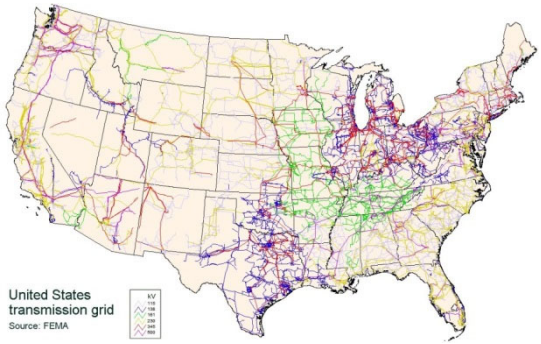
The Energy Revolution

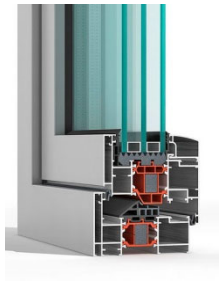
Wikimeida commons Dirk Ingo Franke



Public domain by Rolypolyman at wikimedia commons

Wikimedia commons Gray Watson User:E090

© **Liter of Light // Region Europe** 2012 - Creative Commons License http://literoflightswitzerland.org/idea.php?l=en



Public domain http://www.archiexpo.com/prod/aluminco/tilt-and-turn-windows-thermal-break-aluminium-triple-glazed-1656-1104911.html

Wikimedia commons Alan bron

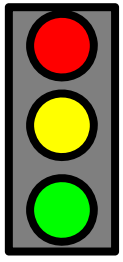
Wikimedia commons Dvortygirl

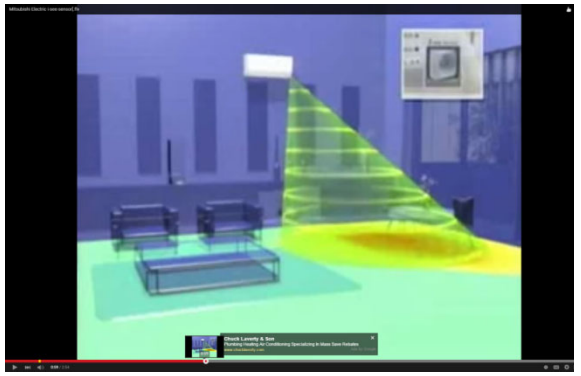
Wikimeida commons Mariordo (talk) - Roadster_2.5_windmills.jpg.

Wikimedia commons Mj-bird

public domain

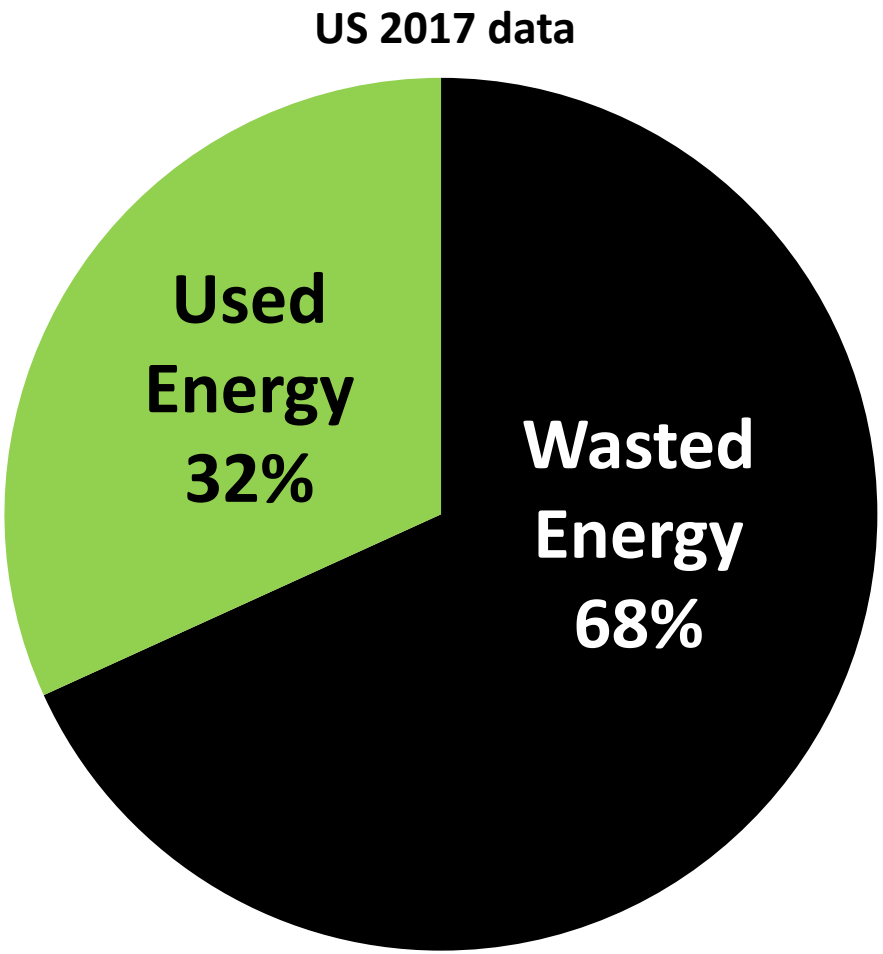
Wikimedia commons Piisamson



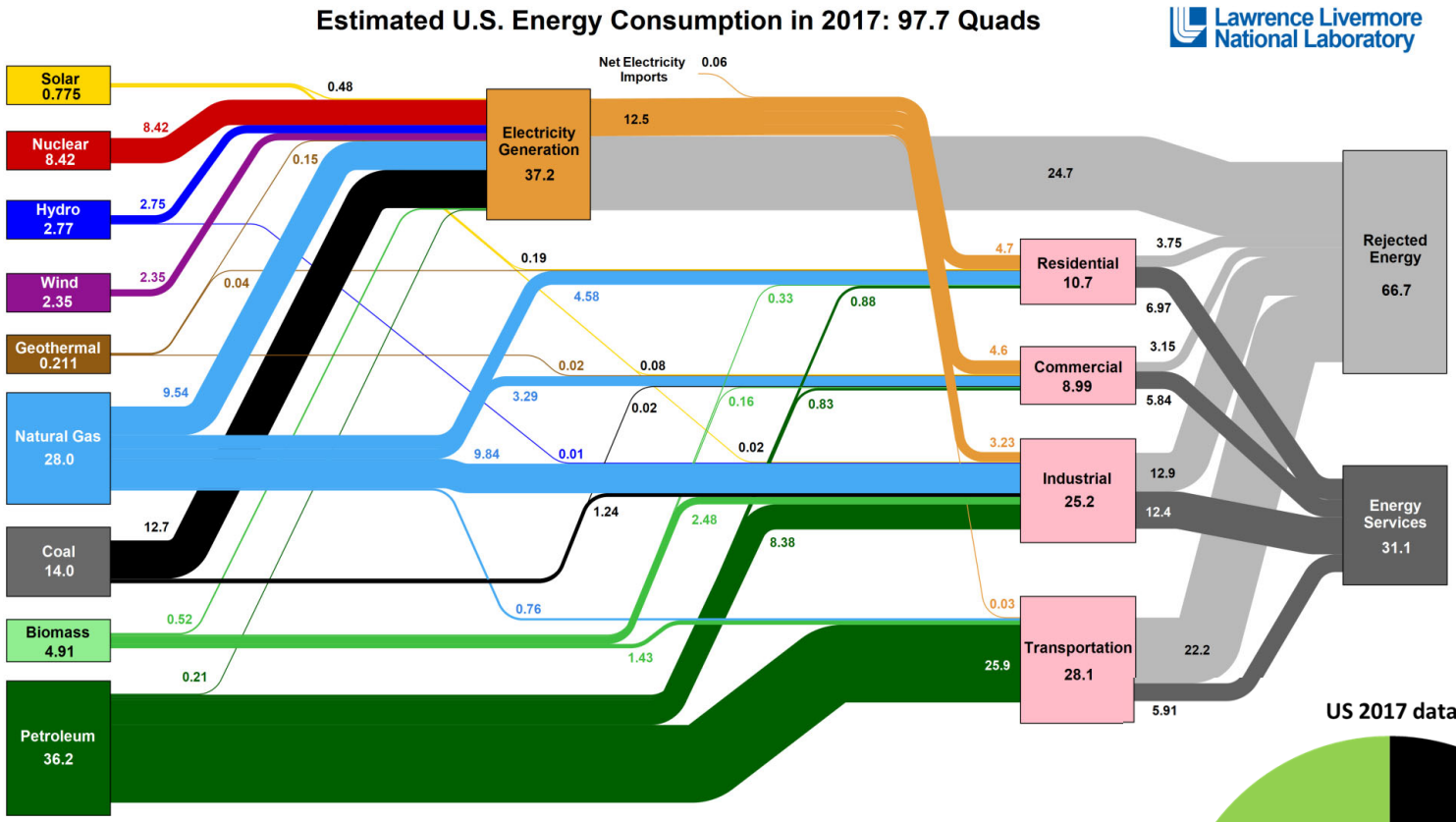


https://www.youtube.com/watch?v=QKF3PYmSTFU

Enormous Opportunities



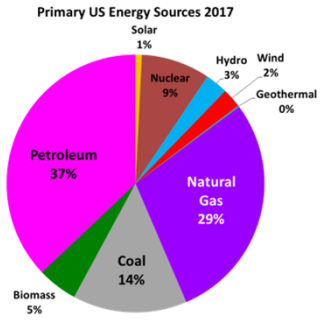
Energy Flow



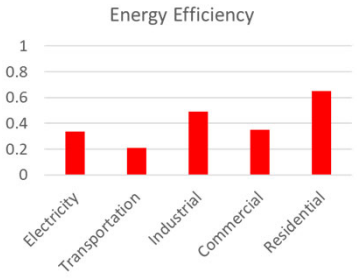
Original Energy

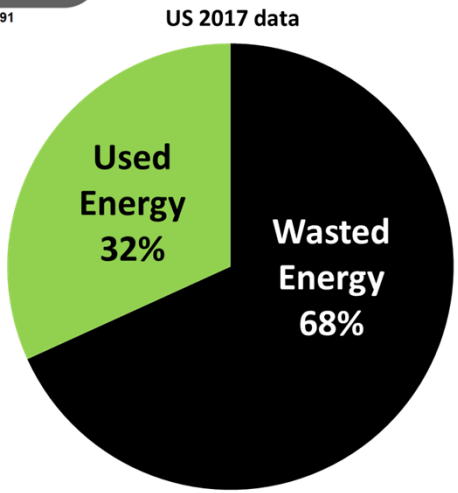
Wasted Energy

Used Energy



80% Fossil Fuel Burning





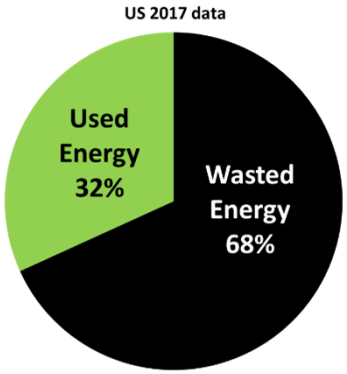
Avoid Cyclic Heat Engines

Why dump heat?

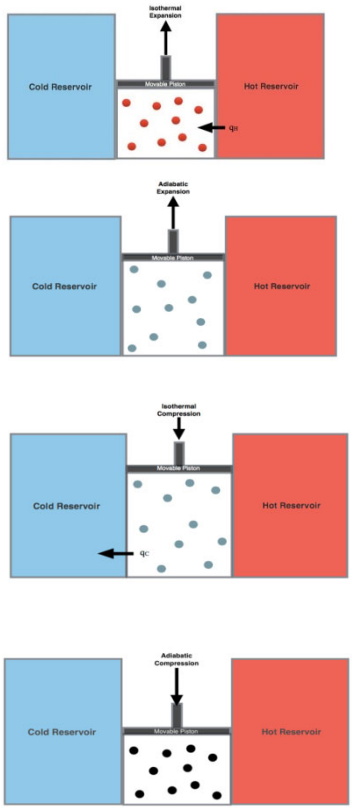
You can’t keep doing that unless you put it back the way you found it.

Benh LIEU SONG wikimedia

Renewable energy does not need to replace dumped heat!



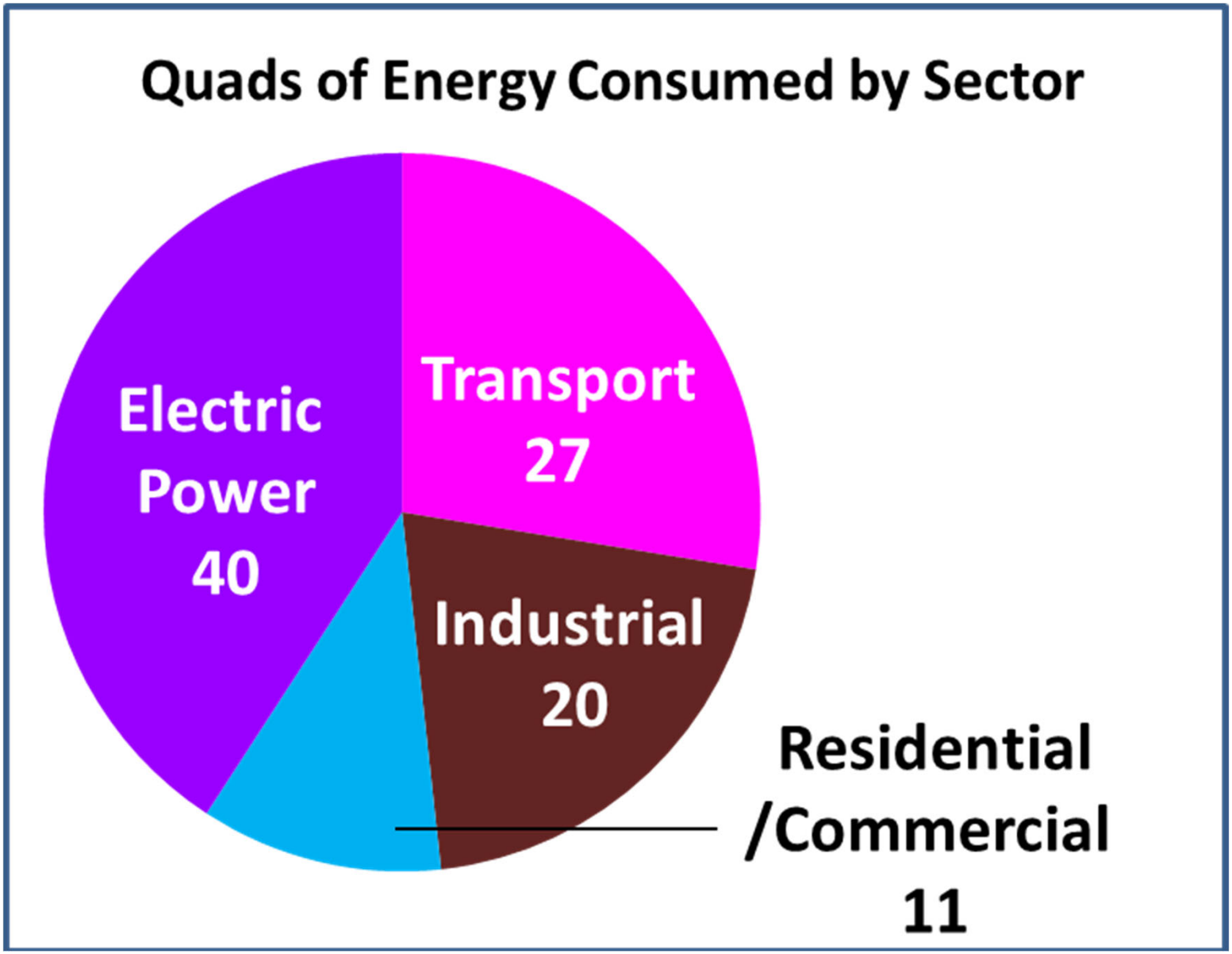
You have to free some heat if you want to keep some work **AND** return to the beginning



