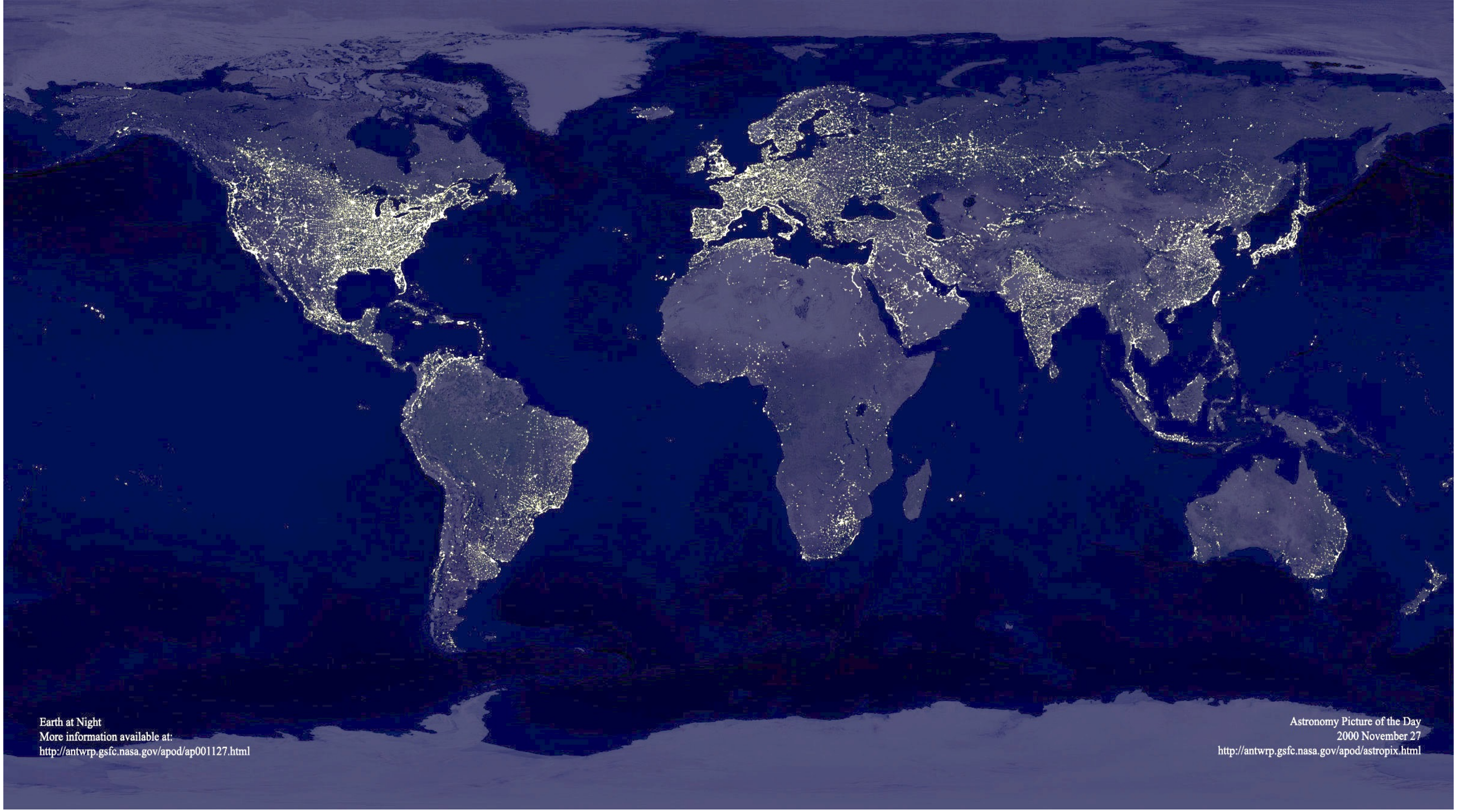

Energy Basics:

Science, Society, and Sustainability

LA 12 Environmental Science for Sustainability
Prof Matt Kondolf

Lecture Overview

1.Fundamental Terms and Concepts
- Energy
- Thermodynamics
- Efficiency

2. Energy Services and Sources
- How do we use energy?
- Coal
- Petroleum
- Hydropower
- Natural Gas

3. Challenges to Sustainability
- Greenhouse gas emissions
- Environmental and human health impacts of energy harvesting, use, and waste products

4. Toward a More Sustainable System
- Using Less
- Decarbonization
- 4 actions to reduce emissions

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What is *energy*?

What is *energy*?

“The capacity to do work”

- Every physics textbook ever

What is *energy*?

"[Energy is] really a property of things…. This property can move from one place to another, and when it moves we can sometimes use the resulting flow of energy to do what physicists call 'work' – that is, to change things in our physical world. "

- Thomas Homer-Dixon,

The Upside of Down (2007)

Energy takes many forms, including:

Kinetic	Energy from the motion of objects
Thermal	The heat of an object
Chemical	Energy stored in chemical bonds
Electrical	Energy associated with moving electrons
Electromagnetic	Energy associated with light waves
Nuclear	Energy contained in atomic nuclei

What is energy?

Energy and work have the same basic unit:

$$1 \text{ joule} = 1 \text{ kg}\cdot\text{m}^2/\text{s}^2 = 1 \text{ (kg}\cdot\text{m)}\cdot\text{(m/s}^2\text{)}$$

Sir Isaac Newton and his insight into gravity prompted by a falling apple

What is energy?

Energy and work have the same basic unit:

$$1 \text{ joule} = 1 \text{ kg}\cdot\text{m}^2/\text{s}^2 = 1 (\text{kg}\cdot\text{m})\cdot(\text{m}/\text{s}^2)$$

If I lift	an apple	(**0.1 kg**) up to
	my hips	(**1 m**) against
	gravity	(**10 m/s^2**)
I do	work	(**1 J**)

What is energy?

Energy and work have the same basic unit:

$$1 \text{ joule} = 1 \text{ kg}\cdot\text{m}^2/\text{s}^2 = 1 \text{ (kg}\cdot\text{m)}\cdot\text{(m/s}^2\text{)}$$

What is power?

Power is a rate of work or energy flow:

1 watt = 1 J/s

So it's energy or work ***over time***

What is energy?

Thus,

Energy = Power x Time

If it takes **1 s** to do

1 J of work (lift the apple)

I work at a rate of **1 W**

What is energy?

Energy = Power x Time

If I work at a rate of **50 W** for
60 seconds

I’ve done **3000 J** of work

What is energy?

Units of Energy and Work

Joule

Kilowatt-hour

Btu & Therm

Calorie

Erg

Units of Power

Watt

Horsepower

Units and Conversions

- Electric power is measured in Watts (W) (W = Joule/second).
- Electric energy is commonly expressed in kilowatt-hours (kWh).
- 1 kWh = 3.6 MJ = 3,412 BTUs (British thermal units).
- 1 kWh = equivalent energy to that contained in 0.03 gallons (0.5 cup, 0.11 liter) of gasoline.
- Mtoe = million tonnes of oil equivalent = 11,630,000,000 kWh

Thermodynamics

1st Law: Energy can move around or change form, but it cannot be created or destroyed (conservation of energy)

Efficiency = $\frac{\text{What you want}}{\text{What you pay}}$

Image from: egrc.net

Potential vs kinetic energy
Energy converted to different forms

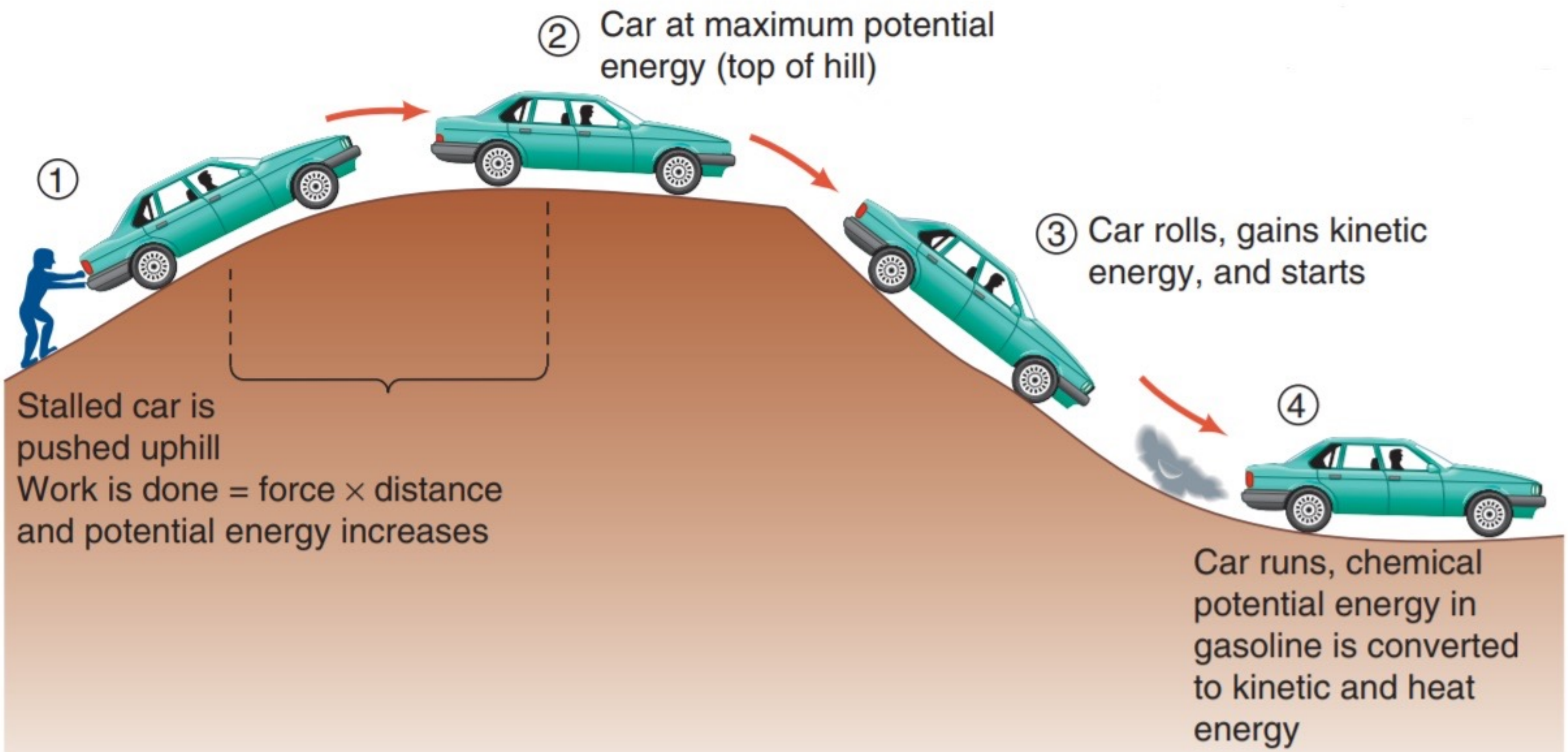
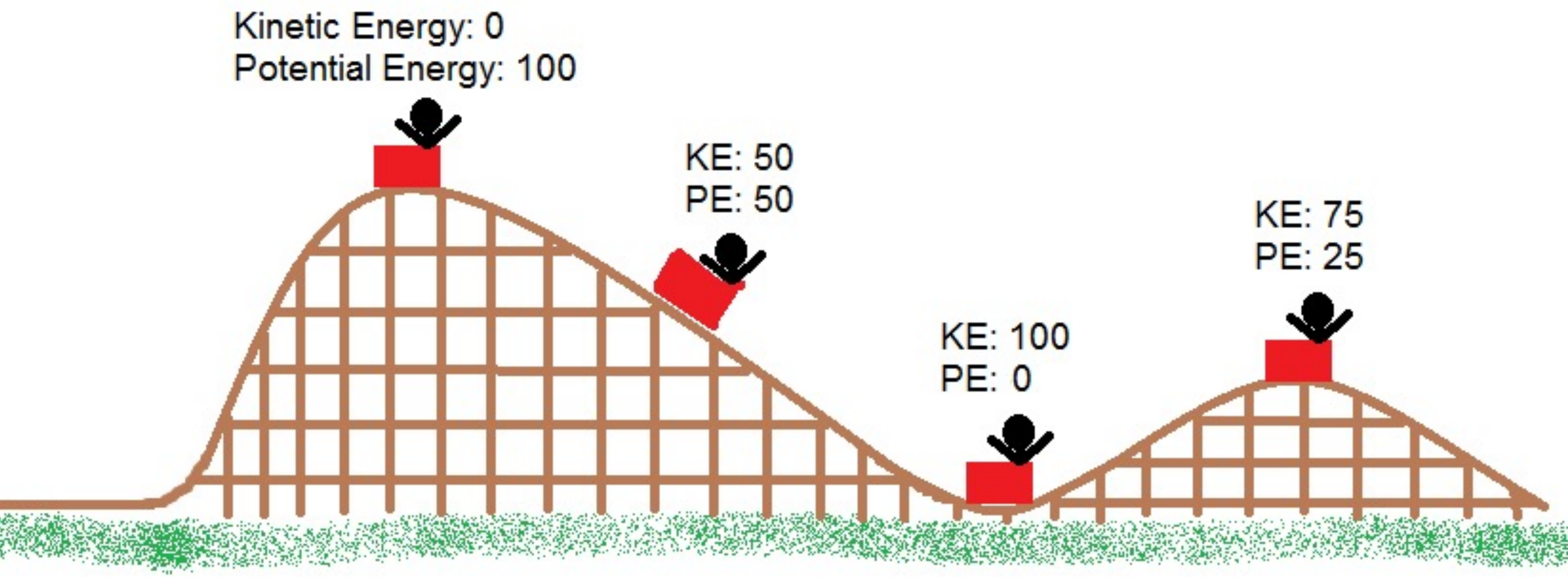


FIGURE 14.2 **Some basic energy concepts**, including potential energy, kinetic energy, and heat energy.

Potential vs kinetic energy
Energy converted to different forms



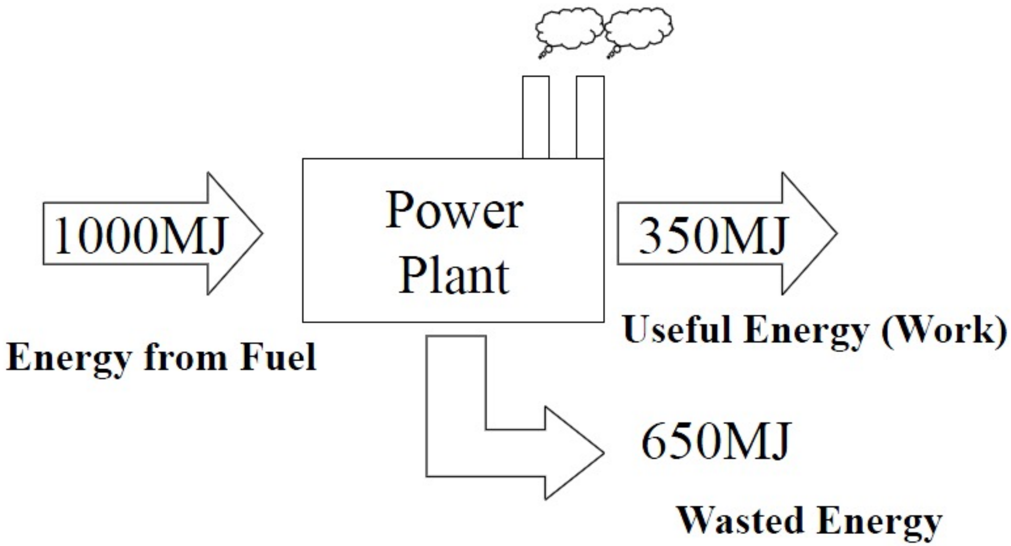
Thermodynamics

2^{nd} Law: Order tends to disorder, concentration to chaos

Heat flows from hot to cold

When doing work or converting energy to another form, some energy is always wasted (*no process is 100% efficient; energy is degraded*)

