Sustainable Energy and Society

T. L. Beck

Univ Cincinnati Chemistry

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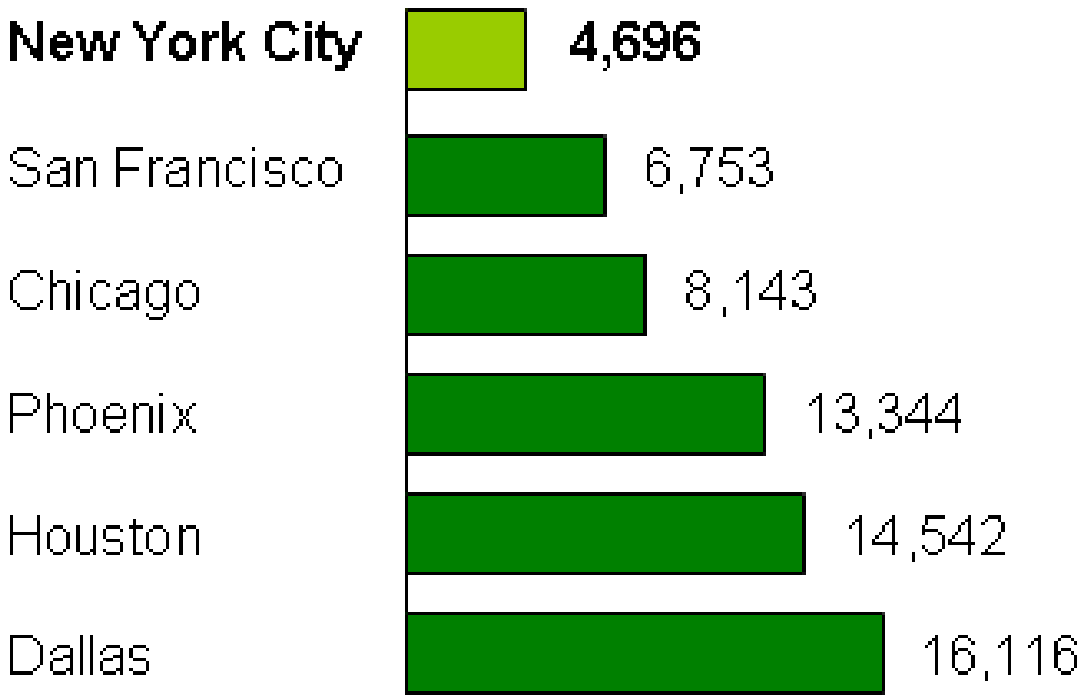
UC Sustainability, November, 2019

Thanks: Many collaborators and friends at UC (PACES etc), Claire Pollock (Cincinnati Museum Center), Steve Melink (Melink Corp.), Matt Doyle (P&G)

Funding: NSF

New York

Surprise: City per capita electricity use (kWh/person-yr)



But Texas produces a LOT of wind energy!

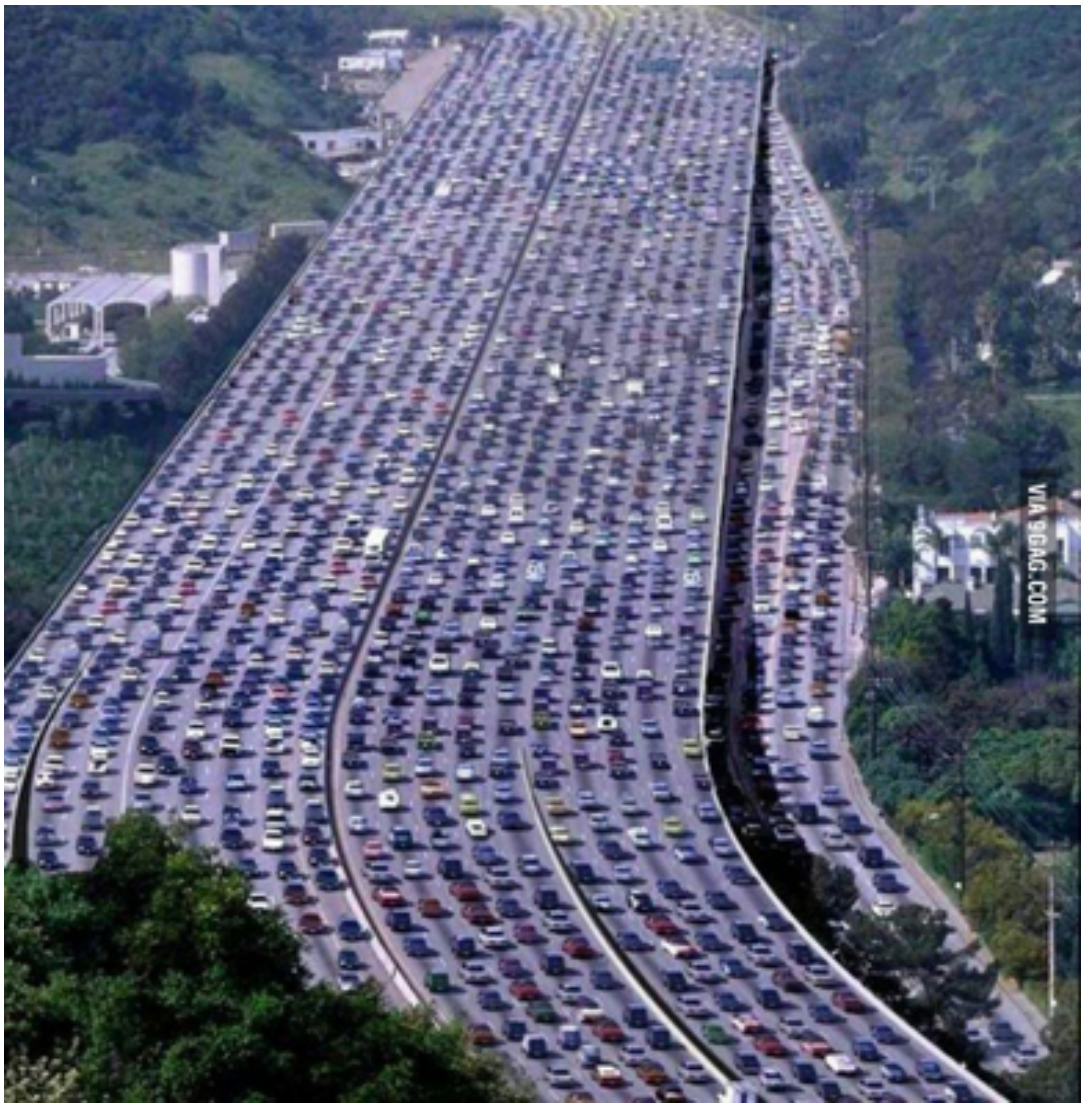
EPA names Dallas top green power user among U.S. cities

The U.S. Environmental Protection Agency (EPA) announced that the City of Dallas is now the largest local government user of green power in the nation. The recognition is part of the EPA's Green Power Partner program, which highlights the annual green power use across industry sectors, including colleges and universities, retail, technology and telecommunications, and local government.

2016

Traffic in CA

Is this an efficient civilization?



Motivation

- This talk has grown out of a freshman seminar course: "Sustainable Energy and Society" (3 yrs freshman seminar, 1 grad course, now Jimmy Jiang)
- Energy, water, food production, and climate/environment are defining issues for next 100 years
- I would rate energy at the top since dealing with this issue will have major impacts on the other 3
- Timing is important (decades)

Useful sites for information

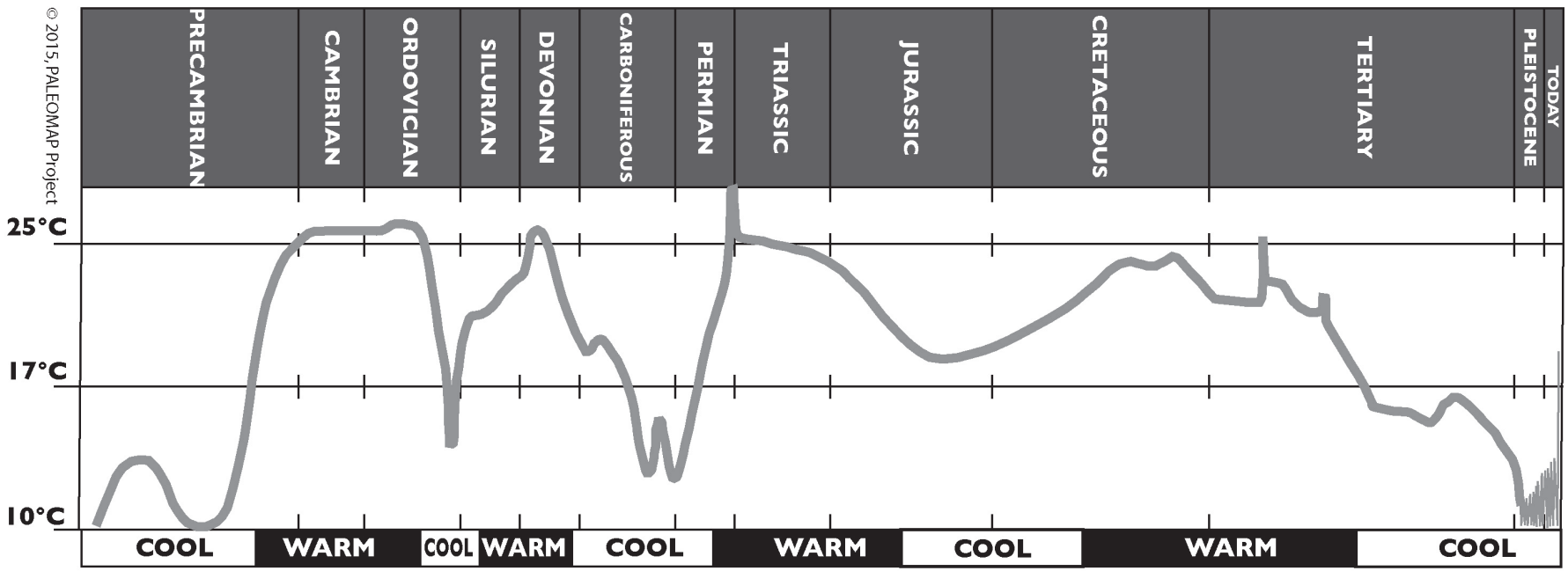
- http://www.eia.gov/energyexplained
- http://homepages.uc.edu/∼becktl/energy.html (go to "online" link for large repository of materials)
- Nearly all information for this talk (and figs) taken from available online materials for the course
- This talk is posted on above website also.