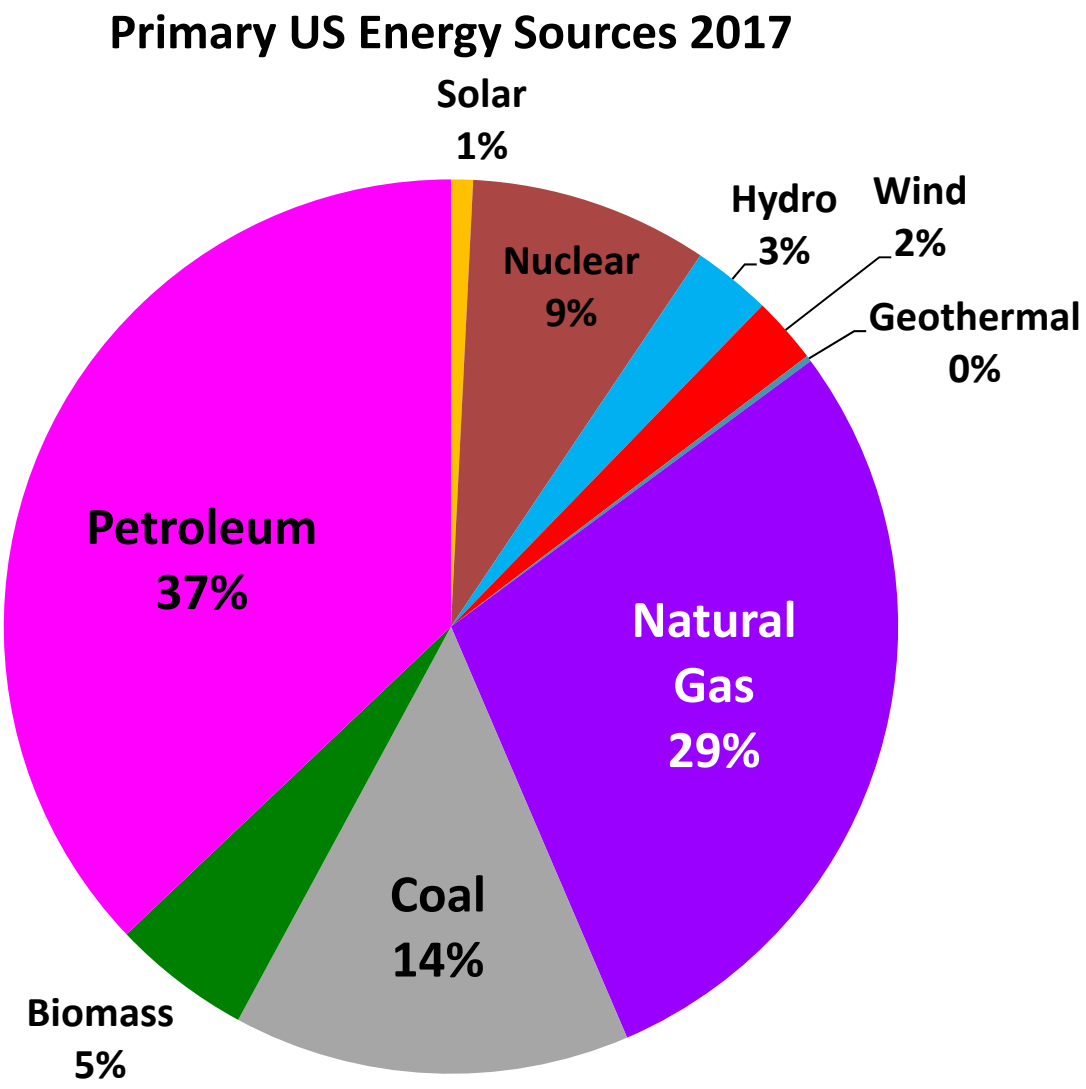
To keep net energy but return to the start, you must pay a price in heat. That price makes so pushing back requires less energy than the heat provided when it pushed forward. The lower the cold T, the lower the price

BlyumJ wikimedia

Current Energy Use

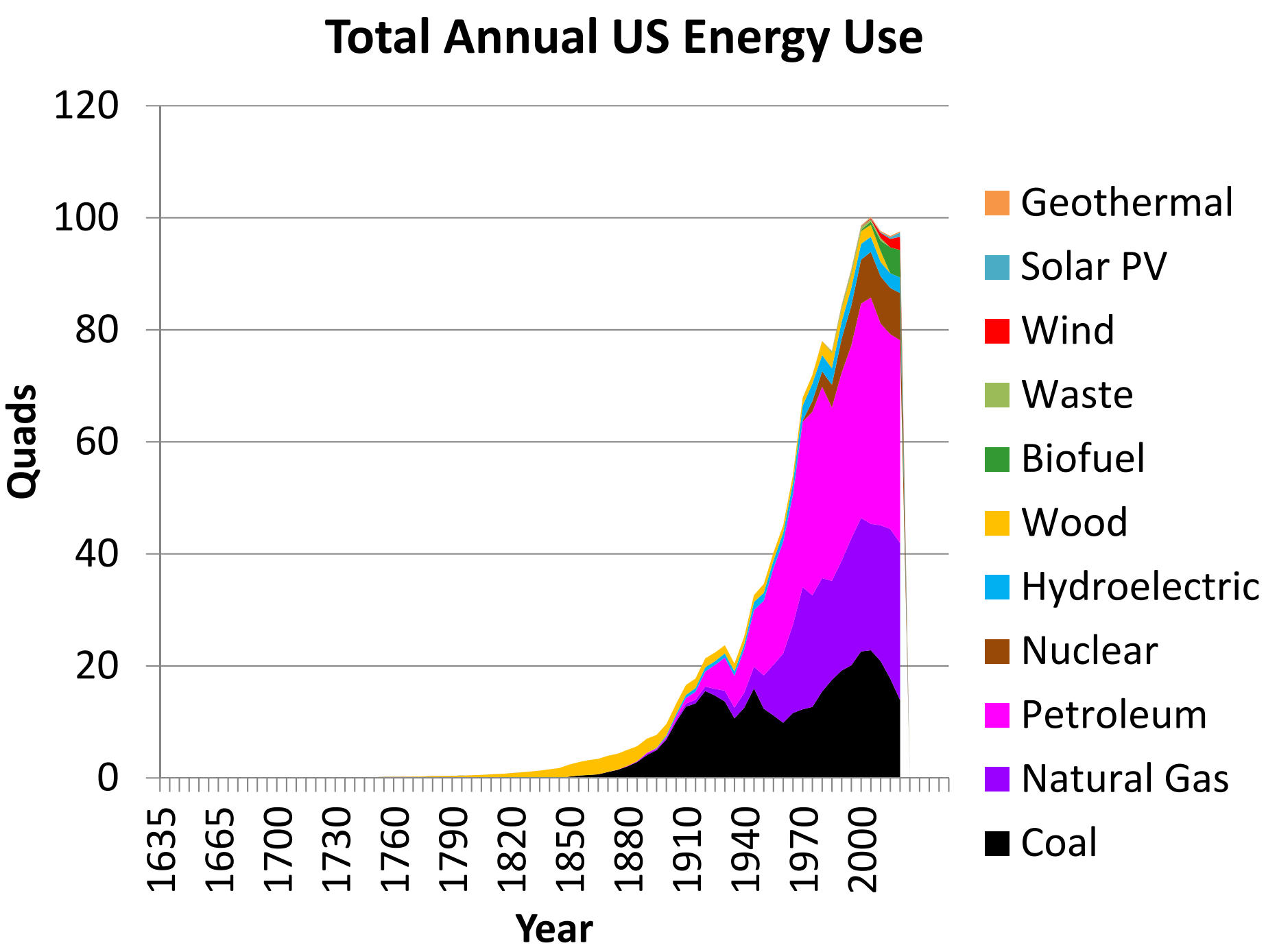


Current Energy Sources

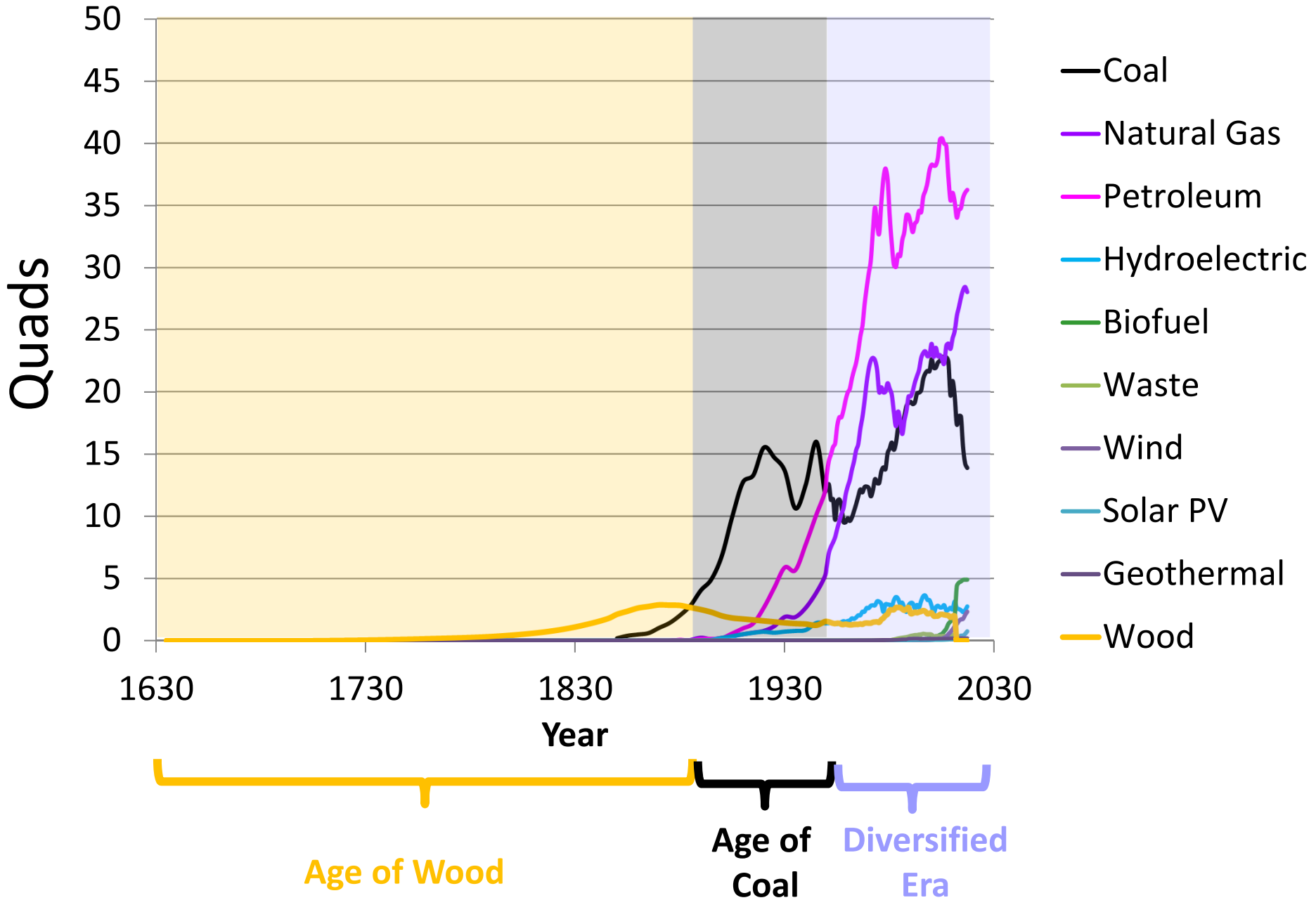


80% Fossil Fuel Burning

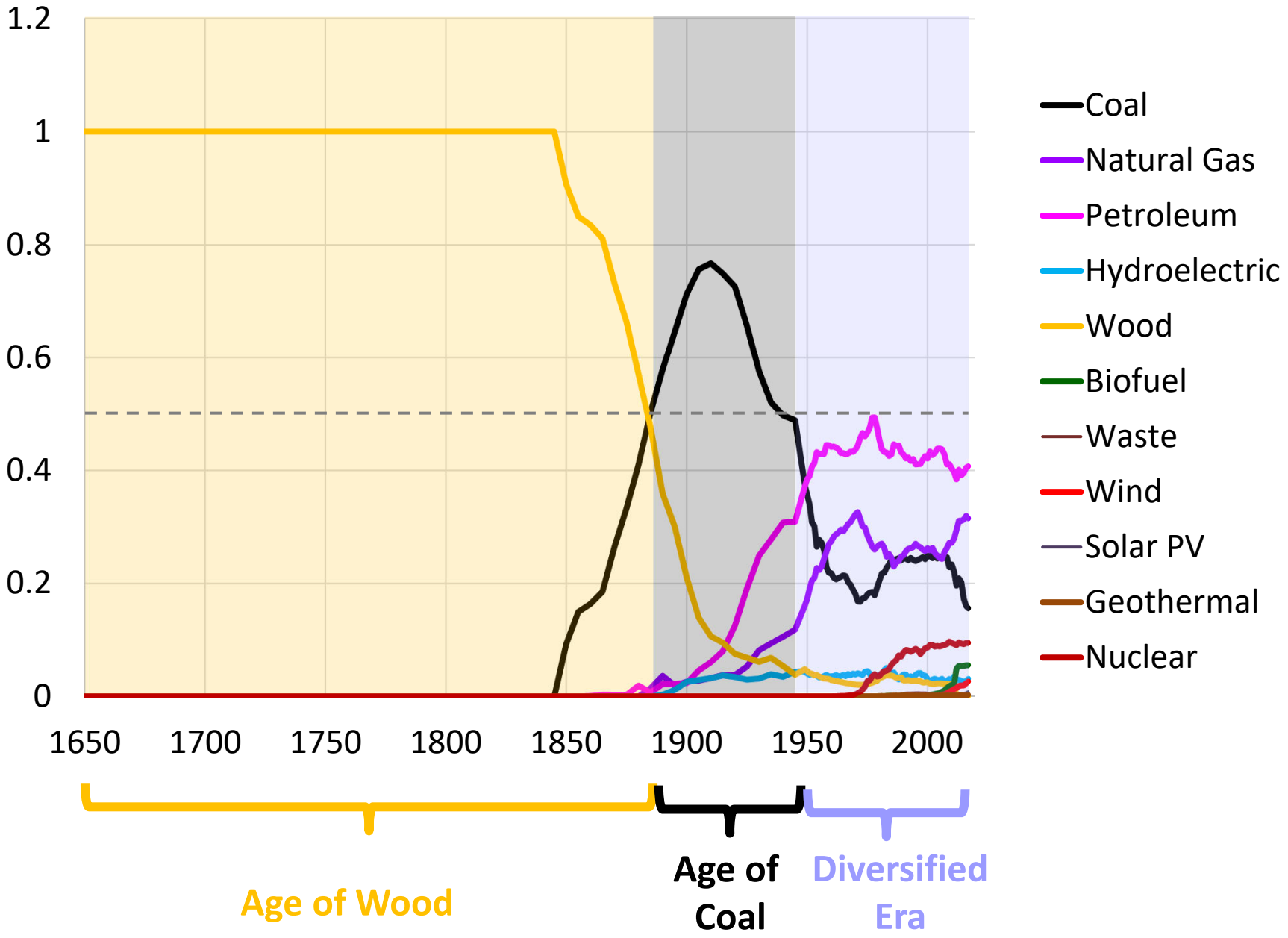
How did we get to 80% fossil fuel burning?


Total Annual US Energy Use
120
100
80
60
40
20
0
Quads
1635
1665
1700
1730
1760
1790
1820
1850
1880
1910
1940
1970
2000
Year
Geothermal
Solar PV
Wind
Waste
Biofuel
Wood
Hydroelectric
Nuclear
Petroleum
Natural Gas
Coal

Annual US Energy Consumption by Source



% of Energy from Sources



Why Change?

