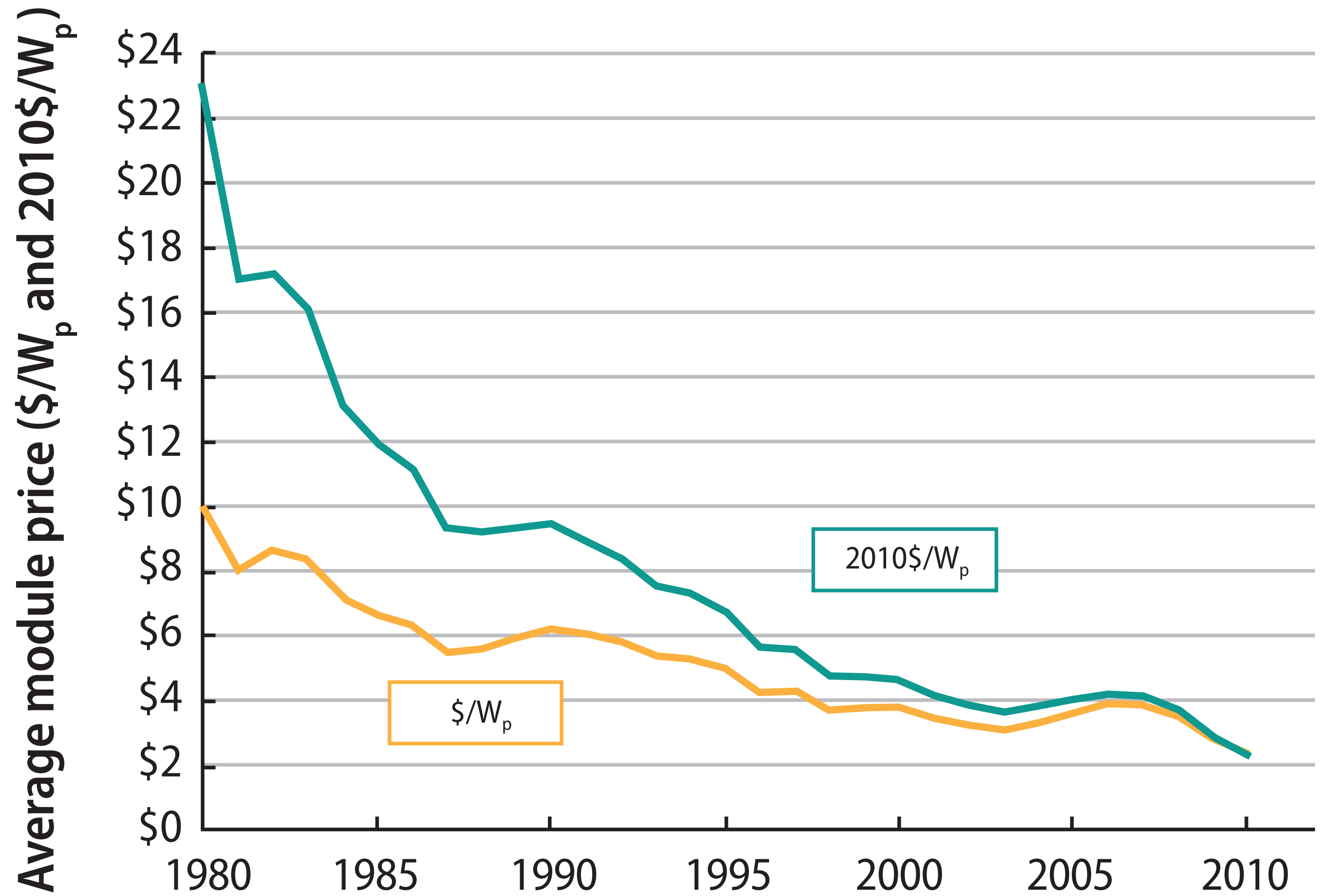
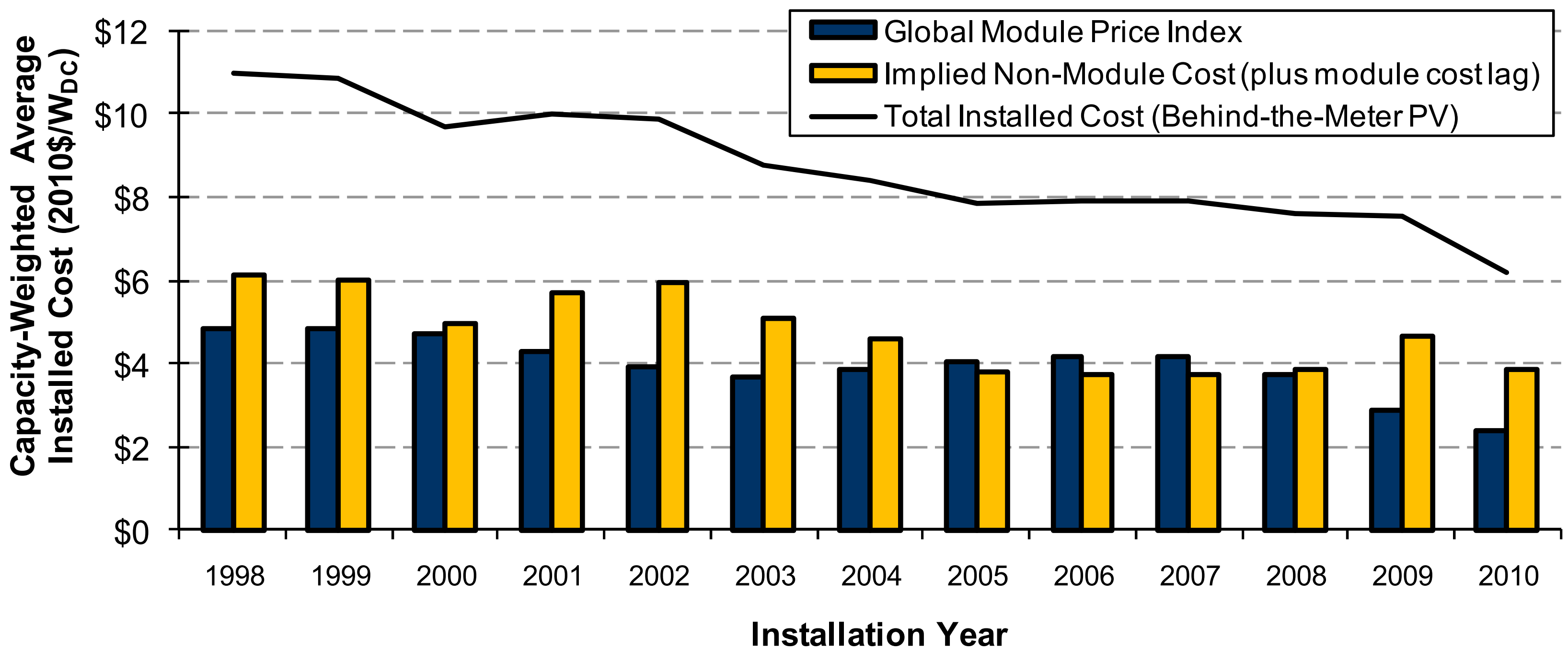


Figure 3.7 Global, average PV module prices, all PV technologies, 1984-2010 (Mints 2011)

At 20% capacity factor, \$1/W_p is competitive with 7 cents/kWh with a payback period of 8 years (not incl. installation costs)

NREL (2011)

At \$1/W_p, what would be the cost of replacing all current production with renewables?



Notes: "Implied Non-Module Cost (plus module cost lag)" is calculated as the reported Total Installed Cost minus Navigant Consulting's Global Module Price Index.

Figure 8. Average Installed Cost, Module Price Index, and Implied Non-Module Costs over Time for Behind-the-Meter PV

~10 TW = ~\$10 trillion

x 2 for installation

x 3 for backup/smart grid/etc

= ~\$60 trillion

LBNL (2011)

At $1/W$_p$, what would be the cost of replacing all current production with renewables?

$60 trillion = ~1 year of world GDP
assume we do this over 30 years, GDP growing at ~3%/year, so GDP doubles in ~22 yr

then this amounts to ~2% GDP/year for the next thirty years

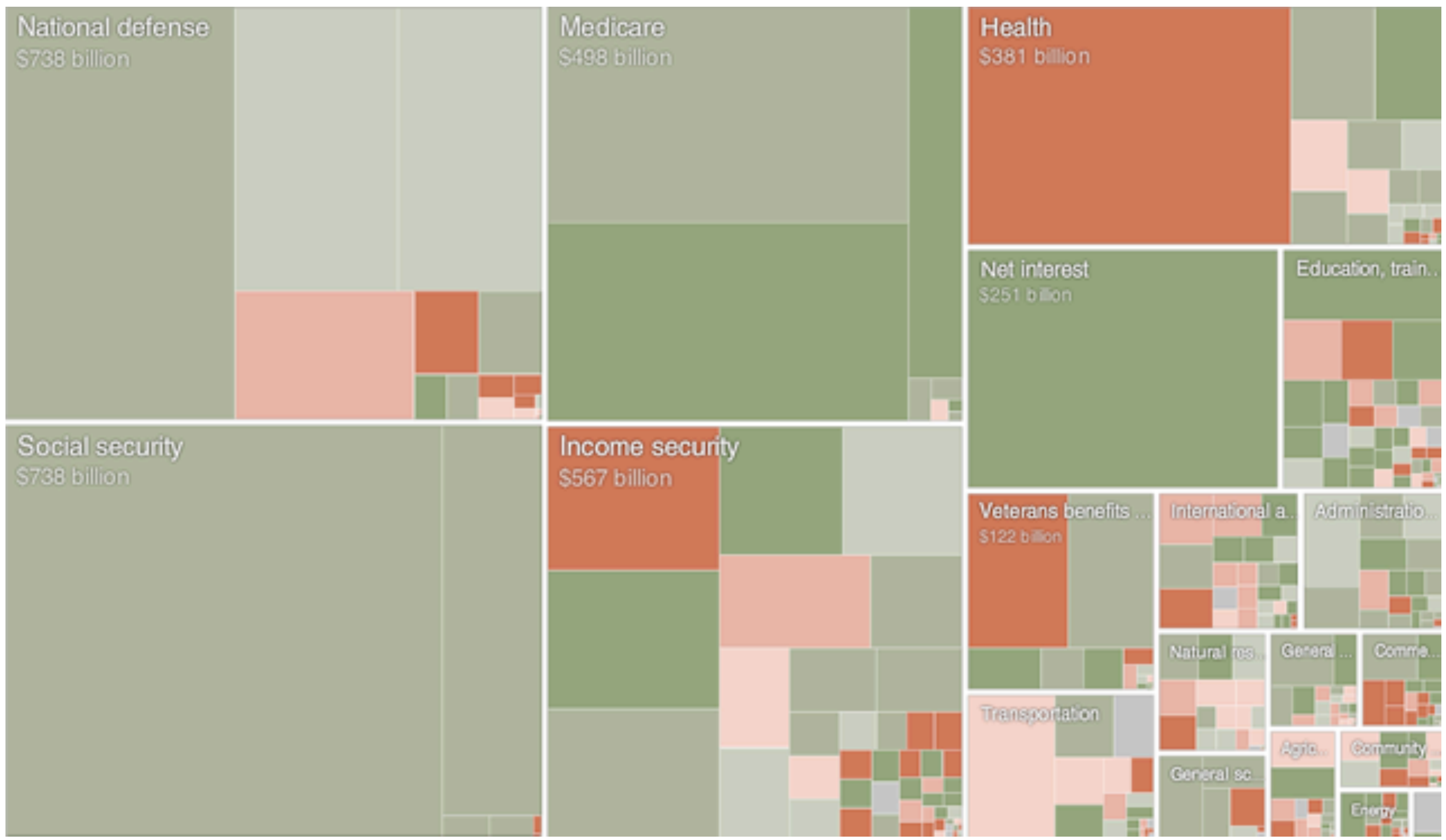
In the US, this would be ~$280 billion/year.
What else do we spend $280 billion/year on?

LBNL (2011)

At $1/W$_p$, what would be the cost of replacing all current production with renewables?

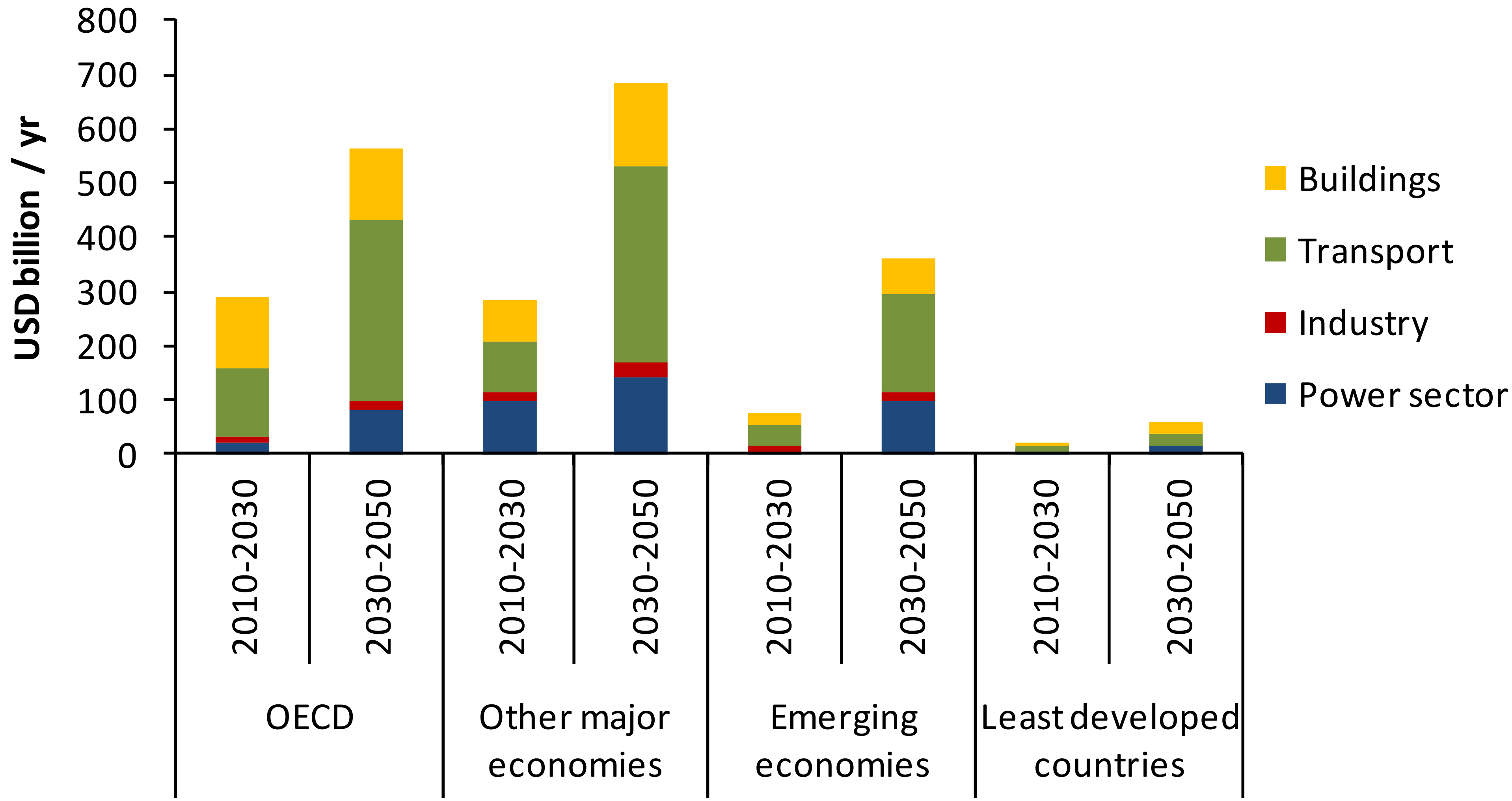
What else do we spend $280 billion/year on?