Global temperature history

Cambrian was about 500 M years ago

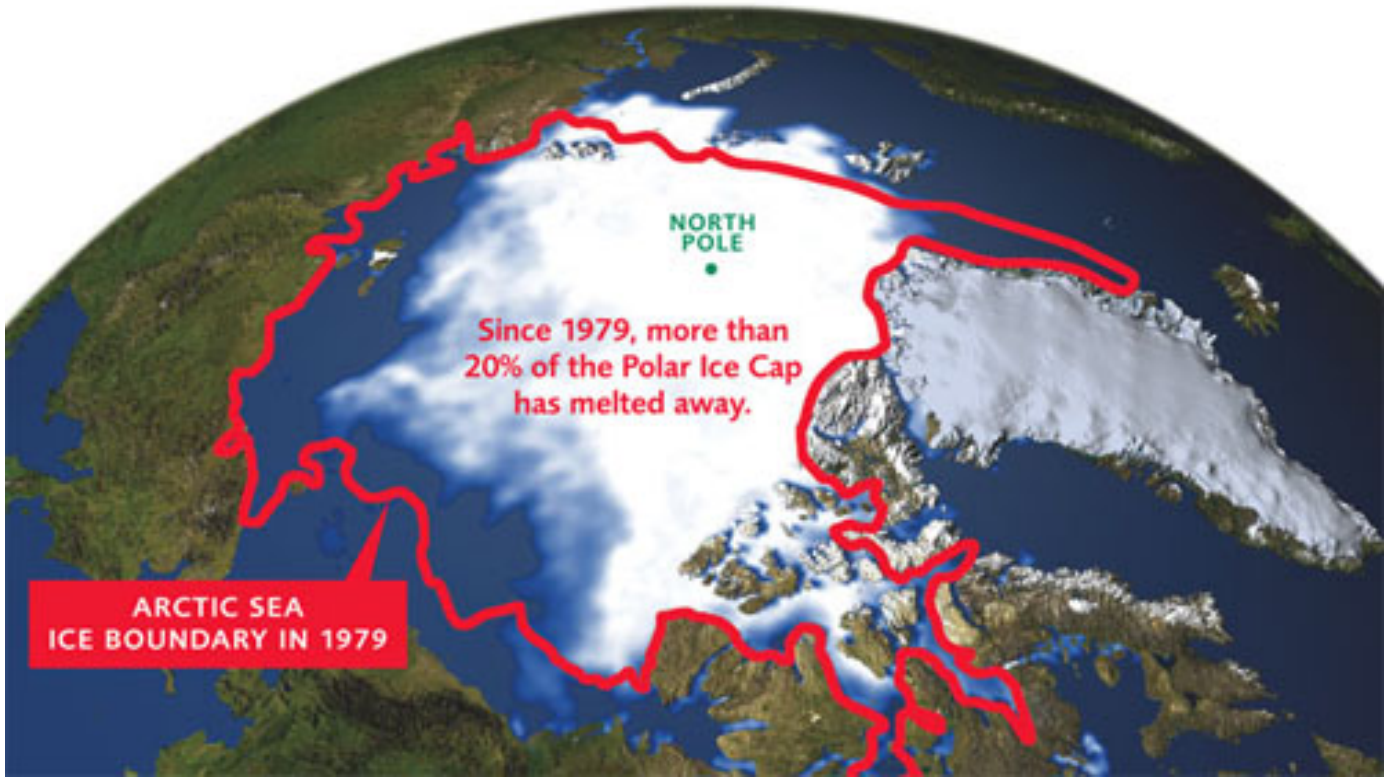
Christopher Scotese, Paleomap Project

Fossil fuel resources are limited



Polar ice cap

There are consequences



Miami Beach

Do you plan to buy real estate here?

What is energy?

- What is energy? Turns out that is not such an easy question to answer (cf. Feynman lectures).
- Capacity to do work? Units are Joules (or cal, or btu, or kWh)
- Power (Watts) is Energy/Time so Power x Time is Energy (kWh for example)
- $E = mc^2$. $E = h\nu$. $V = IR$ $P = IV = I^2R$. $U = mgh$.
- Heat, mechanical, electrical, chemical, nuclear, light, gravity...
- It's something we don't understand that well yet we have ways to measure changes.
- We know the first and second laws: "energy is conserved" and "we can only convert so much available energy into work".

Start at the human scale

- Calculate at the one-person level and scale up if necessary
- Two useful energies: 1 kWh (10 light bulbs for 1 hour), 1 gal of gas (about 25-40 mi driving)
- 1 gal of gas = 33 kWh
- Typical house uses about 30 kWh per day electricity, or about 1 gal gas in energy
- That's about $3 per day: CHEAP
- That is about 1 kW power usage
- Power is the rate of energy 'consumption'. (units J/s)

A few simple calcs from class

- In the U.S. we use roughly 226 kWh/day total per person (6.8 gal of gas energy, \$25/day-person in electricity or \$3 trillion total cost of U.S. E per yr, GDP is \$17 trillion) This is for ALL energy uses.
- *The average American drives 13,500 mi per year*. How much energy is this per day? Answer: 51 kWh vs. 226 kWh total (at least 1/3 of our 'personal' E use, a LOT)
- How long can you power an iPhone on a gal of gas? Answer: 5-10 yrs or less than \$1 per year (but wait, there is *embodied cost* to make the phone).
- Calculate the energy a laptop uses if running for 24 hr. A laptop uses about 45-55 W of power. Answer: 1.2 kWh (peanuts!)
- Work out a personal energy inventory: a very useful exercise! Transport, heat/cool, washer/dryer, water heater, food, devices... Go through a typical day.

A few simple calcs from class (contd)

An example problem: if we had a square wind farm, what would the length of the side be in order to power all energy uses in the U.S.?

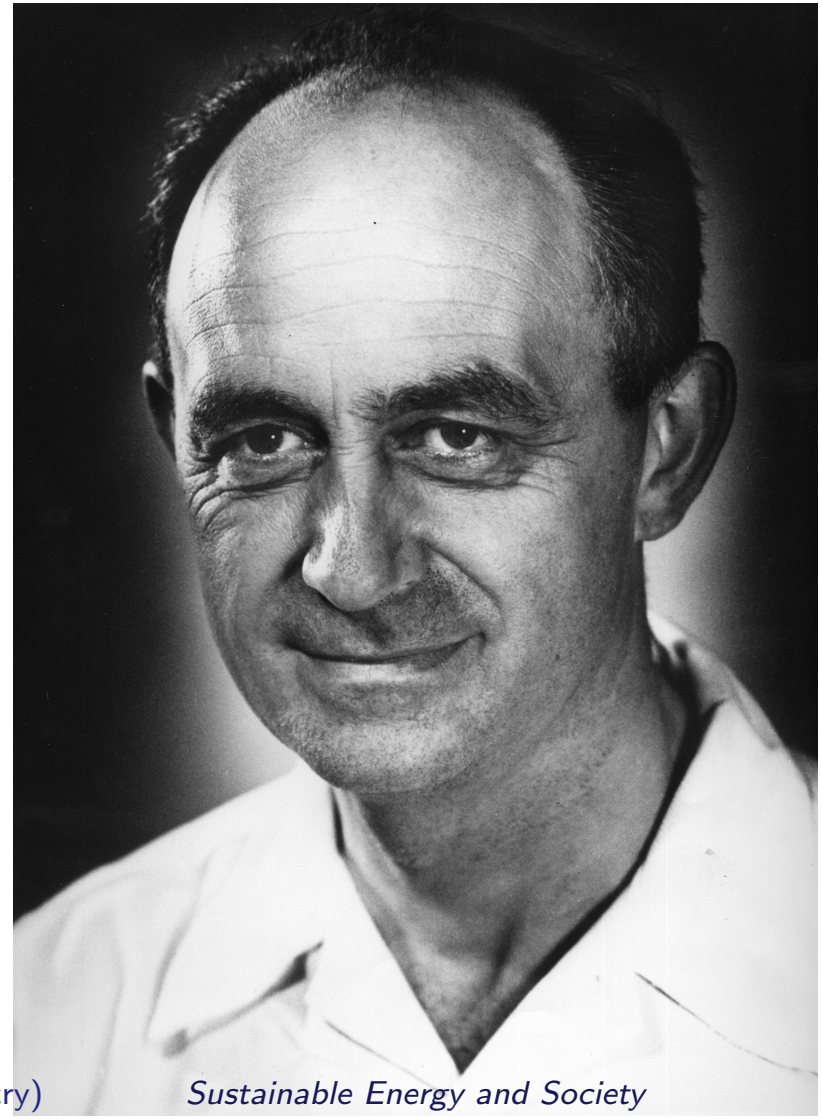
Data: Conservatively, each turbine puts out about 0.5 MW electric power (average). The total power consumption in the U.S. (all processes) is about 3 TW. Each turbine occupies about $(200\ \text{m})^2 = 40000\ \text{m}^2$ area.

Dimensional analysis is essential: units must cancel in conversions.
Answer: about 300 mi on a side (about 15 mi on a side for Cincinnati)
Similar result for solar farm

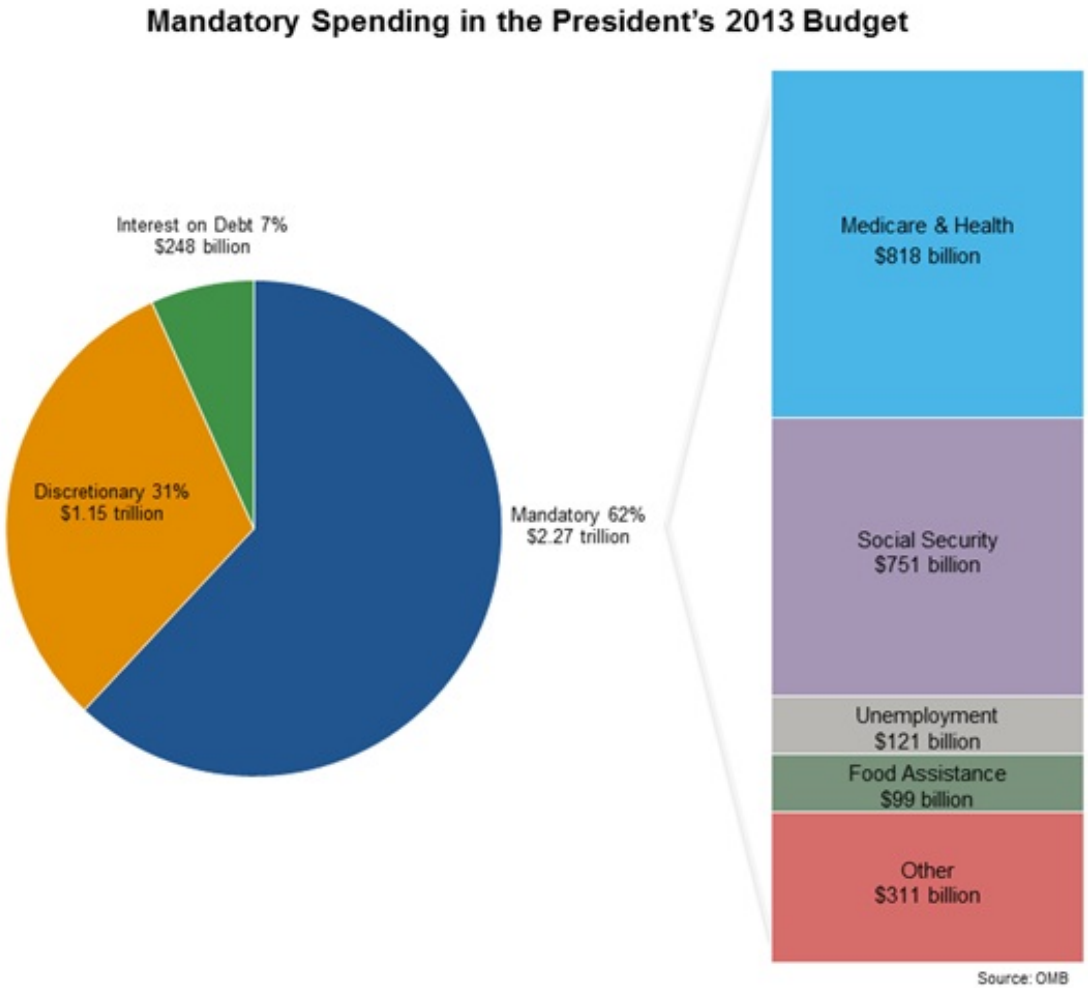
Fermi problem: how to estimate?