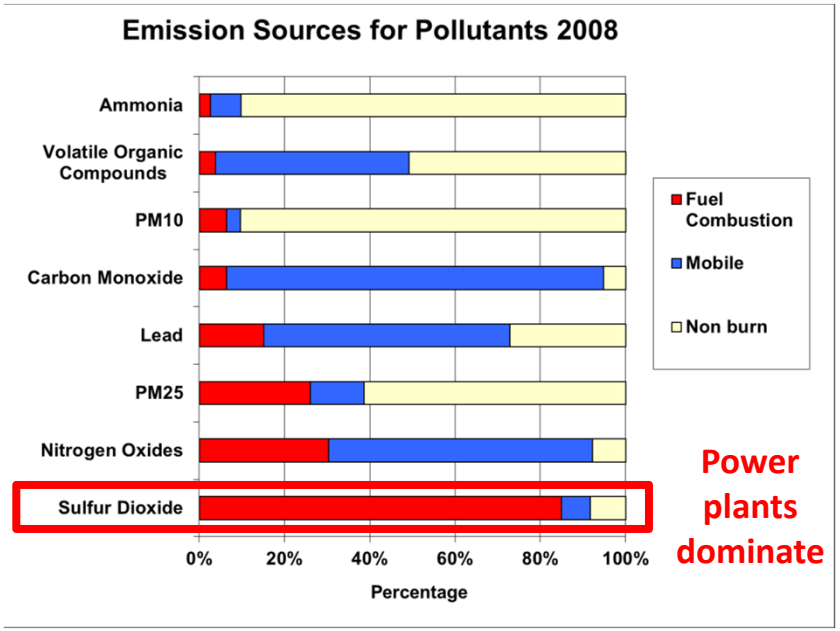
1. National Security
2. Balance of Payments
3. Environment
4. Climate Change
5. Health
6. Flexibility and Fungibility

   Any source can instantly supply any need

Air Quality and Health

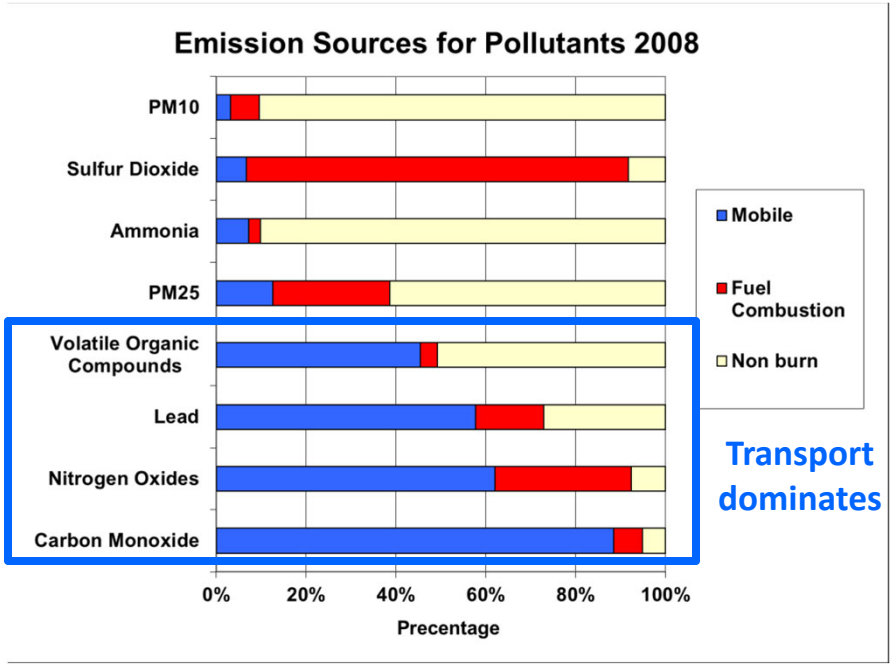
Wikimedia commons Bobak

Beijing Average Lifetime Loss ~ 5 Years



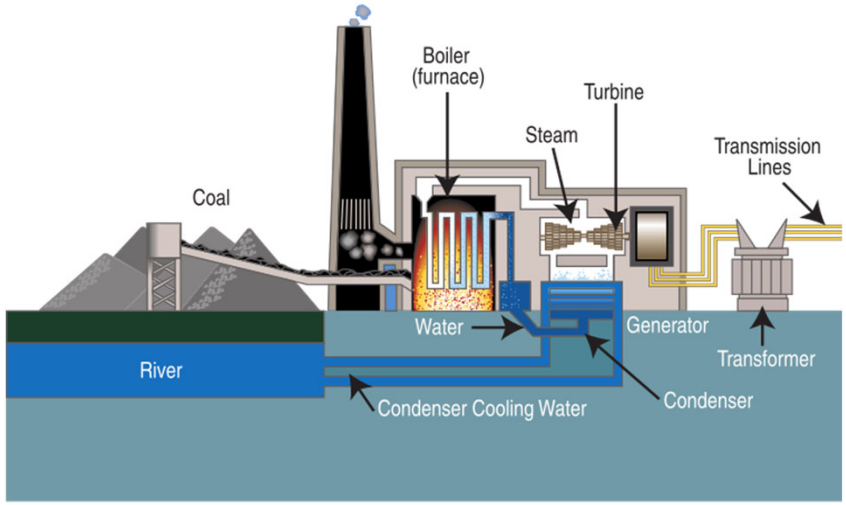
Wikimedia coommons http://www.flickr.com/photos/wili/

India Average ~ 3 Years



Burning is Bad

(US energy ~ 80% from fossil fuel burning)



"Coal fired power plant diagram" by Tennessee Valley Authority - tva.com. Licensed under Public Domain

1. Carnot Efficiency
2. Pollutants
3. Carbon
4. Heat Dumping
5. Extraction

   Deep Water horizon cost >$58 billion

   http://www.economist.com/news/business-and-finance/21656847-costly-mistake
6. Transport

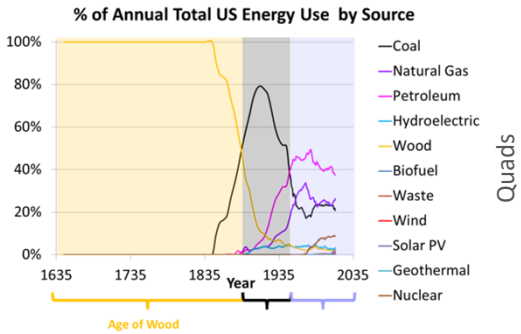
Stop burning by changing sources and uses

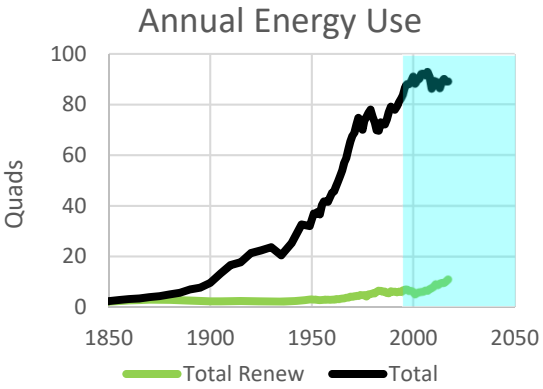
Can we change?

Wikimedia commons Andy Reago & Chrissy McClarren

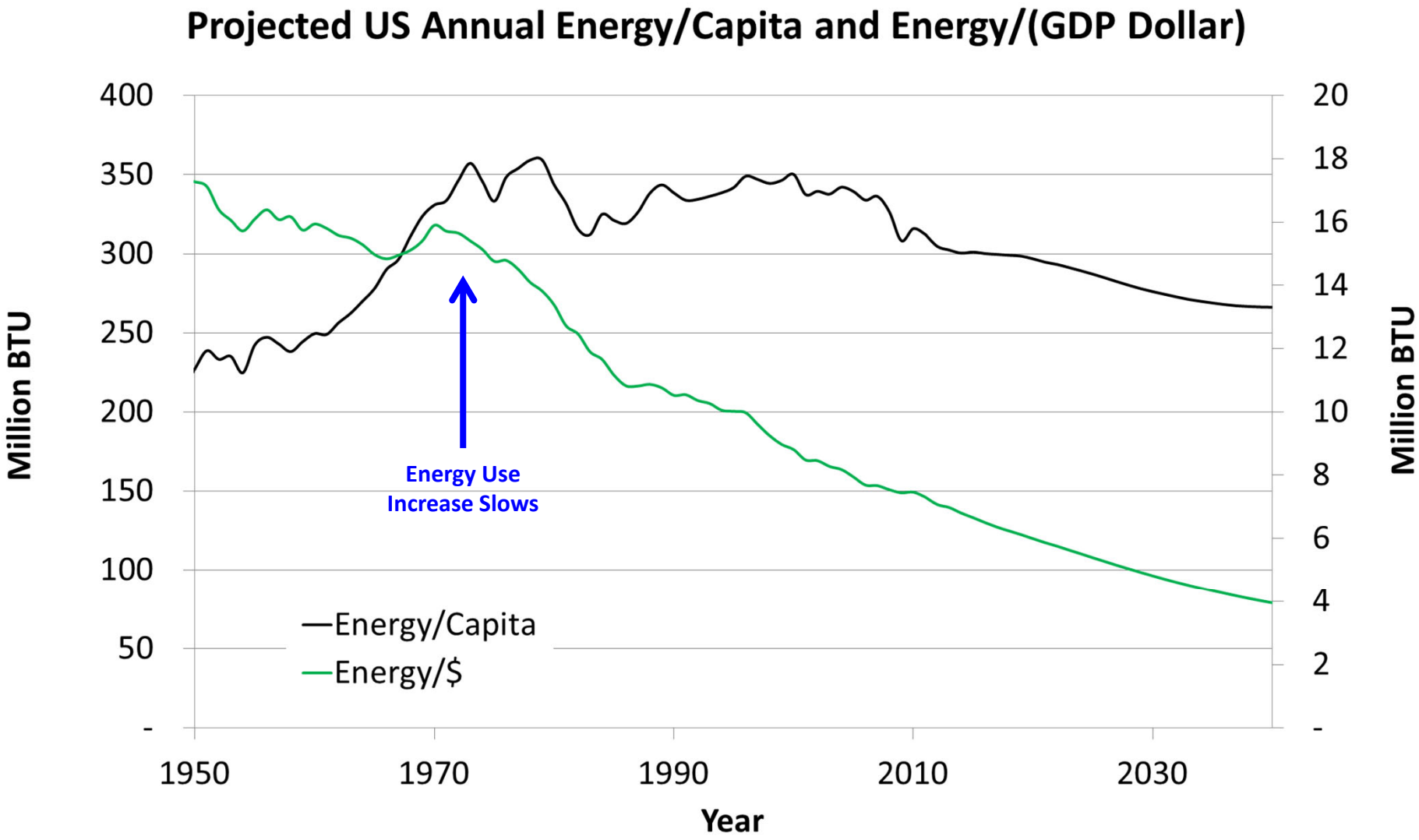
Wikimedia commons Ramon.rovirosa

We already have



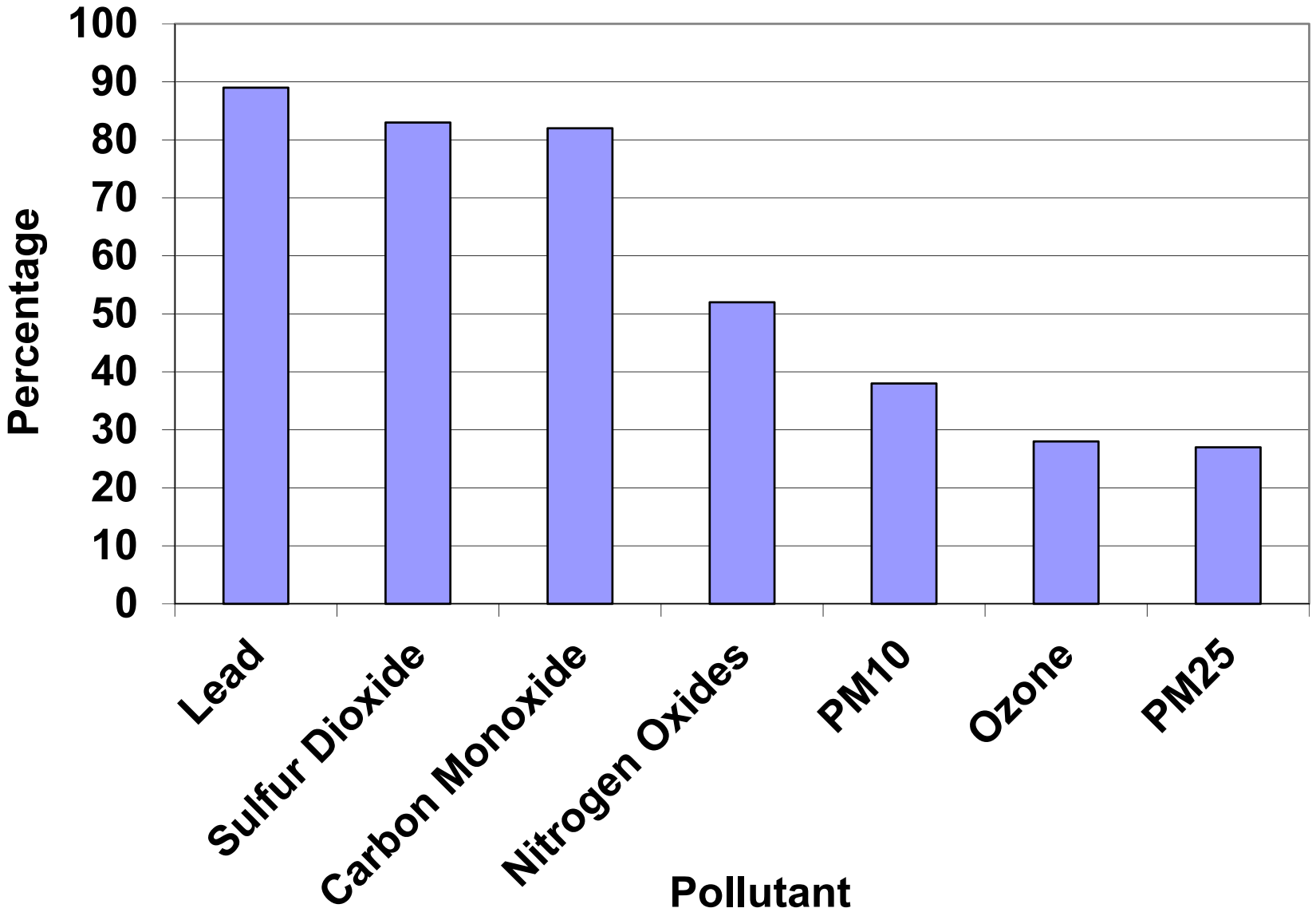


Positive Change



More Positive Change:

U.S. Emission Decrease 1980-2010



How can we change?