As a nation:



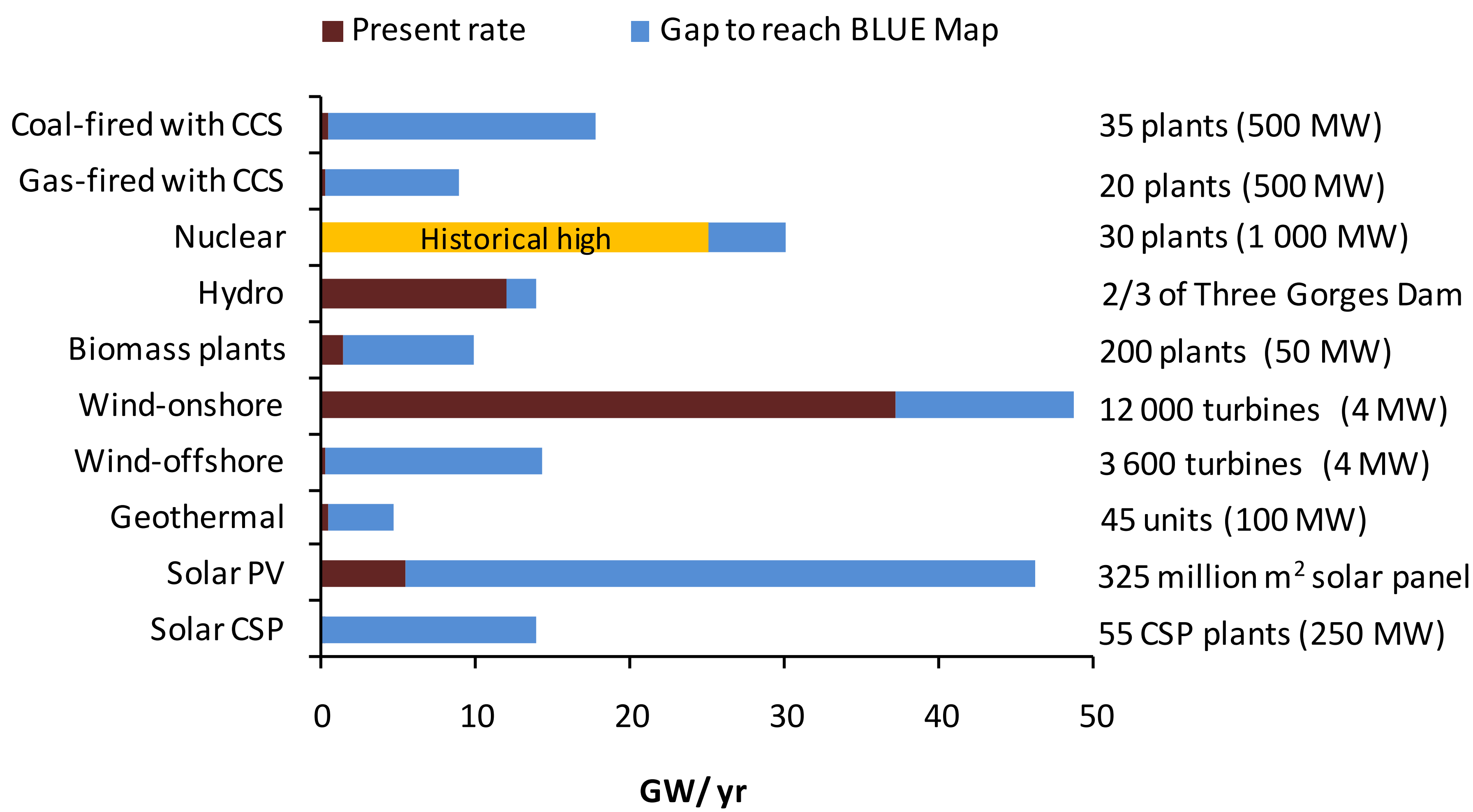
This is ~$2.50/person/day in the US.
What else do we spend that on?

Additional investment needs, BLUE Map scenario vs. Baseline scenario



Over the period to 2050, most of the additional investment in low-carbon technologies will be needed in non-OECD countries.

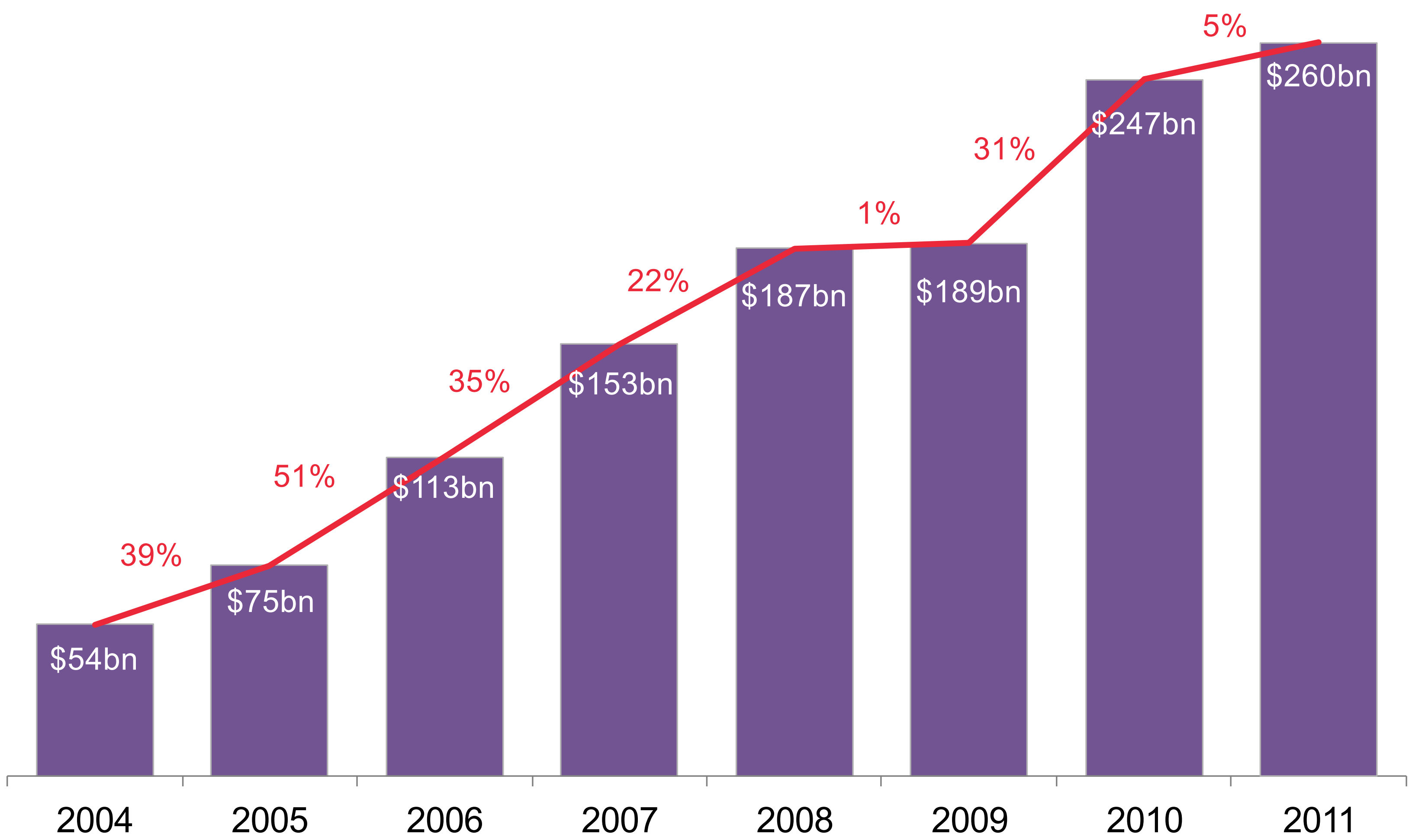
Average annual electricity capacity additions to 2050 needed to achieve the BLUE Map scenario



Annual rates of investment in many low-carbon electricity generating technologies must be massively increased from today's levels.

GLOBAL TOTAL NEW INVESTMENT IN CLEAN ENERGY

2004–11 ($BN)



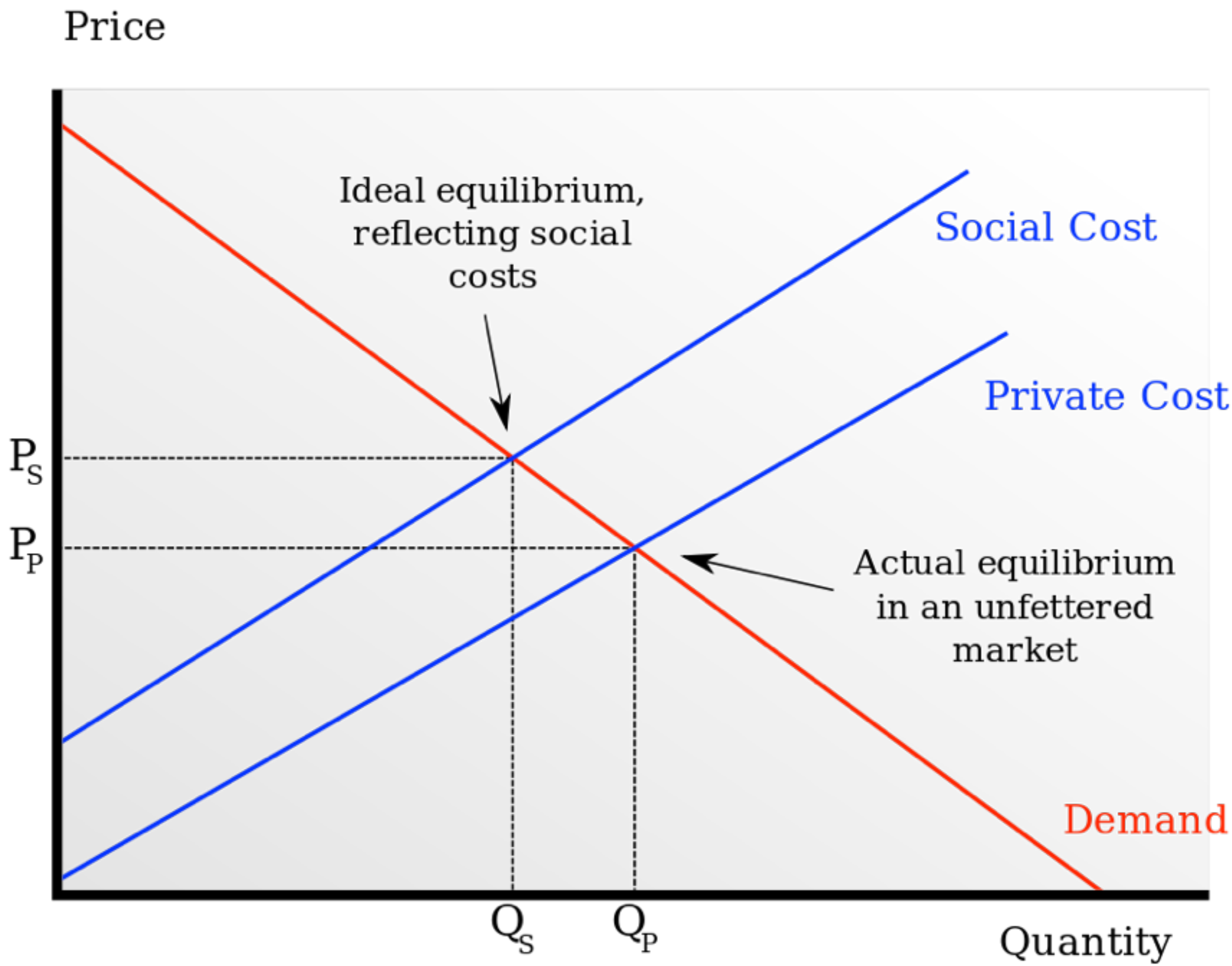
Note: Includes corporate and government R&D, and small distributed capacity. Adjusted for re-invested equity. Does not include proceeds from acquisition transactions

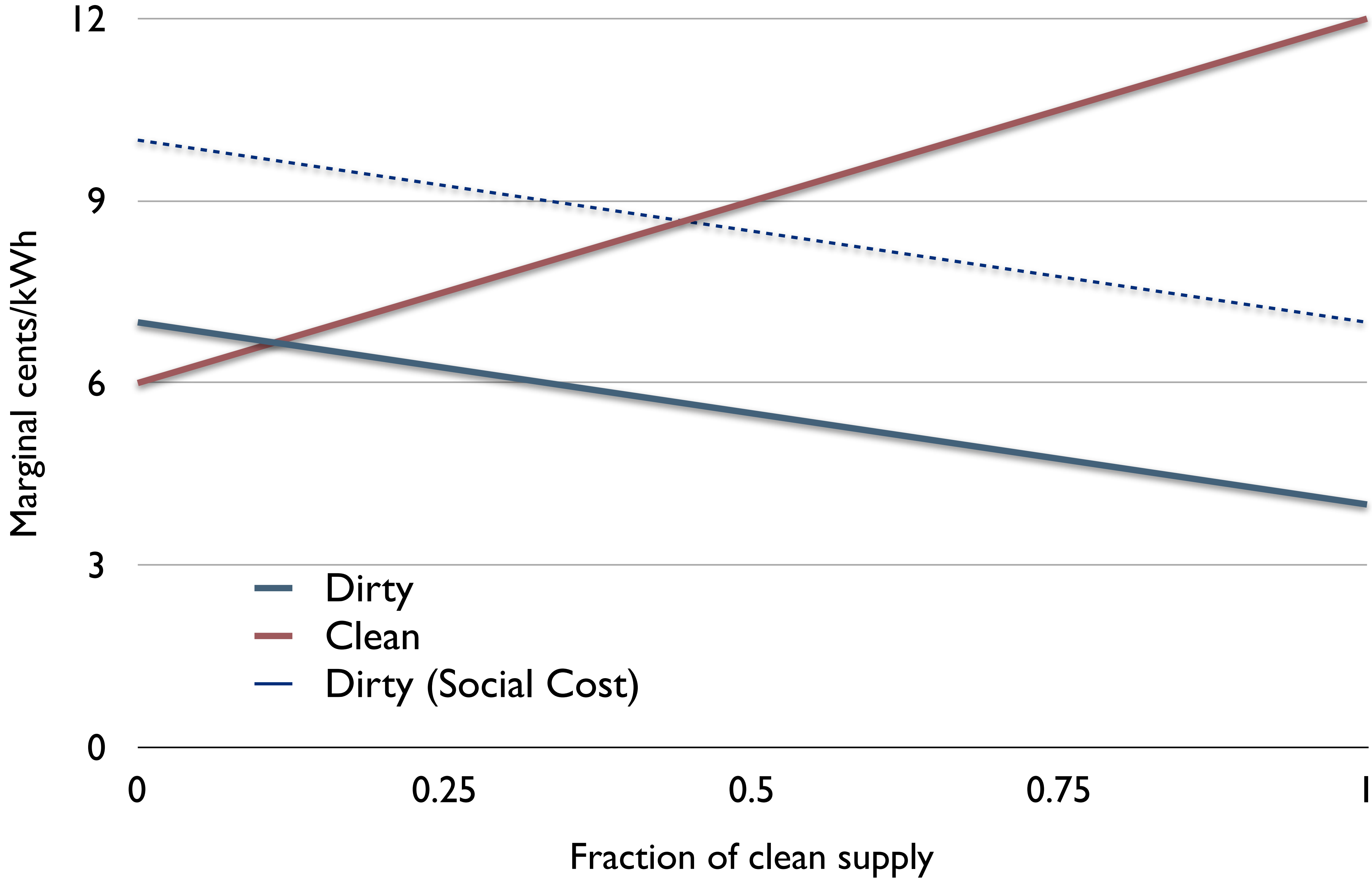
Source: Bloomberg New Energy Finance

What sorts of policies promote energy transformation?