Power Plant Thermodynamics



$E_{fuel} = 1000$ MJ

$E_{useful} = 350$ MJ

$E_{waste} = 650$ MJ

$$E_{fuel} = E_{useful} + E_{waste}$$

1000 MJ = 350 MJ + 650 MJ

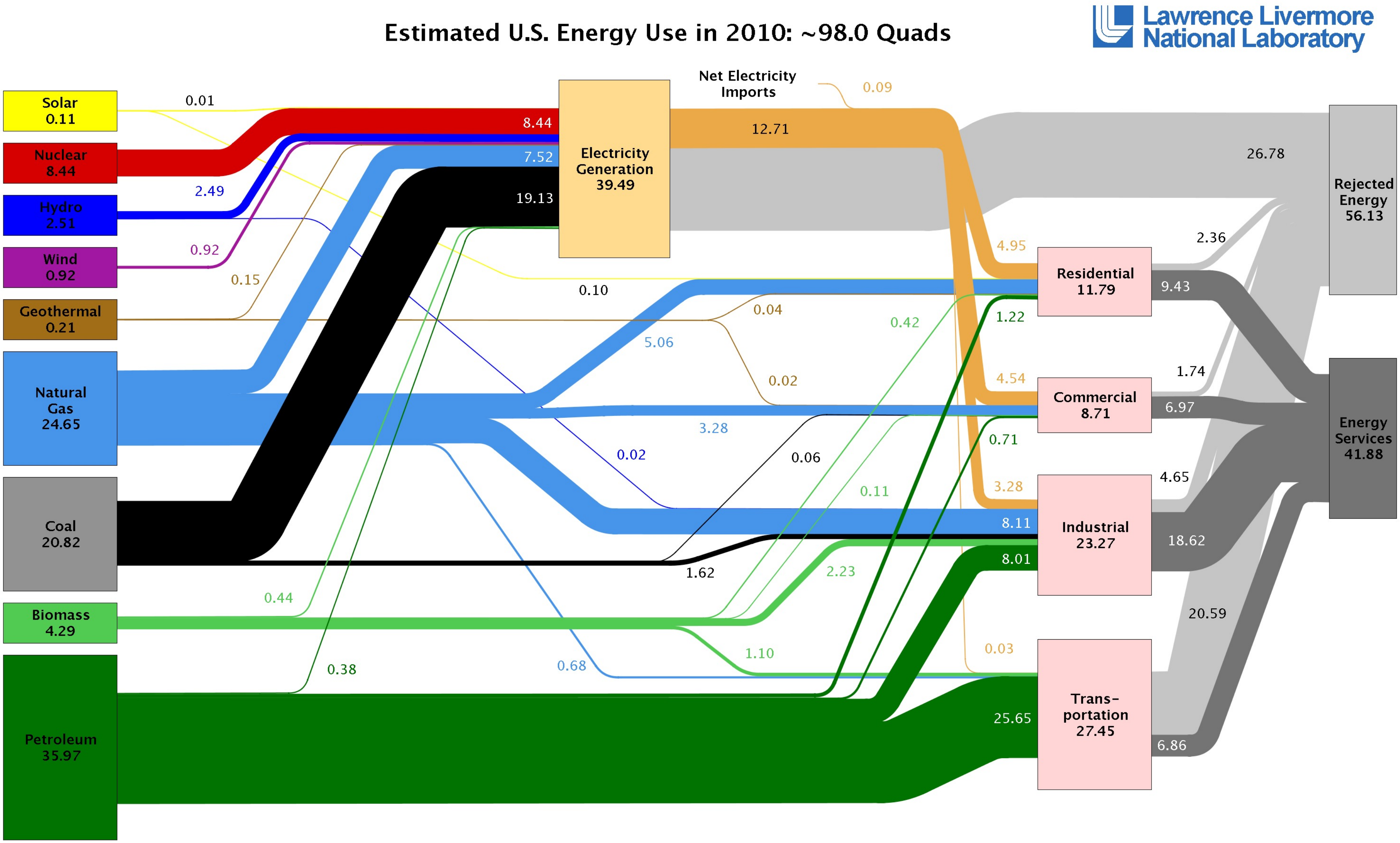
Take-home: in generating plant, most energy is wasted as heat!

Everyday Efficiencies

Conversion	Energies	Efficiency
Natural gas furnace	Chem → Thermal	90-96%
Human lactation	Chem → Chem	85-95%
Car engine	Chem → Mech	15-25%
Mammalian muscles	Chem → Mech	15-20%
Incandescent light bulbs	Elec → Light	2-5%
Photosynthesis	Light → Chem	<1%

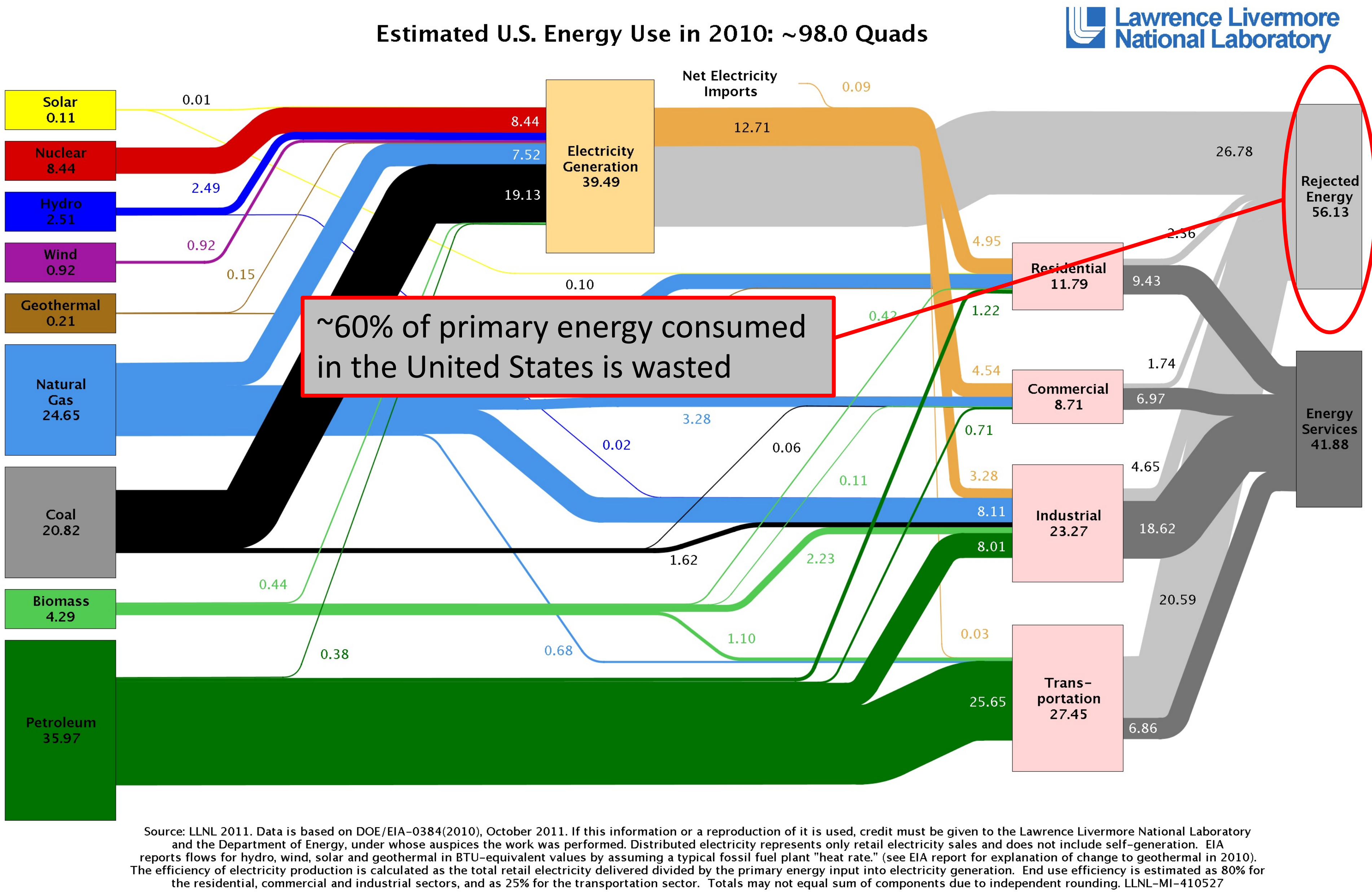
Source: Vaclav Smil, *Energies* (1999)

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



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

https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2010/LLNLUSEnergy2010.png



https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2010/LLNLUSEnergy2010.png

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For what do we use energy in the United States?

Power to the People

Heavy manual laborer …………………… 500 W

Team of plow horses …………………… 5,000 W

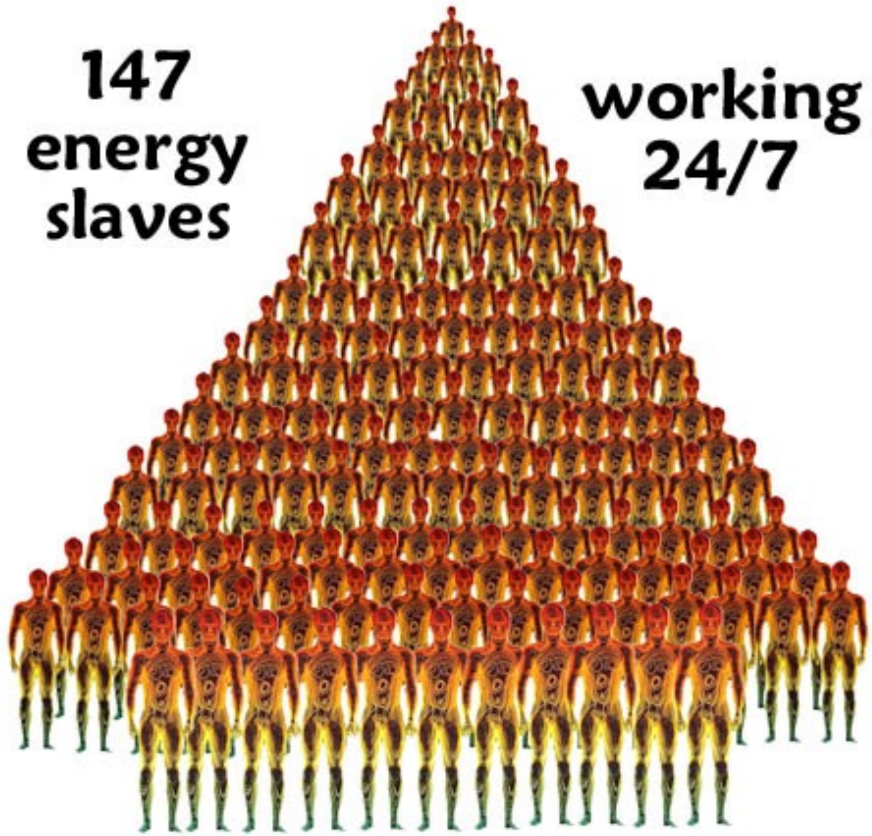
Modern tractor (with AC and stereo) 300,000 W

Steam locomotive (ca. 1900) …… 1,000,000 W

Boeing 747 ……………………….. 45,000,000 W

Nuclear power plant …………. 1,000,000,000 W

Source: Vaclav Smil, *Energies* (1999)



USA: >300 million people use 97 quadrillion BTUs of energy/year
On average we each use 328 million BTUs/yr

Equivalent of 147 ‘energy slaves’ working for each of us 24/7
(Concept proposed by Andrew Nikiforu, author of *Tar Sands: Dirty Oil and the Future of the Continent*)

Image credit: http://www.altenergymag.com/emagazine.php?issue_number=06.08.01&article=slaves

Not all energy is created equal

2nd Law say that energy used for work changes:

Concentrated → Spread out

High quality → Low quality

Useful → Useless

Fossil Fuels are High-Quality Energy Sources

Fuel	*Energy Density (10^6 J/kg)*
Natural gas	49
Gasoline	48
Coal	30
Wood (dry)	15
Bread	12
Beer	1.8
Water (Niagara Falls)	0.0005

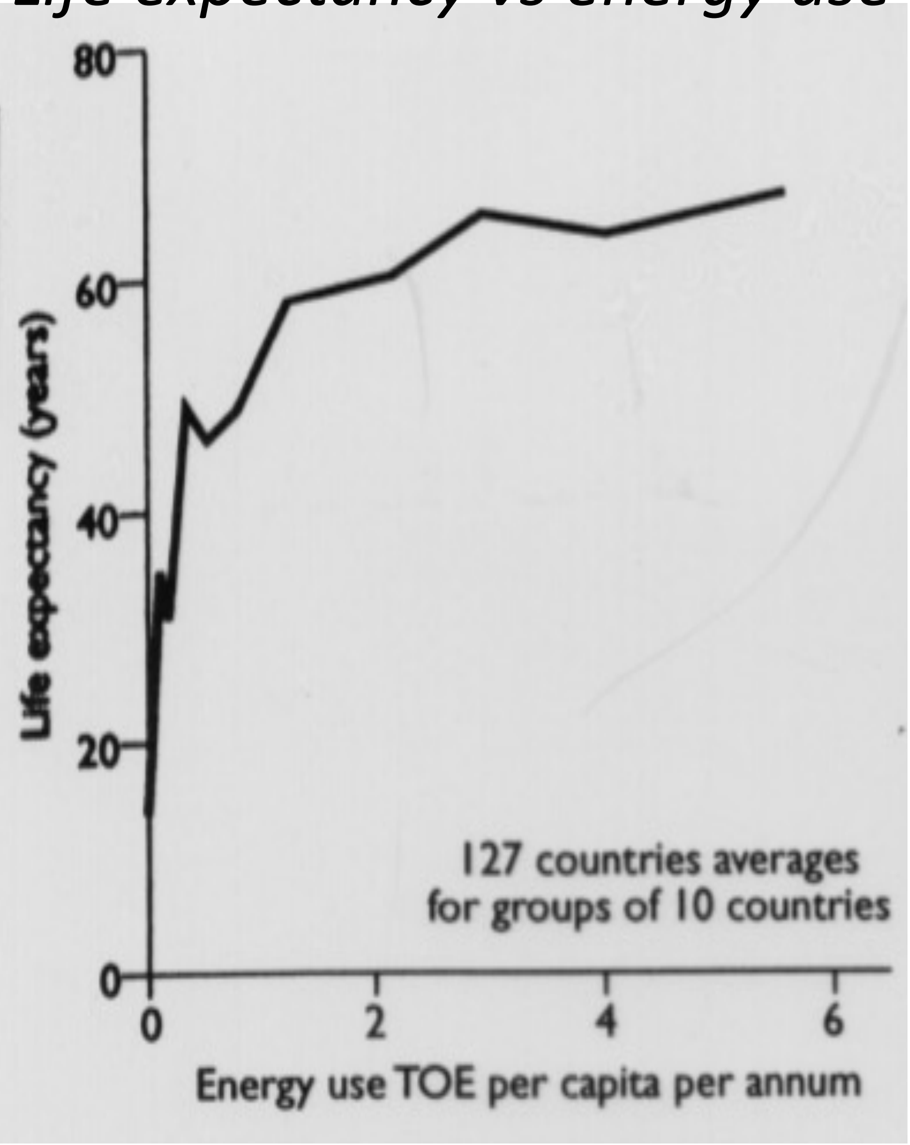
Source: John Harte, *Consider a Spherical Cow* (1988)