Types of Changes in Use

Passive

(require less energy)

http://hdl.loc.gov/loc.pnp/cph.3c28547

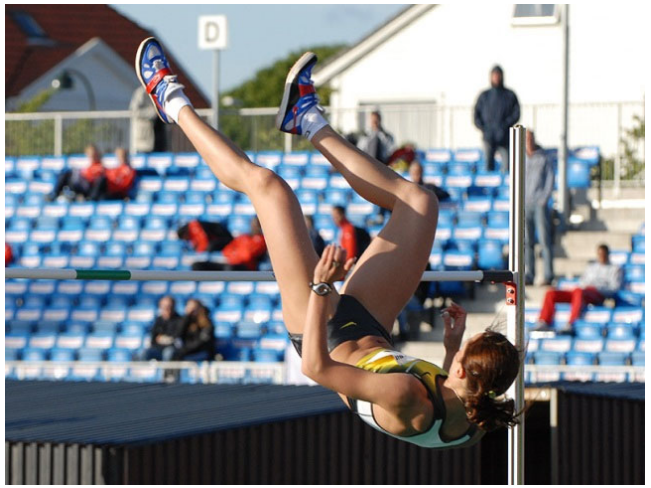
"Portrett av Roald Amundsen crop" by Daniel Georg Nyblin - from Nasjonalbiblioteket / National Library of Norway. Licensed under Public Domain via Commons -

Active

(use energy more effectively)

Gold medal winner Ethel Catherwood of Canada scissors over the bar at the 1928 Summer Olympics. Her winning result was 1.59 metres (5 ft 3 in). Public domain

1.59 meters



> 2 meters

Yelena Slesarenko at Stavanger Games 2007.
Date13 June 2007
Author Bjart Hetland

Passive is Good

(require less energy)

Avoid Heating

Wikimedia commons Alan bron (talk)

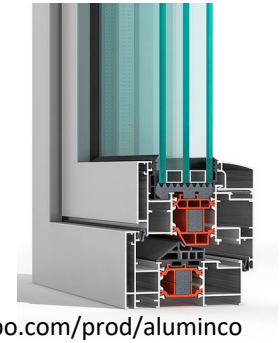
Own work Billy Hathorn

Palazzo Dragoni-porte e finestre Massimilianogalardi

Insulate

Wikimedia commons Dvortygirl

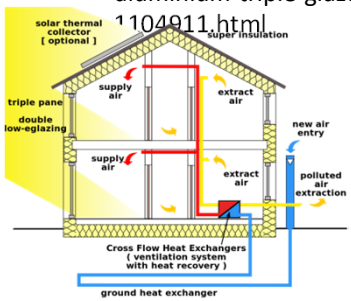
Let Sunlight In



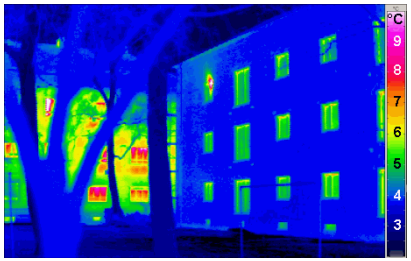
Public domain http://www.archiexpo.com/prod/aluminco/tilt-and-turn-windows-thermal-break-aluminium-triple-glazed-1656-1104911.html

© **Liter of Light // Region Europe** 2012 - Creative Commons License http://literoflightswitzerland.org/idea.php?l=en

Modern Optimized Combinations

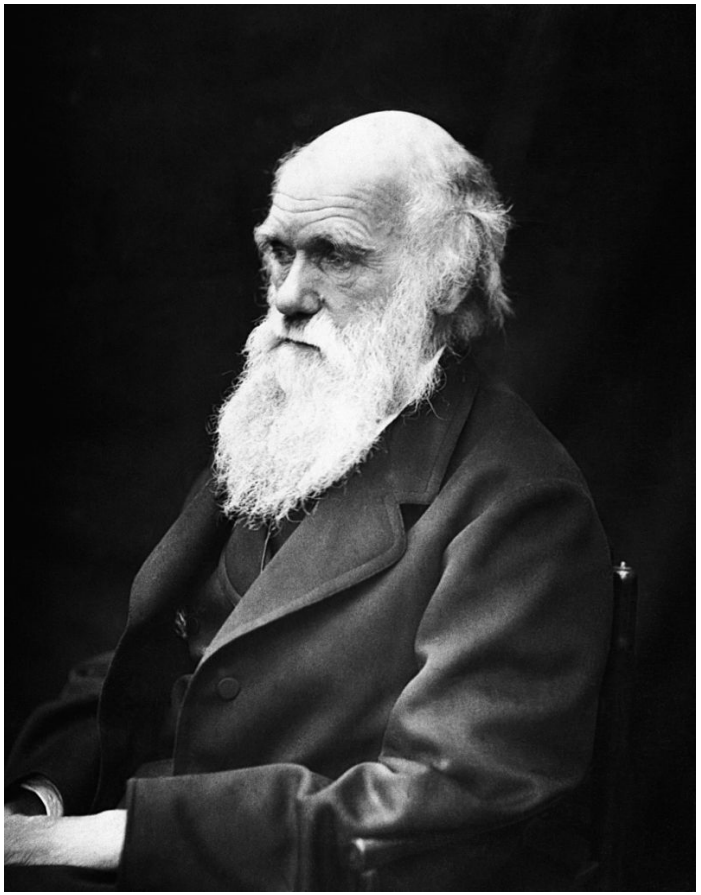


Passivhaus Institut derivative work: Michka B



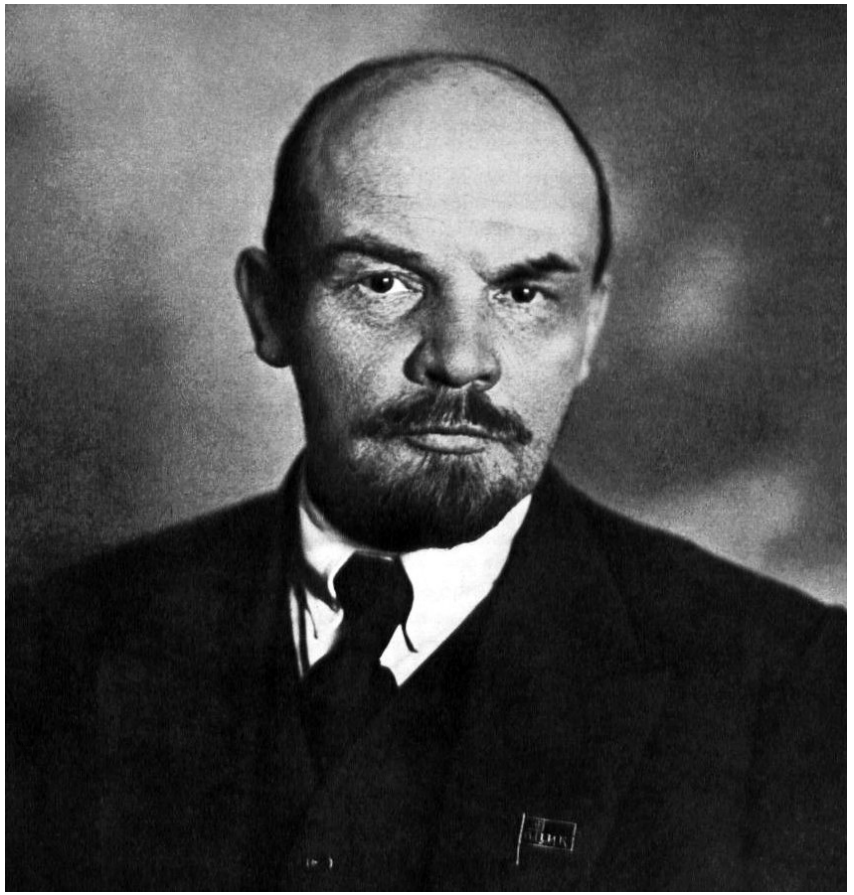
"Passivhaus thermogram gedaemmt ungedaemmt" by Passivhaus Institut -

Active Options



Public domain

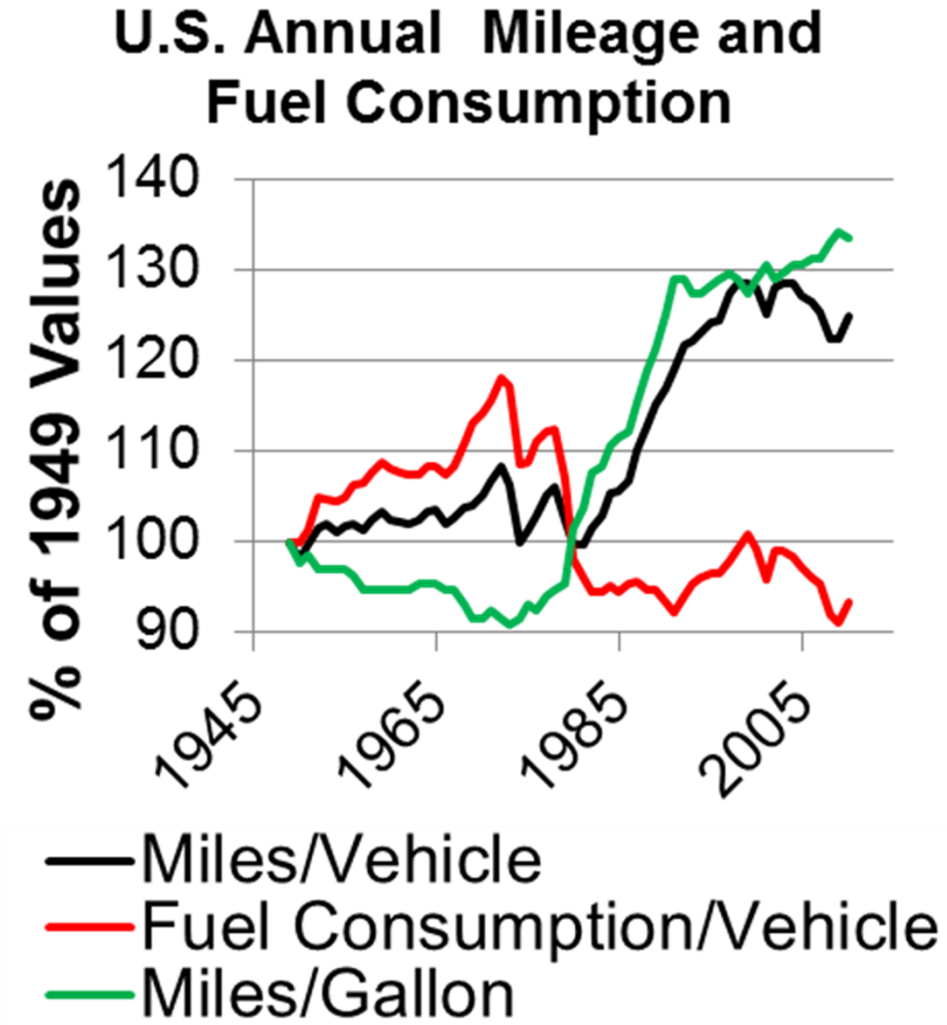
Evolution



Public domain

Revolution

Previous Examples



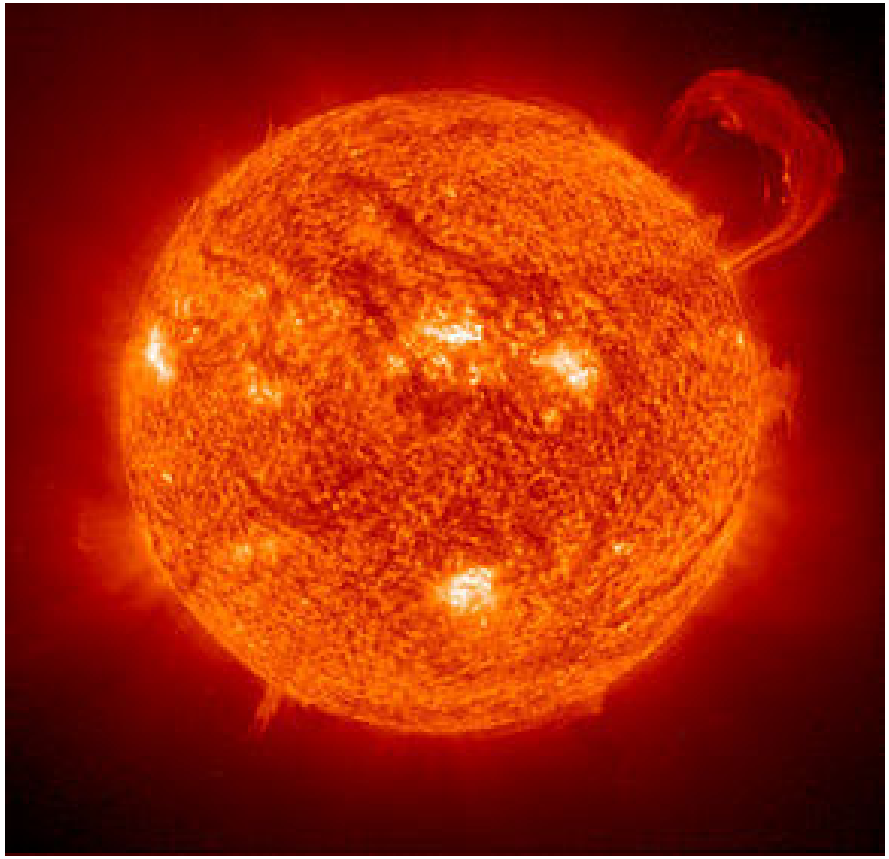
Evolution

Old Charger Style

New Charger Style

Revolution

Change sources:
Switch All Energy to Renewables



NASA public domain http://photojournal.jpl.nasa.gov/catalog/PIA03149 (image link)