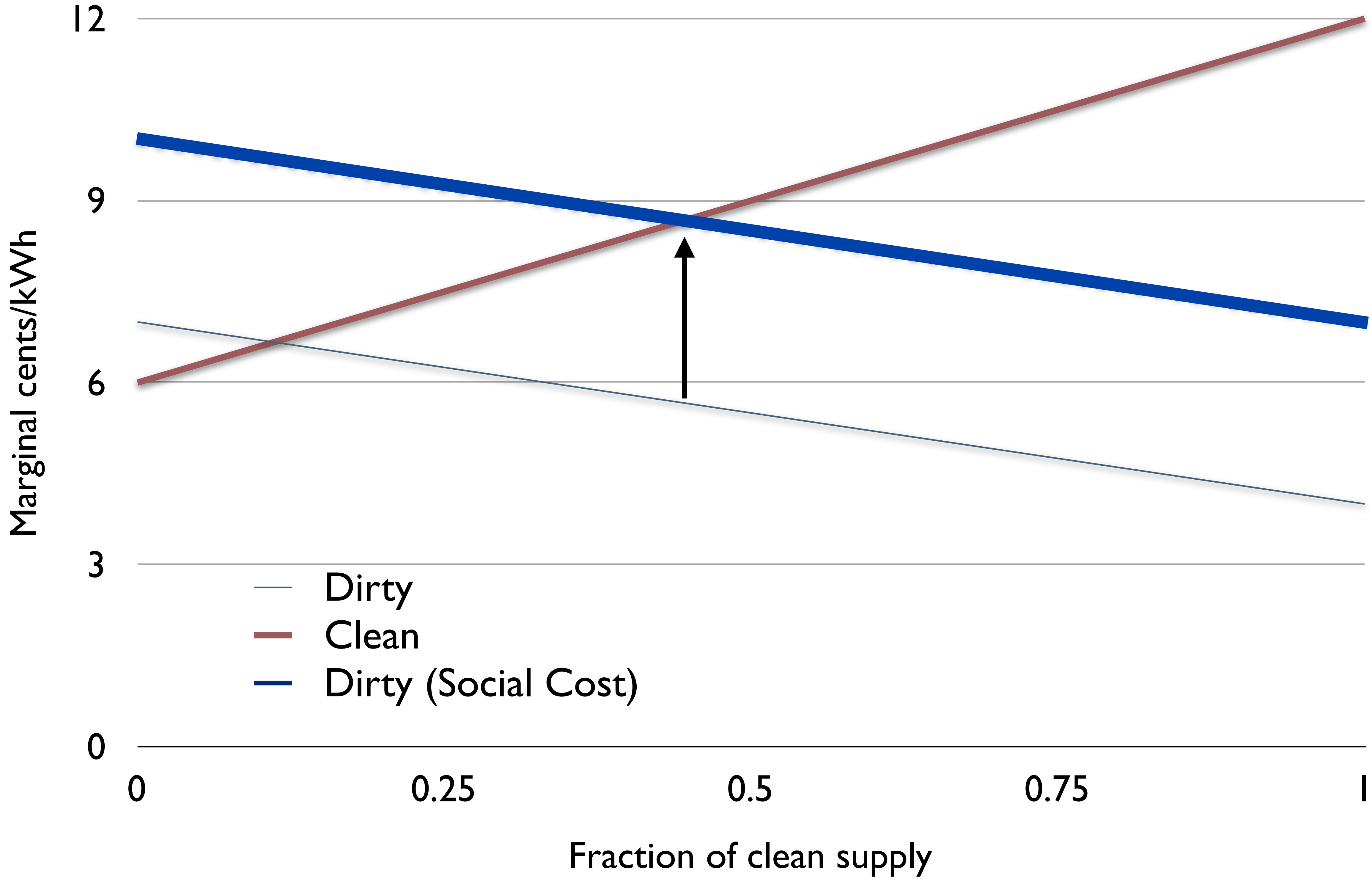
Consider the barriers we identified previously.

What sort of policies might promote energy transformation?

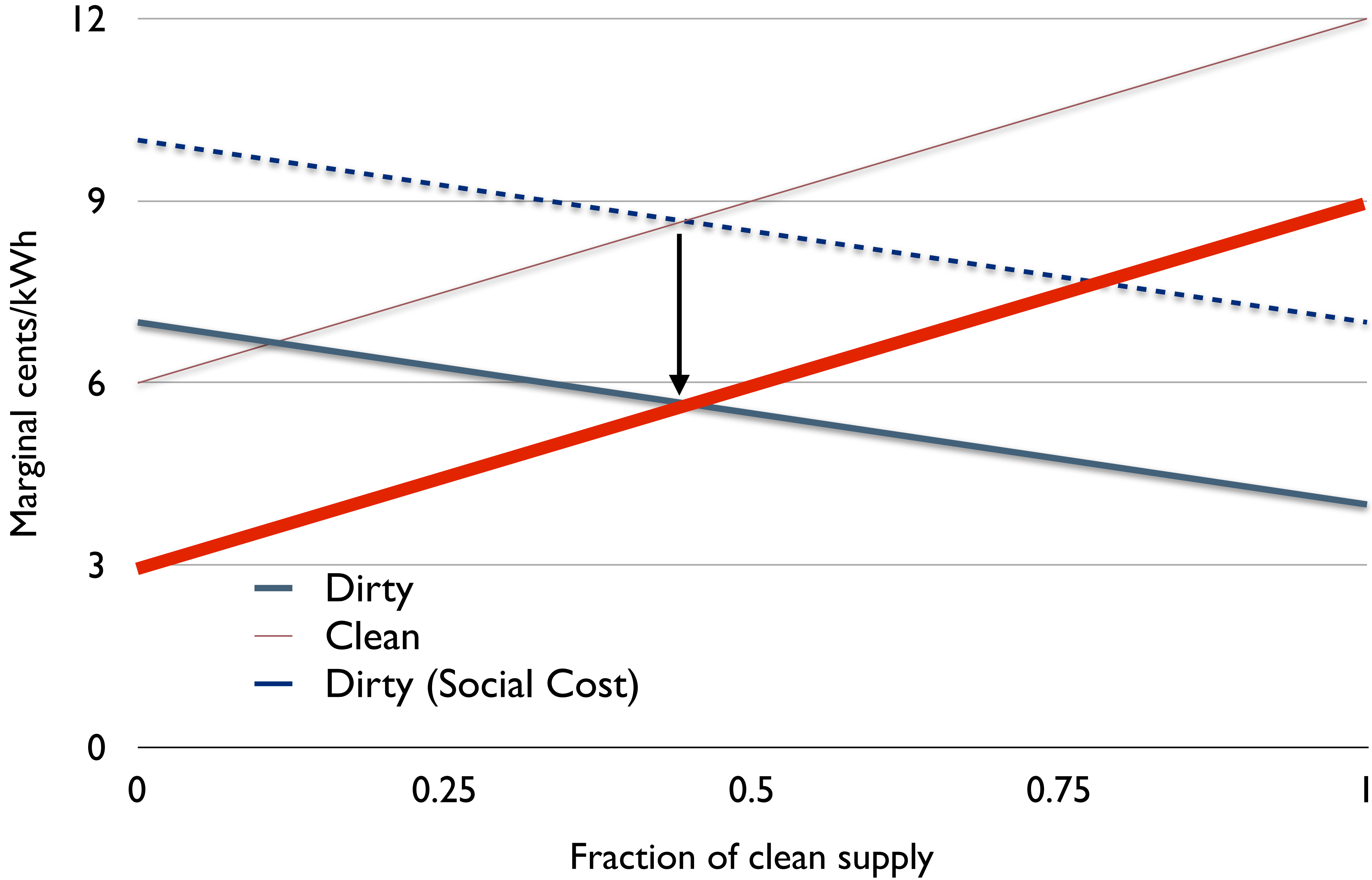

Price
Ideal equilibrium,
reflecting social
costs
Social Cost
Private Cost
P_S
P_P
Actual equilibrium
in an unfettered
market
Demand
Q_S
Q_P
Quantity


12
9
6
3
0
Marginal cents/kWh
0
0.25
0.5
0.75
1
Fraction of clean supply
Dirty
Clean
Dirty (Social Cost)

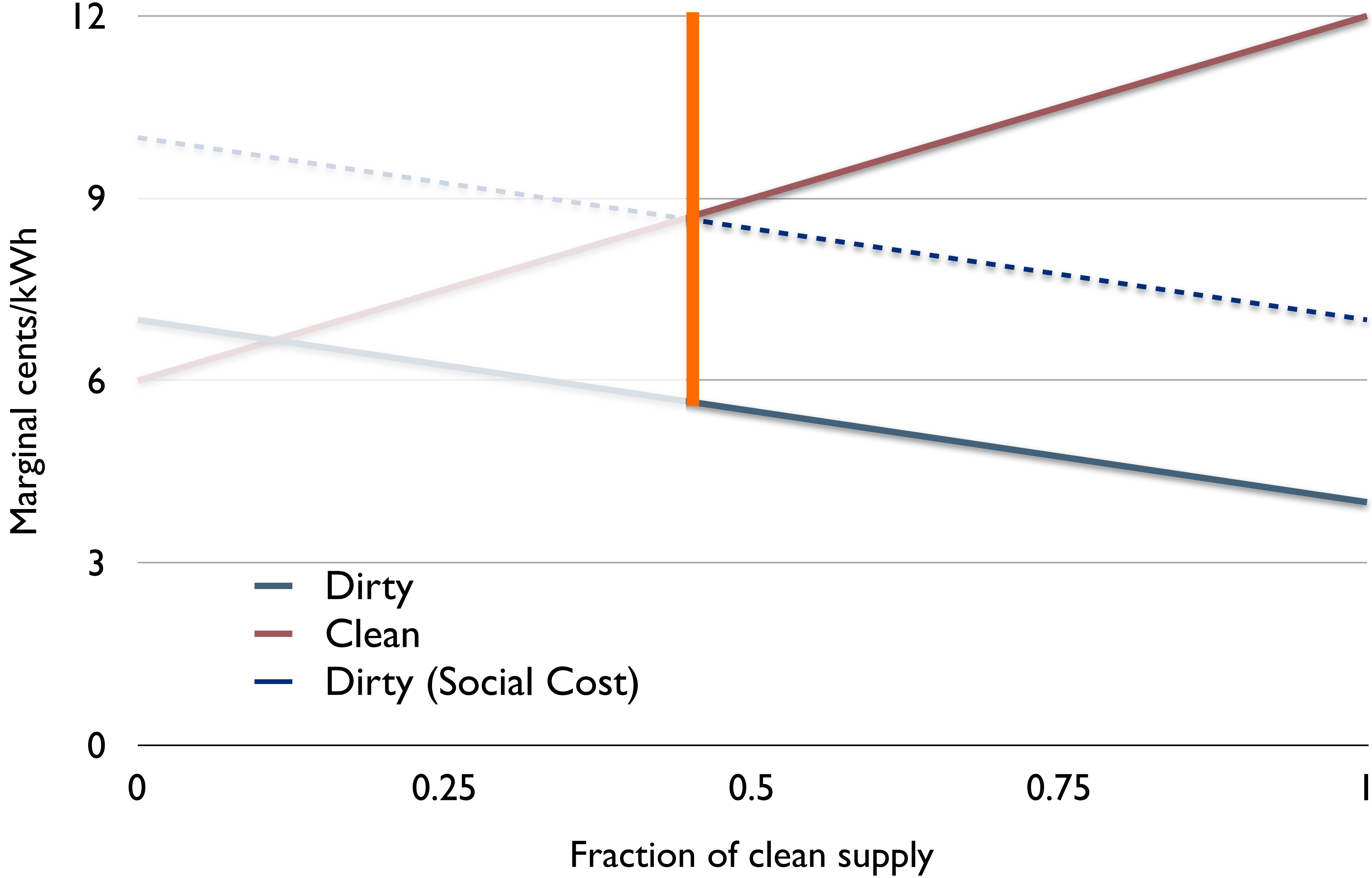
Dirty With Tax (aka Fine, aka Fee)



Clean With Subsidy (aka Incentive, aka Tax Credit)