Time and Energy

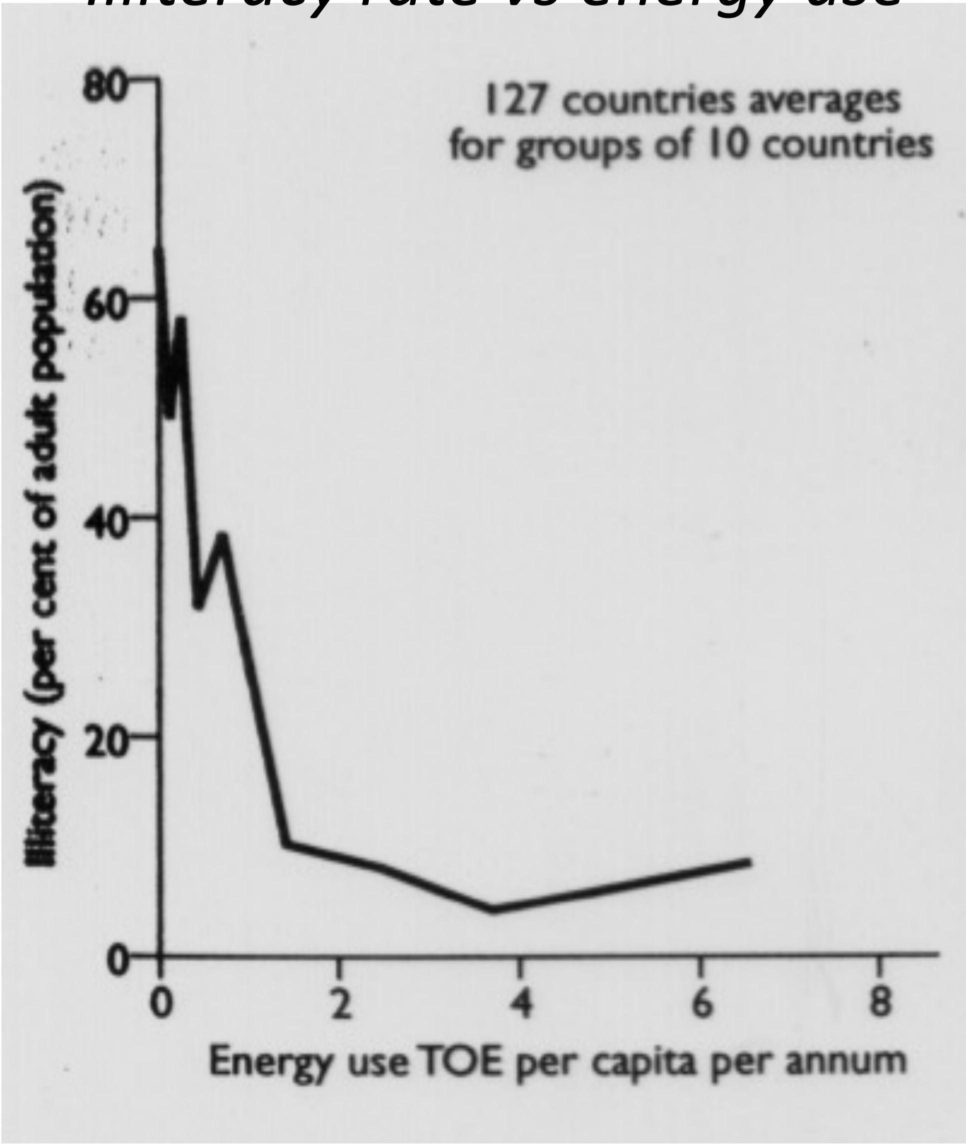
San Francisco to Los Angeles (~380 miles)

Mode	Time (hr)	Energy (MJ)
Walking	130	160
Bicycle	38	65
Car (55 mph)	7	1400
Car (75 mph)	5	2100

Life expectancy vs energy use

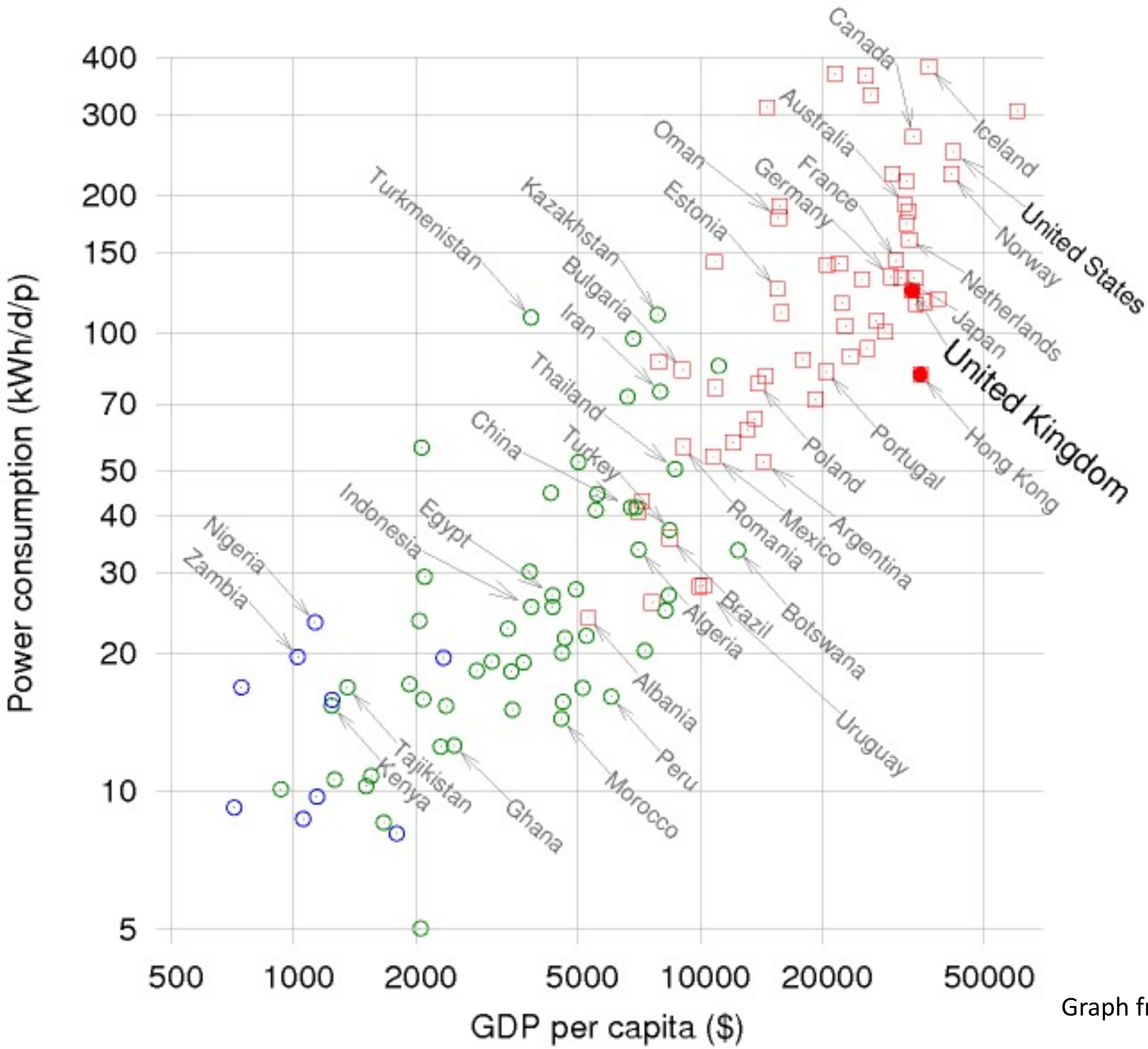


Illiteracy rate vs energy use



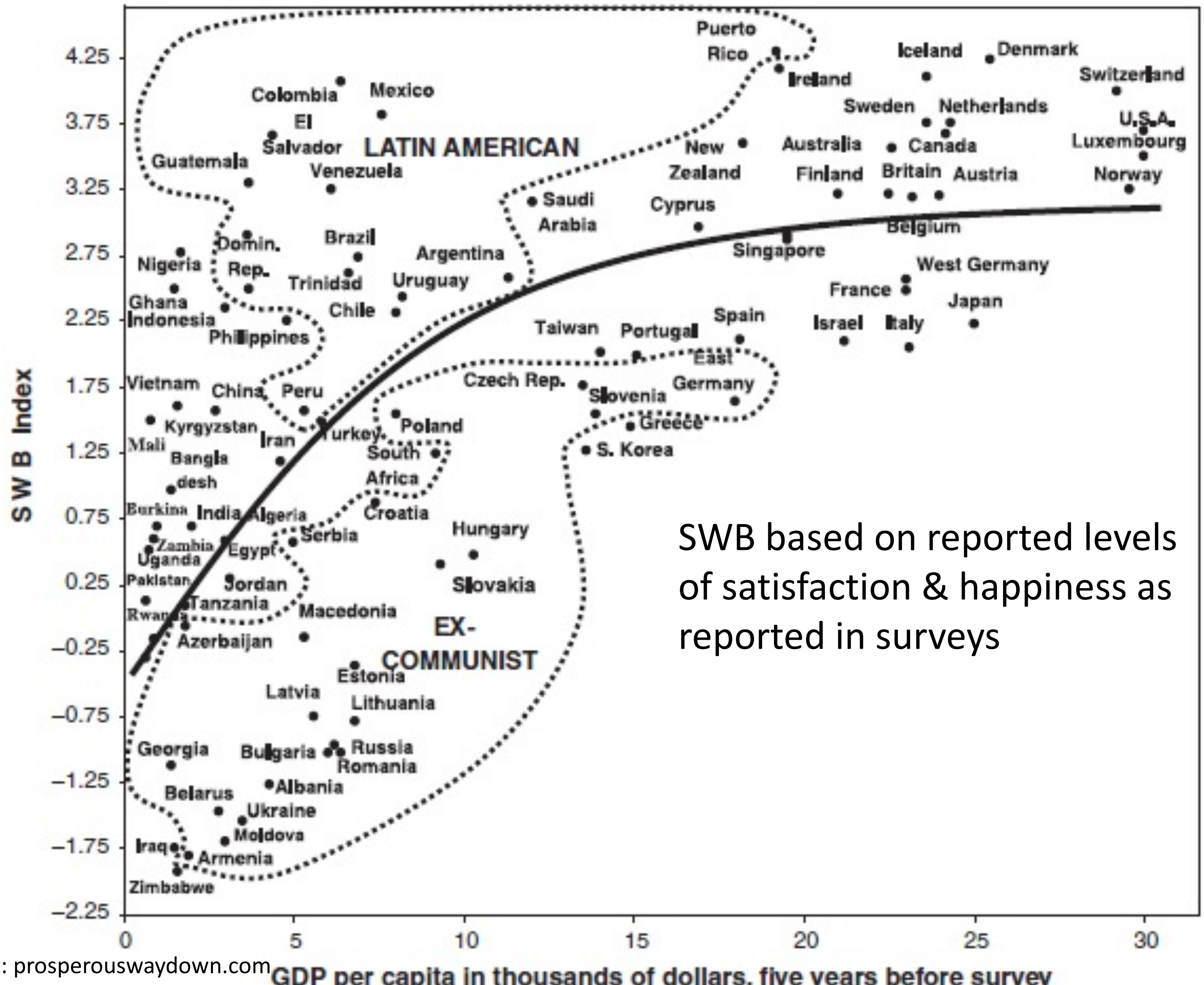
From: Jose Goldemberg (1996), "Energy and Development"

Is it worth it?



Graph from withouthotair.com

Subjective Well-Being Index (SWB)



SWB based on reported levels of satisfaction & happiness as reported in surveys

Image credit: prosperouswaydown.com

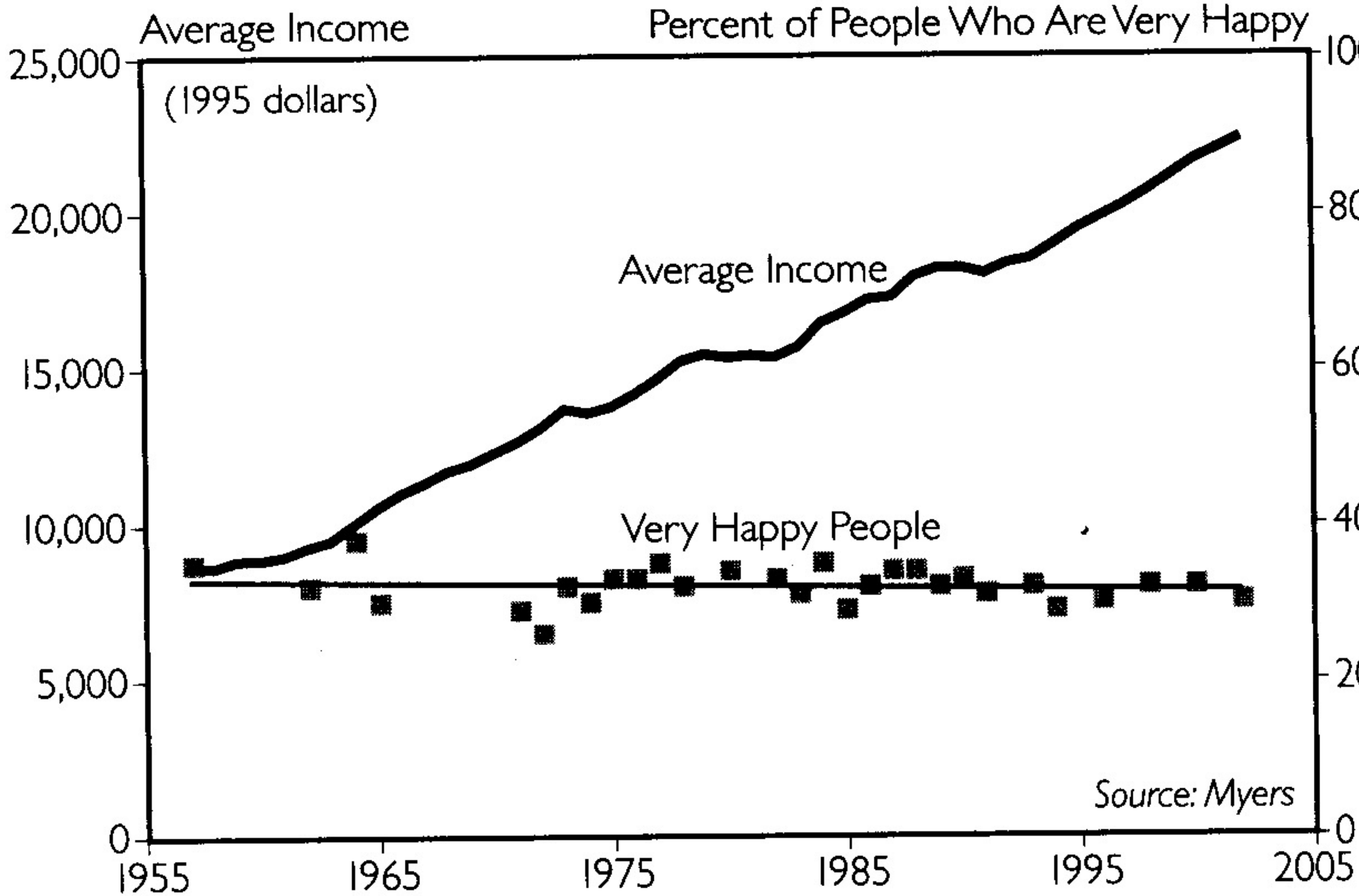


Figure 8–1. Average Income and Happiness in the United States, 1957–2002

Image credit: geraldguild.com

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Greenhouse gases from coal combustion

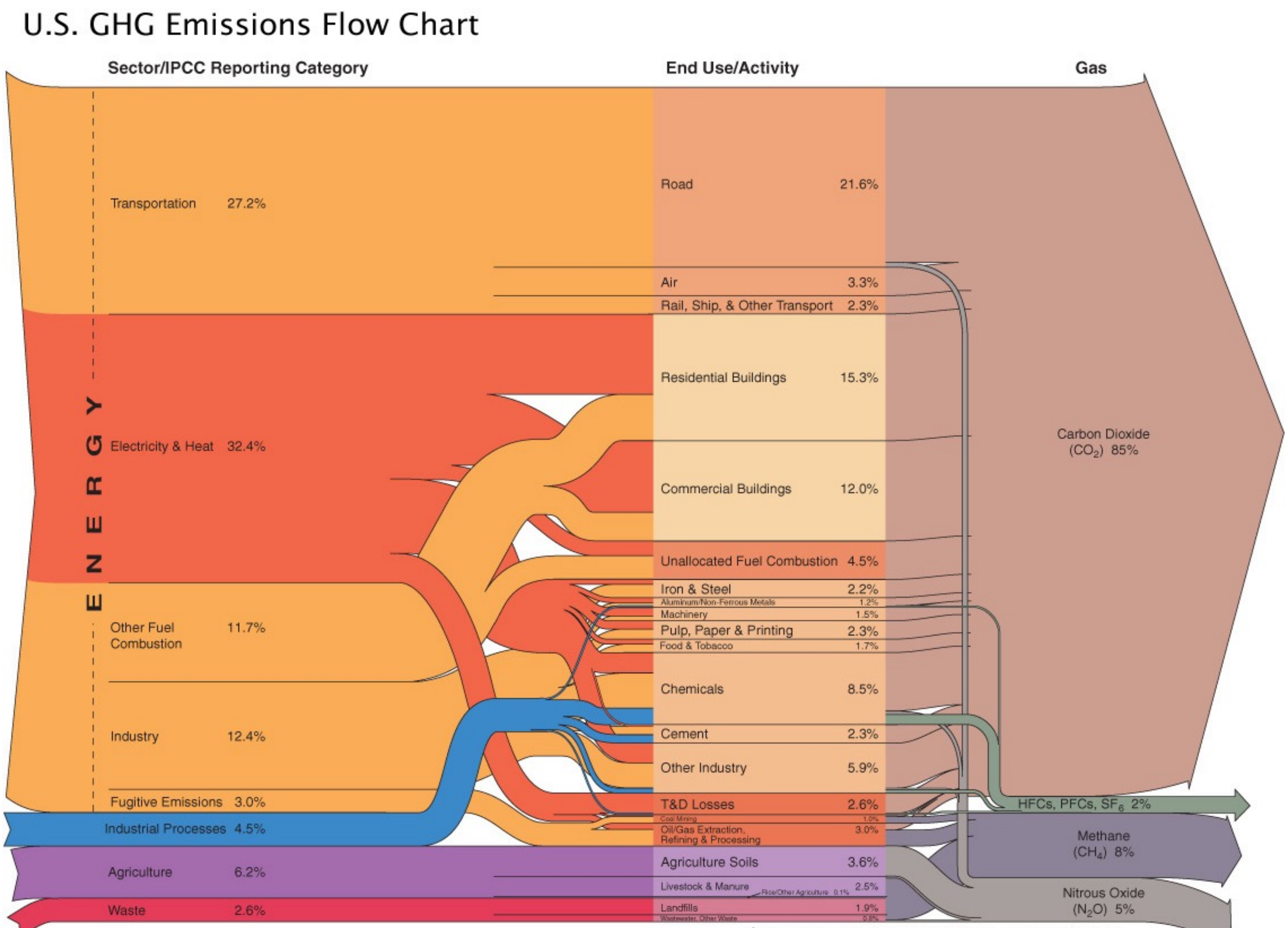
Ideal combustion of coal:

$$C_5H_4O + 6O_2 \rightarrow 5\mathbf{CO_2} + 2H_20 + \text{energy}$$

inevitably produces CO_2!