Use electricity for almost everything

Nuclear

~ 75% of electricity in France

5.5 cents/kWHour

No serious accidents in ~ 40 years x ~20 plants

No permanent waste storage for 138,200 cubic meters of high level waste

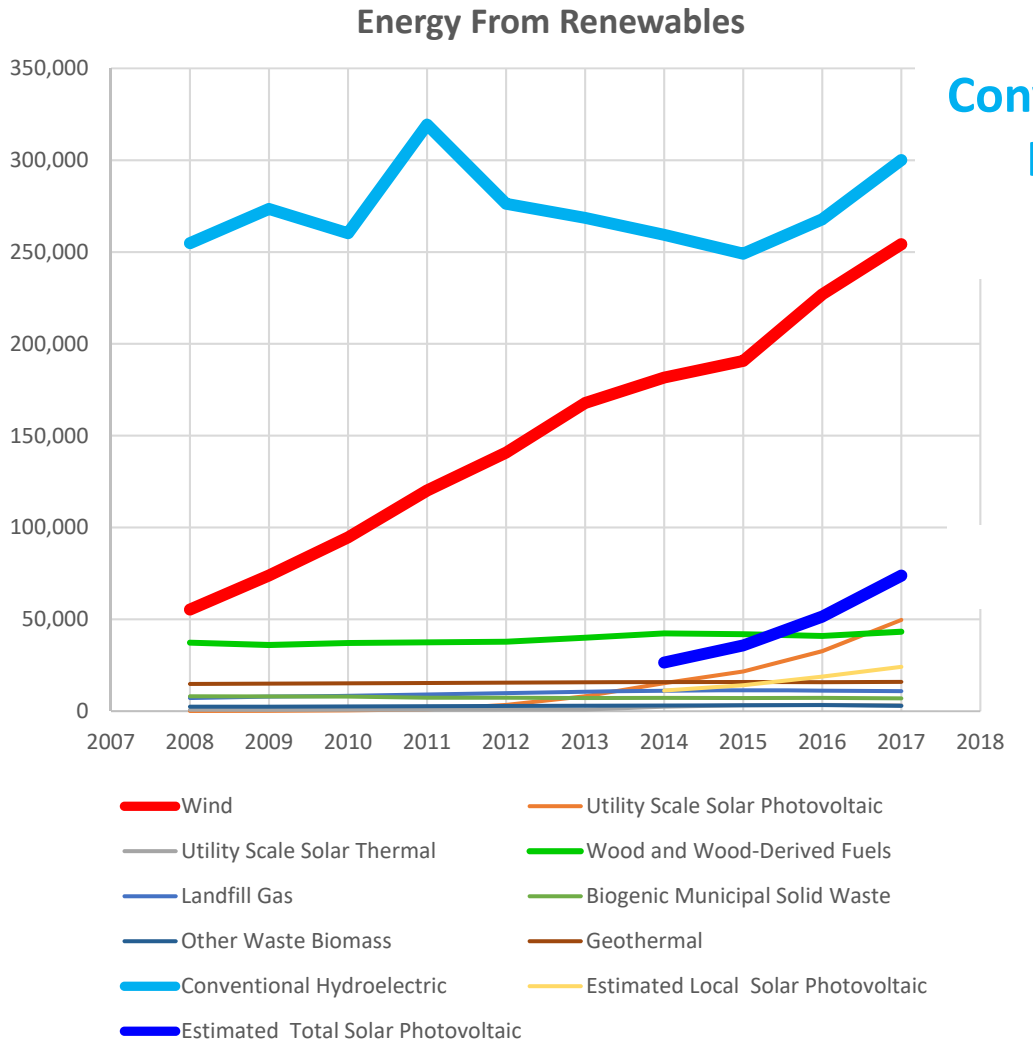
Chernobyl

Fukushima

Terrorism

Natural gas price decrease -> nuclear plant closing

Wind and Solar are Rapidly Increasing



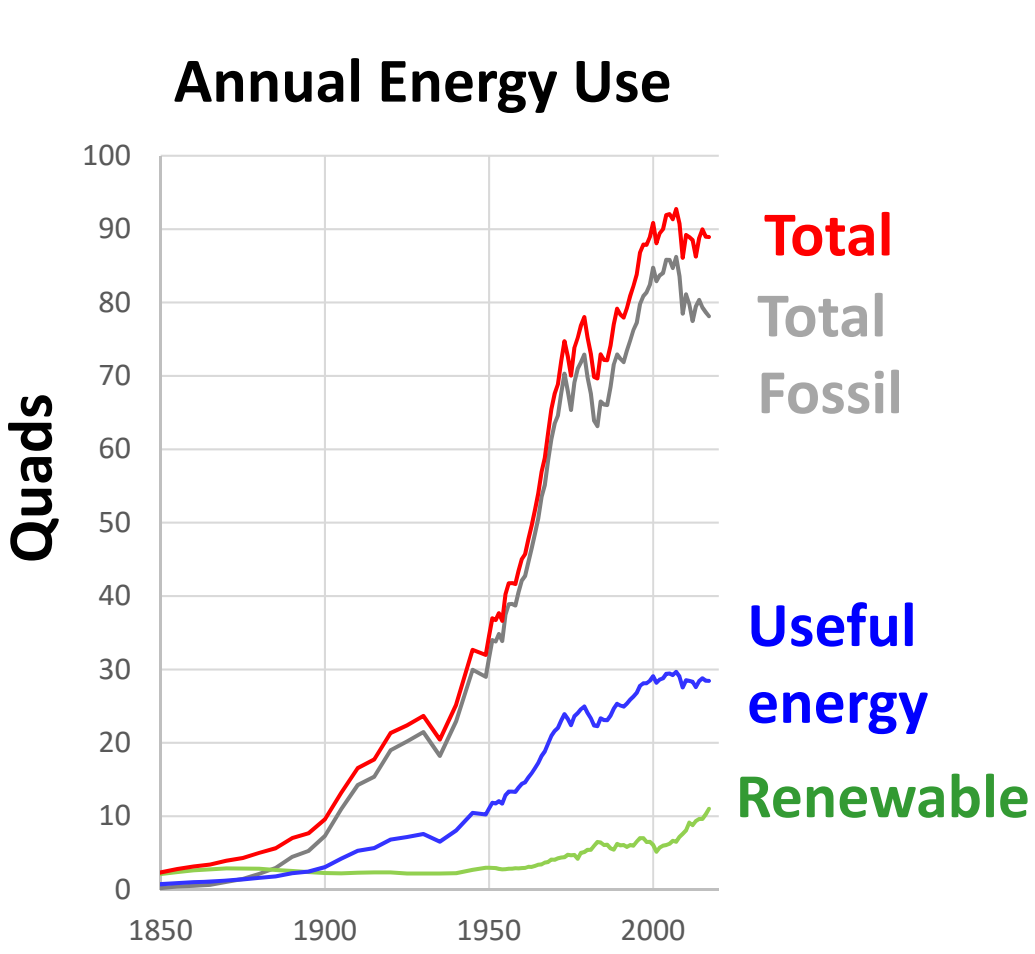
Conventional Hydro

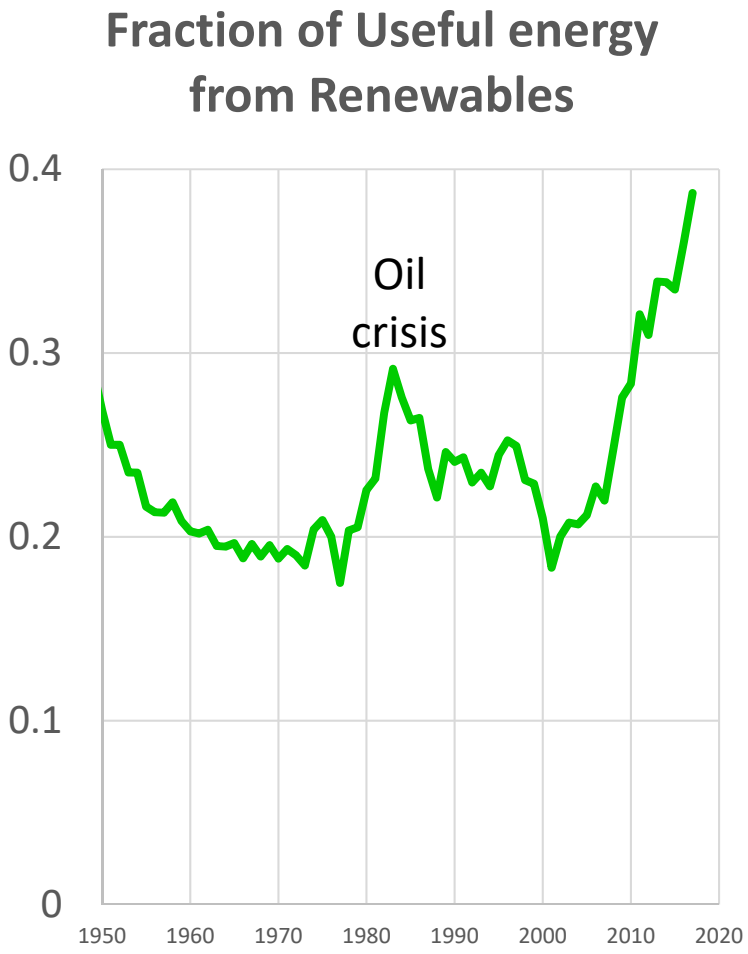
Wind

Solar

The transition is accelerating

(~3x present would be enough)





~ 50 years to reach 100% at current rate

2x rate gives sustainable ~ 25 year replacement

Can it continue?
Would it be enough?

Issues

Social Factors

Do we want to change

Technological Feasibility

Can we change

Cost

Can we afford to change

By victorgrigas (Own work)

"Windmills" by James McCauley from Enon, OH, United States of America - Flickr

By America's Power

The All Electric Revolution

Change Sources

Wikimeida commons Dirk Ingo Franke

Wikimedia commons Gray Watson User:E090

Change Consumption

Wikimeida commons Mariordo (talk) - Roadster_2.5_windmills.jpg.

Wikimedia commons Mj-bird

public domain

Wikimedia commons Piisamson

Wikimedia commons Dmitry_G

US has enough on Average

(power/area)

Wikimeida commons Dirk Ingo Franke

Wikimedia commons Gray Watson User:E090

Total Energy ~ 15% of land ~ 1/3 agriculture land
(~2,000,000 Turbines)

Burning bonus reduces by 50%

Average US Total Power Use/Area = 0.34 Watts/m^2
Average US Electrical Power/Area = 0.044 Watts/m^2

	Hydro	Wind	Solar PV
Available Average Electrical Power W/m^2	0.02	2	40

Total Energy < 1% of land

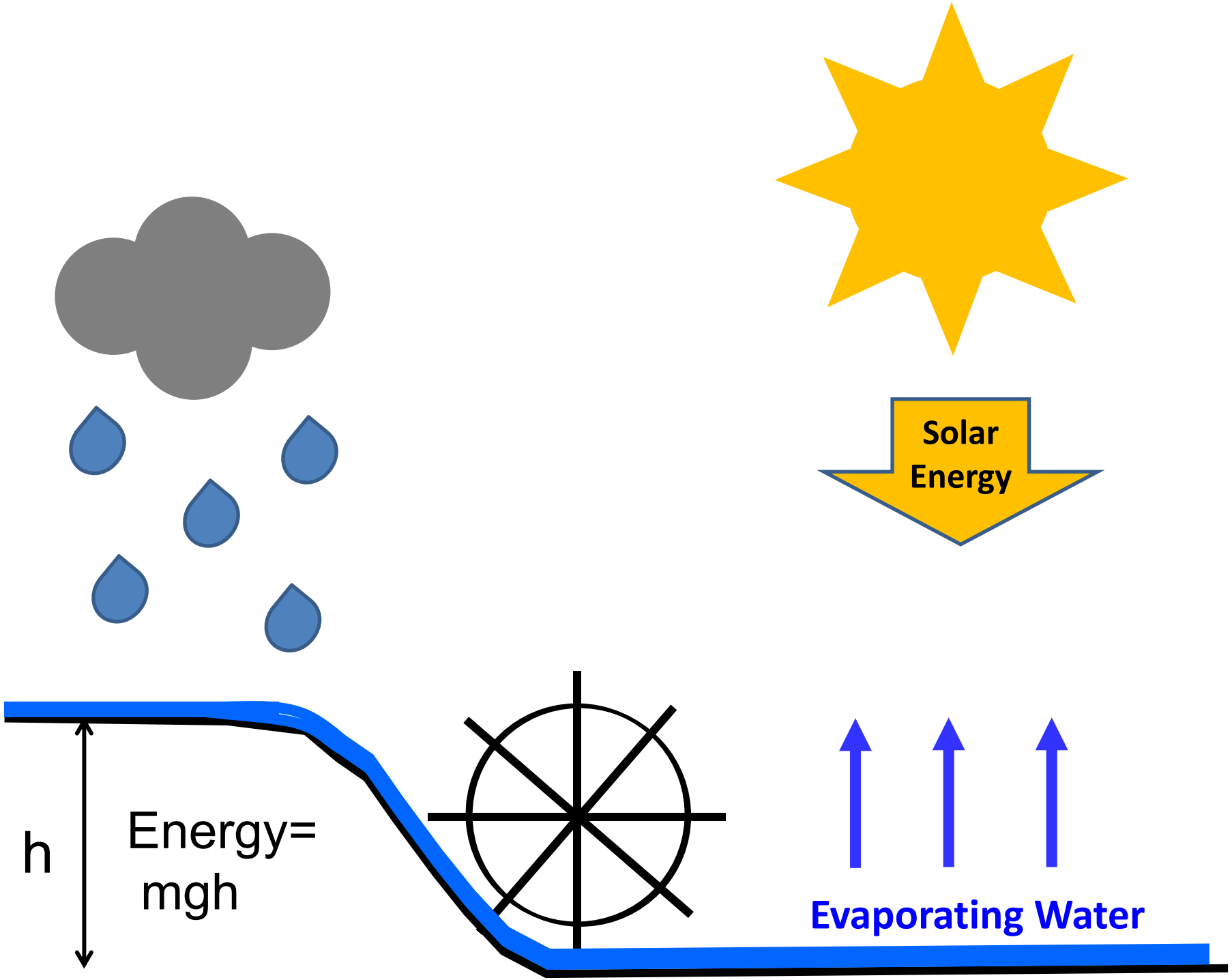
Burning bonus reduces by 50%

grassland pasture and range land, 587 million acres (25.9 percent); cropland, 442 million acres (19.5 percent); http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib14.aspx

Hydro Power

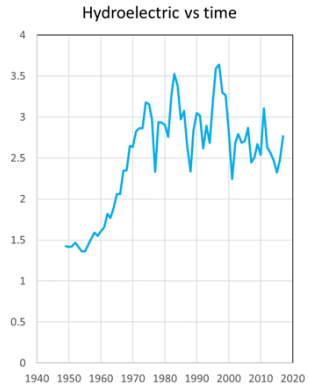
Bureau of Reclamation Public Domain

Offers Storage


Solar
Energy
h
Energy=
mgh
Evaporating Water

Hydro Power Harvesting Can't Increase

Bureau of Reclamation Public Domain

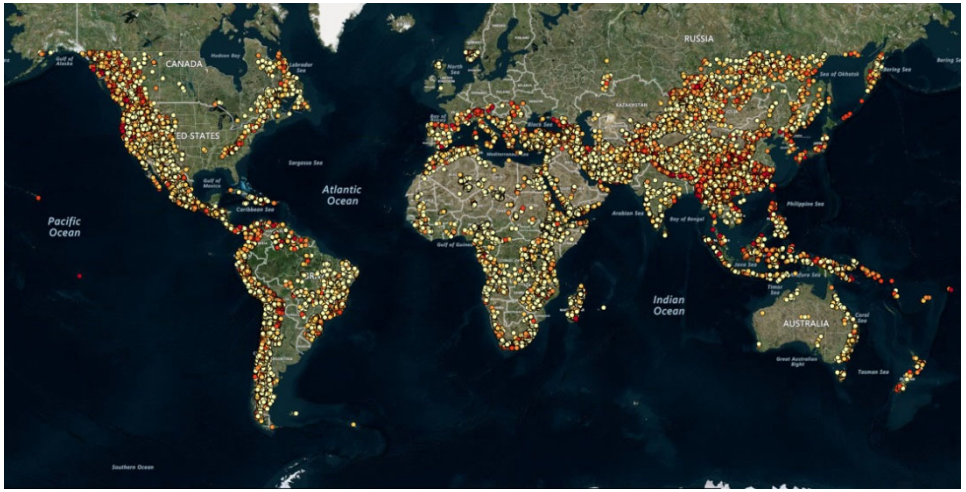


Hydropower ~
stable since 1970

Pumped Hydro Storage is Unlimited

Pumped Storage Options

http://www.visitludington.com/stories/ludington_pumped_storage_project



https://anu.prezly.com/anu-finds-530000-potential-pumped-hydro-sites-worldwide-223526#Applied Energy: https://www.sciencedirect.com/science/article/pii/S0306261918305270

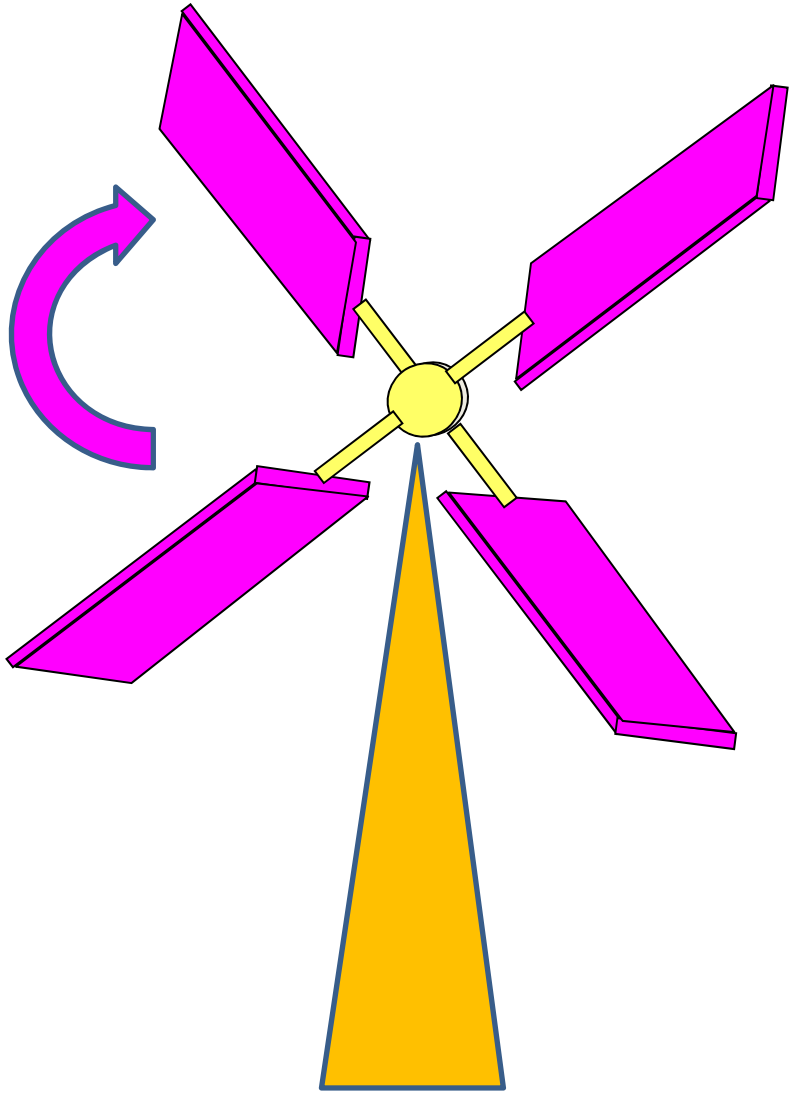
Global energy storage requirements could be met by ~ 1% of The 530,000 potential sites

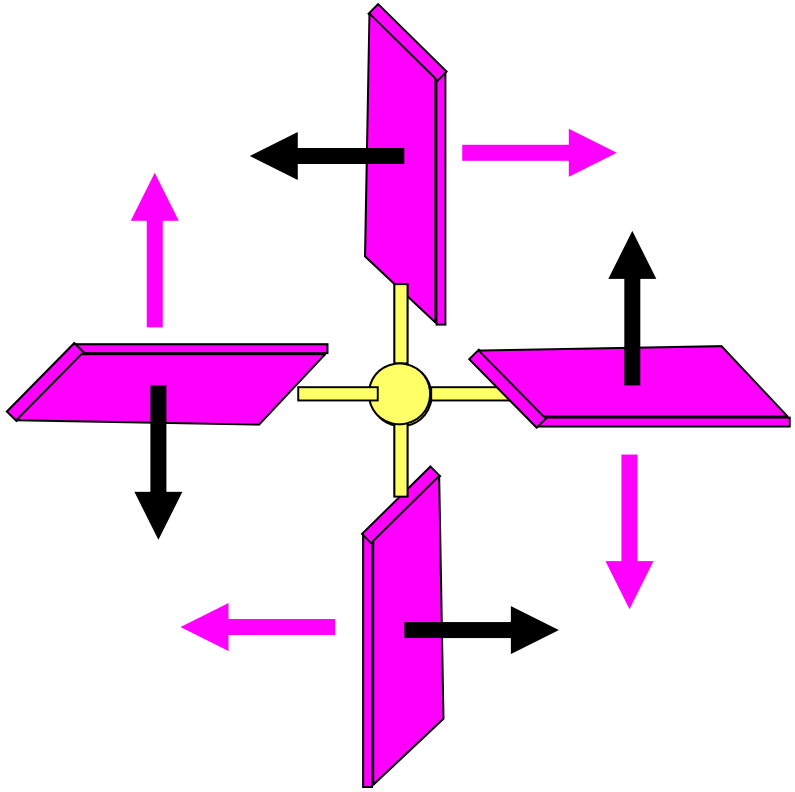
The 27 billion gallon reservoir, which measures 2.5 miles long and one mile wide, can generate up to 1,872 megawatts of electricity. That's enough power to serve a community of 1.4 million residential customers. The power plant consists of six reversible turbines that can each generate 312 megawatts of electricity. It was built between 1969 and 1973 at a cost of $315 million. It was built to store electricity generated by nuclear power to allow constant nuclear output to meet fluctuating demant.