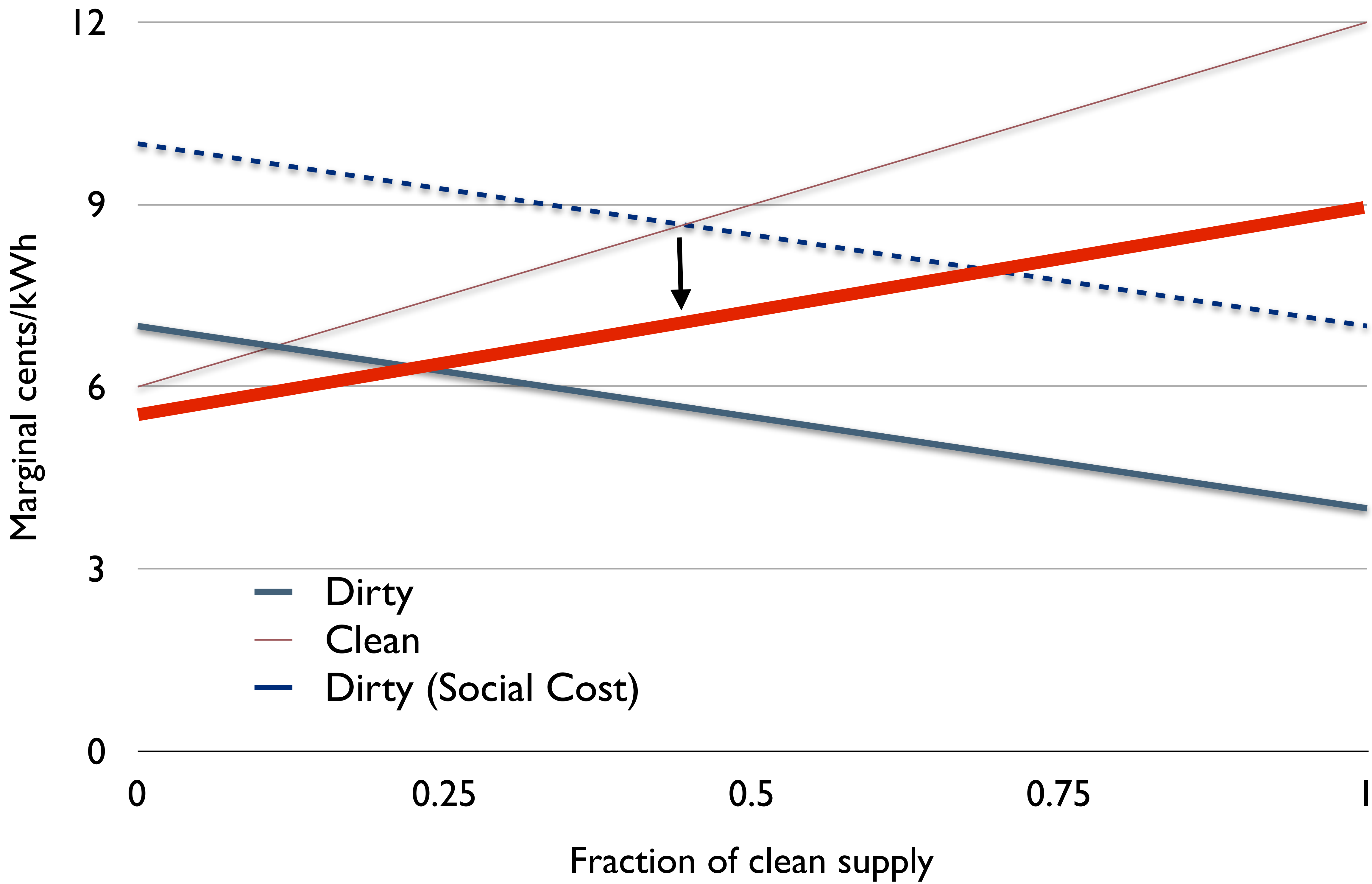


Regulation

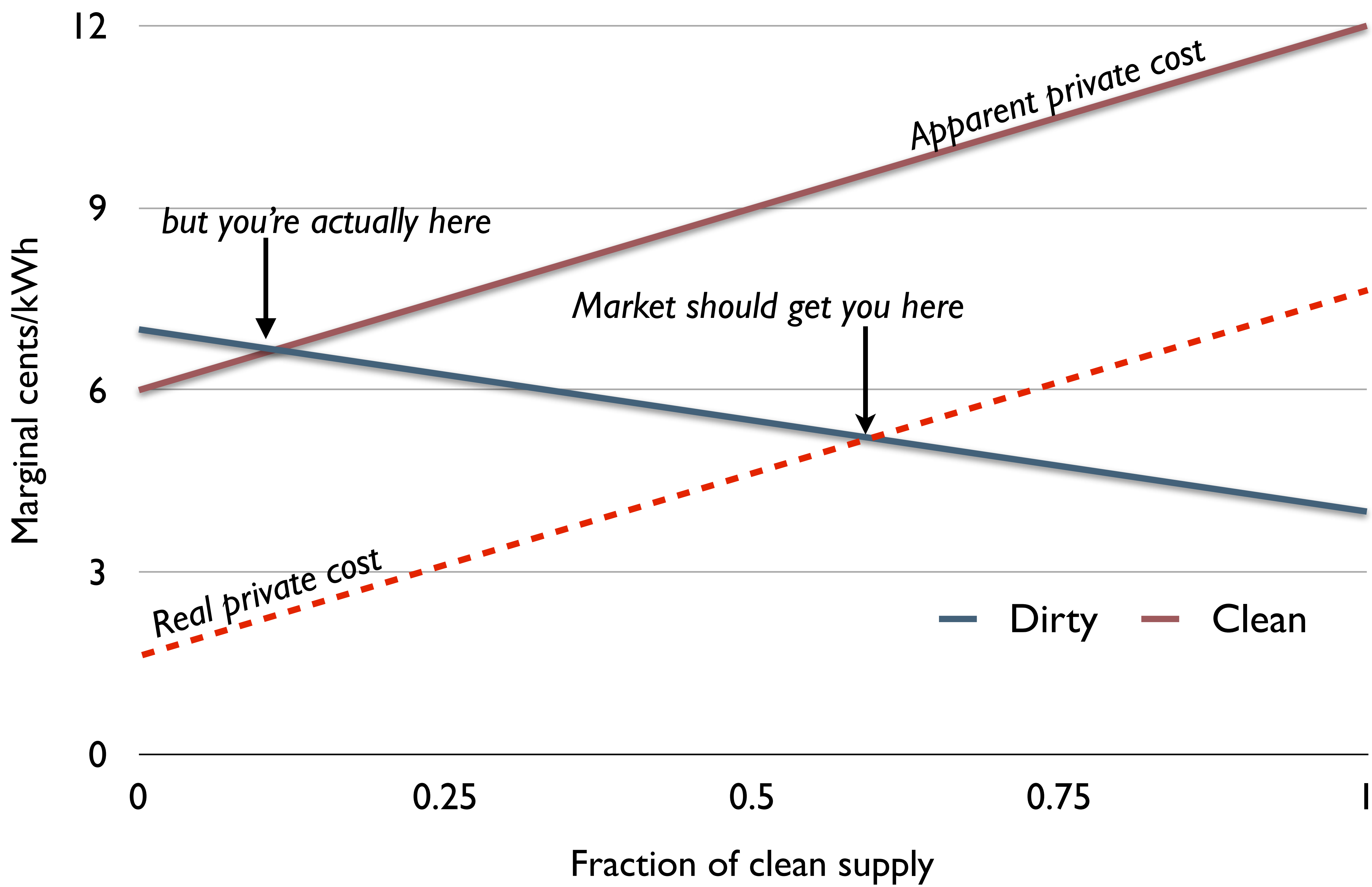


12
9
6
3
0
Marginal cents/kWh
Dirty
Clean
Dirty (Social Cost)
0
0.25
0.5
0.75
1
Fraction of clean supply

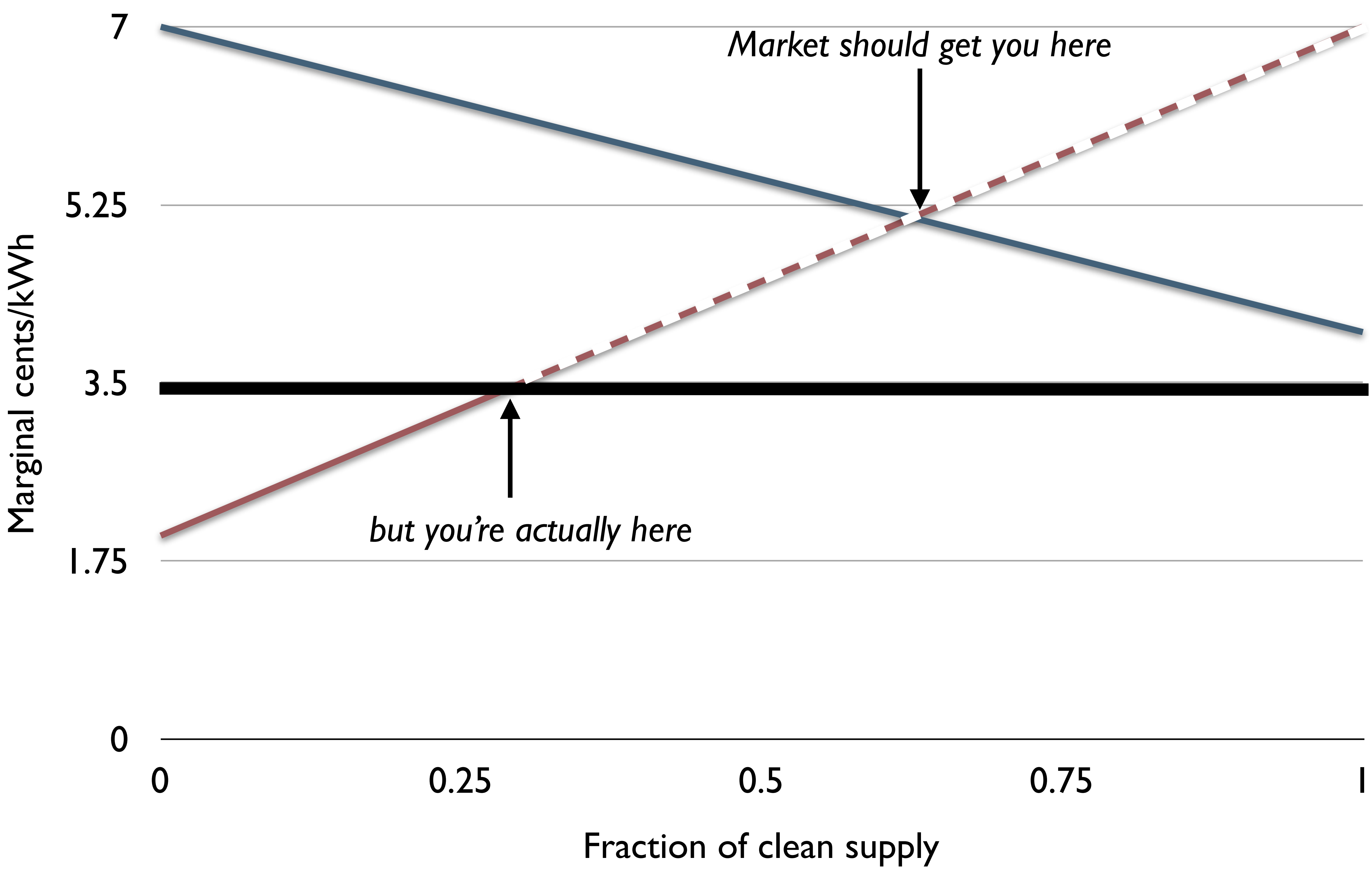
Clean after learning or R&D



Informational barriers, agency problems



Lack of finance



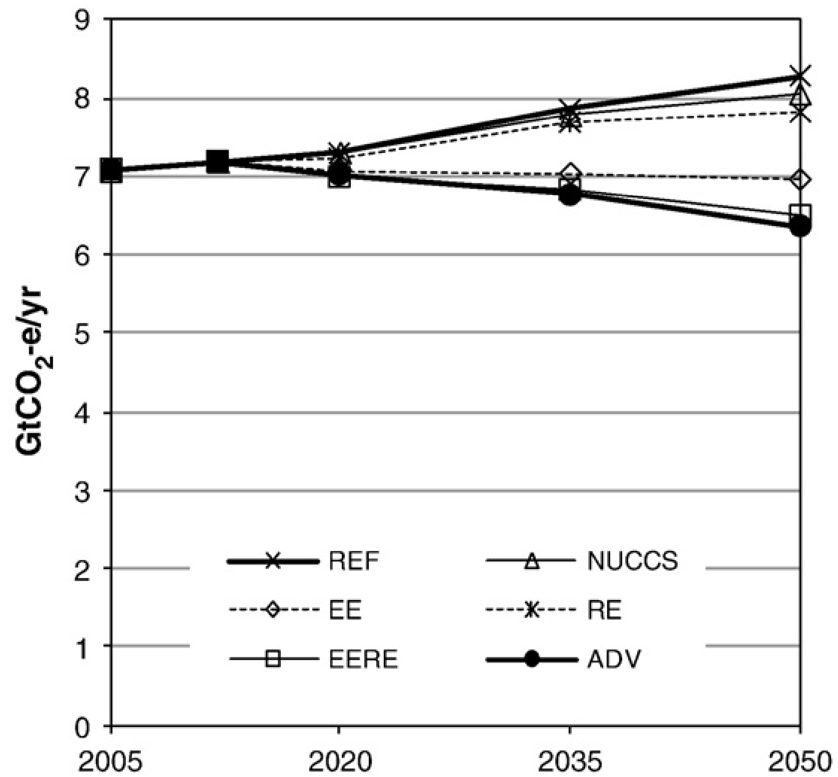


Fig. 1. U.S. CO_2-equivalent emissions for different technology scenarios absent a policy, 2005–2050.

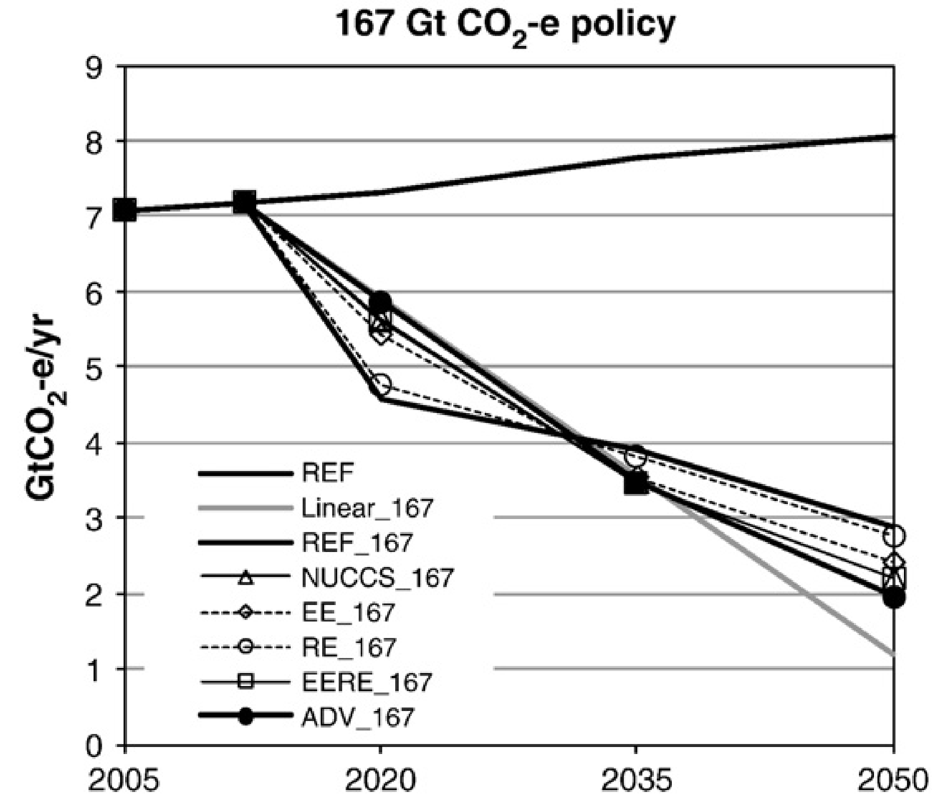


Fig. 4. Total CO_2-equivalent emissions by the U.S. with 203 and 167 Gt CO_2-e policies across six technology scenarios.

Carbon price associated with a 80% reduction in US CO_2 emissions by 2050

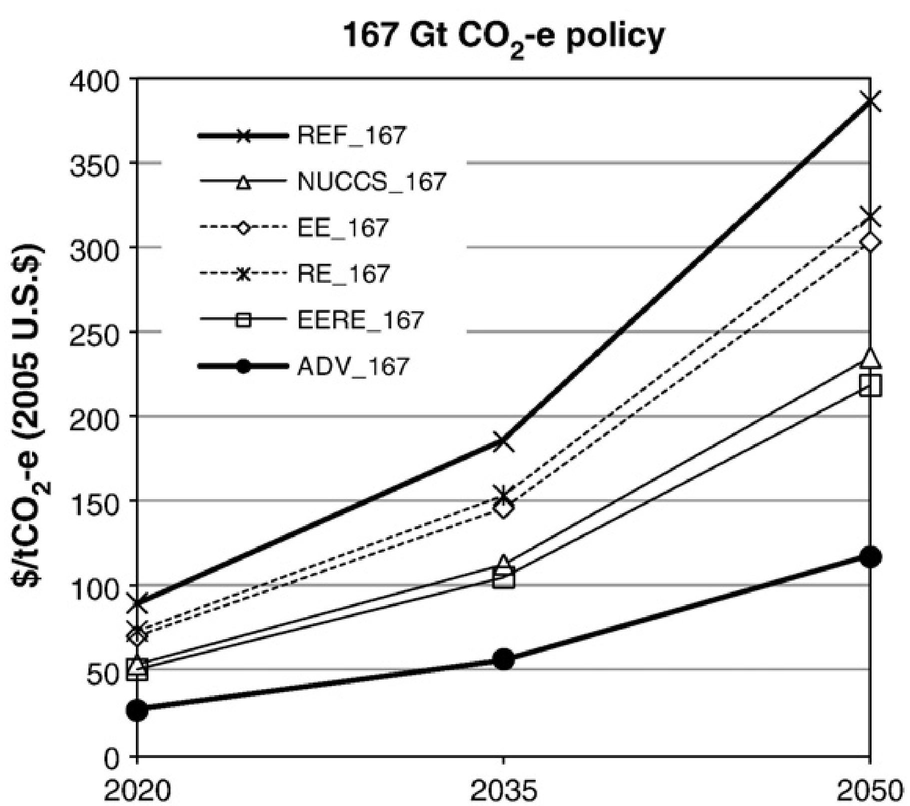


Fig. 2. CO_2 emissions prices by technology scenario, for 203 and 167 Gt CO_2-e U.S. policies.