Leader in physics and nuclear energy development

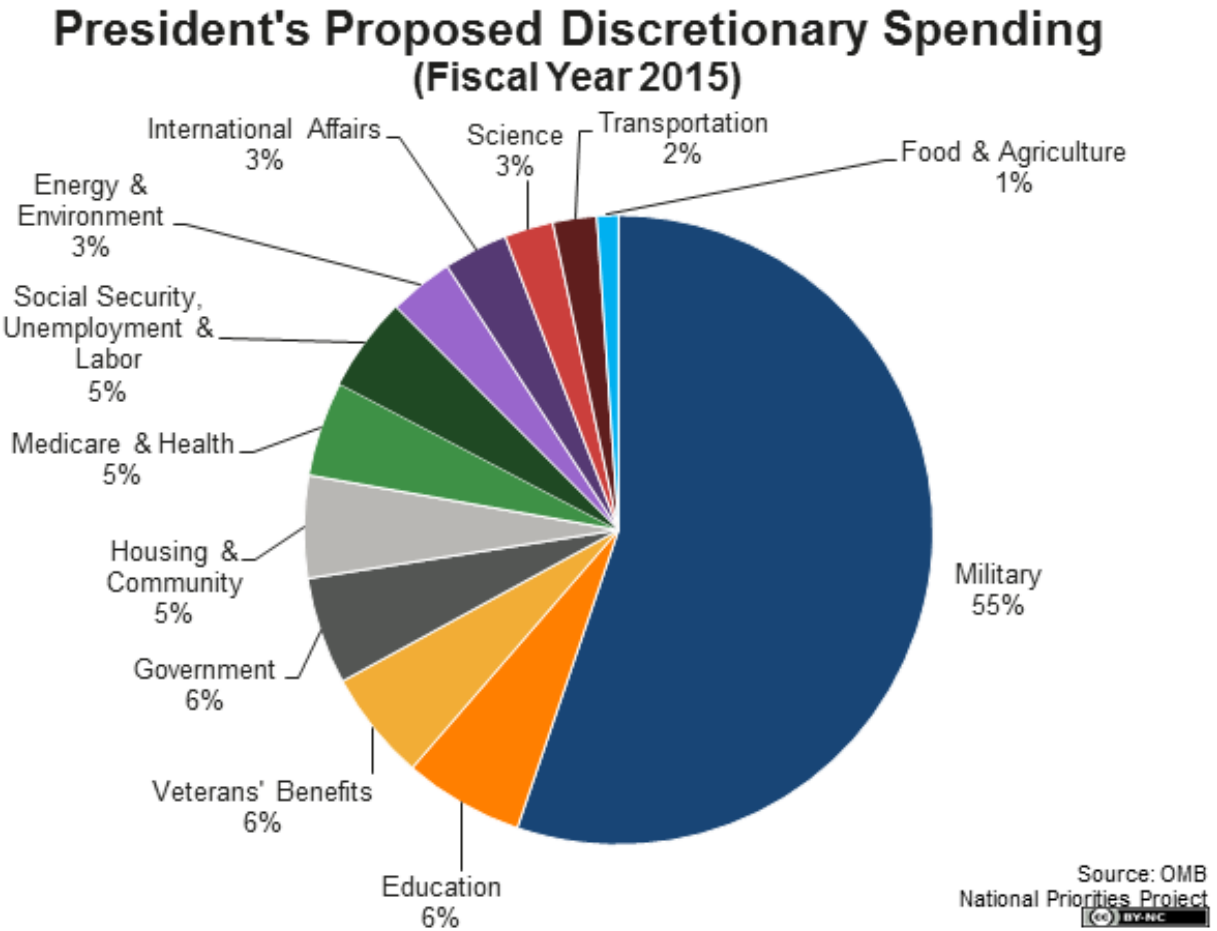
How many piano tuners are there in Chicago?