Burning 1 ton of coal produces nearly 3 tons CO_2

CO_2 is the dominant GHG emitted in the US (85%), but methane (8%) is a powerful GHG



Greenhouse gases and other emissions from burning coal

Ideal combustion of coal:

$$C_5H_4O + 6O_2 \rightarrow 5\mathbf{CO_2} + 2H_20 + \text{energy}$$

Real combustion of coal:

$$\text{Fuel}(C,H,O,N,S,Hg,\text{ etc.}) + \text{air}(O_2, N_2) \rightarrow$$
$$(CO_2, H_2O, CO, NO_X, SO_X, \text{VOCs, particulates}) + Hg + \text{ash} + \ldots + \text{energy}$$

Other sources of energy have impacts (burning coal is not the only culprit)

Impacts can occur throughout the life cycle:

- Harvesting
- Producing energy
- Waste products

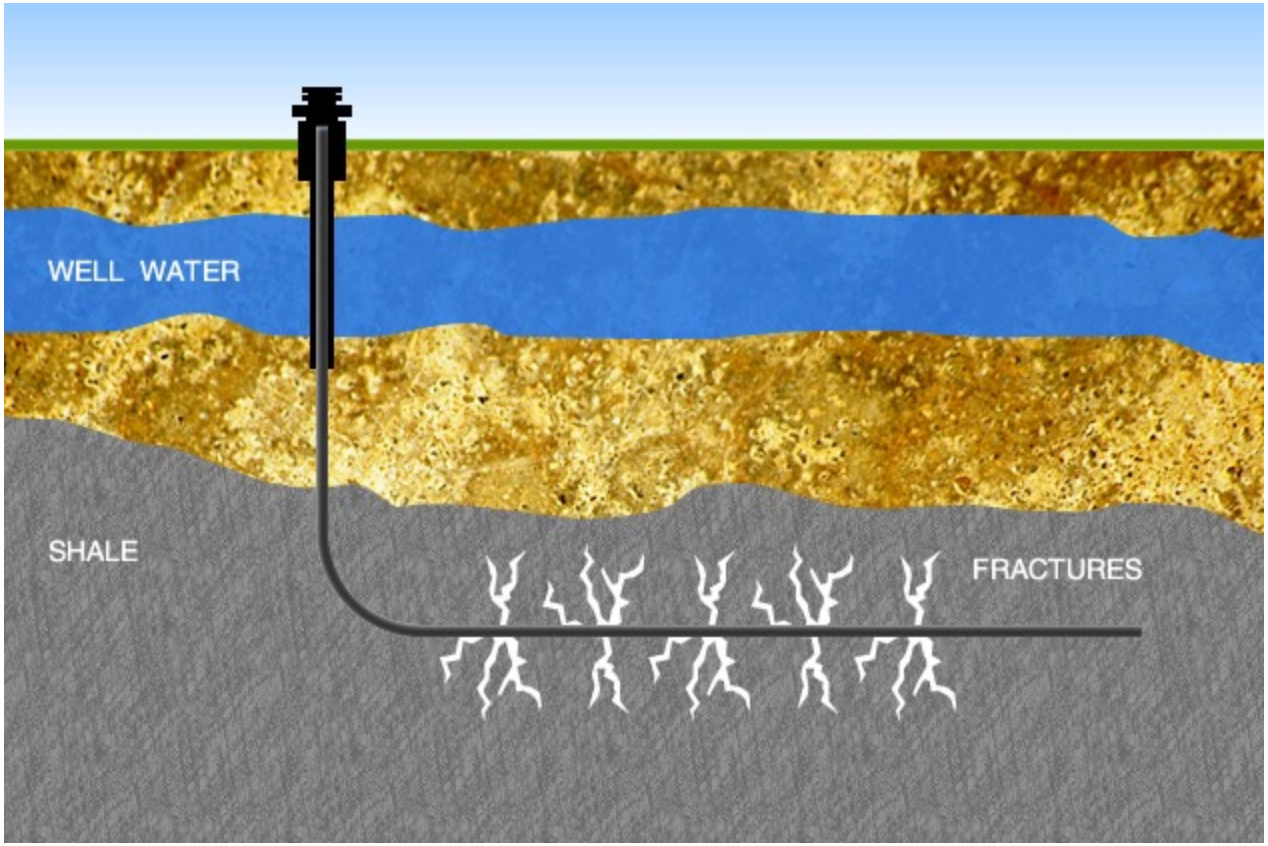
Harvesting Energy

Mountain-top removal

Removal of entire top of the mountain to expose coal seam, material used to fill stream valleys. Occurring across the Appalachian Mts

Acid mine drainage released from coal mines is a slurry of acid and toxic metals

Image source: science.kqed.org



Hydraulic fracturing can appropriate and contaminate significant amounts of water

Image from: louisianarecord.com

Harvesting Energy (cont)

Crops grown to make biofuels can affect food prices and supply; modern agricultural practices are water-, fertilizer-, and pesticide-intensive

Image from: biowesleyan.wordpress.com

Harvesting Energy (cont)

Hydroelectric dams disrupt fish populations and habitats

Image source: physics.ucsd.edu

Harvesting Energy (cont)

Wind turbines have claimed the lives of countless birds and bats

Image from: ecofriend.com

Transporting energy

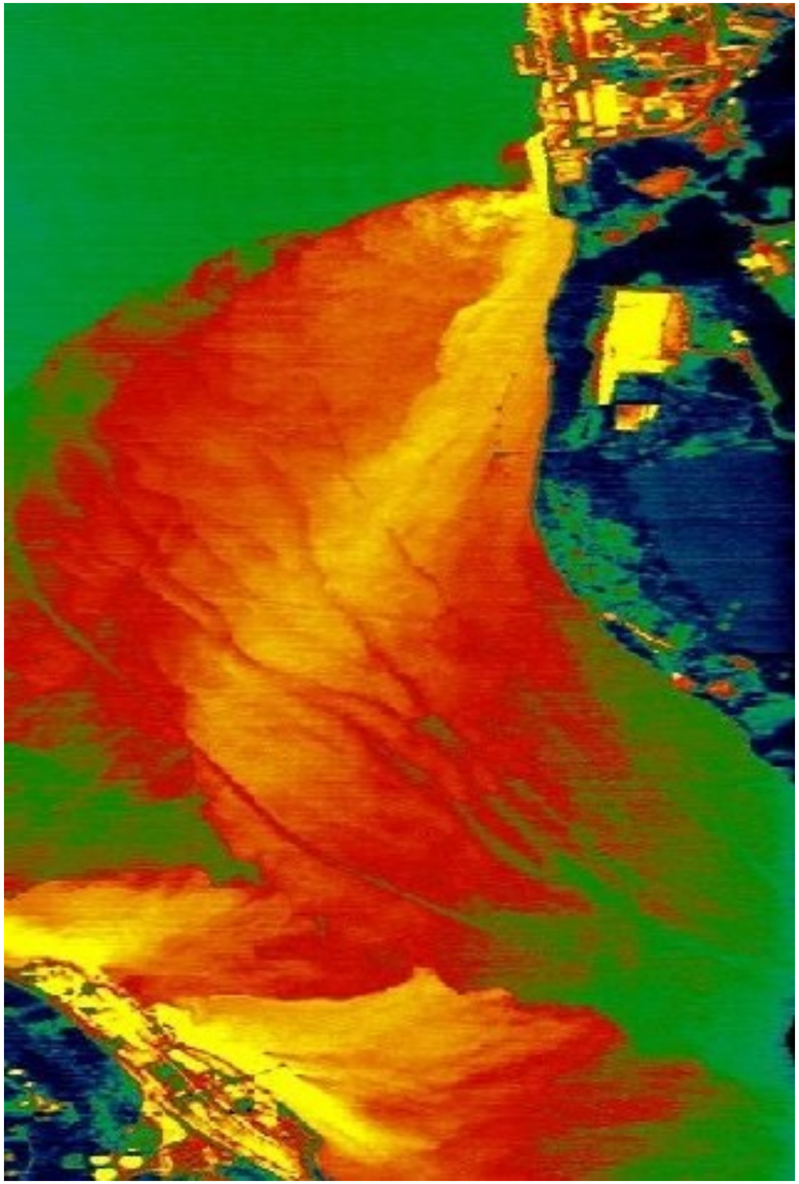
The tanker *Exxon Valdez* oil spilled 10.8 million gallons of oil in 1989, affecting sensitive ecological areas and important salmon runs. Its effects have persisted even to present.

Waste Products

Sulfur piles accumulated by processing Canadian tar sands (Alberta)

Image credit: Dan Kammen

Waste Products (cont)



Rejecting heat from power plants can decrease dissolved oxygen levels and reduce biodiversity

Image from: http://spoonsenergymatters.files.wordpress.com/2011/10/ip-thermal-plume.jpg

Waste Products (cont)

Radioactive wastes from uranium mining and nuclear reactors can impair human and ecosystem health

Image from: energyclub.stanford.edu

Waste Products (cont)

The manufacturing of solar photovoltaic cells involves the use of toxic chemicals, and the cells themselves can pose a health threat

Image from: oilandenergy.com

External costs

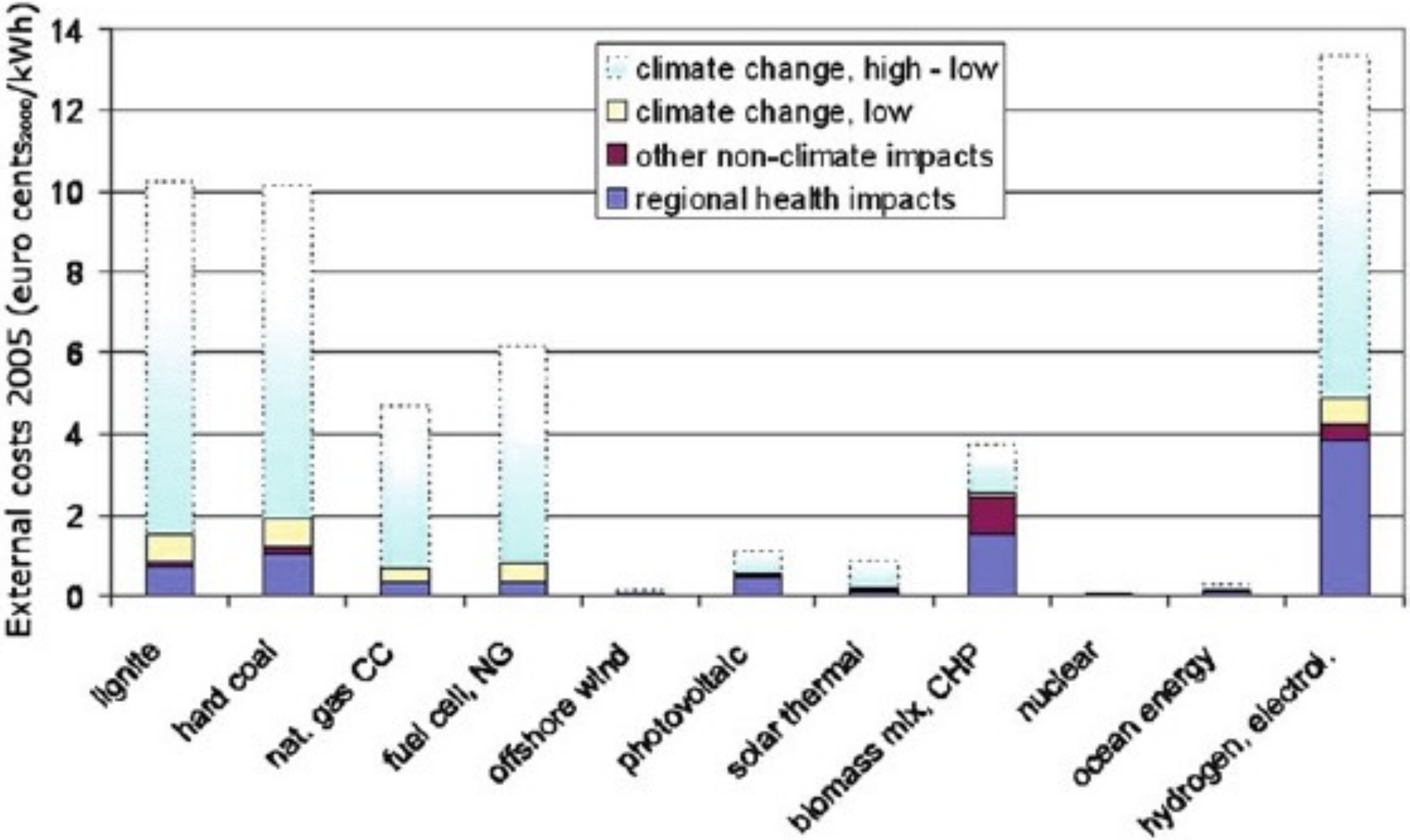


Fig. 4 External costs of various energy technologies in Western Europe in 2005 (Source: Adapted from DLR et al. 2009; Note: *CC* combined cycle, *NG* natural gas, *CHP* combined heat and power, *electrol* electrolysis)