Kyle et al. (2009)

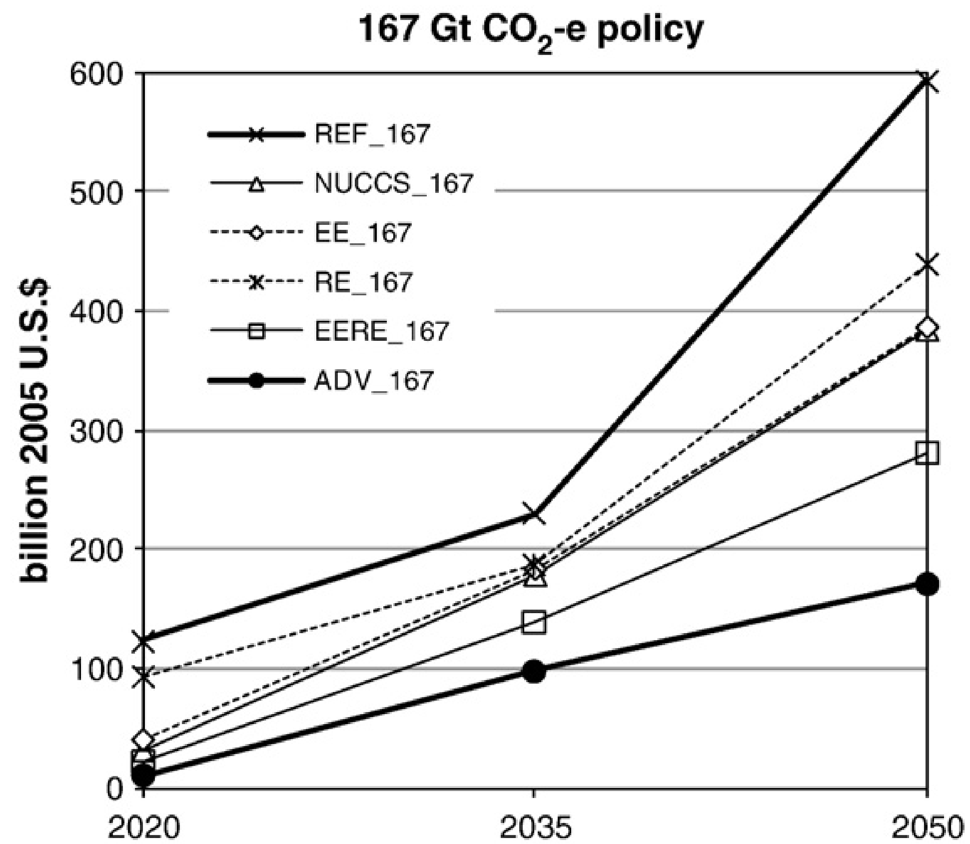
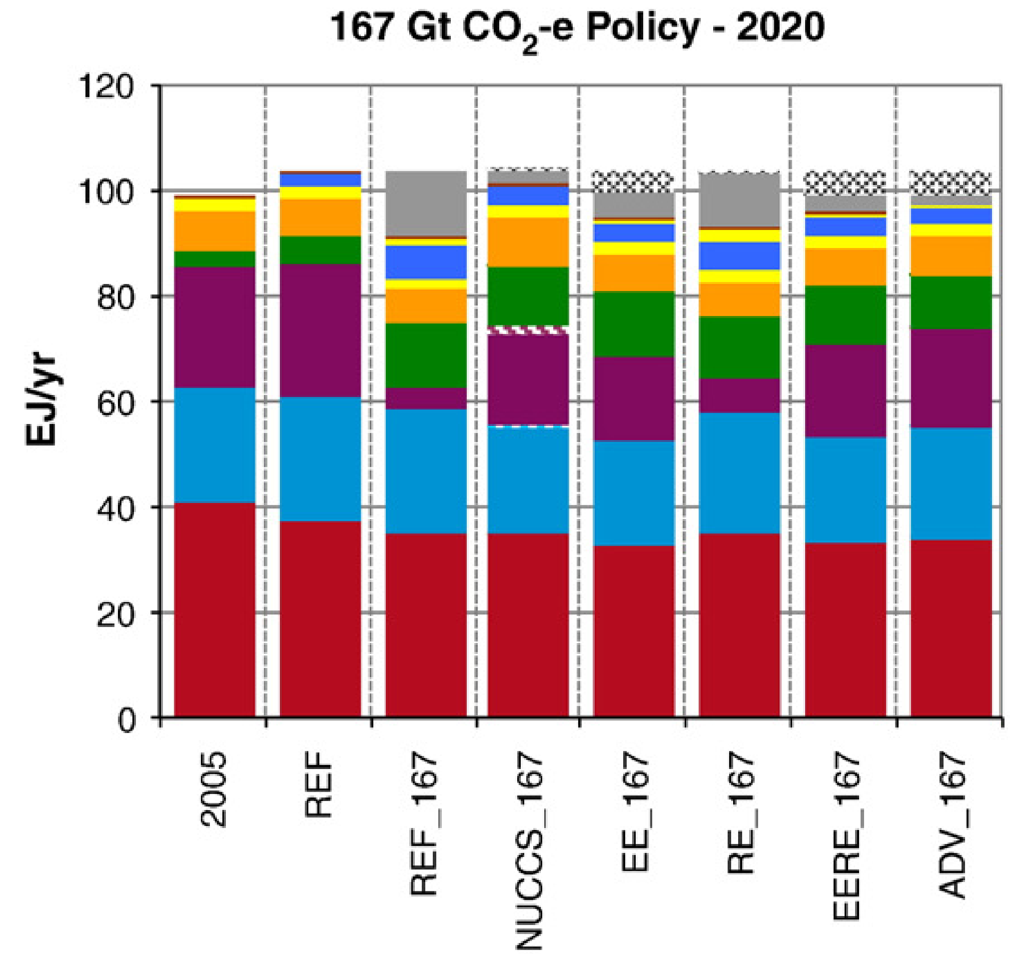
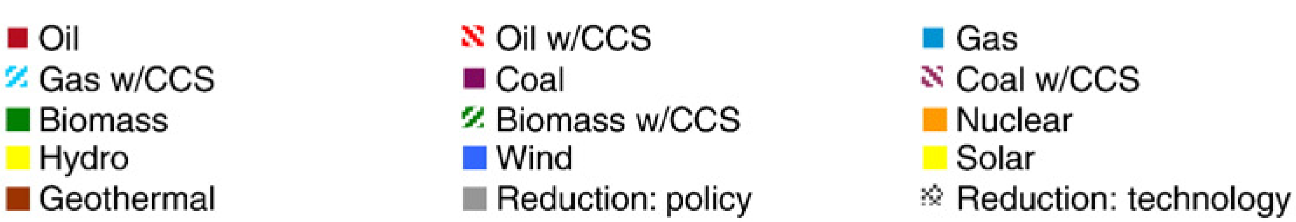
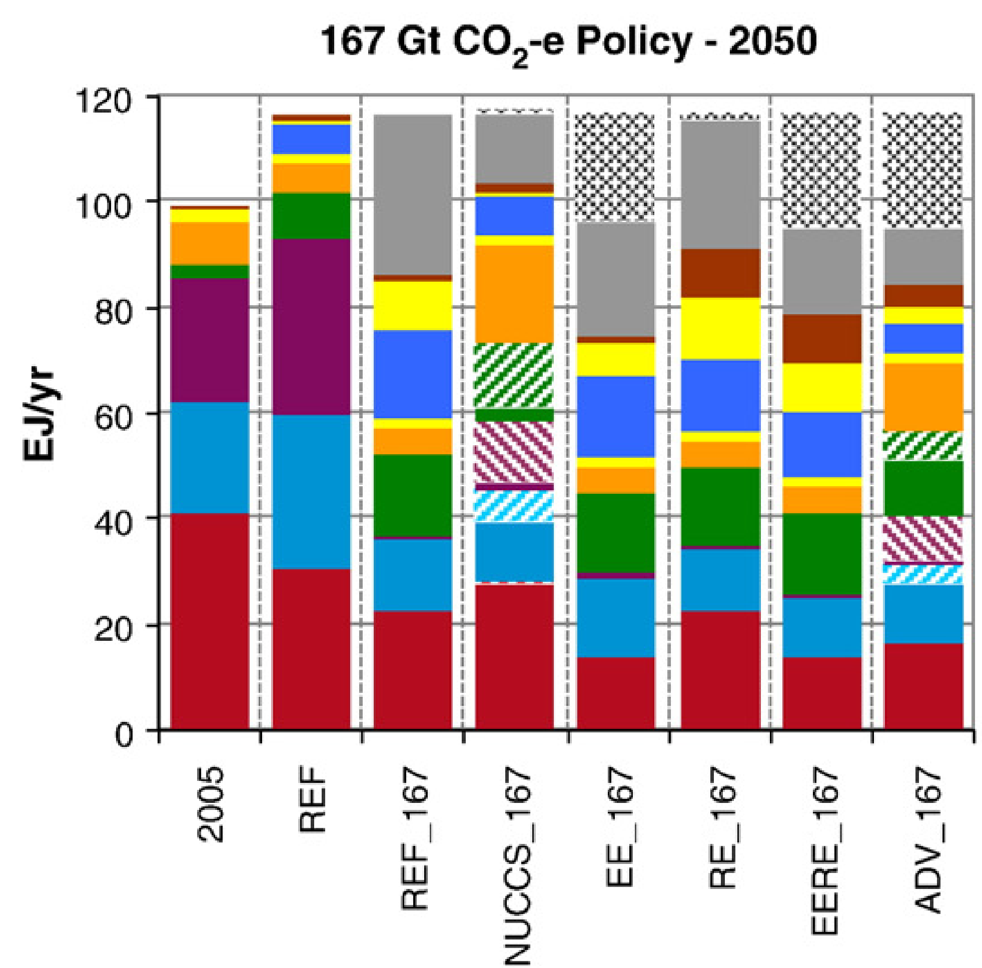


Fig. 3. Annual policy costs by technology scenario, for 203 and 167 Gt CO_2-e U.S. policies, 2005–2050. Policy costs are calculated as the area under the marginal abatement cost curve for each time period.



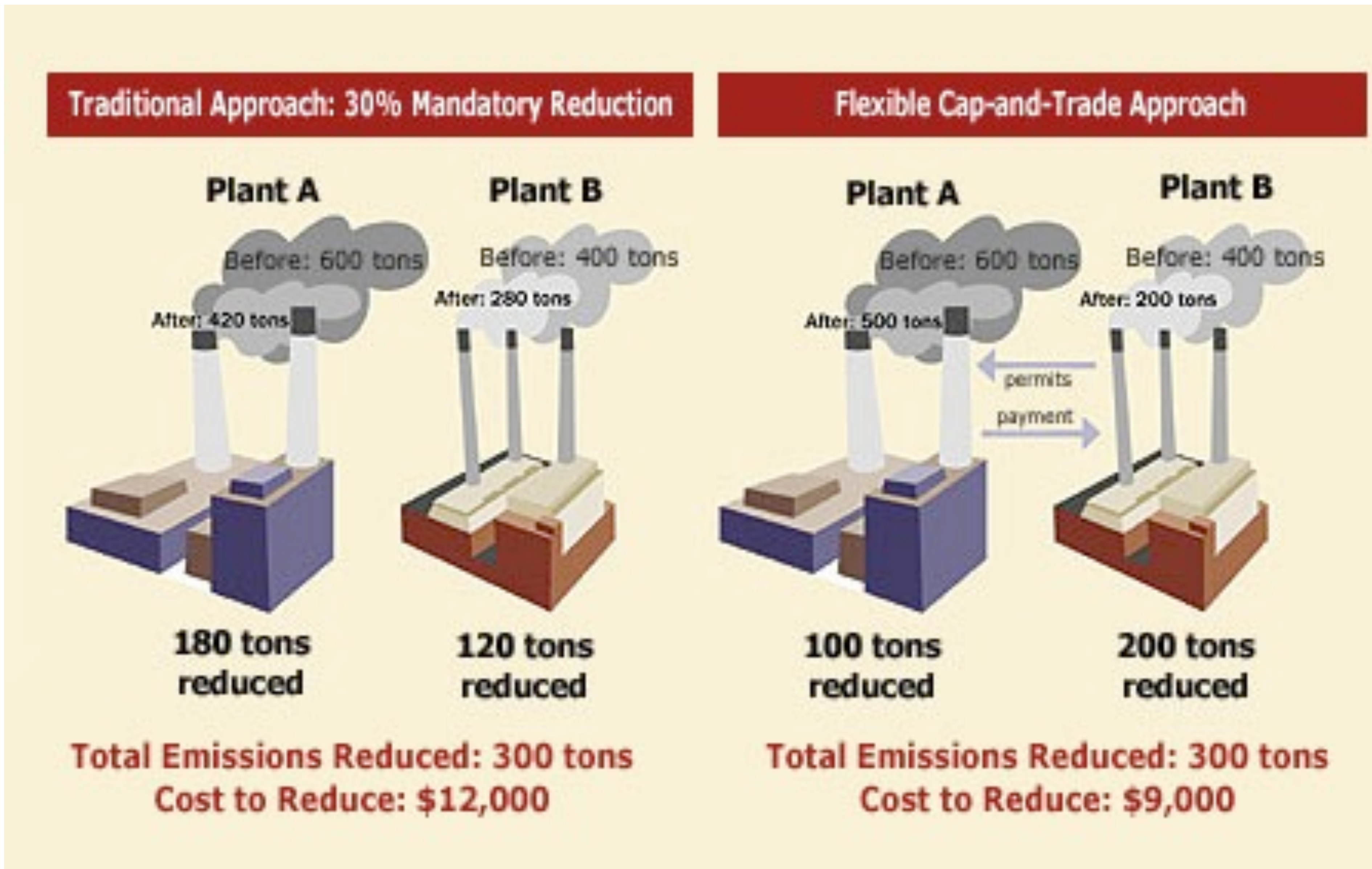




80% reduction in US CO_2 emissions by 2050

Kyle et al. (2009)

Cap-and-trade is a price mechanism with quantity certainty



UCS
http://climatelab.org/Cap_and_Trade

What is the current state of national and global energy policy?