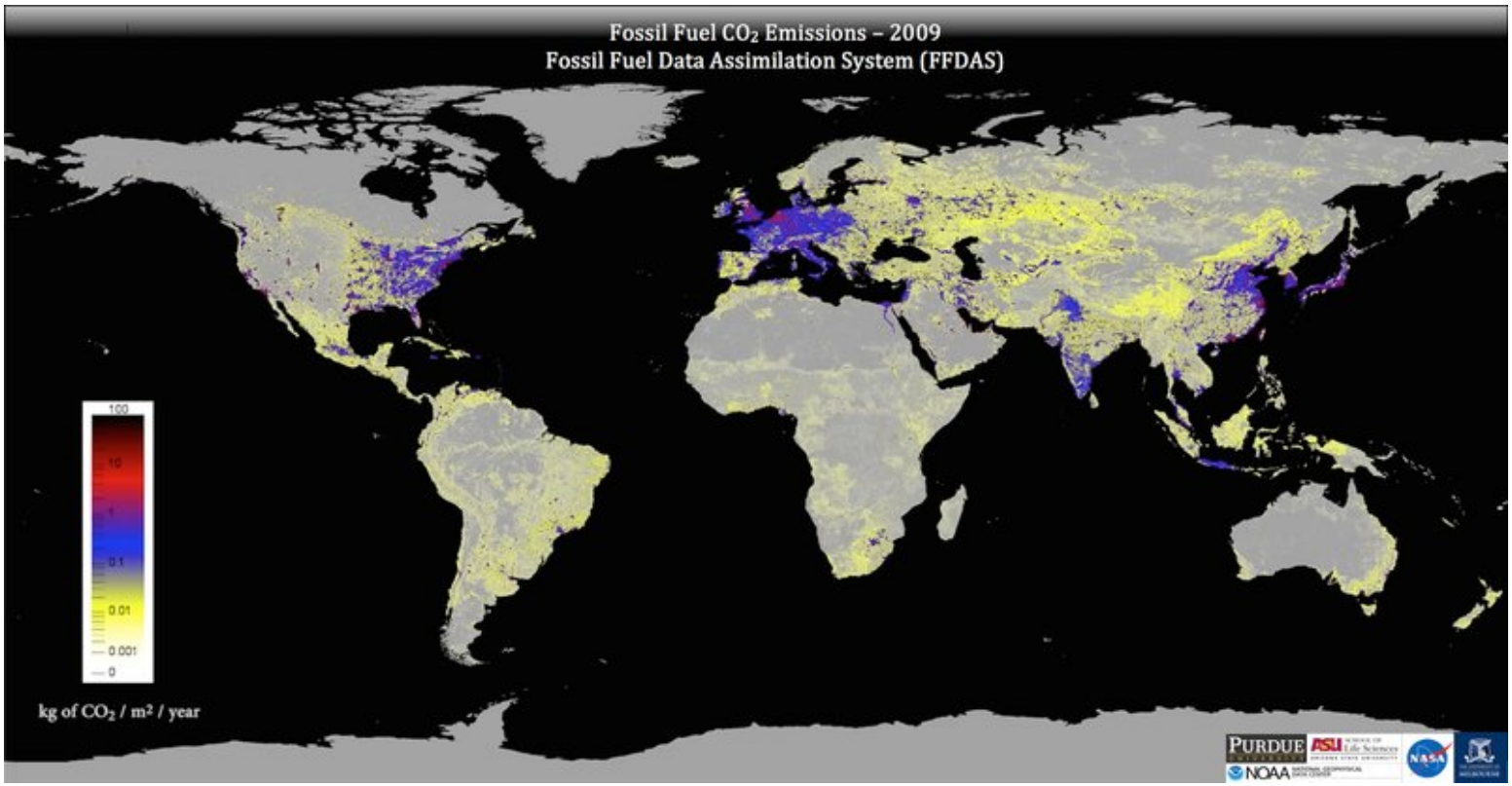
U.S. mandatory spending



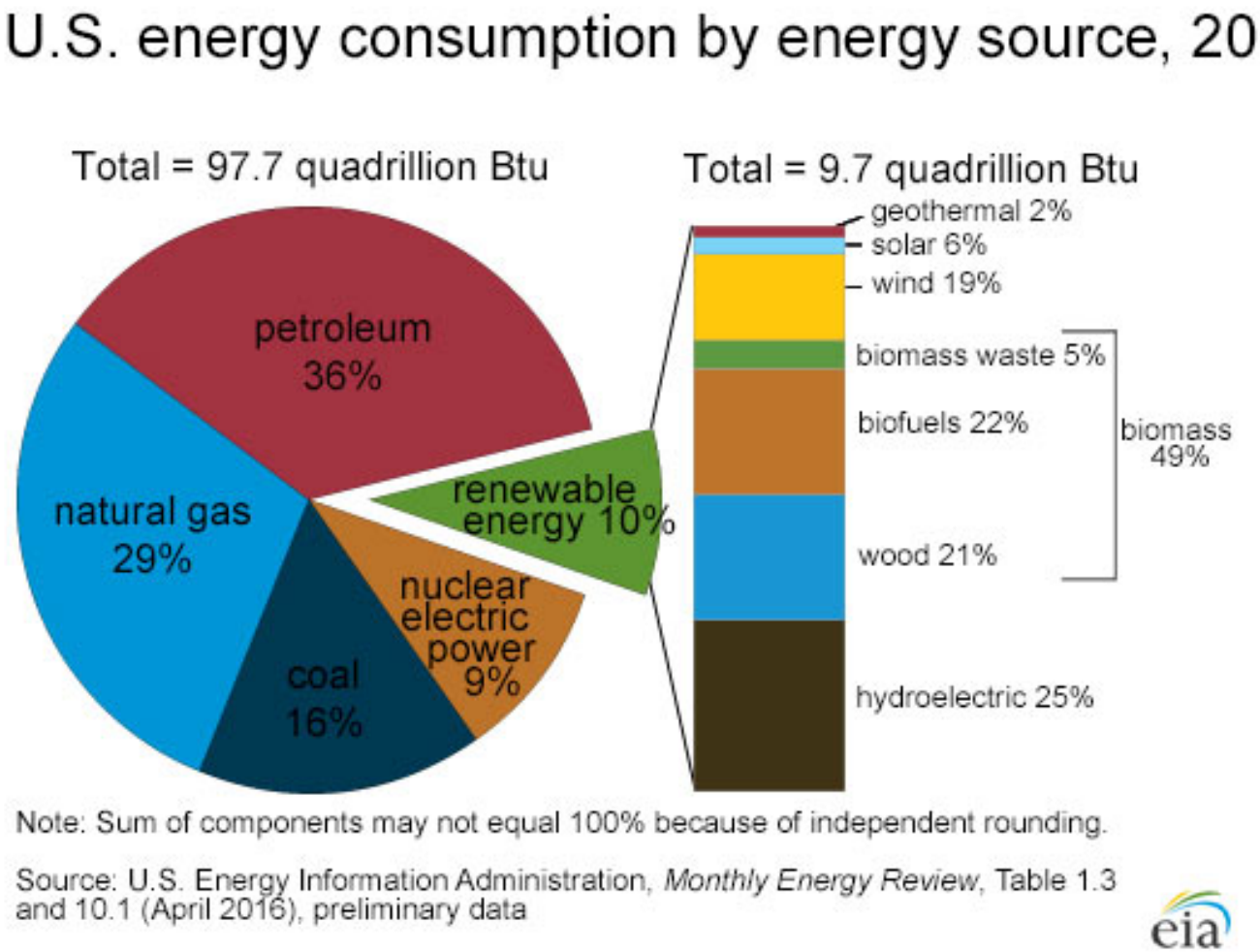
Discretionary spending



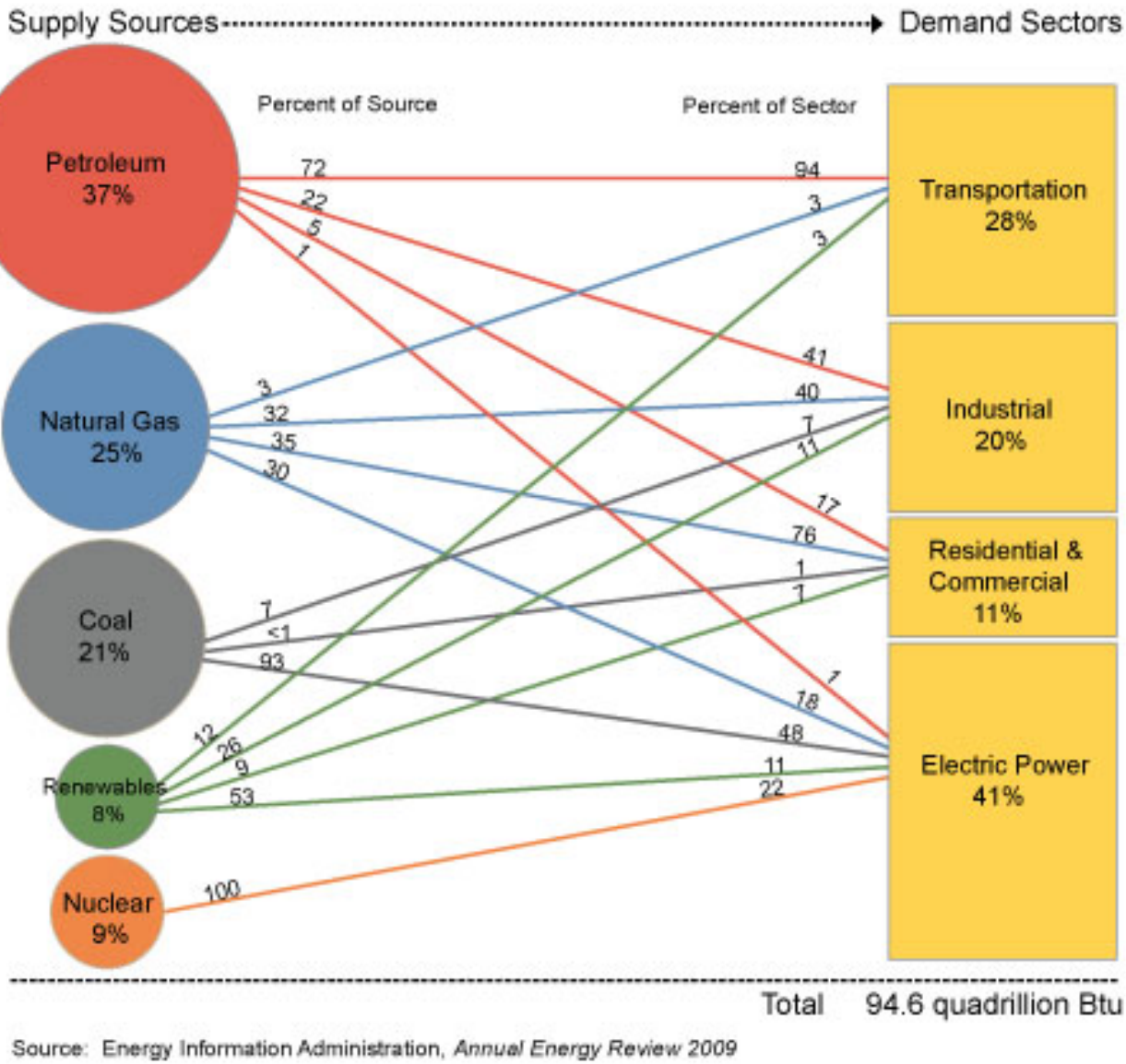
CO2 by country



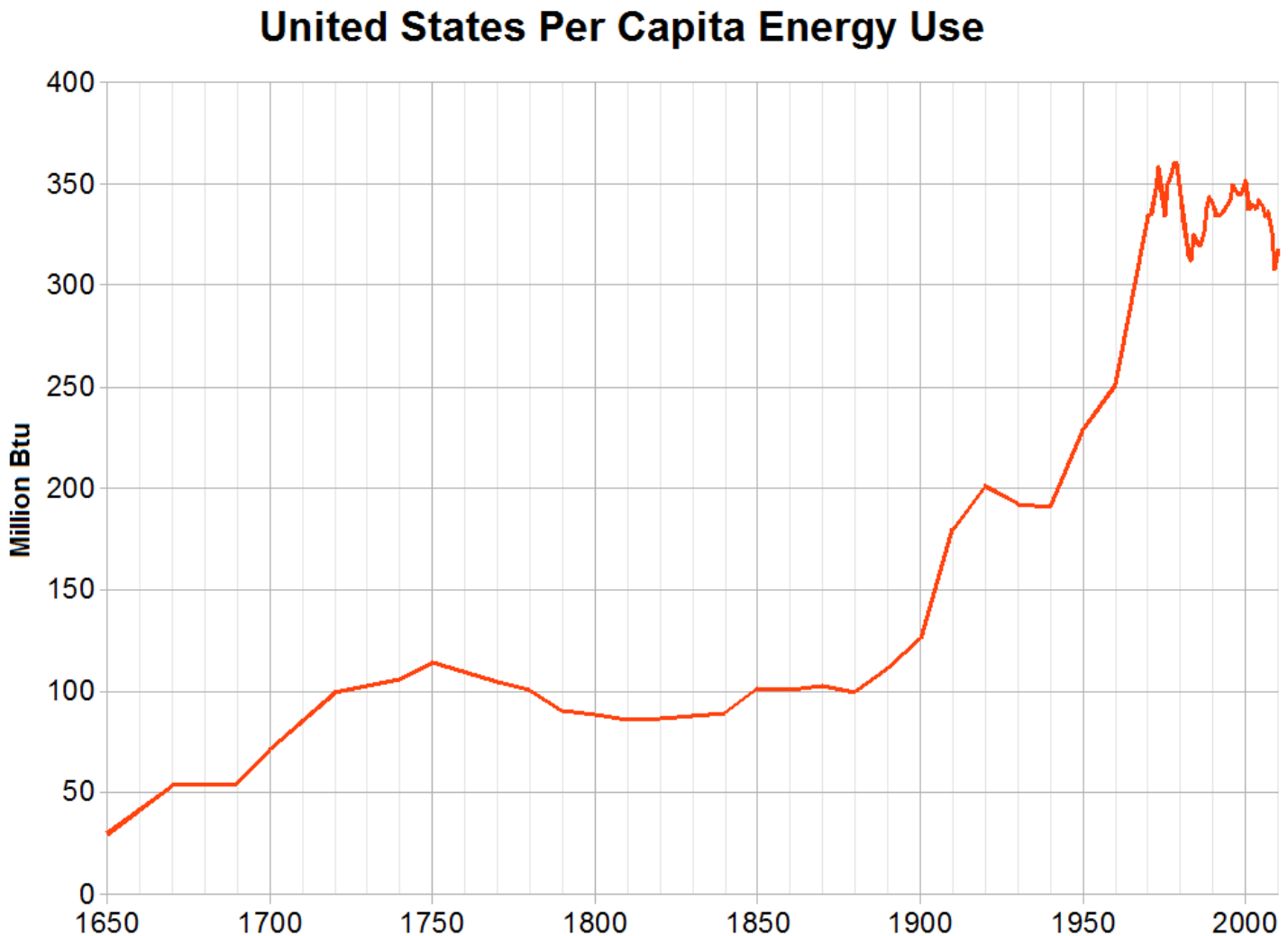
E consumption by source