Wind Power

Wikimedia commons Dirk Ingo Franke

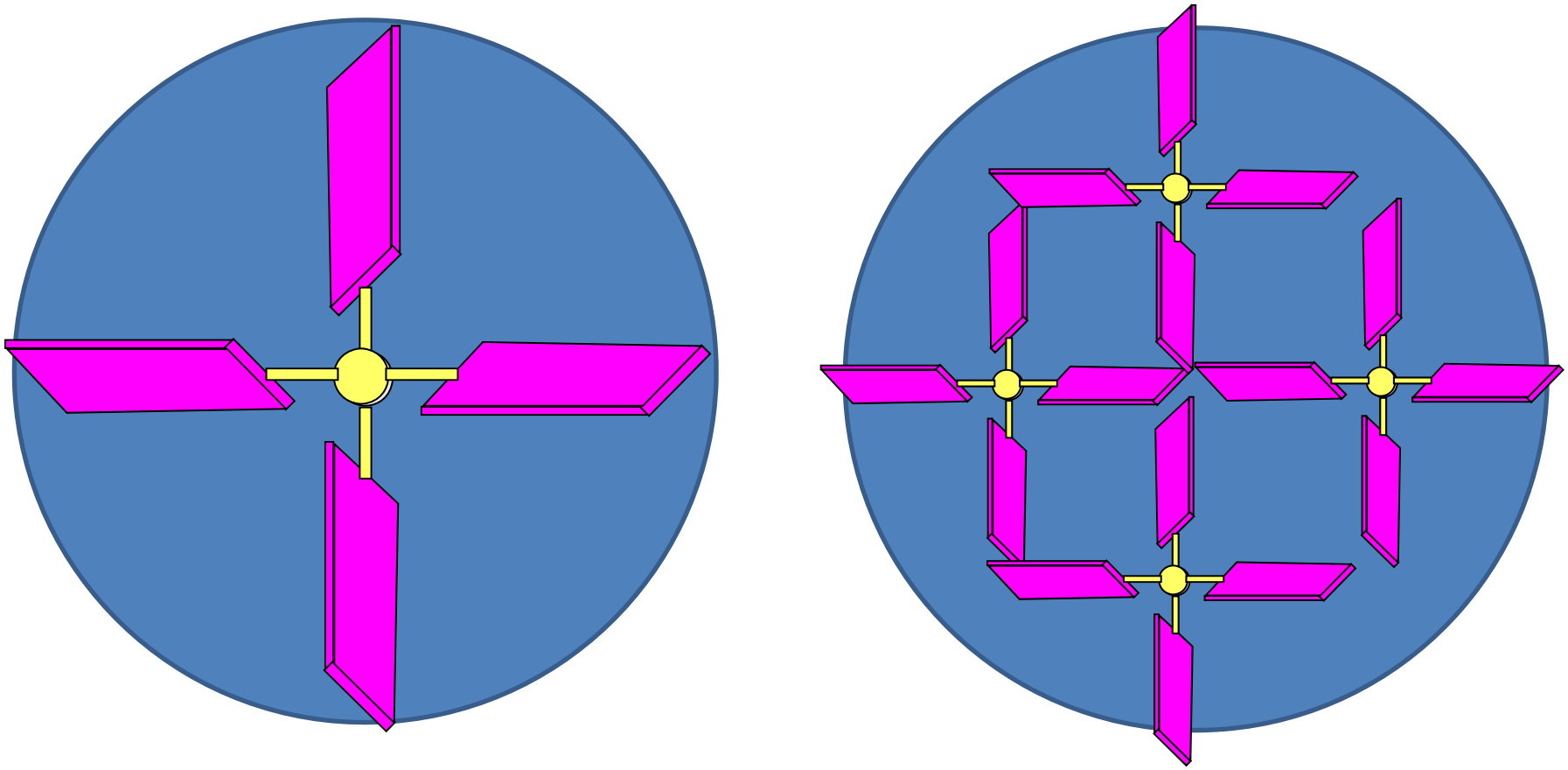
Wind Blowing into the page





Sunlight creates temperature differences
that produce wind

Use Big Rotors



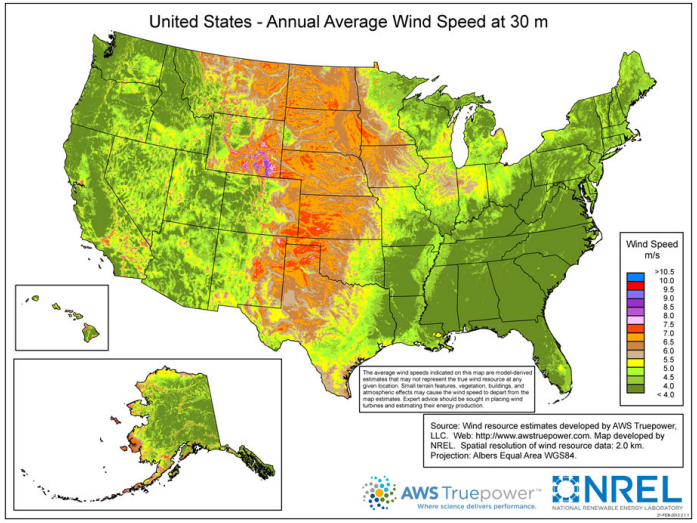
Rotor Length Squared -> 2X Rotor length= 4x Power

Wind Velocity Cubed -> 2X windspeed = 8x Power

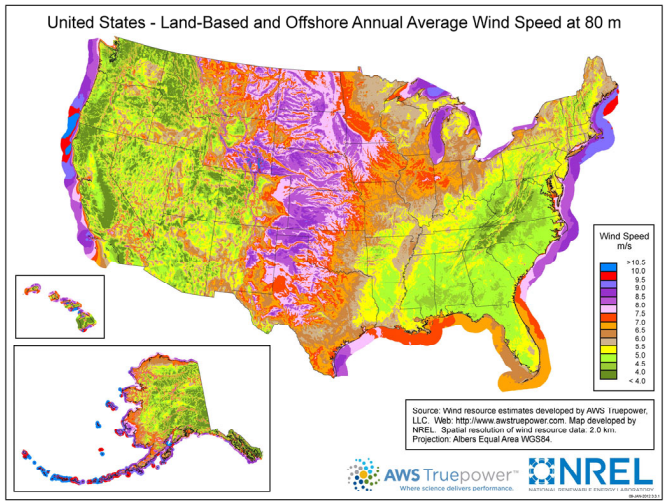
Square Root Height -> 4x higher = 2 x Power

Build High Towers

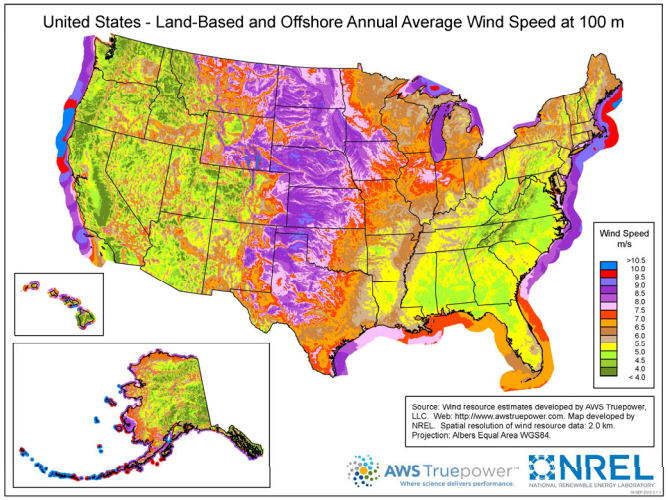
30 m



80 m



100 m



Build Wind Farms

Coexists with agriculture

Total US electricity ~ 3% of land

Wikimeidiacommons DirkIngo Franke

Wind Power in Iowa

37% of electricity

For new plants, wind is cheaper than natural gas, nuclear, or coal.

Almost no additional fast-acting power reserves back up
10 GW of wind

https://www.iaenvironment.org/webres/File/Iowa%20Wind%20Energy%20Fact%20Sheet.pdf

Siting is Crucial

Windy locations (power α v^3)

Large Rotors (power α R^2)

High Towers (power α ~$h^{1/2}$)

Space by 10-20 x R

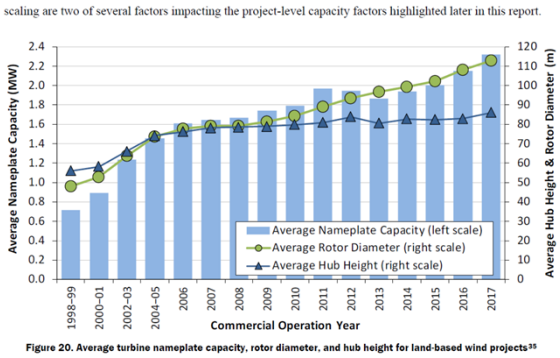
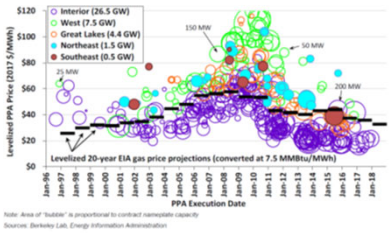


Figure 20. Average turbine nameplate capacity, rotor diameter, and hub height for land-based wind projects[35]

https://www.energy.gov/sites/prod/files/2018/08/f54/2017_wind_technologies_market_report_8.15.18.v2.pdf



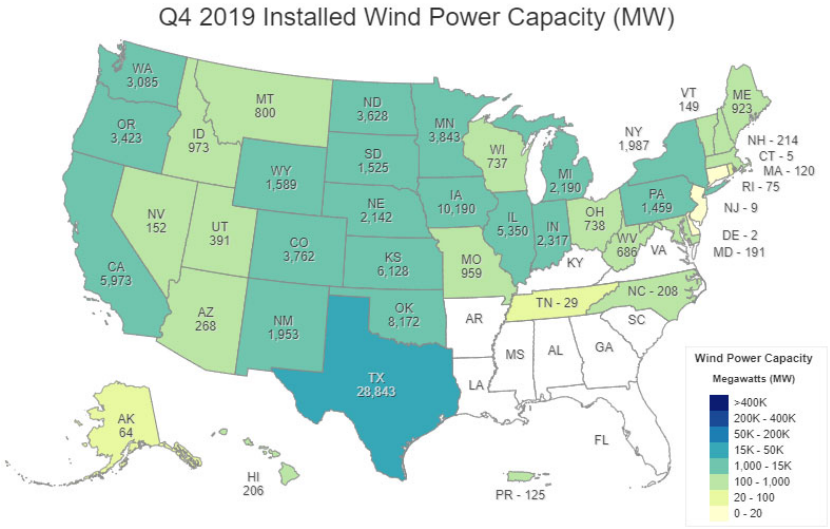
In some areas costs are already lower than power from fossil fuels
Some future contracts ½ natural gas price

http://www.nytimes.com/2014/11/24/business/energy-environment/solar-and-wind-energy-start-to-win-on-price-vs-conventional-fuels.html?_r=0

Electricity Generated by Wind

2019 Installed Wind Power

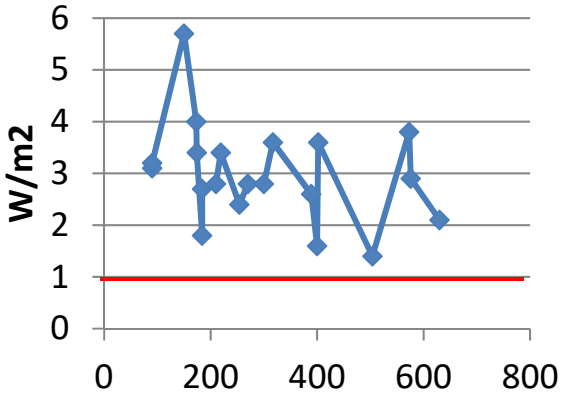
Annual Average Capacity Factor ~ 33%



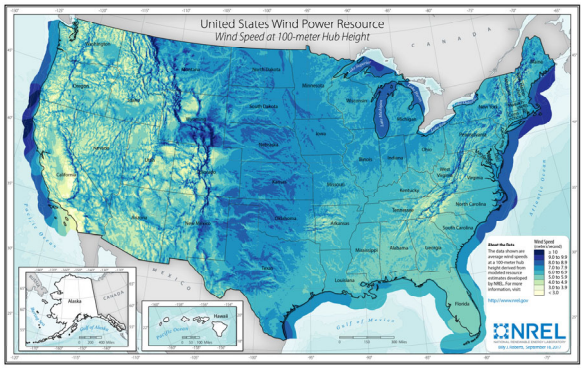
Total Installed Wind Capacity: 105,583 MW

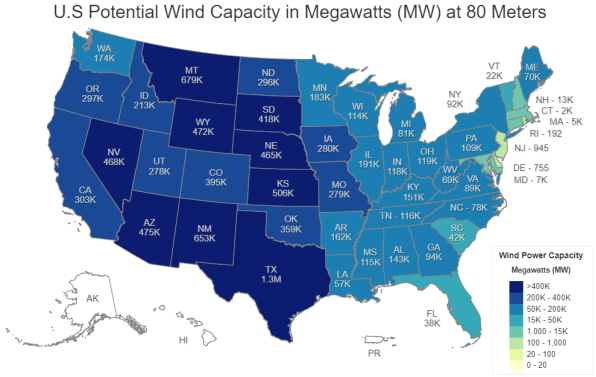
Source: American Wind Energy Association Market Report