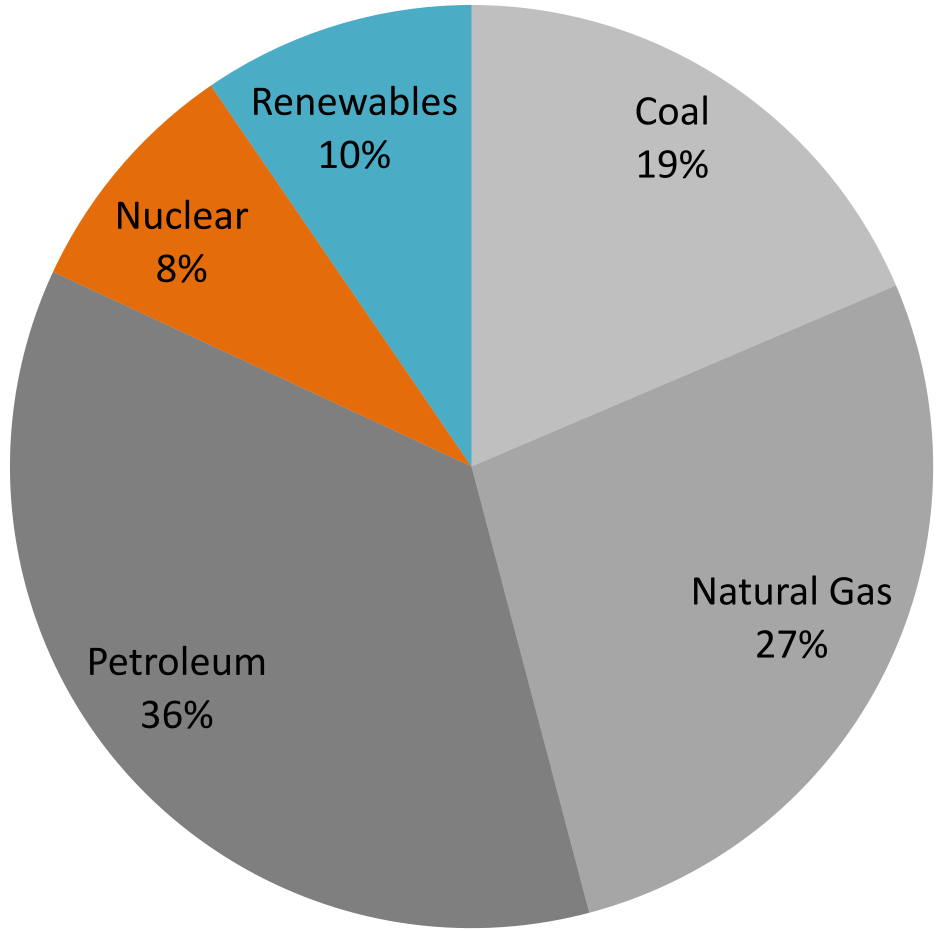
Graph from: Hirschberg (2012), "Externalities in the Global Energy System"

Climate Change Impacts: as described in *An Inconvenient Truth*

US Primary Energy Use by Source, 2013
Total Consumption = 97.4 Quads = 103 EJ

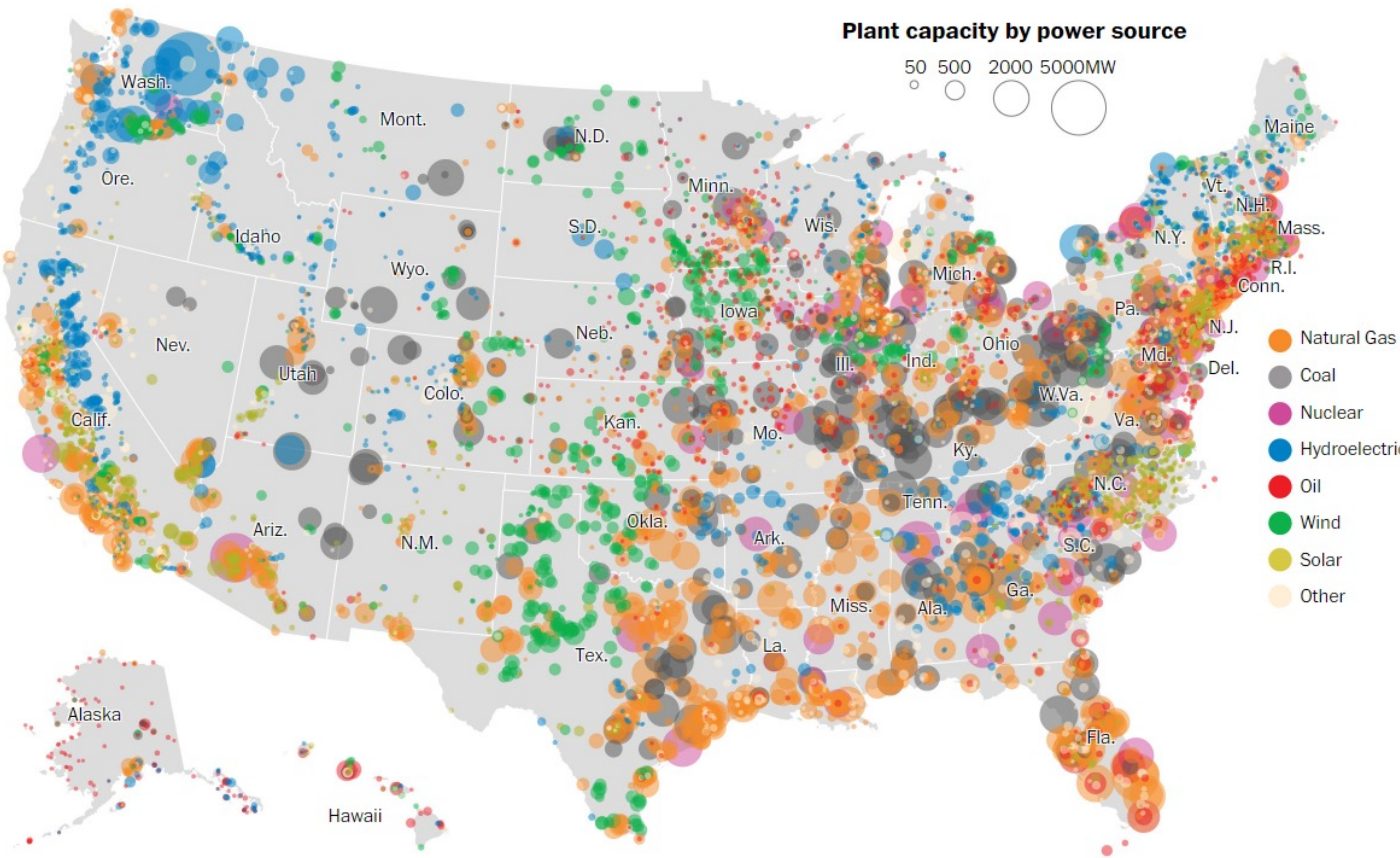
About 80% of the energy consumed in the United States comes from fossil fuels

Note: *total energy use, not just electricity production*



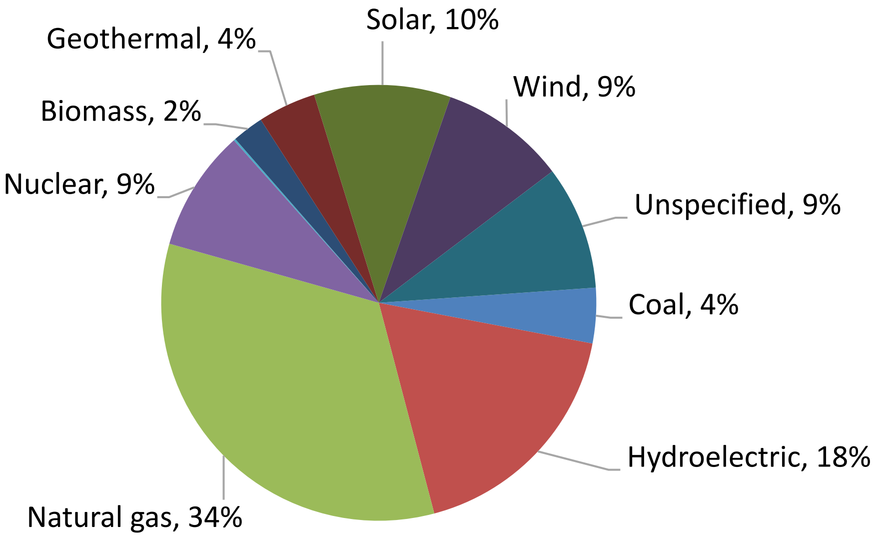
Data source: http://www.eia.gov/totalenergy/data/monthly/pdf/sec1_7.pdf

Energy mix for electrical generation

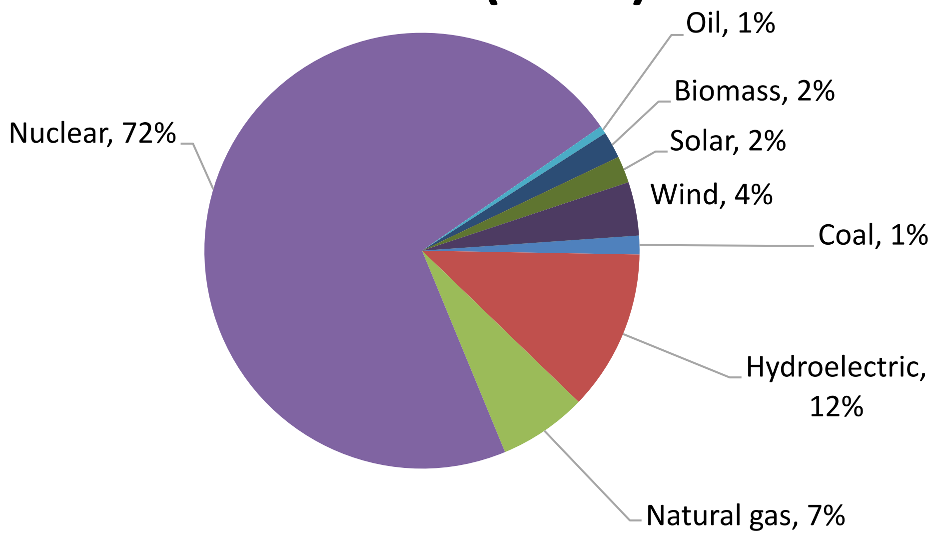


Comparing sources for electricity generation

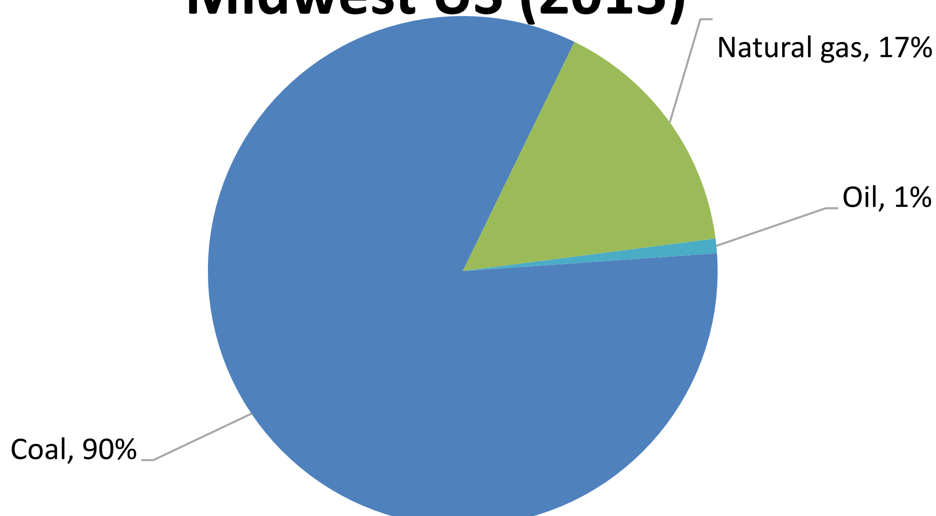
California (2017)



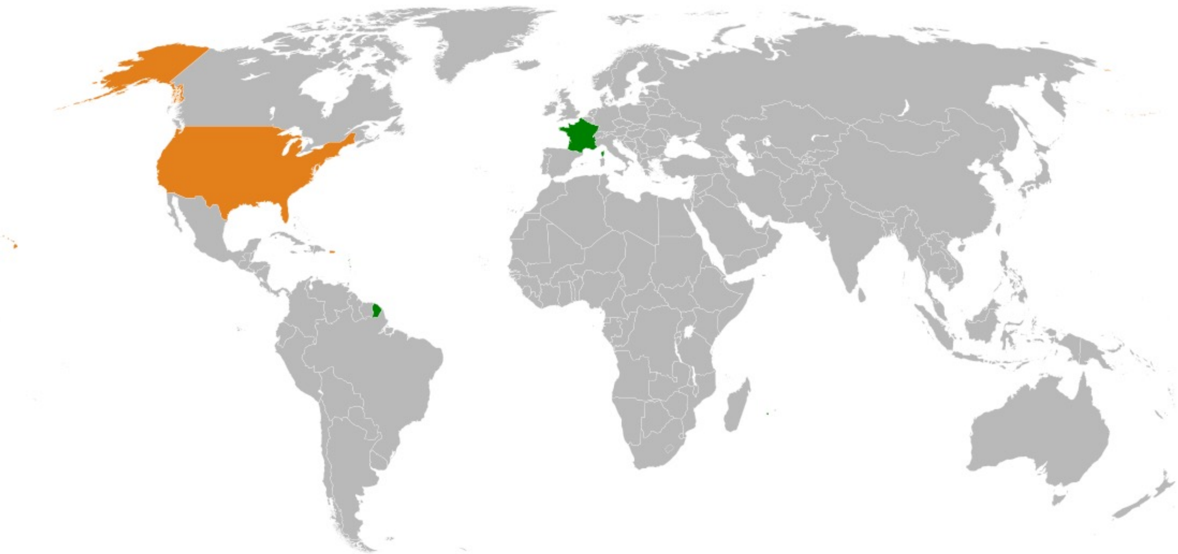
France (2016)



Midwest US (2013)



How to quantify these differences?



Comparing the equivalent CO2 emissions associated with life-cycle of each energy source.

	Coal	Natural Gas	Oil	Nuclear	Hydropower	Biomass	Solar PV	Wind	Geothermal
MJ/kWh	10	8.6	9	11	0.29	0.43	0.64	0.29	0.59
g $CO_{2(eq)}$/kWh	1059	696	957	17	55	56	64	31	

Source: Table 15 from Horvath, A., Stokes, J. (2011) "Life-cycle Energy Assessment of Alternative Water Supply Systems in California." California Energy Commission.
http://www.energy.ca.gov/2013publications/CEC-500-2013-037/CEC-500-2013-037.pdf

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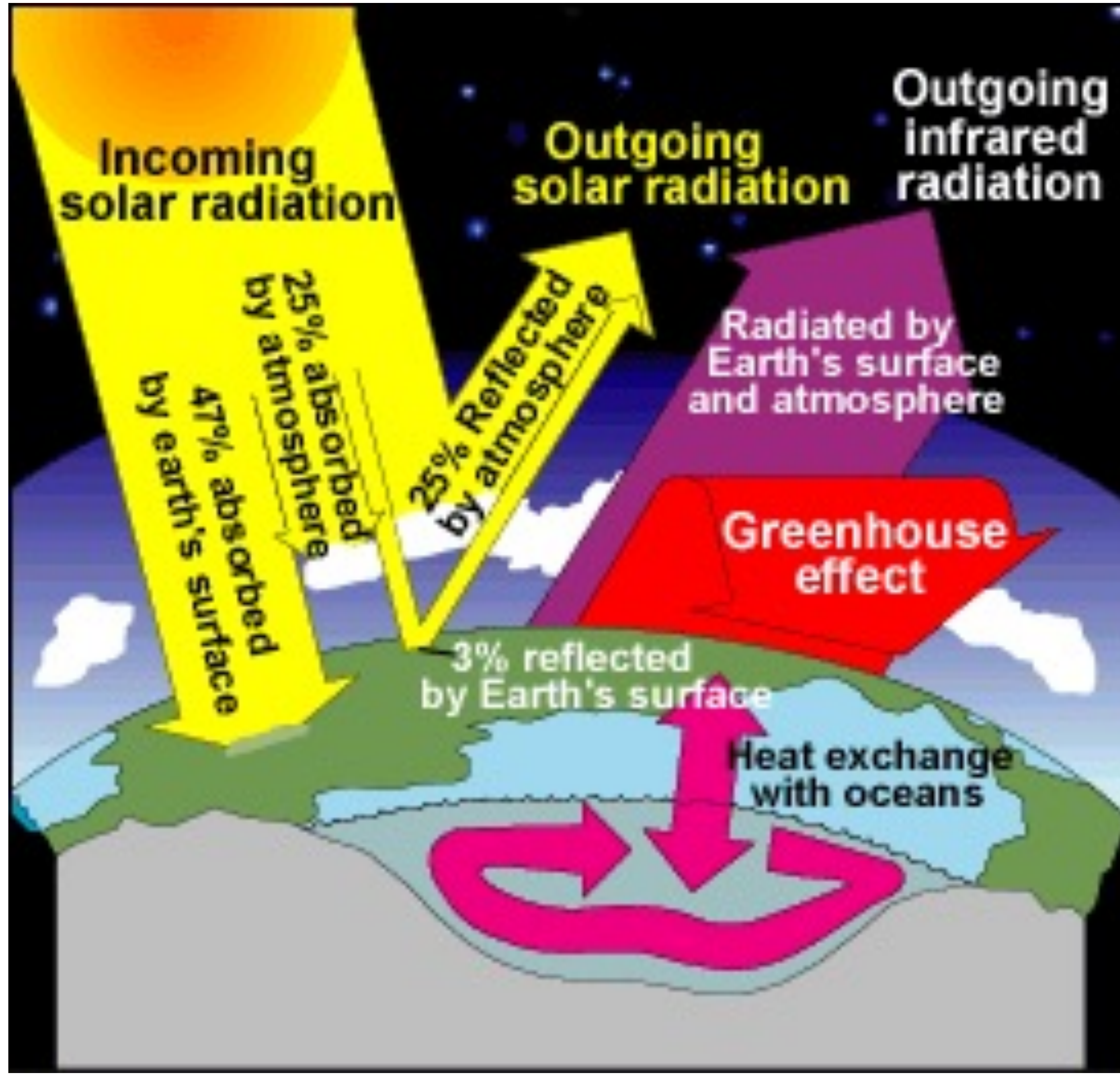
Climate Change Drives Push For Sustainability

- "The stone age didn't end because we ran out of stones"
  - Former Saudi oil minister Sheik Ahmed Zaki Yamani
- Fossil fuel reserves will last for decades
  - Severe and adverse climate change will occur if we use them all up



Towards (more) sustainable energy

1- **Using Less Energy** – how?