House Vote On Passage: H.R. 2454 [111th]: American Clean Energy and Security Act of 2009

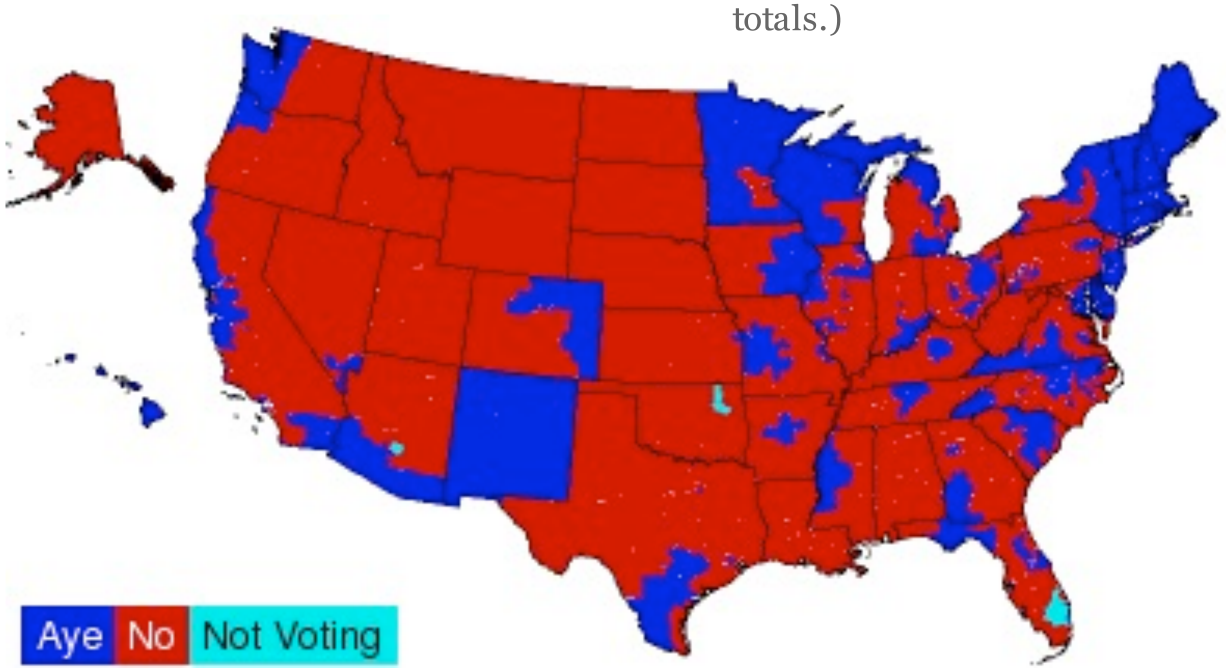
Number: House Vote #477 in 2009 [primary source: house.gov]
Date: Jun 26, 2009 7:17PM
Result: Passed
Bill: H.R. 2454 [111th]: American Clean Energy and Security Act of 2009

VOTE OVERVIEW

	Totals		Democrats	Republicans	Independents
Aye:	219	(50%)	210	8	0
No:	212	(49%)	43	169	0
Present:	0	(0%)	0	0	0
Not Voting:	3	(1%)	1	2	0
Required:	Simple Majority of 431 votes (=216 votes)				

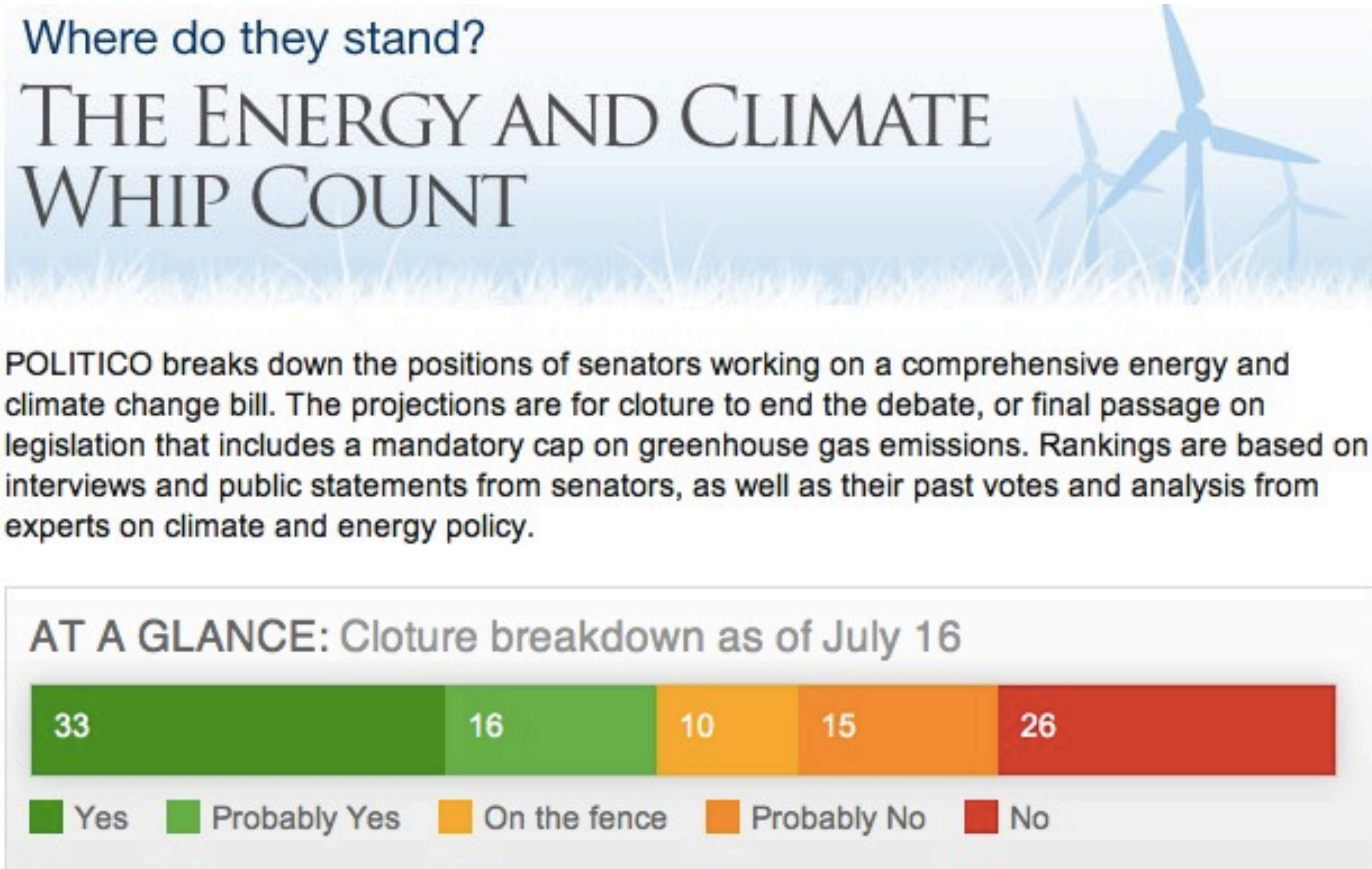
Needed To Win

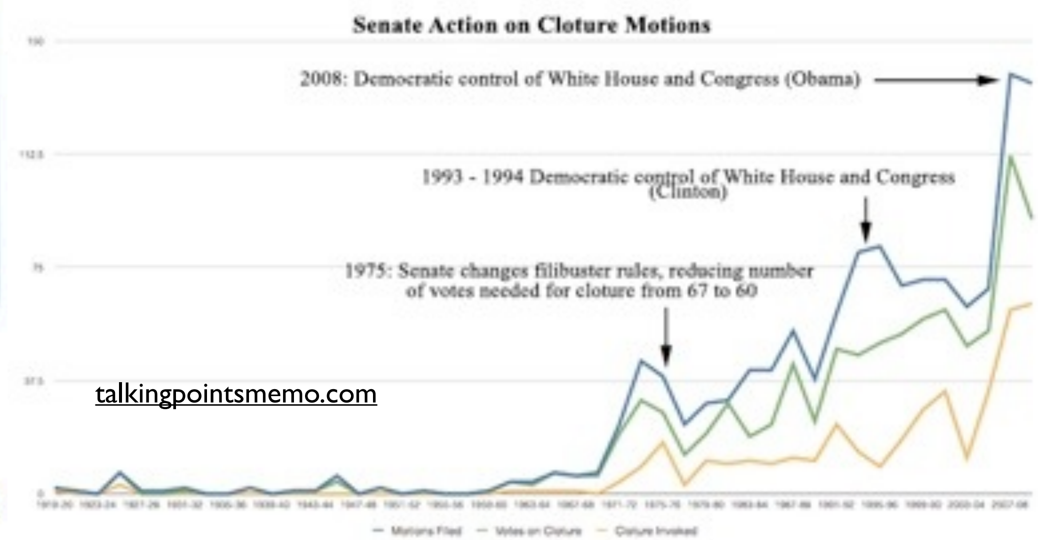
(Vacancies in Congress will affect vote totals.)



http://www.govtrack.us/congress/vote.xpd?vote=h2009-477

One year later... (July 2010)





59 Dems, 41 GOP total in Senate – 60 votes needed to break cloture under the post-2008 "new normal"

47 Dems "yes" or "probably yes"
6 Dems "on the fence": Conrad (D-ND), Landrieu (D-LA), Levin (D-MI), McCaskill (D-MO), Pryor (D-AR), Webb (D-VA)
5 Dems "probably no": Bayh (D-IN), Dorgan (D-ND), Goodwin (D-WV), Lincoln (D-AR), Rockefeller (D-WV)
1 Dem "no": Nelson (D-NE)

2 GOP "probably yes": Collins (R-ME), Snowe (R-ME)
4 GOP "on the fence": Brown (R-MA), Graham (R-SC), Gregg (R-NH), LeMieux (R-FL)
35 GOP "no" or "probably no"

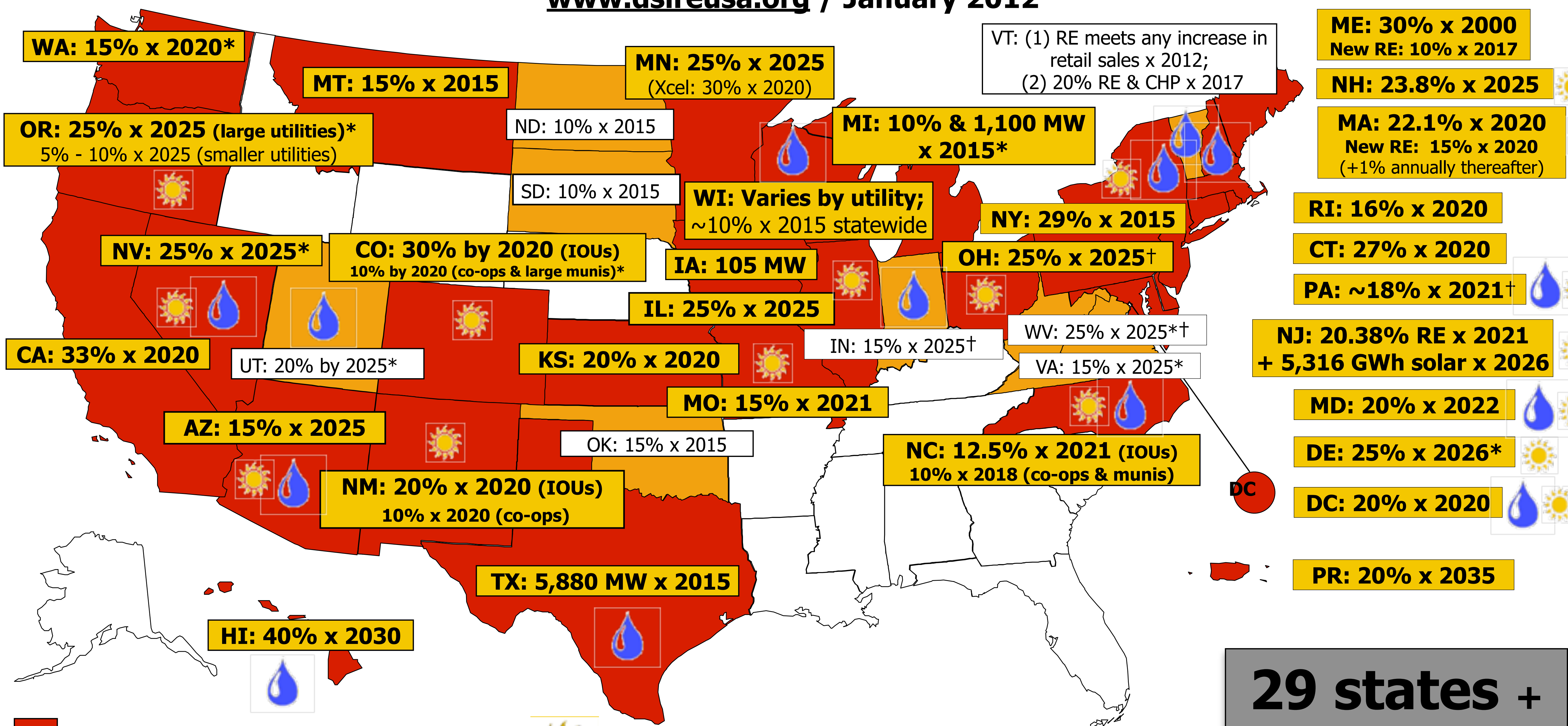
http://www.politico.com/energy-climate-whip-count/

State of the Union, January 2011

"Now, clean energy breakthroughs will only translate into clean energy jobs if businesses know there will be a market for what they're selling. **So tonight, I challenge you to join me in setting a new goal: By 2035, 80 percent of America's electricity will come from clean energy sources.** Some folks want wind and solar. Others want nuclear, clean coal and natural gas. To meet this goal, we will need them all -- and I urge Democrats and Republicans to work together to make it happen."