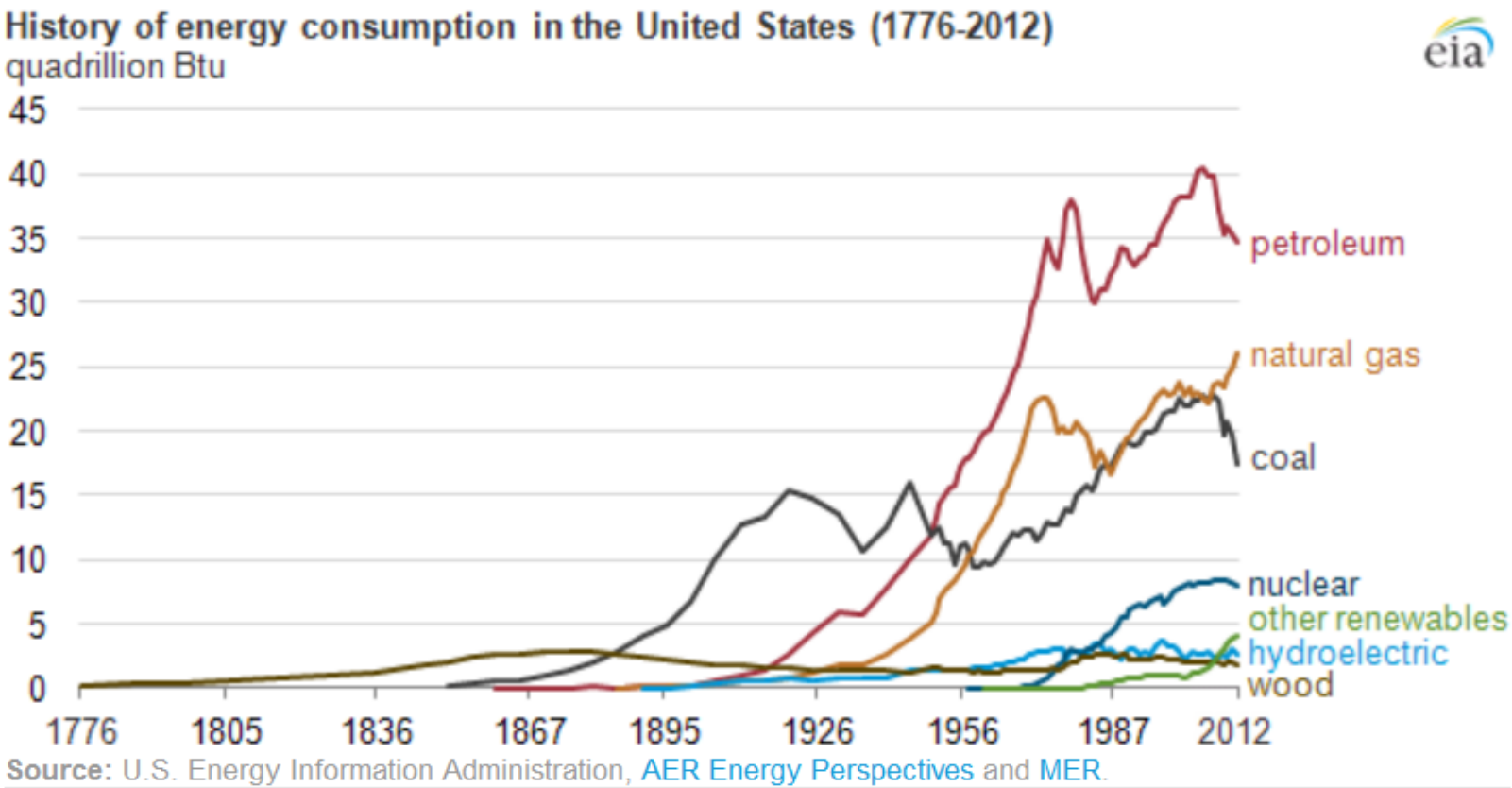
U.S. energy 2009



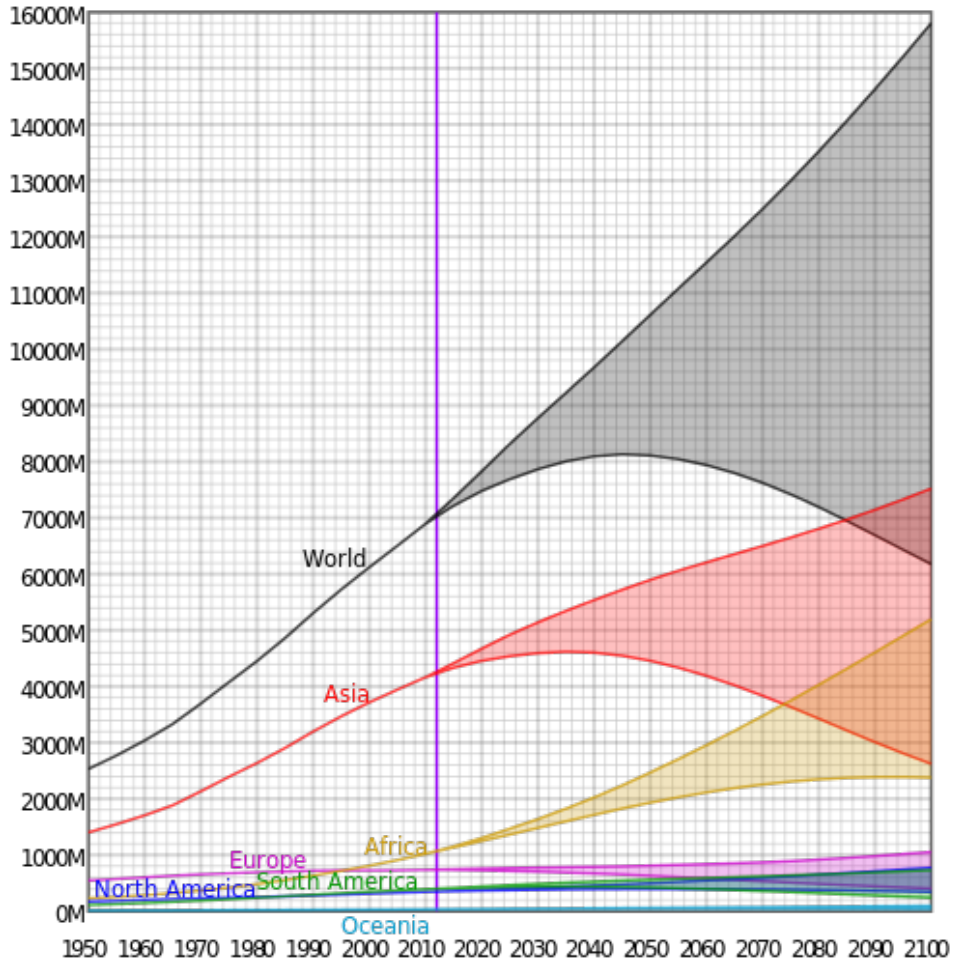
U.S. E use vs. time



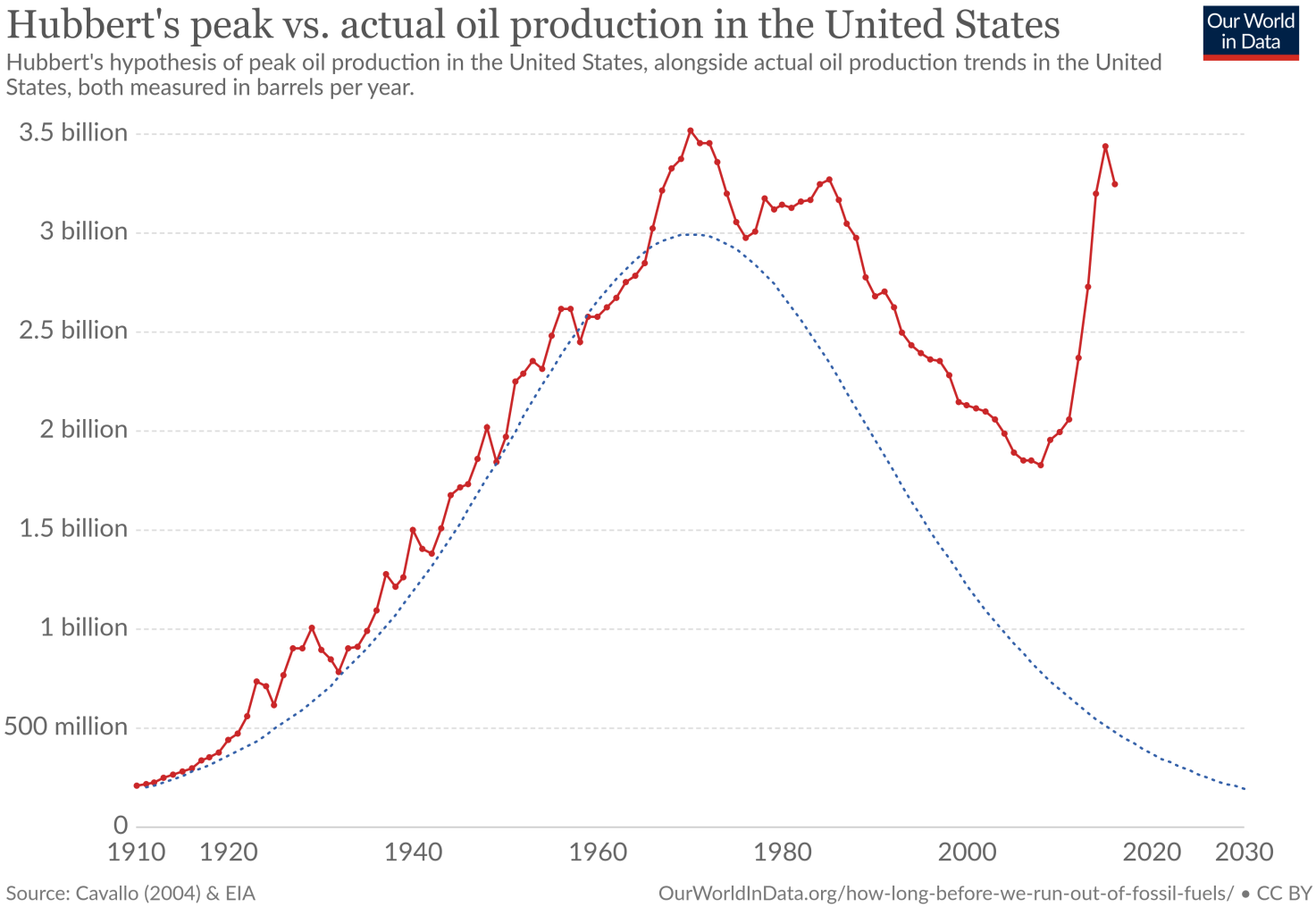
U.S. historical E consumption



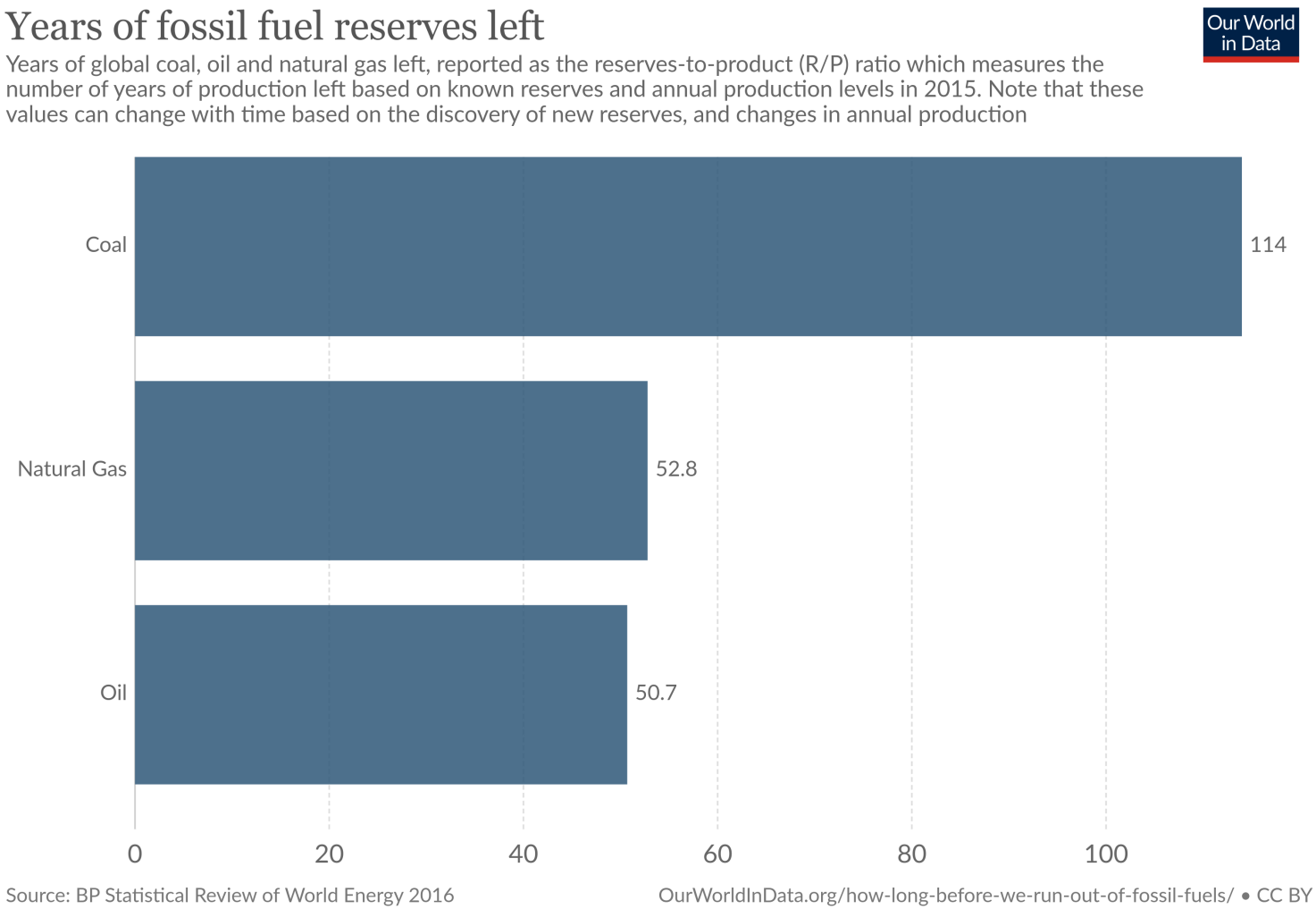
World population predictions



End of fossil fuels?