Conservation: Adjusting our needs/uses to use less energy. E.g., dry laundry on a clothesline, turn off lights when leaving room

Energy efficiency: Designing equipment to yield more energy output or to do more work from a given energy input

Image credit: theblackberryalarmclock.com

Towards (more) sustainable energy

2 – **Decarbonize** – how?

Substitute non-fossil fuel energy sources for generating electricity, etc.

Image credit: oag.ca.gov

Using less

Conservation	Efficiency
Turn off the lights	Use CFL or LED bulb
Walk or bike	Drive high-mpg vehicle
Buy less stuff	Buy stuff with lighter manufacturing-energy

Using less

Passive solar

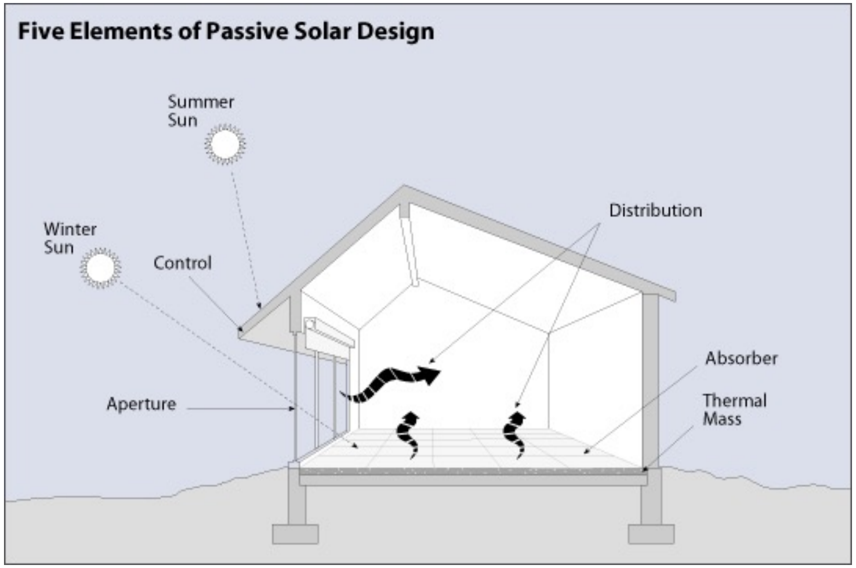


Image credit: redhookgreen.com

Zero-energy buildings

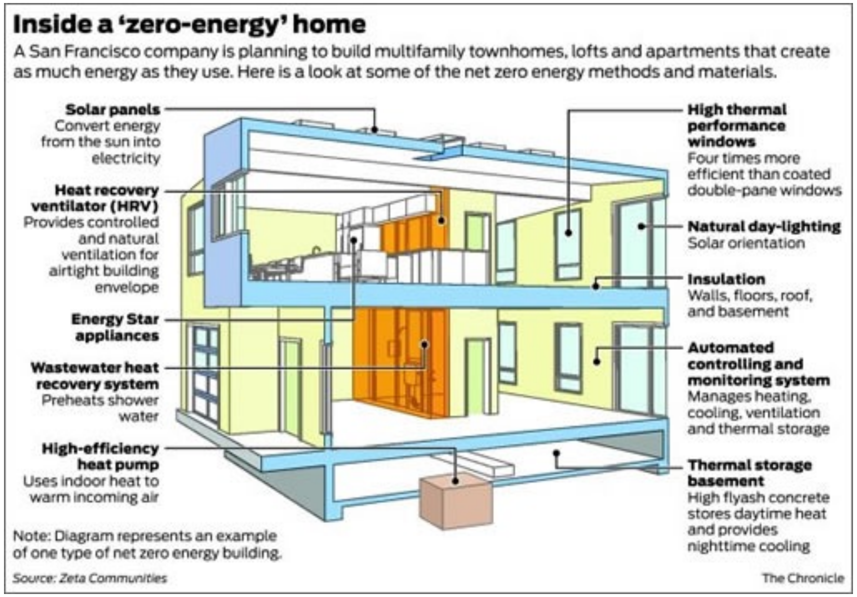


Image credit: socketsite.com

More on these concepts in our lecture on sustainable buildings

Using less

Sustainable Cities

Encourage bicycles, mass transit:

- high density neighborhoods (avoid sprawl)
- good transit & bicycle routes

Reduce/Reuse/Recycle

Using less

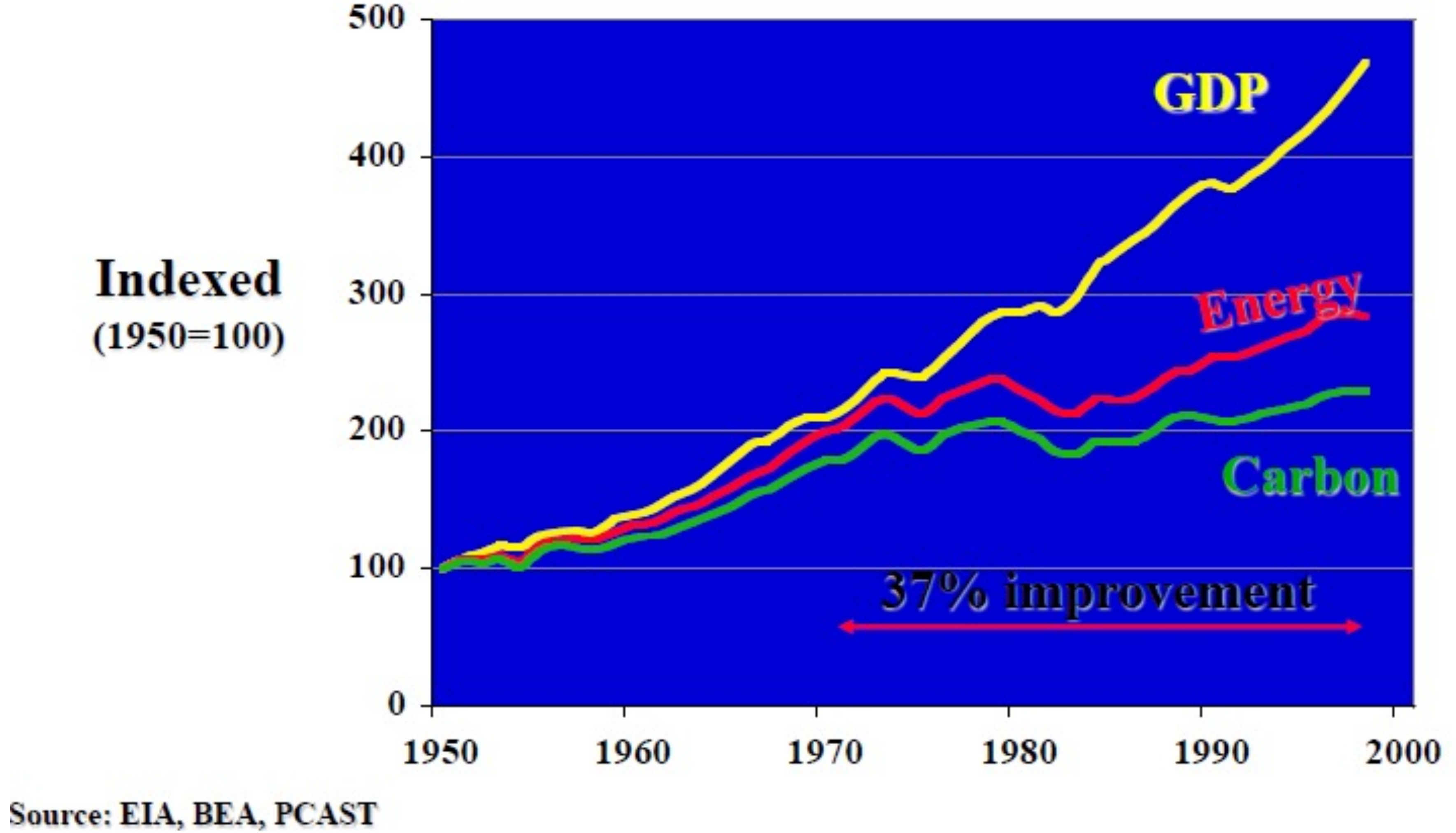
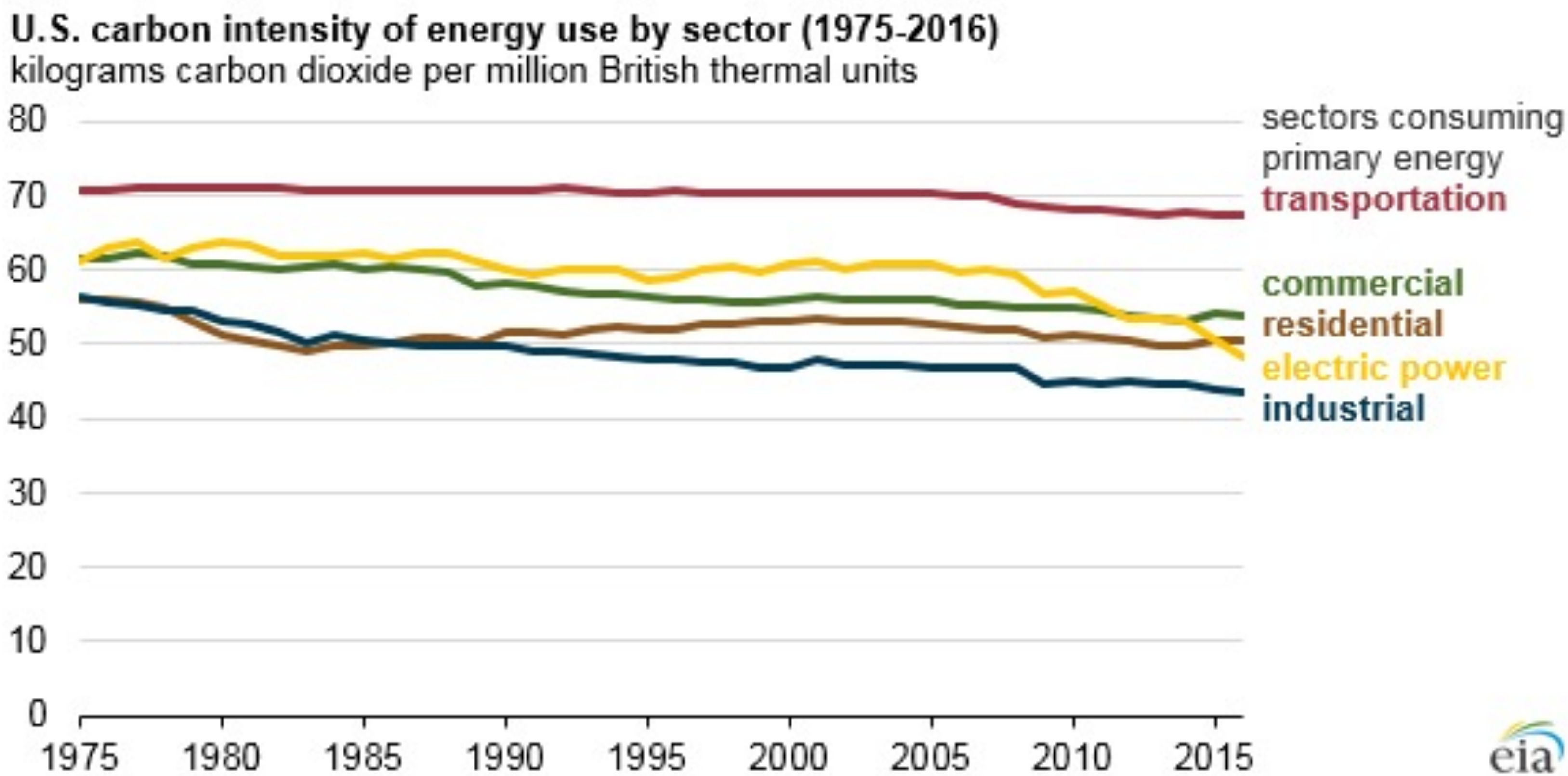


Image credit: Dan Kammen

Decarbonization

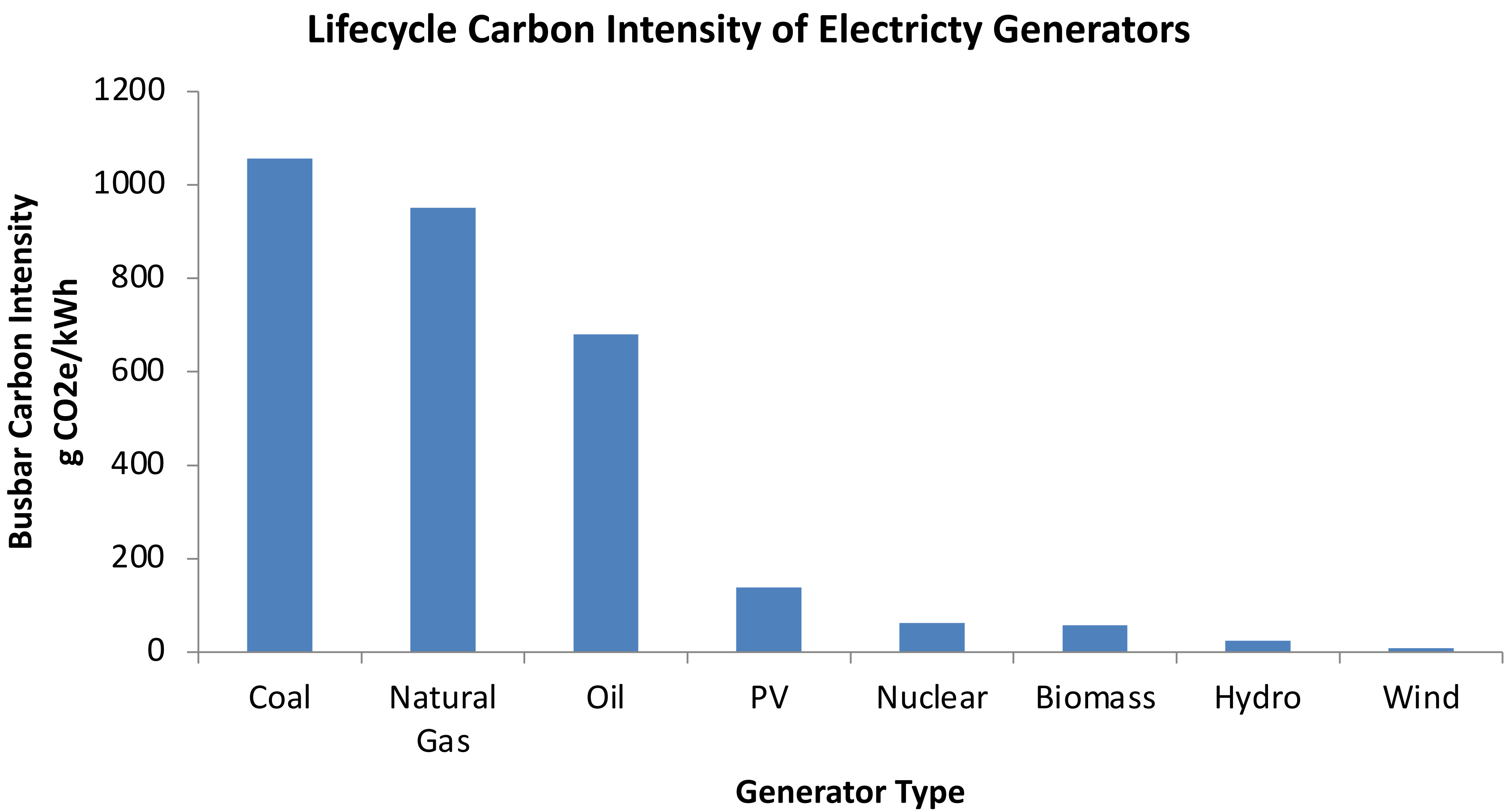
Carbon intensity:

mass of greenhouse gas emissions associated with a given amount of (delivered) energy