RPS Policies

www.dsireusa.org / January 2012



Renewable portfolio standard

Renewable portfolio goal

Solar water heating eligible

Minimum solar or customer-sited requirement

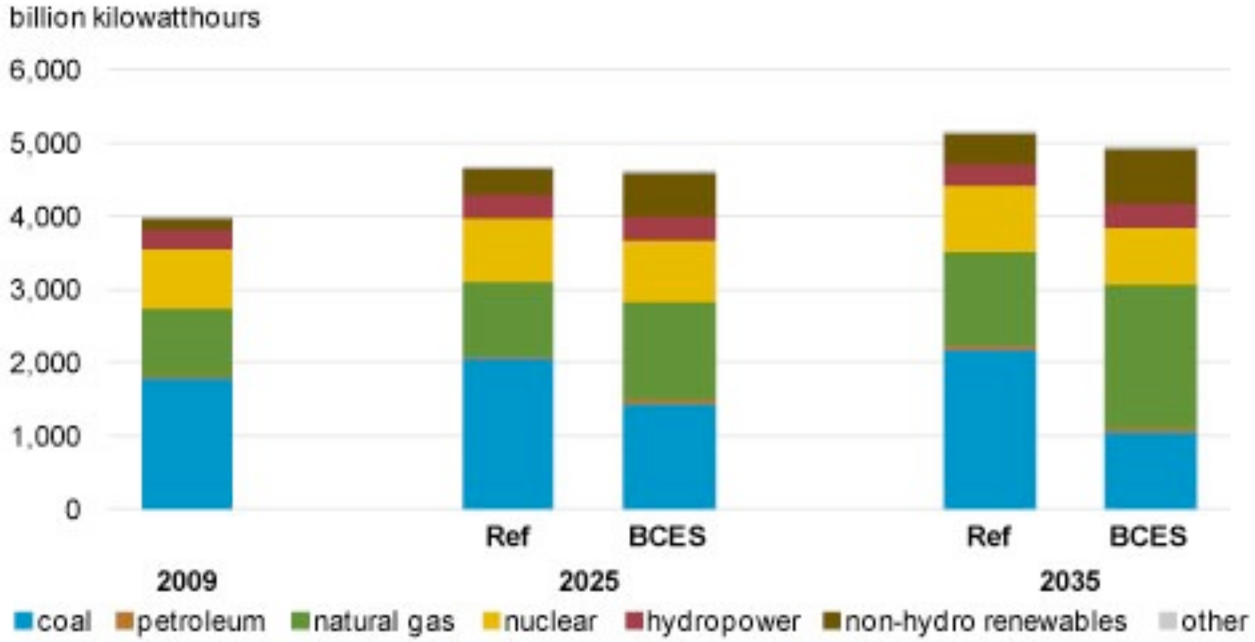
* Extra credit for solar or customer-sited renewables

† Includes non-renewable alternative resources

29 states + DC and PR have an RPS
(8 states have goals)

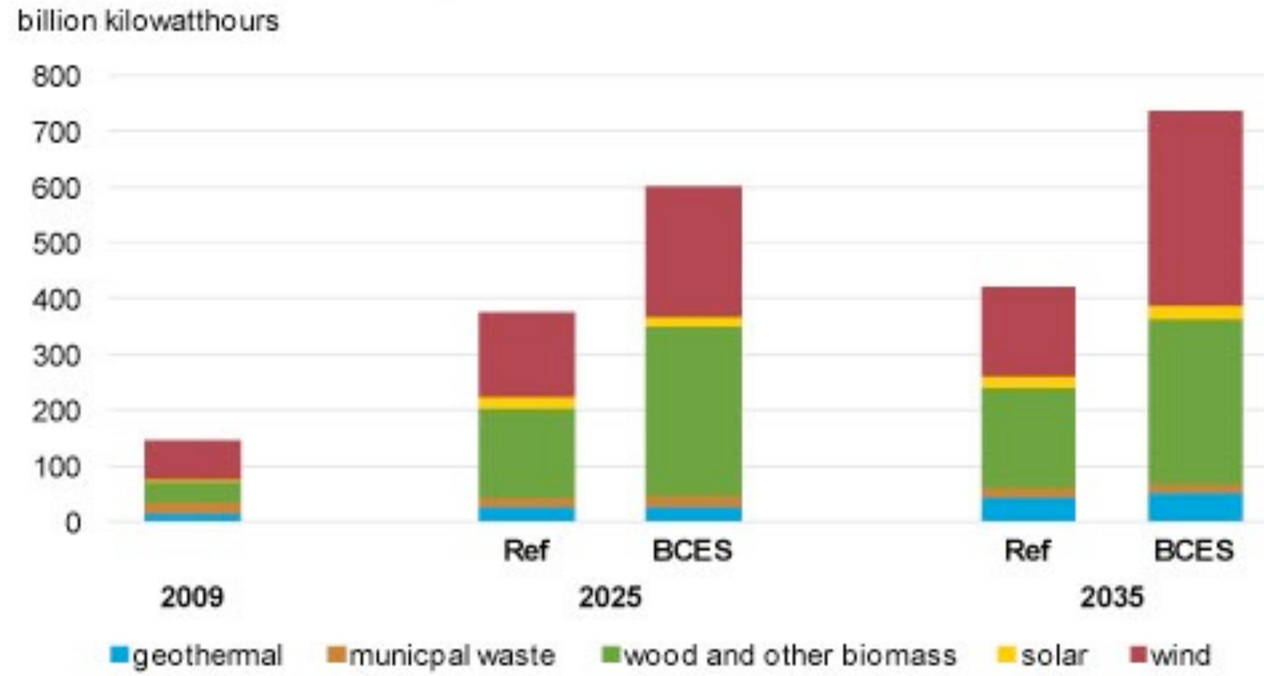
EIA Analysis of Bingaman CES Proposal, Nov. 2011

Figure 1. Total Net Electricity Generation



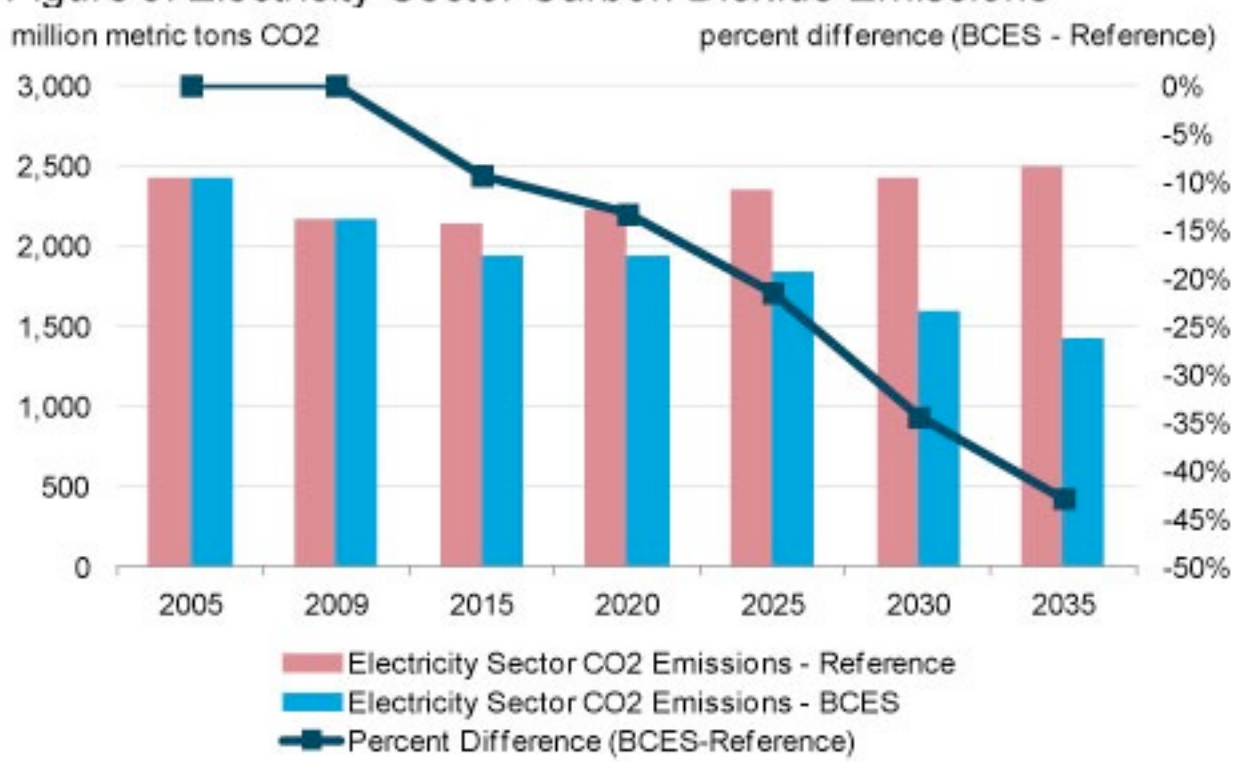
Source: U.S. Energy Information Administration. National Energy Modeling System, runs refhall.d082611b and cesbingbk.d100611a.

Figure 2. Total Non-Hydroelectric Renewable Generation



Source: U.S. Energy Information Administration. National Energy Modeling System, runs refhall.d082611b and cesbingbk.d100611a.

Figure 3. Electricity Sector Carbon Dioxide Emissions



Source: U.S. Energy Information Administration. National Energy Modeling System, runs refhall.d082611b and cesbingbk.d100611a.

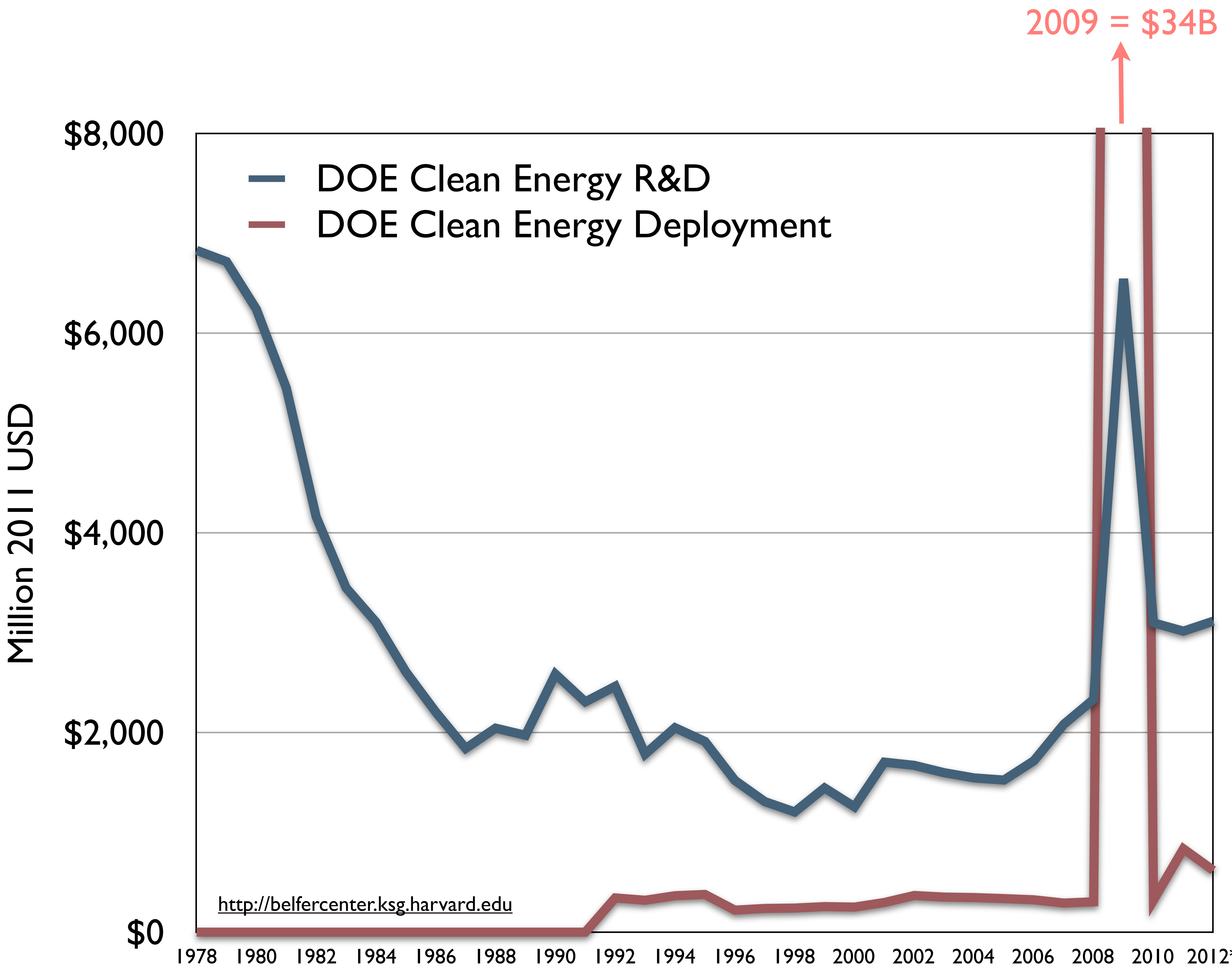
http://www.eia.gov/analysis/requests/ces_bingaman/

United Nations
Sept. 22, 2009

“We're making our government's **largest ever investment in renewable energy** – an investment aimed at doubling the generating capacity from wind and other renewable resources in three years. Across America, entrepreneurs are constructing wind turbines and solar panels and batteries for hybrid cars with the help of **loan guarantees and tax credits** – projects that are creating new jobs and new industries. We're **investing billions to cut energy waste** in our homes, buildings, and appliances – helping American families save money on energy bills in the process. We've **proposed the very first national policy aimed at both increasing fuel economy and reducing greenhouse gas pollution for all new cars and trucks** – a standard that will also save consumers money and our nation oil. We're moving forward with our nation's first offshore wind energy projects. We're **investing billions to capture carbon pollution so that we can clean up our coal plants**. Just this week, we announced that for the first time ever, we'll begin **tracking how much greenhouse gas pollution is being emitted throughout the country**. Later this week, I will **work with my colleagues at the G20 to phase out fossil fuel subsidies** so that we can better address our climate challenge. And already, we know that the **recent drop in overall U.S. emissions** is due in part to steps that promote greater efficiency and greater use of renewable energy.

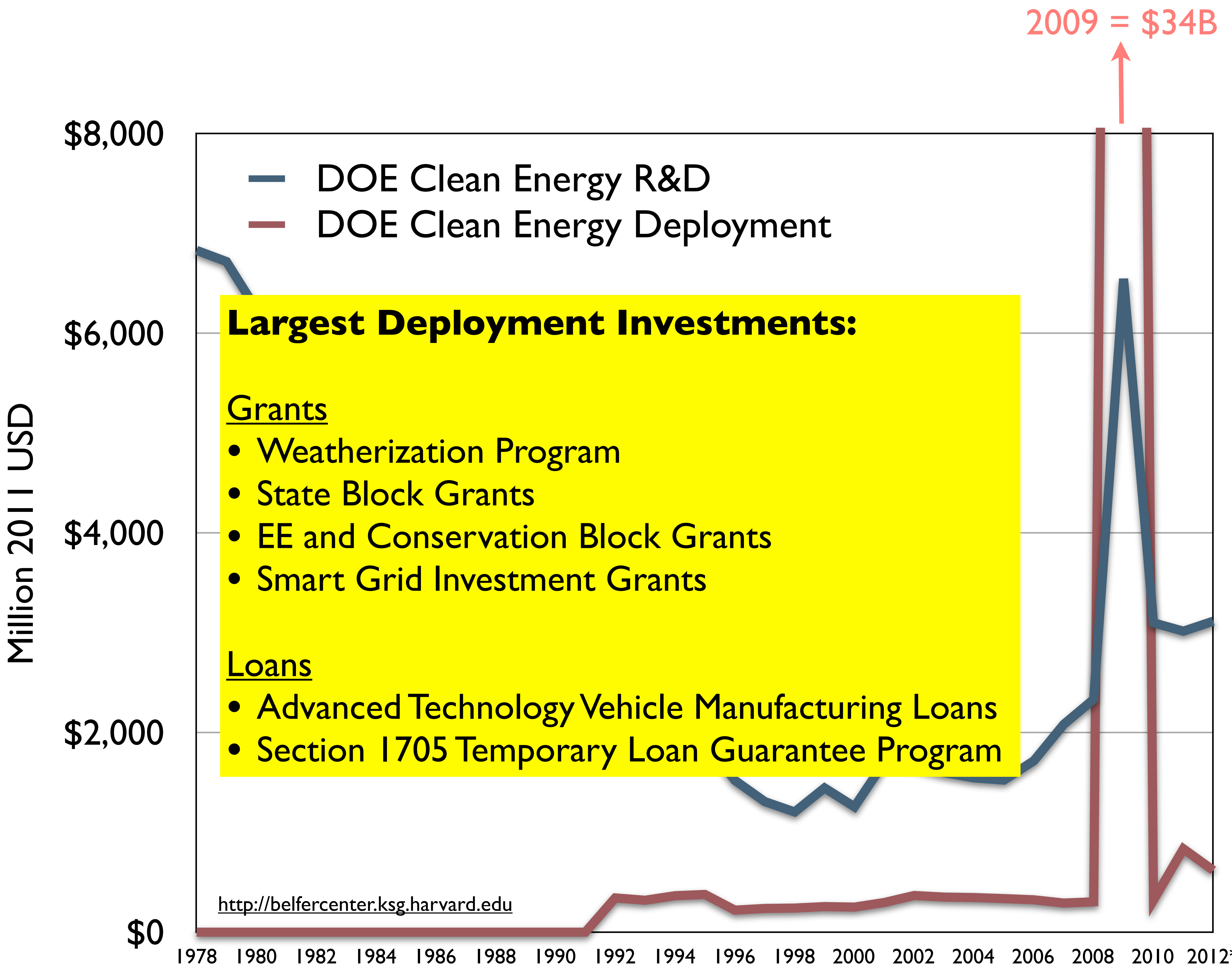
“Most importantly, the **House of Representatives passed an energy and climate bill in June** that would finally make clean energy the profitable kind of energy for American businesses and dramatically reduce greenhouse gas emissions. **One committee has already acted on this bill in the Senate and I look forward to engaging with others** as we move forward.”