End of fossil fuels? ("Our world in data" site)



What is the scale of the problem?

- Each American uses about 226 kWh/day-person (all energy processes including industrial), about 7 gallons of gas in energy, 330 million people
- Let's imagine we run out of oil, natural gas, and coal use is reduced
- Each large energy power plant generates about 1 GW
- That's about 4mi^2 PV, 1000 wind turbines, 1 nuclear plant
- How many such sites do we need?

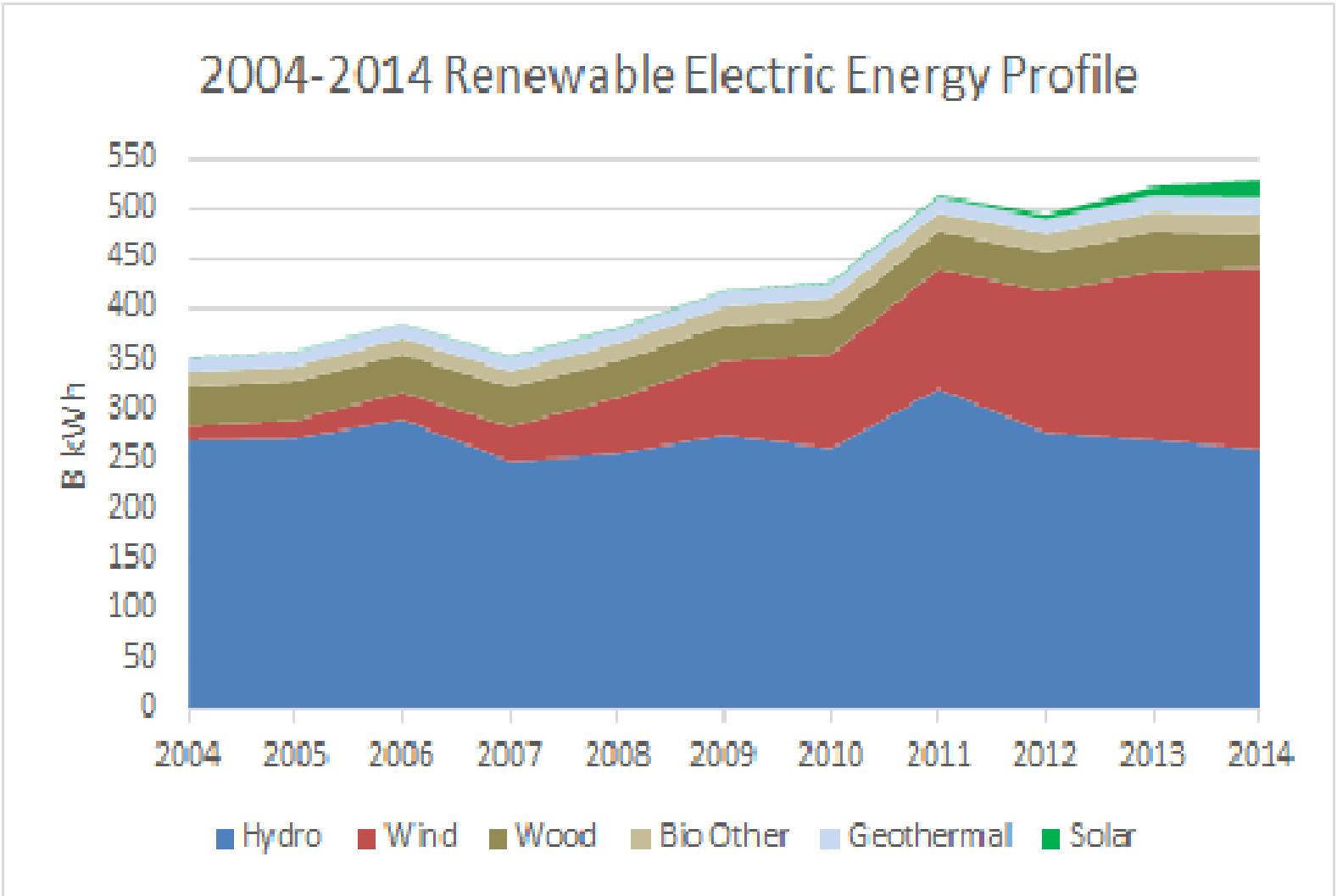
What is the scale of the problem? (2)

- The answer is about 3000 to power the U.S. (at current usage rates)
- What do we have now? 100 nuclear, 100 wind, 25 solar??
- It is a similar problem worldwide: a *doubling* of demand and a significant reduction in supply
- Major increase in demand will come from developing world

Promising candidates

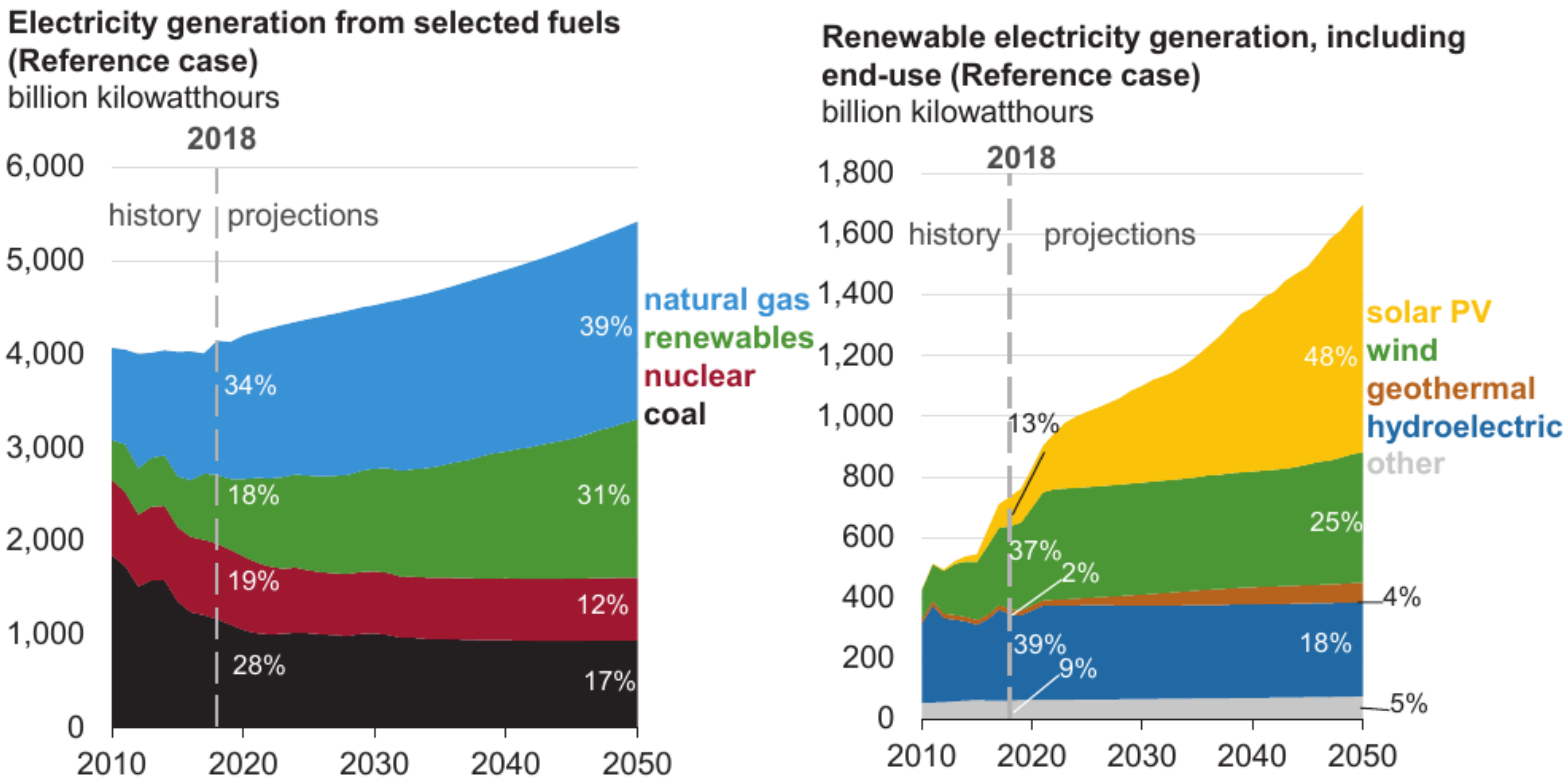
- Top competitors for renewable sources that can be scaled up? (from simple dimensional analysis)
- Wind (moving along well)
- Solar (LONG ways to go)
- Bio/Synthetic fuels including Hydrogen (LONG ways to go, but promising)
- Nuclear (non-renewable but low carbon)