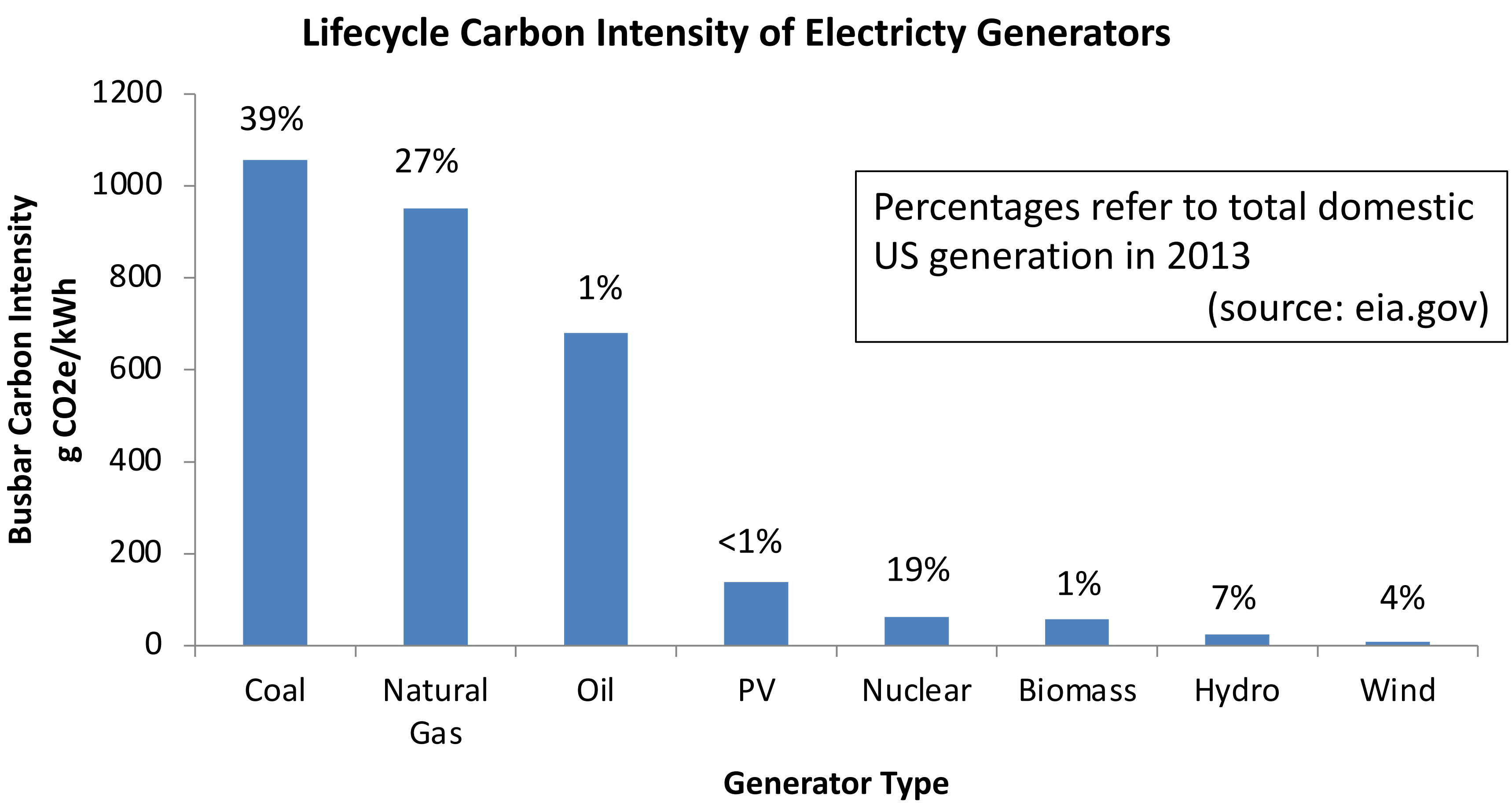
Source: US Energy Information Administration

Decarbonization



Data source: Horvath, A., Stokes, J. "Life-cycle Energy Assessment of Alternative Water Supply Systems in California." California Energy Commission, 2011.

Decarbonization



Data source: Horvath, A., Stokes, J. "Life-cycle Energy Assessment of Alternative Water Supply Systems in California." California Energy Commission, 2011.

Decarbonization

Replace this…	…with this
Coal	Natural gas
	Geothermal
	Biofuels
	Nuclear
	Hydroelectricity
	Solar thermal

Decarbonization

Replace this…	**…with this**
Petroleum	Electricity
	Biofuels (?)
	Natural gas
	Hydrogen

Decarbonization

Replace this…

Natural gas

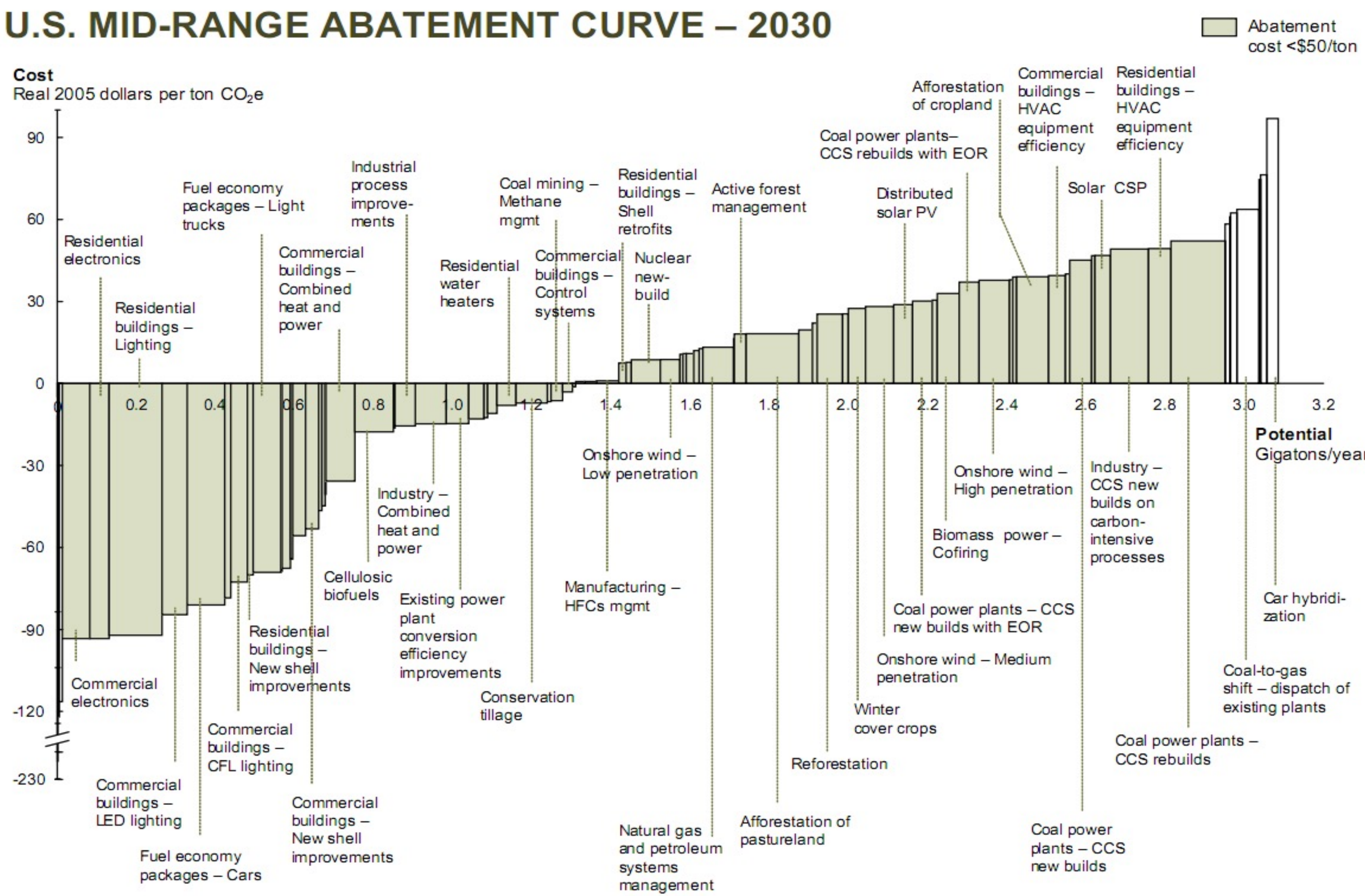
…with this

Storage/Batteries

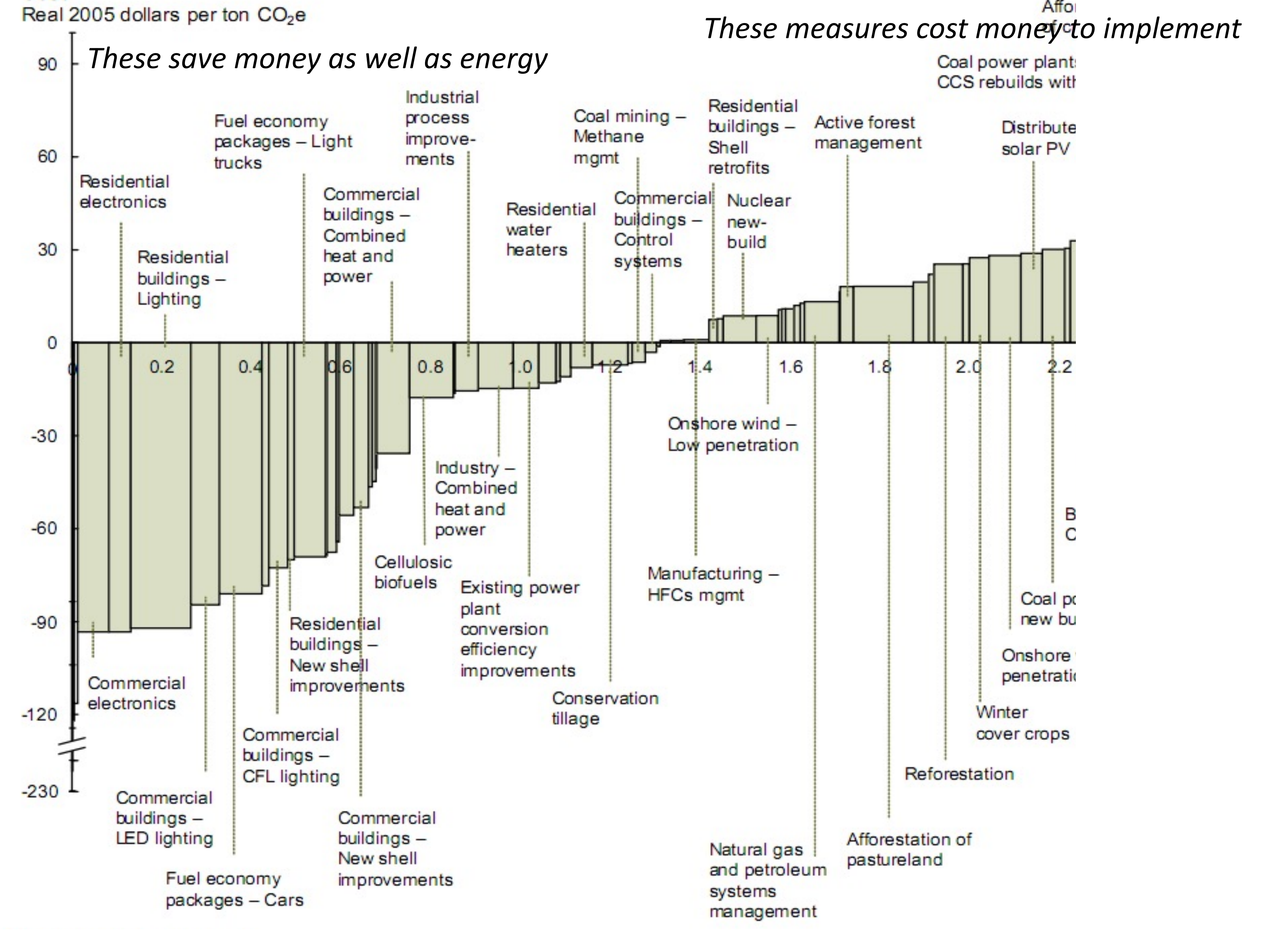
- Hydrogen
- Hydroelectricity

Biogas

McKinsey Curves



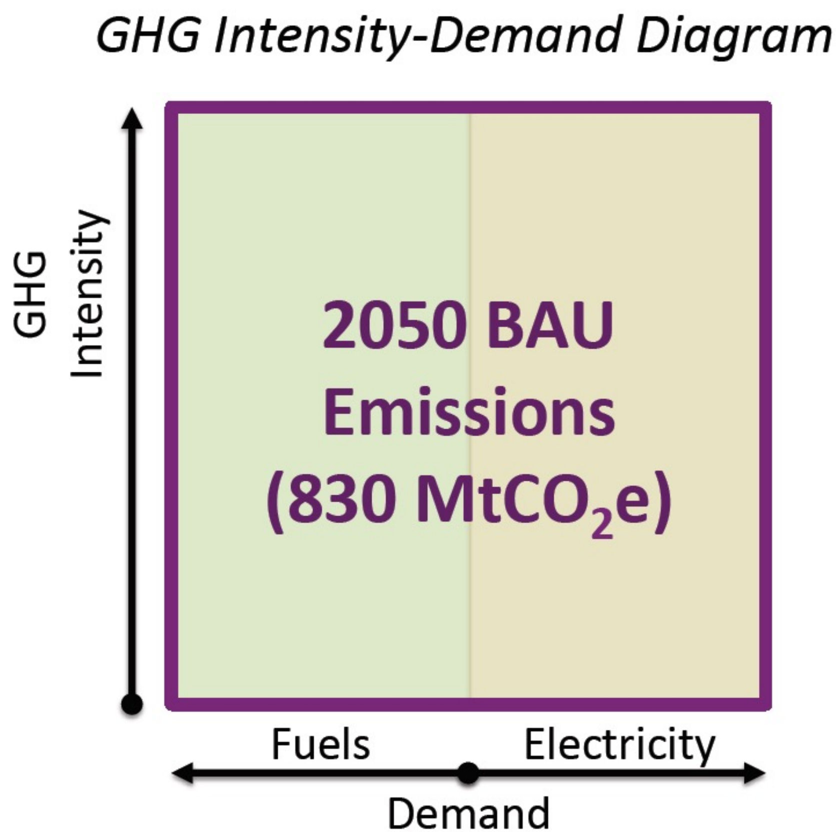
Discussed in more detail when we consider energy-efficient buildings



Real 2005 dollars per ton CO_2e
These save money as well as energy
These measures cost money to implement
90
60
30
0
-30
-60
-90
-120
-230
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
Residential electronics
Residential buildings – Lighting
Fuel economy packages – Light trucks
Commercial buildings – Combined heat and power
Industrial process improvements
Residential water heaters
Coal mining – Methane mgmt
Commercial buildings – Control systems
Residential buildings – Shell retrofits
Nuclear new-build
Active forest management
Coal power plants CCS rebuilds with
Distribute solar PV
Commercial electronics
Commercial buildings – LED lighting
Fuel economy packages – Cars
Commercial buildings – CFL lighting
Residential buildings – New shell improvements
Commercial buildings – New shell improvements
Cellulosic biofuels
Industry – Combined heat and power
Existing power plant conversion efficiency improvements
Conservation tillage
Onshore wind – Low penetration
Manufacturing – HFCs mgmt
Natural gas and petroleum systems management
Afforestation of pastureland
Reforestation
Winter cover crops
Onshore penetrati
Coal po new bu