Actual Power Densities UK Windfarms through 2018



http://energynumbers.info/uk-offshore-wind-capacity-factors





Total Potential Wind Capacity: 10,640,080 MW

Source: AWS Truepower, NREL

https://windexchange.energy.gov/maps-data/321

100% of total US energy =3,000,000 MW

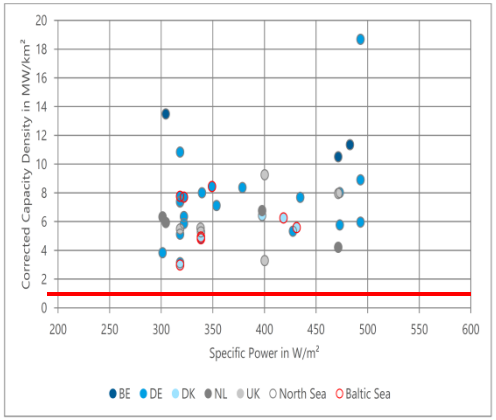
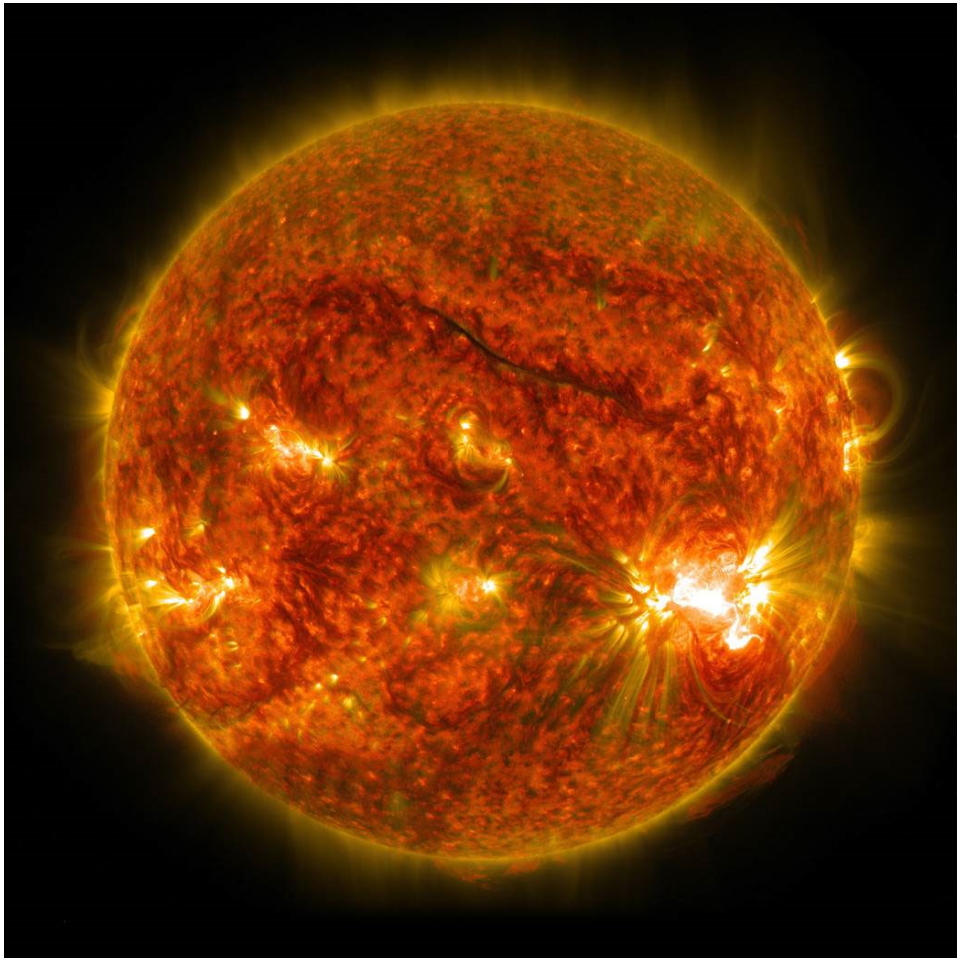


Figure 9:
Capacity density as a function of specific power

https://vasab.org/wp-content/uploads/2018/06/BalticLINes_CapacityDensityStudy_June2018-1.pdf

Red line is David Keith UPPER limit

Solar Power

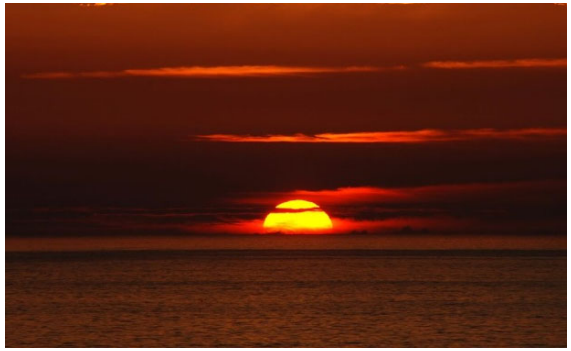


NASA public domain
http://www.nasa.gov/mission_pages/sunearth/images/index.html?id=341205

1365 vs 35

Sunlight Varies Daily

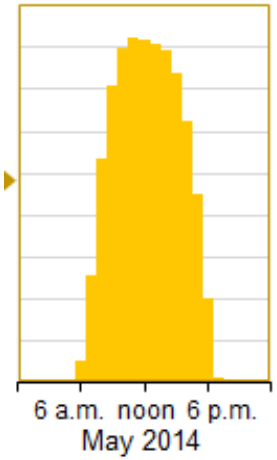
Sun rising over the Atlantic Ocean in Hollywood, FL James. E. K



"Sunset 2007-1" by Alvesgaspar - Licensed under CC BY-SA 3.0 via Commons -

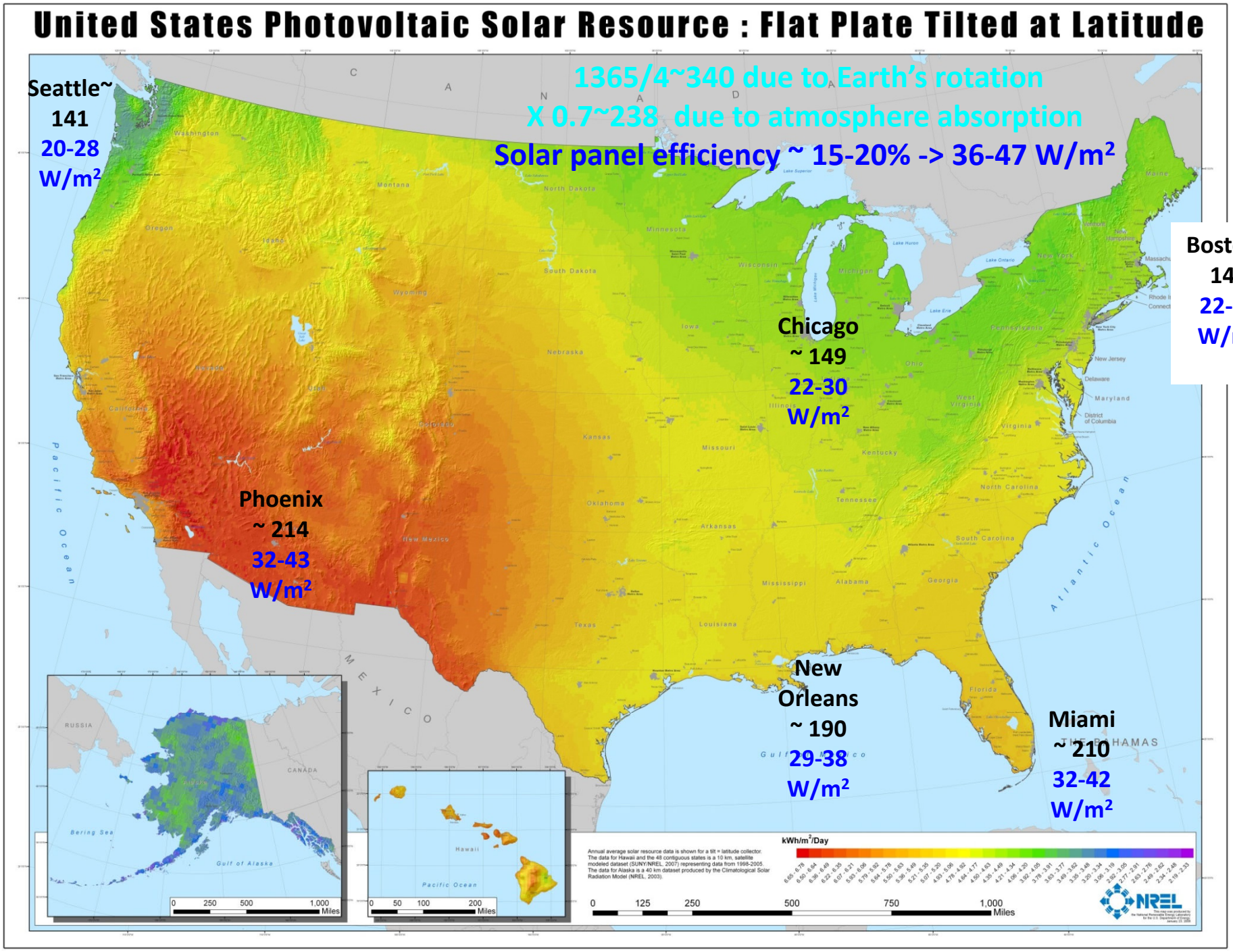
"Cala Lily Sundial Carmichael" by John Carmichael -

Average hourly solar power for CA May 2014 from eia



24 hour average
~ ¼ Peak Value

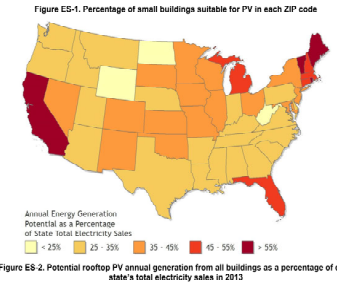
United States Photovoltaic Solar Resource : Flat Plate Tilted at Latitude



Put Solar Panels on Roofs, Roads, Deserts

Can't Coexists with agriculture

Total US electricity ~ 0.1% of land



https://www.nrel.gov/docs/fy16osti/65298.pdf

Local is Good

Suburban Roofs could supply ~ 30% of US Electricity

In 2016 ~ 50% of solar pv is residential

https://www.eia.gov/todayinenergy/detail.php?id=31452

Solar represents > 10% of in state electricity generation in Massachusetts, California, Hawaii, Nevada and Vermont

https://www.pv-magazine.com/2018/08/28/solar-supplies-more-than-10-of-electricity-in-five-us-states/

Wikimedia commons Gray Watson User:E090

Most suburban home owners could eliminate **ALL** fossil fuel use by installing solar panels + battery storage

(assumes heat pumps and electric cars)

On average US has enough Renewable Energy

Averages can be Deceptive

Average age ~50

Steve Gawley derivative work: Truu

By Jeandff (Own work)

"Tina Fey by Gage Skidmore

Avda / www.avda-foto.de

jelizen - Flickr.

"Sean Combs 2" by Arthur from Westchester County north of NYC, USA, at Arthur@NYCArthur.com

Born ~ 1970

Average age ~50

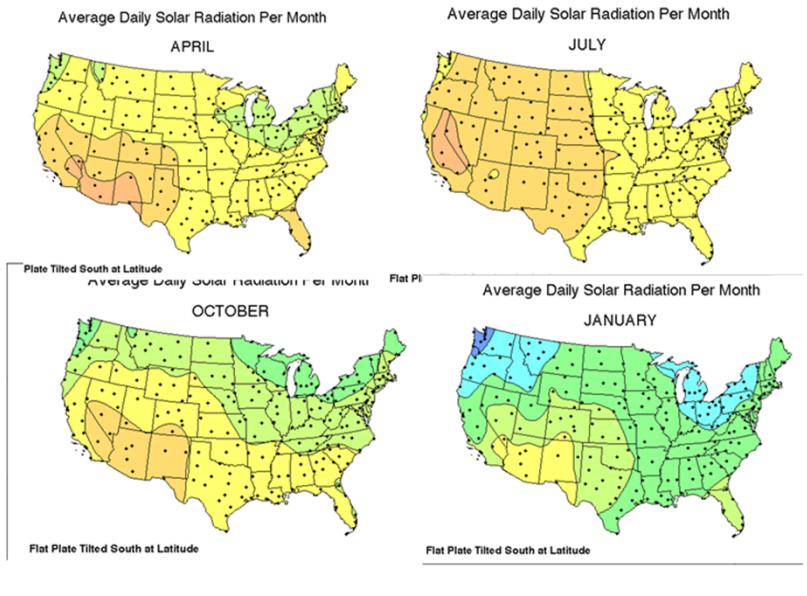
attribute gg.gov.au.

By Joel Rouse/ Ministry of Defence [OGL 3 (http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3)]

NOT Born ~ 1970

Crucial Issue: Variations and Fluctuations

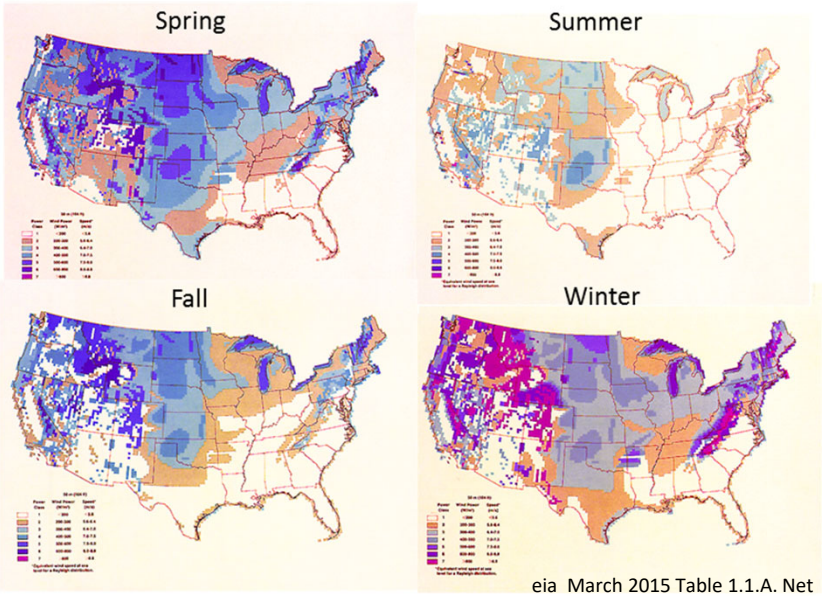
Solar Energy



http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/

NREL Maps

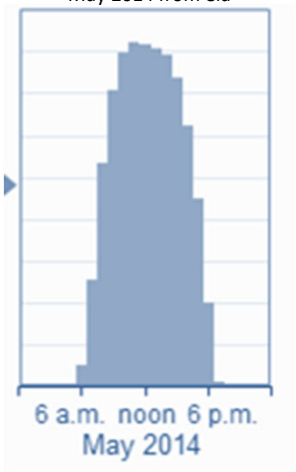
Wind Speed at 50 m height



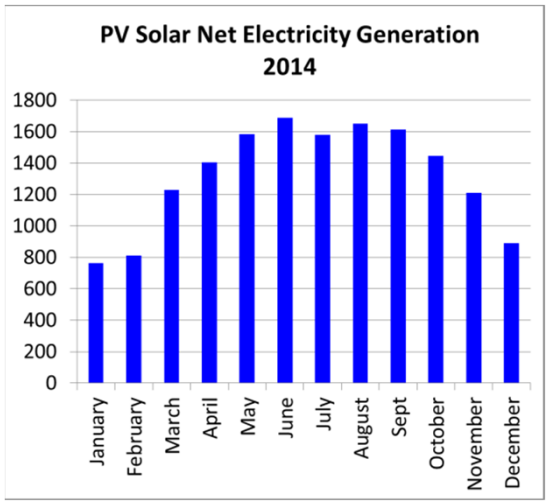
http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-12m.html

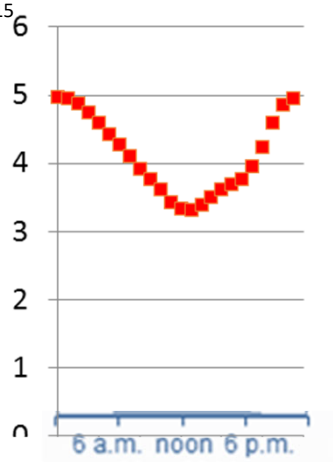
eia March 2015 Table 1.1.A. Net Generation from Renewable Sources: Total (All Sectors), 2005-March 2015

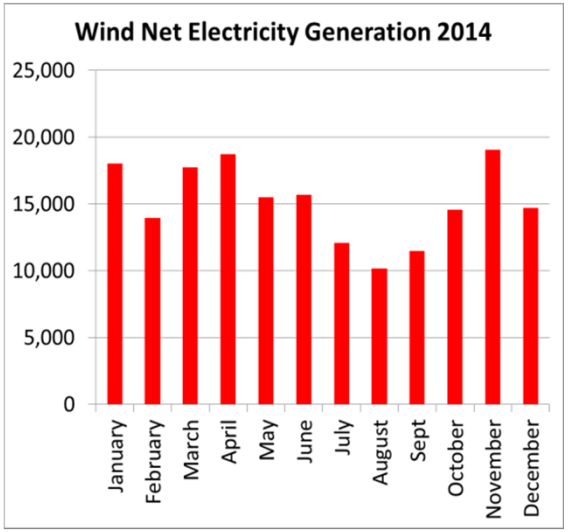
Average hourly solar power for CA May 2014 from eia



eia March 2015 Table 1.1.A. Net Generation from Renewable Sources: Total (All Sectors), 2005-March 2015