Renewable E profile



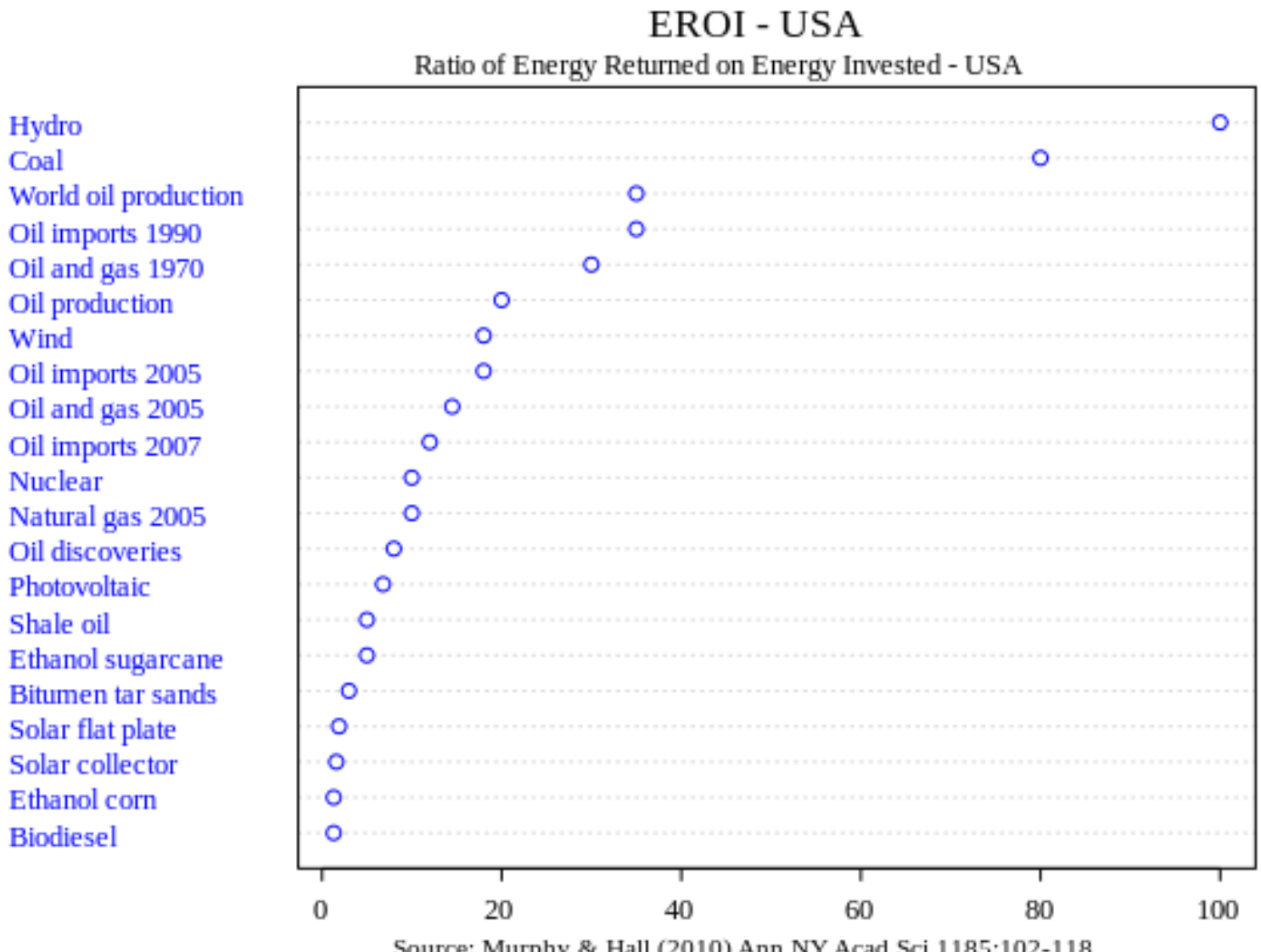
EIA (DOE) projection

Electricity generation from natural gas and renewables increases, and the shares of nuclear and coal generation decrease—



Energy return on investment

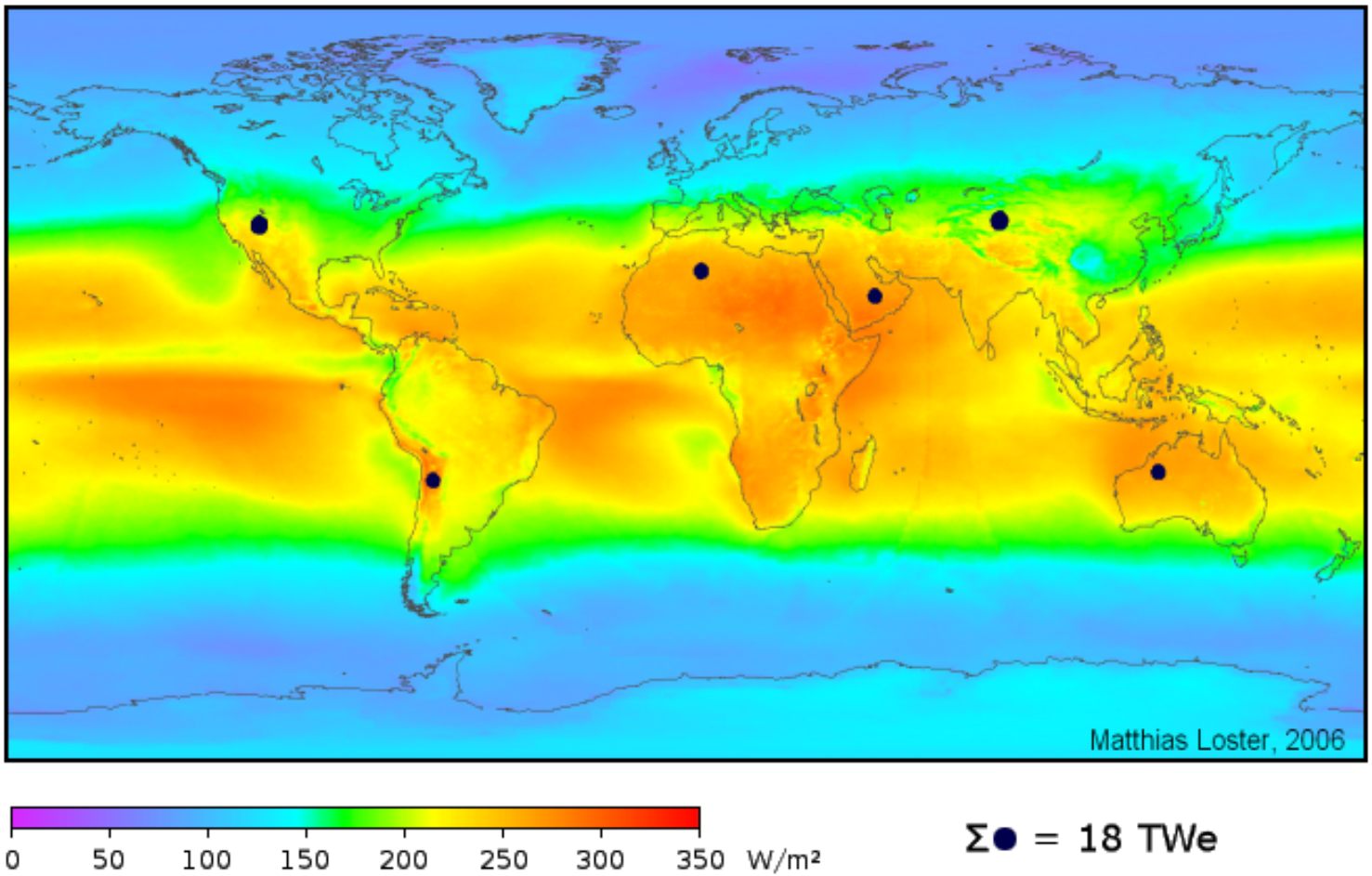
Economics really matters!



Solar potential

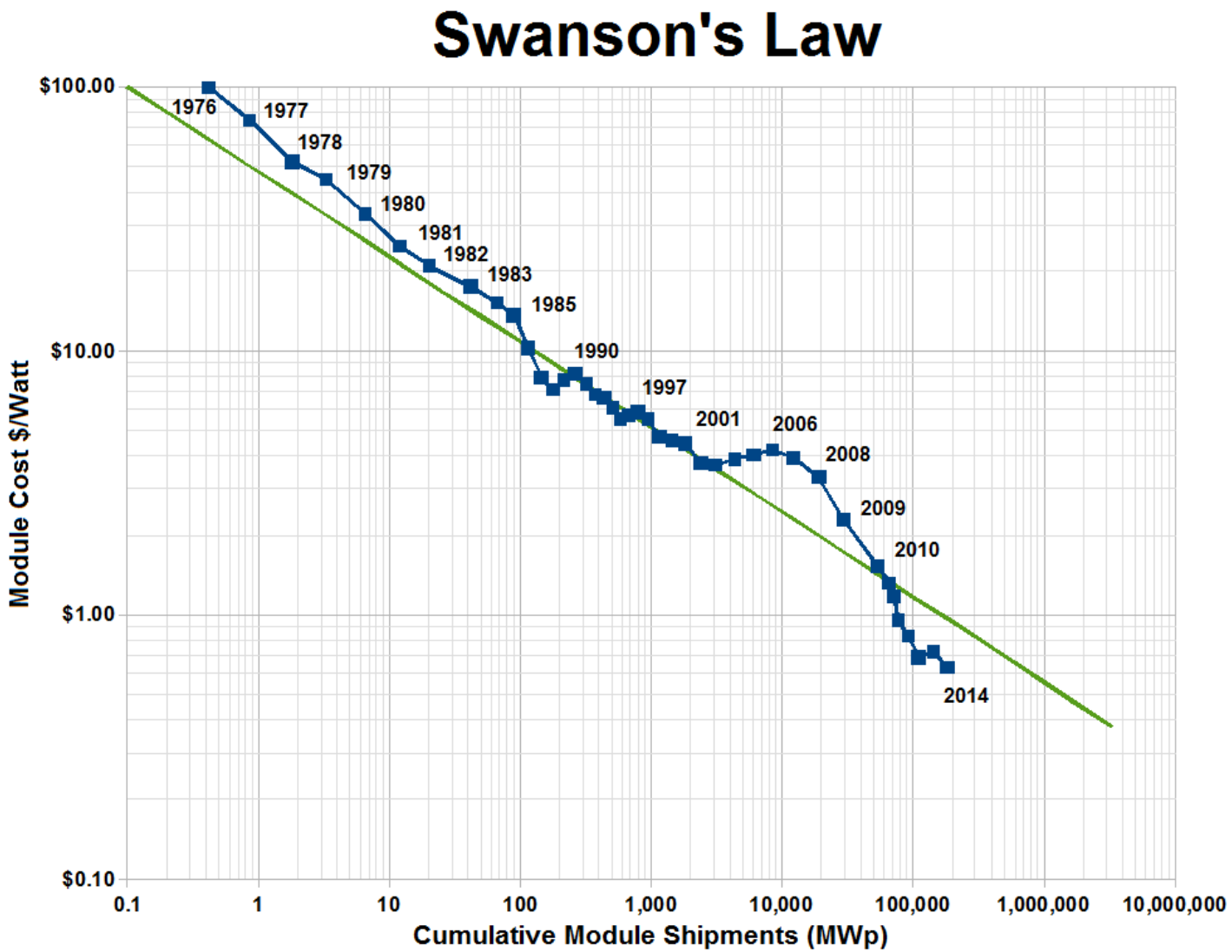
- 170 W/m^2
- Only 1 photon in 10^{10} (from the sun) hits the earth
- Yet this is enough to provide all human E use 5000 times over, in principle
- To power the whole earth we need to cover Spain with PV solar panels. To power the U.S. we need to pave Colorado with panels. To power Cincinnati we need a square 14 mi on a side (all energy uses).