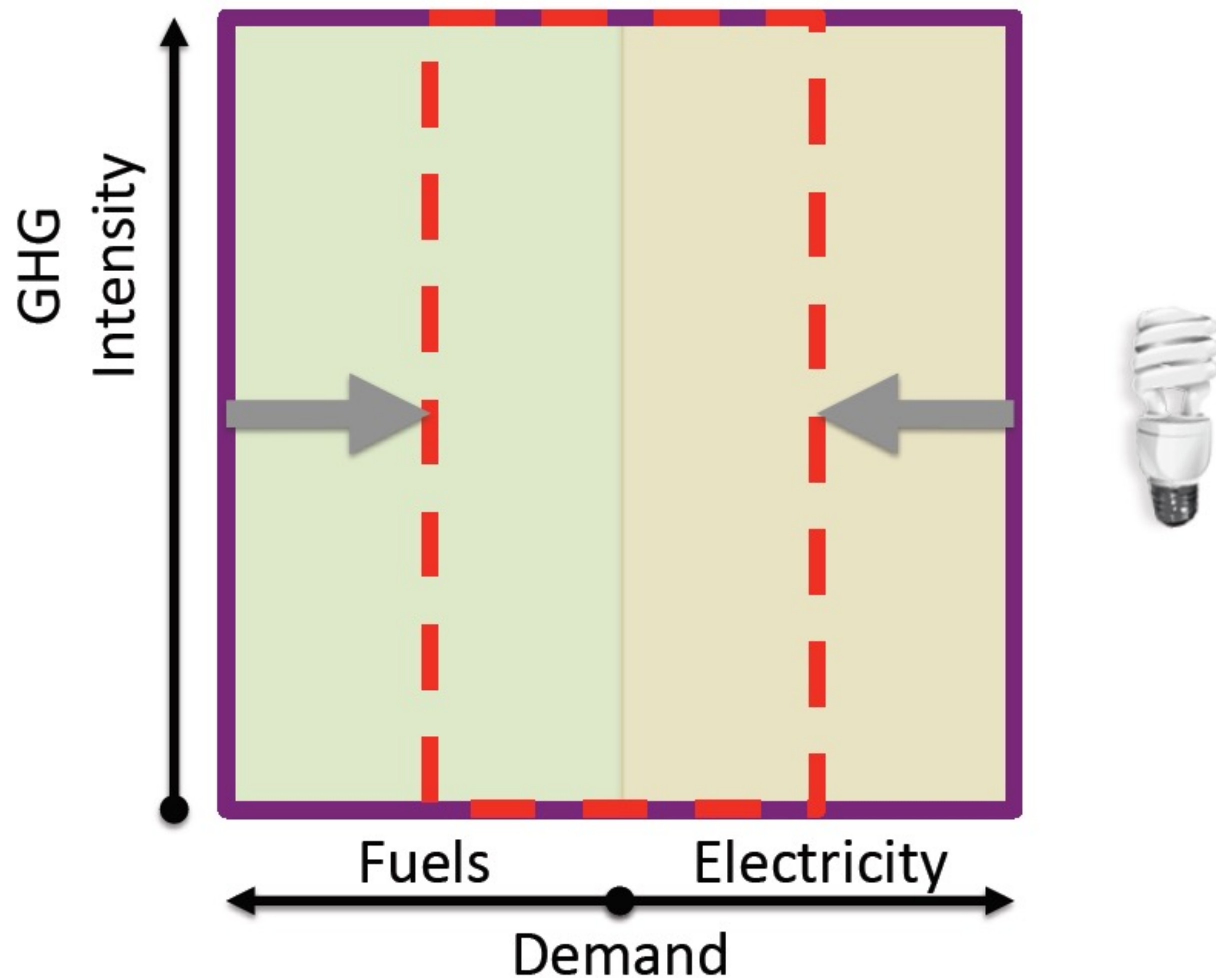
To be covered in Unit 2
(alternative energy lecture):

Four Actions to Reduce Emissions

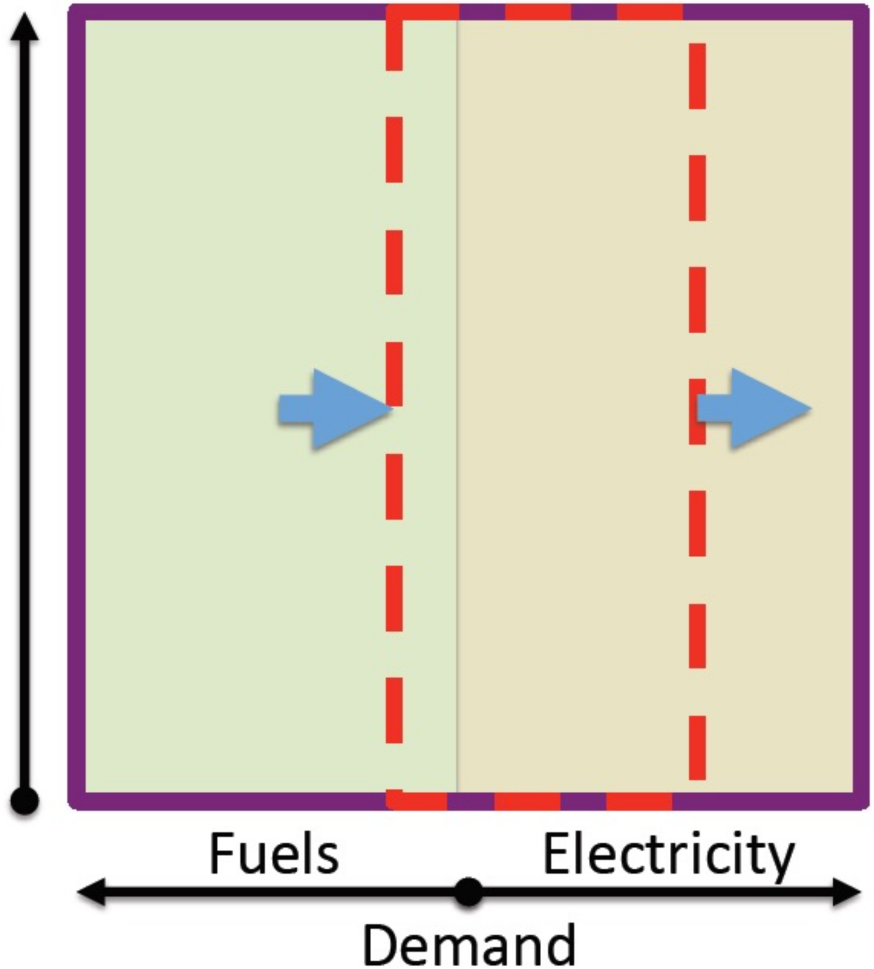


Source: California's Energy Future – The View to 2050, California Council on Science and Technology, 2011

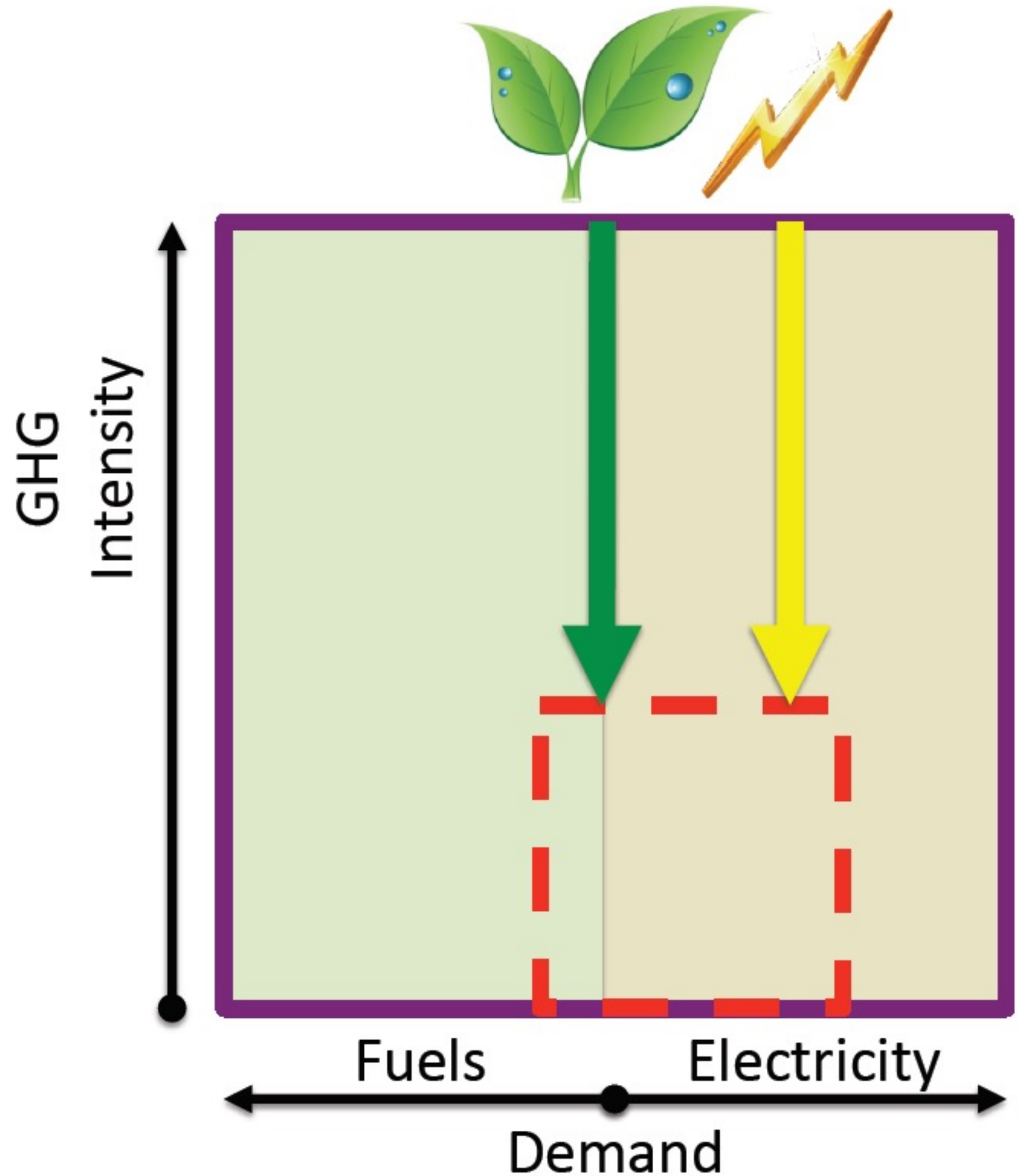
1. Efficiency



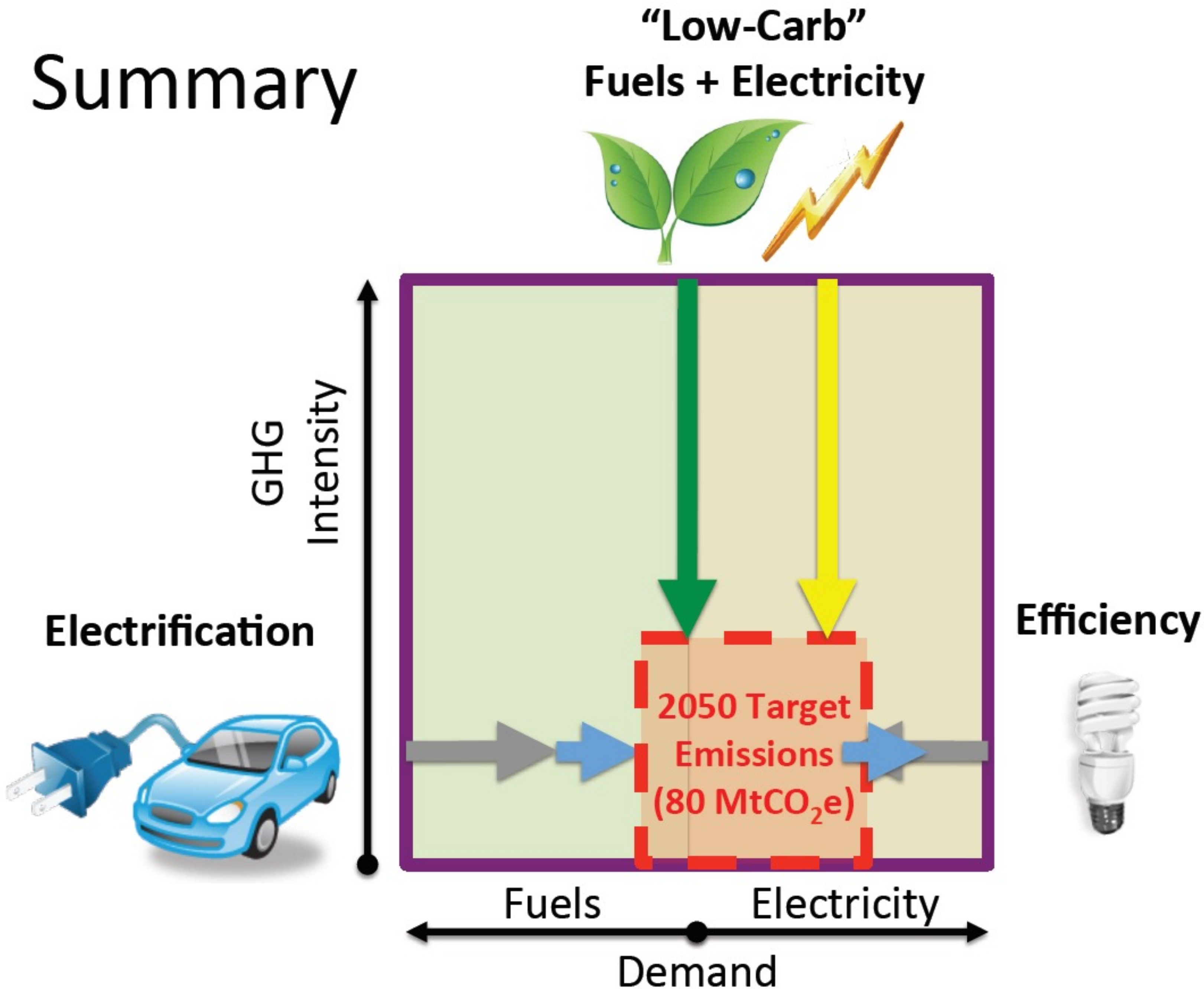
2. Electrification



3 + 4. “Low-Carb” Fuels + Electricity



Summary


"Low-Carb"
Fuels + Electricity
GHG
Intensity
Electrification
2050 Target
Emissions
(80 $MtCO_2e$)
Efficiency
Fuels
Electricity
Demand

Energy Courses on Campus

ER 100/Pub Pol 184 – Energy and Society

Civ Eng 107 – Climate Change Mitigation

Anthro 137 – Energy, Culture, and Organization

EEP 147 – Regulation of Energy and the Environment

Arch 140 – Energy and Environment

Energy Data Sources

California: California Power Content Labels

http://www.energy.ca.gov/pcl/labels/

Domestic: Energy Information Agency

eia.gov

International: International Energy Agency

iea.org

Summary – 1 of 2

- Energy is in units of joules, Kilowatt-hour (kWh), BTU, calorie, Erg
- Power is measured in watts (W), horsepower (Hp)
- 1st law of thermodynamics: conservation of energy
- 2nd law of thermodynamics: some energy is always wasted (no process is 100% efficient)
- Energy comes from a variety of sources: coal, natural gas, petroleum, nuclear, renewables. In the US, 80% of energy comes from fossil fuels. The energy we receive from PG&E is a mix (energy-mix) of different sources: coal, natural gas, hydro-electric, nuclear, and renewables.

Summary – 2 of 2

- There are many negative impacts from using different energy sources, which occur throughout the life-cycle of the energy source:
    - Coal mining causes acid mine drainage
    - Hydraulic fracturing can contaminate water
    - Biofuel harvest can affect food prices, and rely on water, fertilizer, and pesticides
    - Hydroelectric dams affect fish habitat
    - Wind turbines are a threat to birds and bats
    - Transporting petroleum results in frequent spills
    - Waste products accumulate and can leach pollutants into the environment and impact human health
- Two major approaches to a more sustainable system: use less and decarbonize.
- Four actions to reduce emissions (decarbonize): efficiency, electrification, low-carb fuels, electricity
- McKinsey Curve – range of costs of actions to reduce emissions