Recovery Act Investments at DOE



2011 and 2012 data are estimates based on overall reductions from budget request.

Recovery Act Investments at DOE



2011 and 2012 data are estimates based on overall reductions from budget request.

U.S. DEPARTMENT OF ENERGY • NEW JERSEY RECOVERY ACT SNAPSHOT

Funding for selected DOE projects: $350.4 million

DOE Recovery Act projects in New Jersey: 107

Clean energy tax credits and grants: 59

For total Recovery Act jobs numbers in New Jersey go to www.recovery.gov

New Jersey has substantial natural resources, including wind and biomass. The **American Recovery & Reinvestment Act (ARRA)** is making a meaningful down payment on the nation's energy and environmental future. The Recovery Act investments in New Jersey are supporting a broad range of clean energy projects, from energy efficiency and the smart grid to alternative fuels and vehicles, as well as the Princeton Plasma Physics Laboratory in Plainsboro. Through these investments, New Jersey's businesses, universities, non-profits, and local governments are creating quality jobs today and positioning New Jersey to play an important role in the new energy economy of the future.

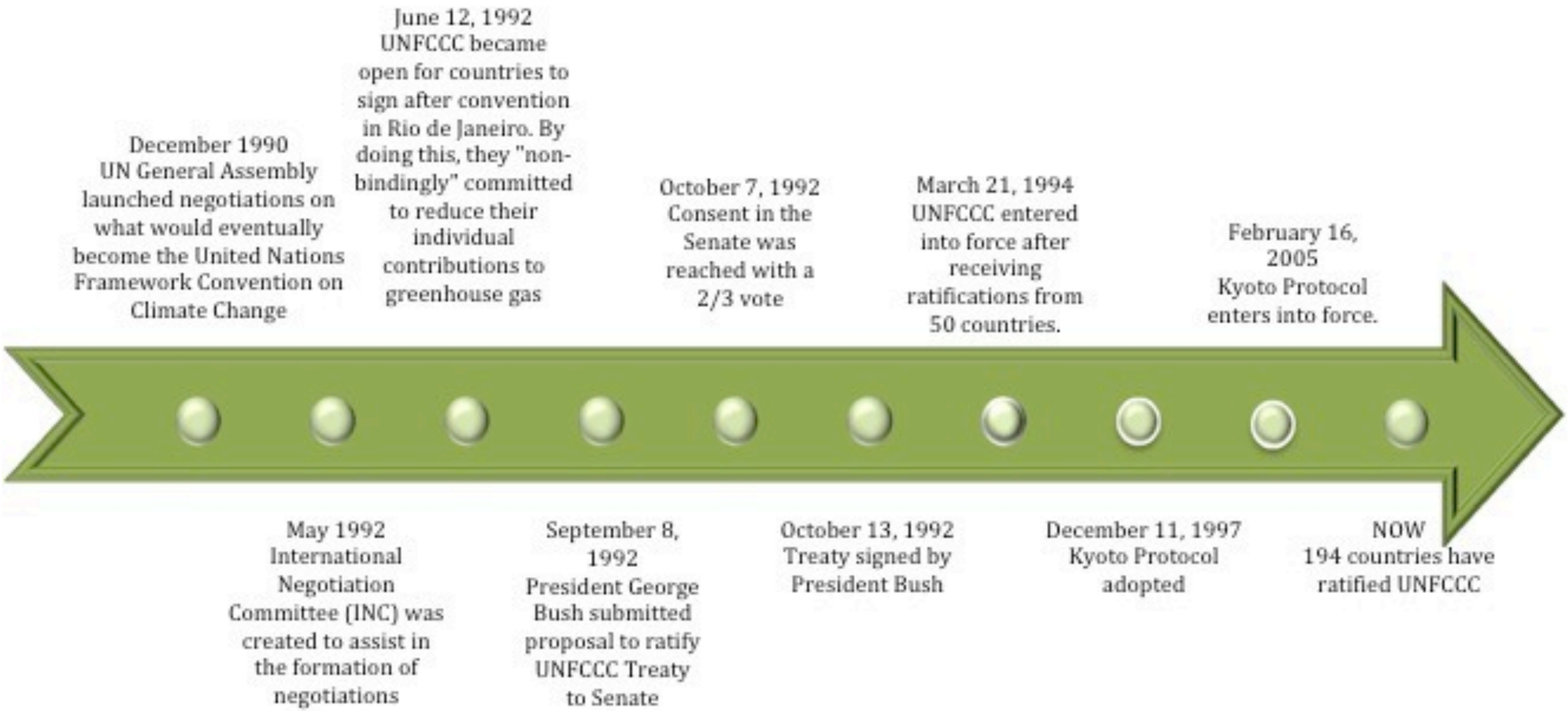
EXAMPLES OF NEW JERSEY FORMULA GRANTS

Program	State Energy Program	Weatherization Assistance Program	Energy Efficiency Conservation Block Grants	Energy Efficiency Appliance Rebate Program
Award (in millions)	$73.6	$118.8	$75.5	$8.3
	The New Jersey Department of Treasury has received $73.6 million in State Energy Program funds to invest in state-level energy efficiency and renewable energy priorities.	The State of New Jersey has received $118.8 million in Weatherization Assistance Program funds to scale-up existing weatherization efforts in the state, creating jobs, reducing carbon emissions, and saving money for New Jersey's low-income families. Over the course of the Recovery Act, New Jersey expects to weatherize nearly 13,400 homes. The program also includes workforce training and education as part of the state's efforts to develop a green workforce.	Seventy-six communities in New Jersey have received a total of $75.5 million for Energy Efficiency and Conservation Block Grants (EECBG) to develop, promote, implement, and manage local energy efficiency programs.	The New Jersey Department of Treasury has received $8.3 million for the Energy Efficient Appliance Rebate Program, which offers consumer rebates for purchasing certain ENERGY STAR® appliances. These energy efficient appliances reduce energy use and save money for families, while helping the environment and supporting the local economy.

EXAMPLES OF NEW JERSEY COMPETITIVE GRANTS AND TAX CREDITS

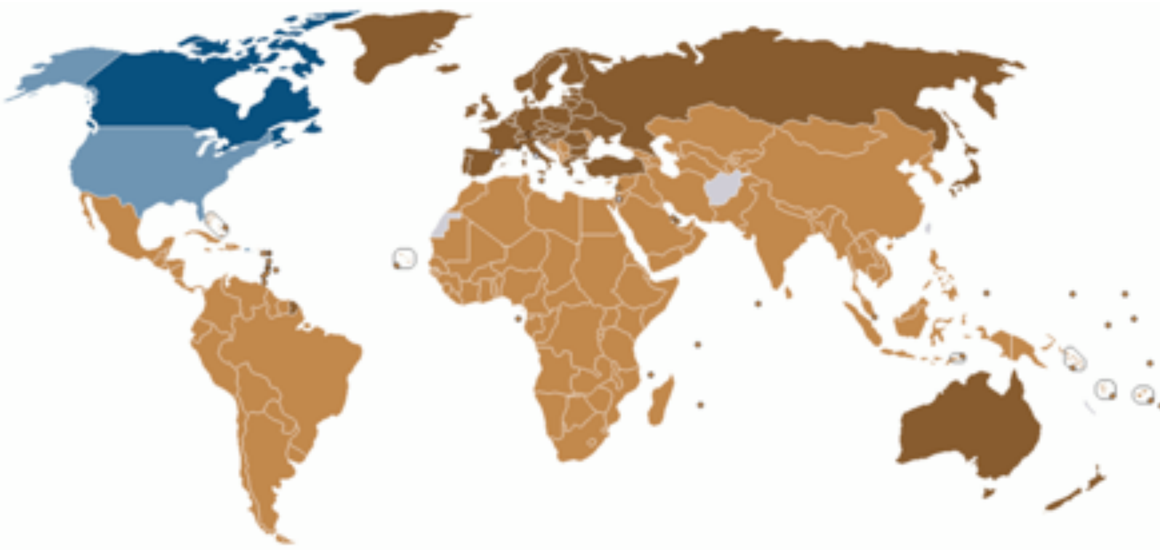
Award	$26.8 million	$18.7 million	$15 million	$7 million
	New Jersey received **fifty-eight 1603 payments for renewable energy generation** totaling **$26.8 million**, which include solar and combined heat and power projects.	**Atlantic City Electric Company** was awarded a **Smart Grid Investment Grant** for **$18.7 million** to take the lead in installing 25,000 direct load control devices and deploy communications and grid monitoring infrastructure across New Jersey.	The **New Jersey Clean Cities Coalition** was awarded **$15 million** under **the Clean Cities Alternative Fuel Vehicle (AFV) Grant Program** to deploy more than 225 compressed natural gas (CNG) vehicles and develop four CNG fueling sites.	**Princeton University** was awarded **$7 million** for **National Spherical Torus Experiment (NSTX) Facility Upgrades**. The funds will be used to upgrade key components of the experiment, accelerating advancement of understanding in plasma and fusion technologies.

UNFCCC Timeline

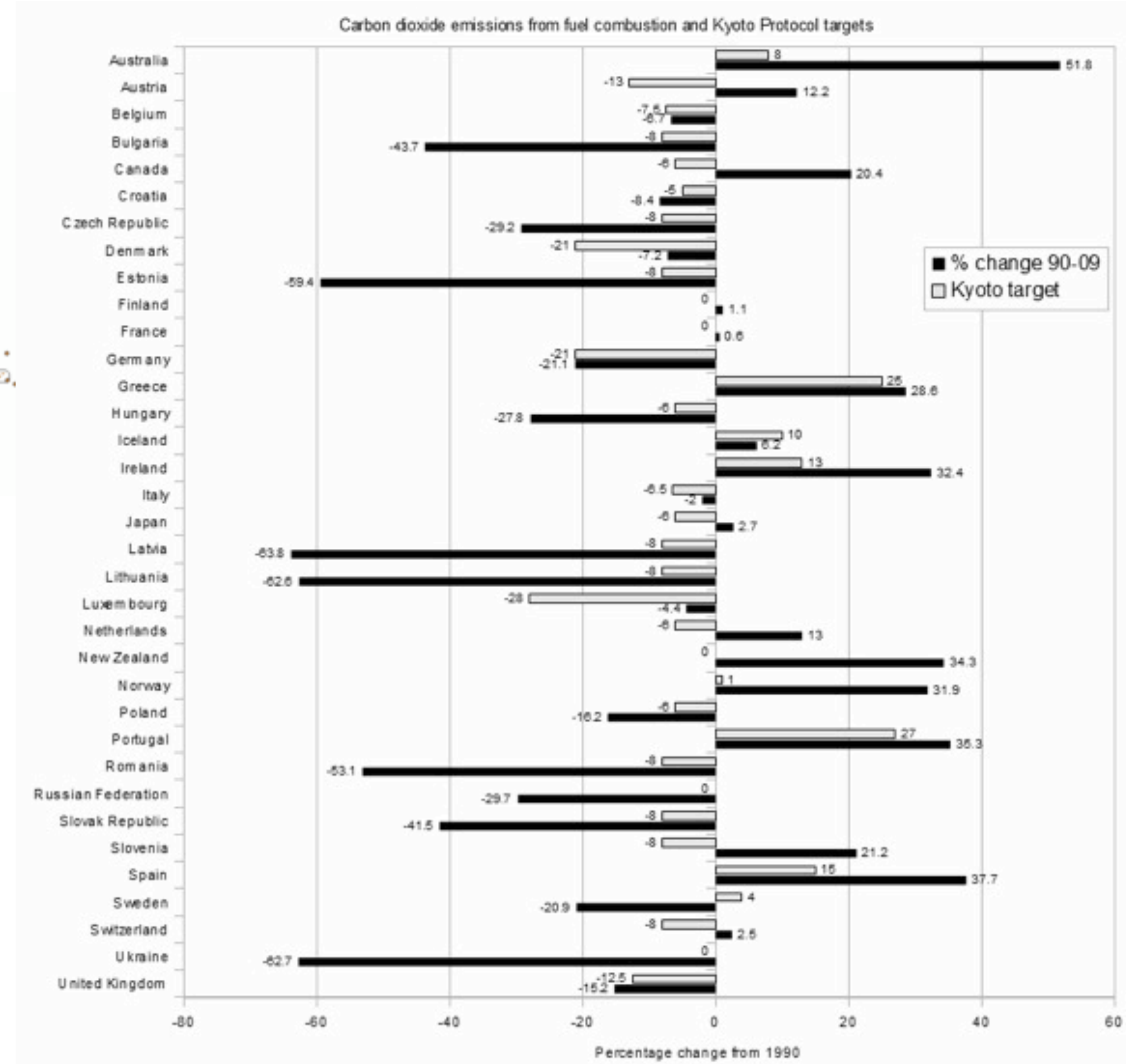


http://gcc.aos.ecu.edu/fall-2010/country-expert-talks/india/

Kyoto Protocol



Annex I
Non-Annex I
Never In
Withdrawn



Wikipedia

Annex I Parties	*Quantified economy-wide emissions targets for 2020*	
	Emissions reduction in 2020	Base year
United States of America	In the range of 17%, in conformity with anticipated U.S. energy and climate legislation, recognizing that the final target will be reported to the Secretariat in light of enacted legislation. [1]	2005

[1] The pathway set forth in pending legislation would entail a 30% reduction in 2025 and a 42% reduction in 2030, in line with the goal to reduce emissions 83% by 2050.

Objectives of Copenhagen Accord, as reflected in 2010 Cancun Agreements

- Establish clear objectives for reducing human-generated greenhouse gas emissions over time to keep the global average temperature rise below **two degrees**
- Encourage the **participation of all countries** in reducing these emissions, in accordance with each country's **different responsibilities and capabilities** to do so
- Ensure the **international transparency** of the actions which are taken by countries and ensure that global progress towards the long-term goal is reviewed in a timely way
- Mobilize the **development and transfer of clean technology** to boost efforts to address climate change, getting it to the right place at the right time and for the best effect
- Mobilize and provide **scaled-up funds in the short and long term** to enable developing countries to take greater and effective action
- **Assist the particularly vulnerable** people in the world to adapt to the inevitable impacts of climate change
- **Protect the world's forests**, which are a major repository of carbon
- **Build up global capacity**, especially in developing countries, to meet the overall challenge
- **Establish effective institutions and systems** which will ensure these objectives are implemented