World solar map



Solar PV Germany

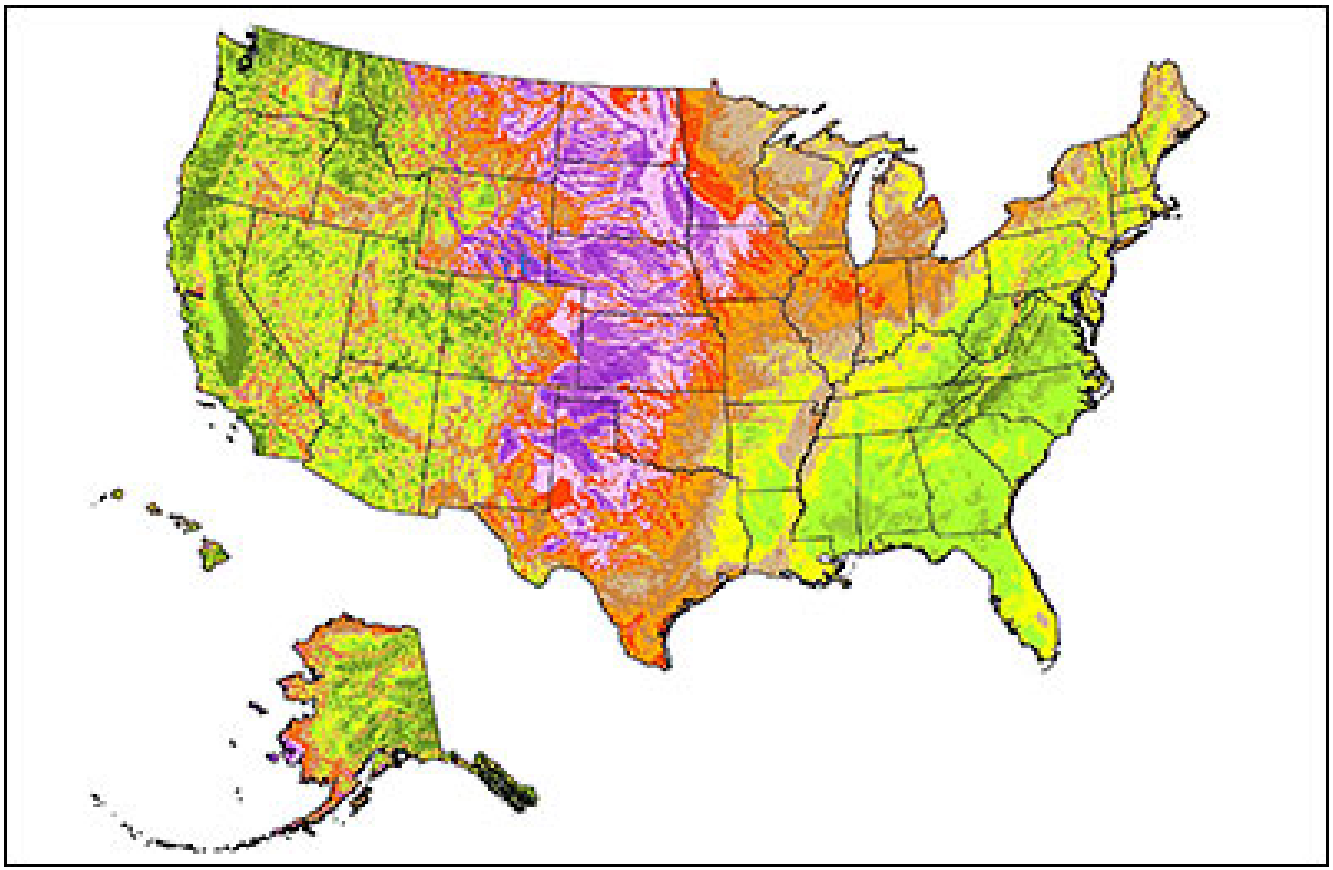
Swanson's law



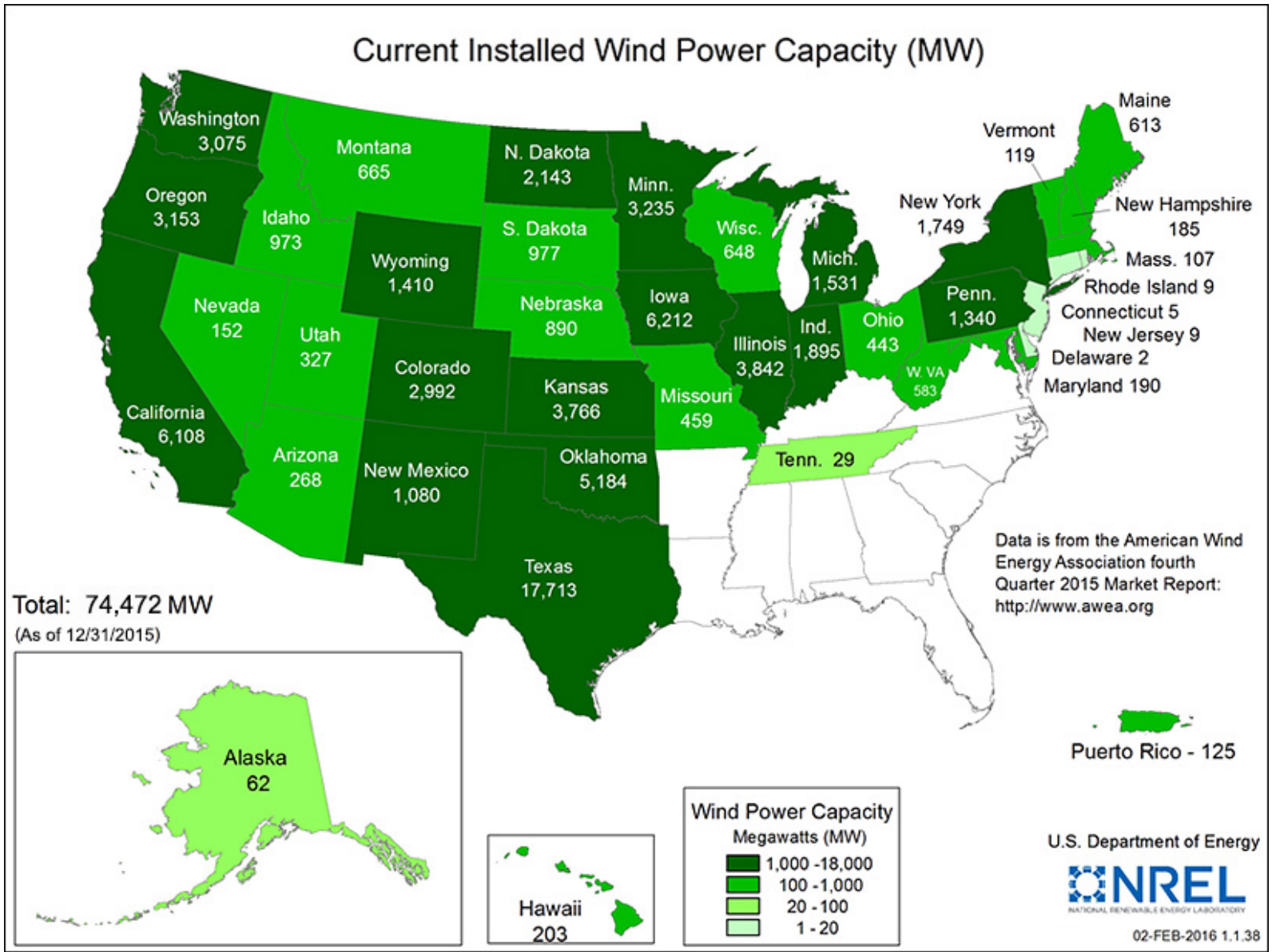
Wind potential

- 1 GW wind farm (1000 turbines) powers *total E* of 106,000 people
- 3000 such wind farms would power the whole U.S.
- But that's about $3-6 trillion or so

Map of wind in U.S.



Installed wind capacity



Shepherds Flat Wind Farm 2011 (Oregon)

Wind in Ohio

Politics matters

NEWS

Blue Creek Wind Farm in Ohio. (Courtesy Iberdrola Renewables)

Industry: Setback changes will end new wind farms in Ohio

Kathiann M. Kowalski | 06/19/2014

Wind in Iowa

FutureStructure
(/fs)
AUTOMATION (/fs/automation)

Iowa Approves Massive Wind Farm Amid Utility's Push for 100 Percent Renewable Energy

The Iowa Utilities Board has approved a $3.6 billion wind energy investment that will help convert the state's power grid to clean energy.

BY MITCHELL SCHMIDT, THE GAZETTE (CEDAR RAPIDS, IOWA) / AUGUST 31, 2016 8

Important steps will be LOCAL

UC Climate Action Plan
https://www.uc.edu/af/pdc/sustainability/climate_action.html

Mary Beth McGrew Assoc. VP of Planning + Design + Construction and University Architect
Daniel Hart, Sustainability Coordinator, Planning + Design + Construction 513-556-3492
daniel.hart@uc.edu

City of Cincinnati Green Cincinnati Plan
https://www.cincinnati-oh.gov/oes/citywide-efforts/climate-protection-green-cincinnati-plan/
Moving towards

Is Cincinnati the Greenest City in America?

https://cleantechnica.com

Synthetic fuels

- An algae pond 387 mi on a side could supply fuel equivalent to all current world oil production
- Roles for CO2 capture
- Water splitting (using solar) and hydrogen economy? Fuel cells

Garbage trucks to run on waste?

- NYT Aug. 19, 2016: "Garbage trucks that run on waste"
- Proposal is to use organic waste from NY City (producing renewable natural gas)

Algae for biofuels? Other biomass?

Estorage

- Solar and wind are intermittent!
- Pumped hydro
- Li ion batteries
- Li air batteries
- Supercapacitors
- Hydrogen as energy carrier (fuel cell)
- Of course transmission is crucial too

Estorage

Vaclav Smil, University of Manitoba (Bill Gates's favorite author):

"Give me mass-scale storage and I don't worry at all. With my wind and photovoltaics I can take care of everything. But we are nowhere close to it."

See "Energy: a Beginner's Guide" and "Energy Myths and Realities"

Nuclear potential

- Each nuclear plant produces about 1 GW power
- 3000 of those would power the U.S.
- We only have 100 so far and not likely to scale up to that level
- Thorium?
- What happens of cost of fossil fuels hits a steep wall? Likely nuclear will kick in unless renewables can make a huge leap in next few decades. We're at only a few percent for wind/solar so far.

Swiss nuclear site

How dangerous is nuclear?

Fossil fuels are far deadlier than nuclear power

By Phil McKenna

Read more: "Special report: Rescuing nuclear power"

IN THE wake of the nuclear crisis in Japan, Germany has temporarily shut down seven of its reactors and China, which is building more nuclear power plants than the rest of the world combined, has suspended approval for all new facilities. But this reaction may be more motivated by politics than by fear of a catastrophic death toll. It may be little consolation to those living around Fukushima, but nuclear power kills far fewer people than other energy sources, according to a review by the International Energy Agency (IAE).

"There is no question," says Joseph Romm, an energy expert at the Center for American Progress in Washington DC. "Nothing is worse than fossil fuels for killing people."

A 2002 review by the IAE put together existing studies to compare fatalities per unit of power produced for several leading energy sources. The agency examined the life cycle of each fuel from extraction to post-use and included deaths from accidents as well as long-term exposure to emissions or radiation. Nuclear came out best, and coal was the deadliest energy source.

2011, New Scientist

Conclusions

- WE HAVE A LARGE PROBLEM FACING US
- To give an idea, we would need to build 2 coal plants per week for 50 yrs to cover 1/4 of the expected new demand in the next 50 yrs
- Same idea for nuclear, 1 plant per week for 50 yrs to cover 1/4 needed E
- We need bright, innovative young scientists to tackle these problems!
- Chemistry: photovoltaics, materials for wind turbines, catalysis for synthetic fuels (biomass conversion), energy storage, energy efficiency in chemical processes, etc.

Conclusions (contd)

- This talk has focused on supply
- AT LEAST half the problem is *consumption*
- Challenges especially for the younger scientists: 1) design better, more efficient cities/spaces 2) focus on consumption: food, transport, etc 3) solve the energy storage problem! 4) work hard for a long time!
- It could get bumpy, but humans are resourceful in facing challenges.