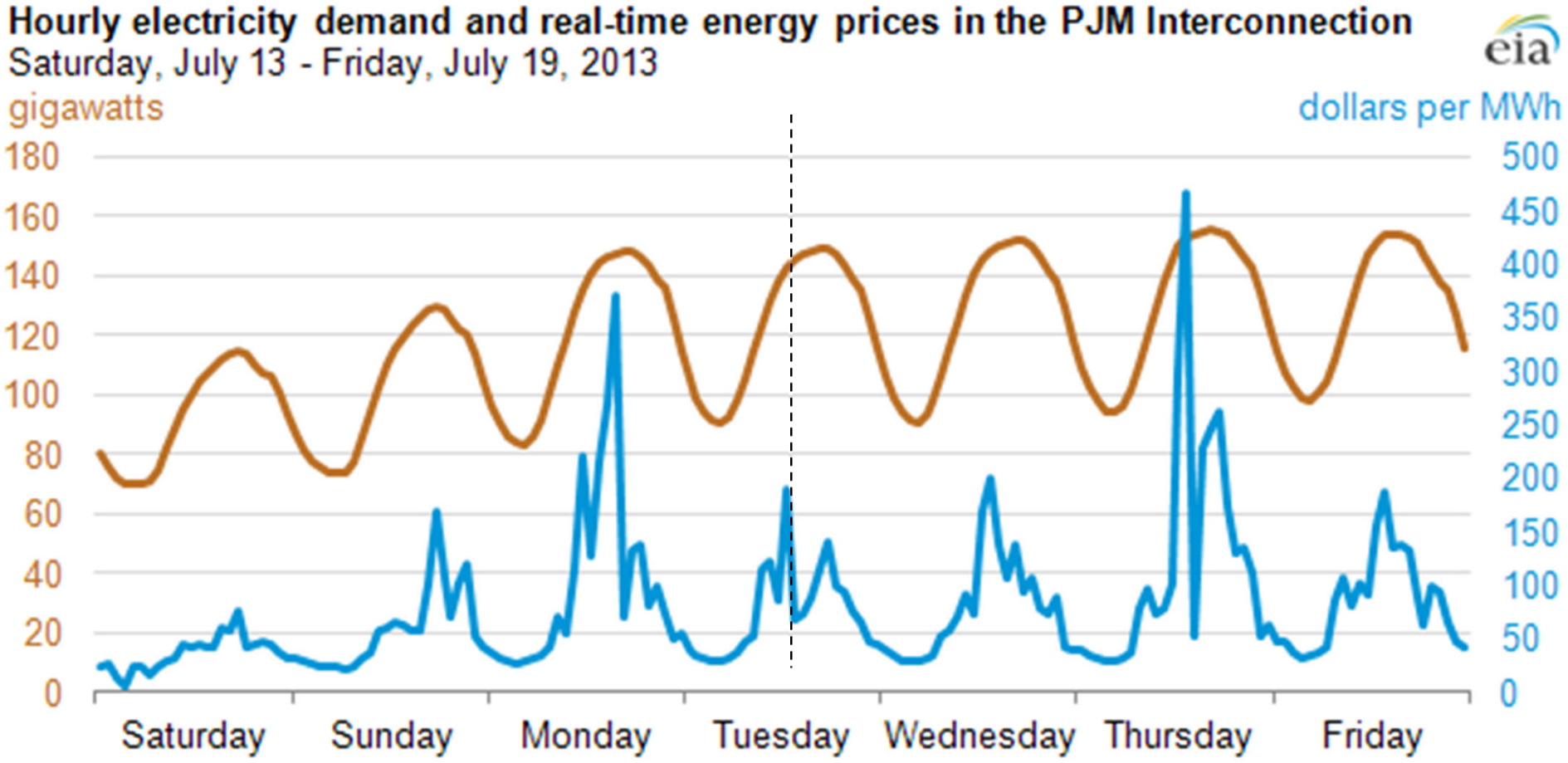






So far focused on variations in energy supply…

Meeting Fluctuating Demand can be Costly



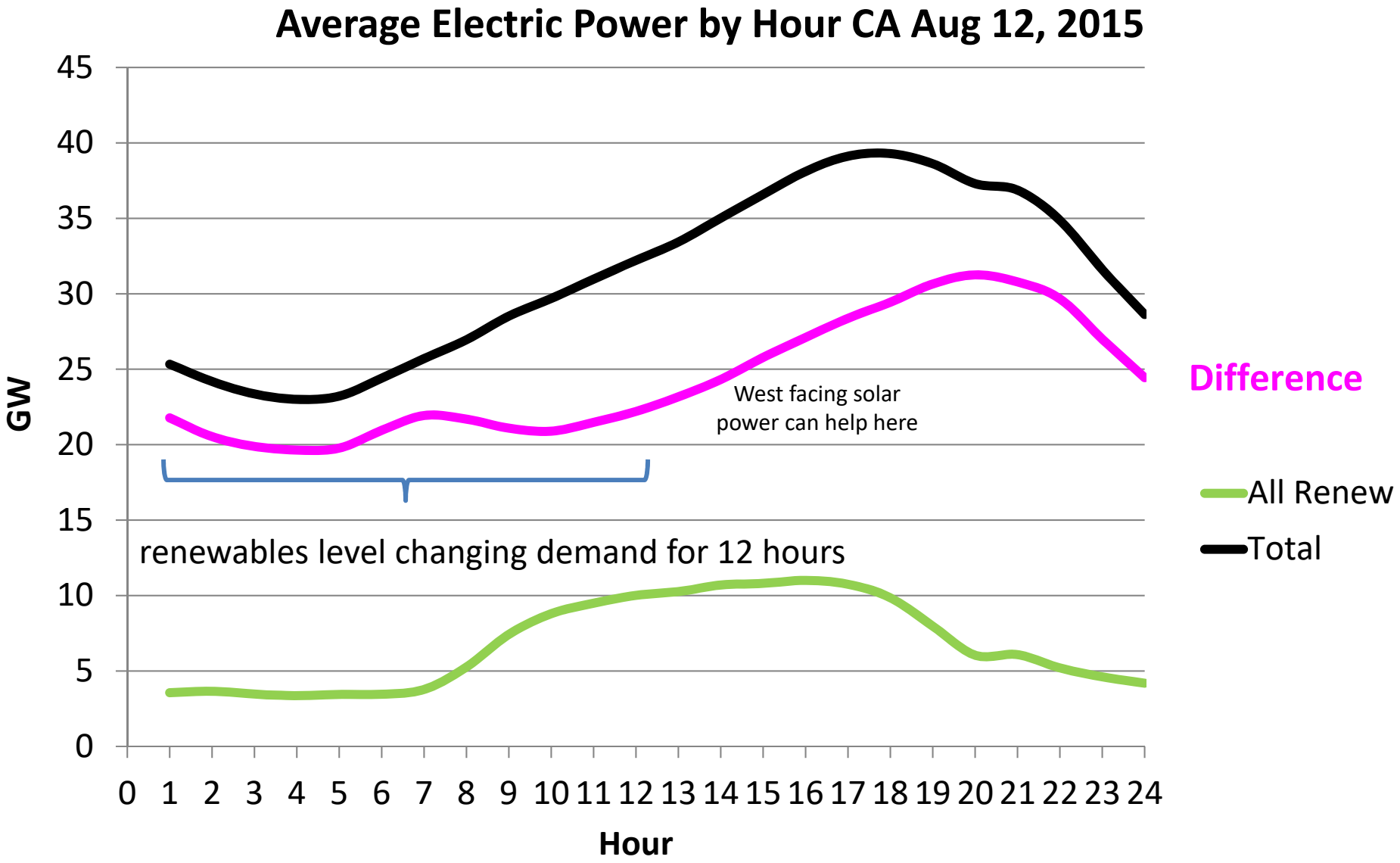
Source: U.S. Energy Information Administration based on PJM data
Note: Hourly demand for East Kentucky Power Cooperative, which joined PJM on June 1, 2013, is not included

Demand fluctuations by a factor of 2, Price by a factor >100
20% of the grid is used 1-2% of the time

The Smart Grid: Power for the 21st Century George W. Arnold, Eng.Sc.D. National Coordinator for Smart Grid Interoperability National Institute of Standards and Technology 3 June 2011

Renewables can naturally correlate with demand

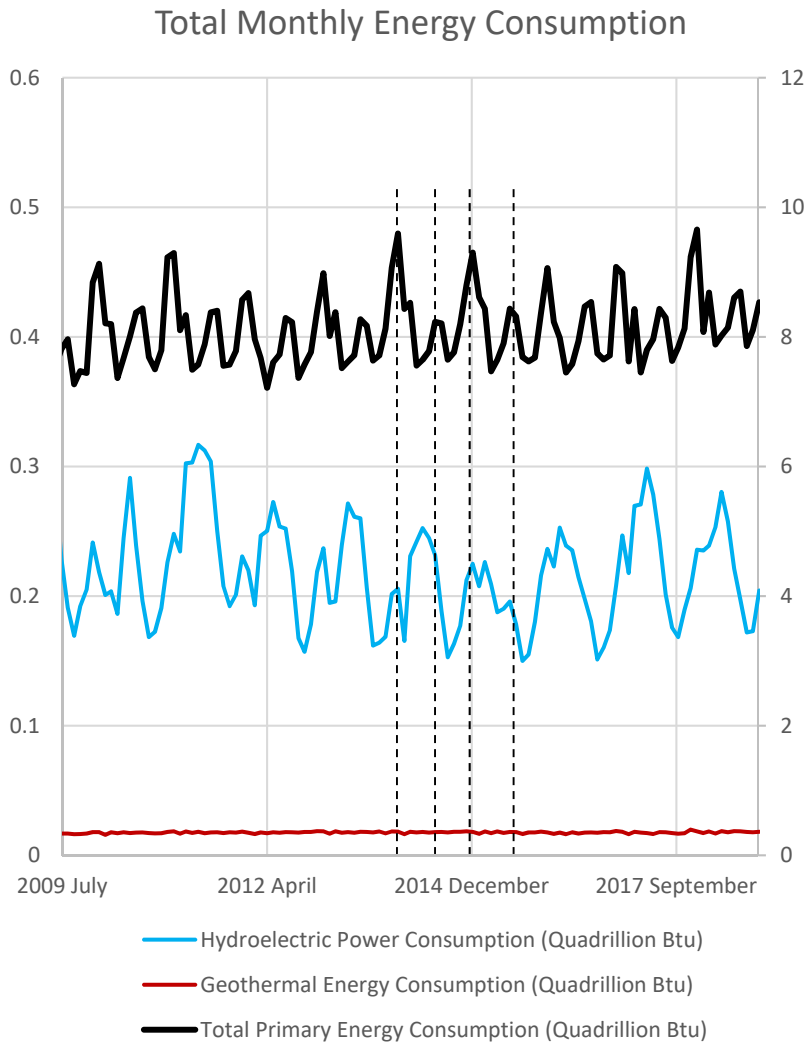
(naturally reduces mismatch between supply and demand, reducing cost)



http://www.caiso.com/outlook/SystemStatus.html#SupplyandDemand

For Germany: https://www.energy-charts.de/power.htm

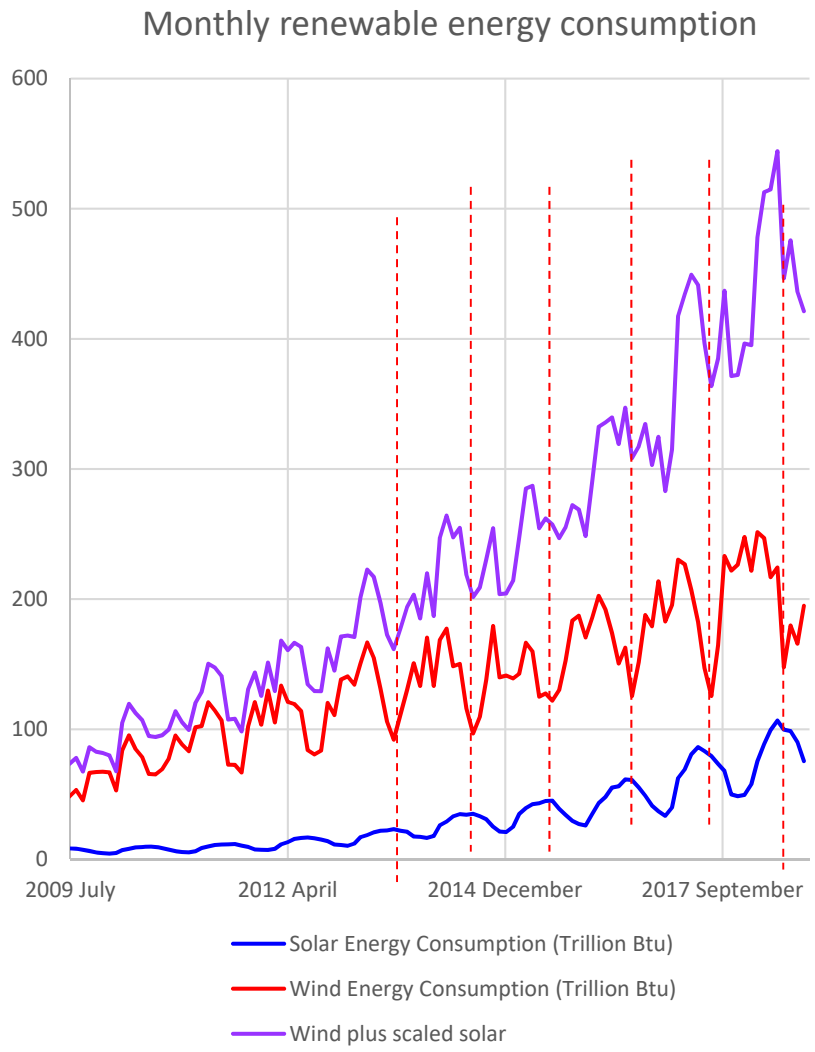
Seasonal Consumption Variations



Consumption peaks in January and July

Heat pumps can lower January

Solar + Wind reduces seasonal fluctuations



Wind minima near solar maxima
Wind and solar each have ~ 50% seasonal variation
Wind + scaled solar has ~ 30 % seasonal variation

Is switching to renewables too costly?

US Annual Fossil Fuel Production Subsidy = $4,700,000,000

https://www.treasury.gov/open/Documents/USA%20FFSR%20progress%20report%20to%20G20%202014%20Final.pdf

By Ansgar Walk (photo taken by Ansgar Walk)

Wikimedia commons Bobak

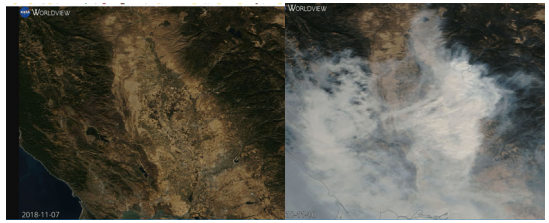
Beijing Average Lifetime Loss ~ 5 Years

- US Coast Guard - 100421-G-XXXXL- Deepwater Horizon fire

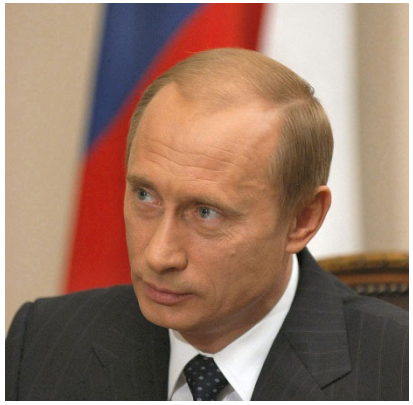
Hurricane Sandy ~ $71 billion

U.S. Air Force photo by Master Sgt. Mark C. Olsen

Ca Wildfires $71.1 - $347.8 billion/year



Waste -> required electrical energy < 50% of fossil fuel energy



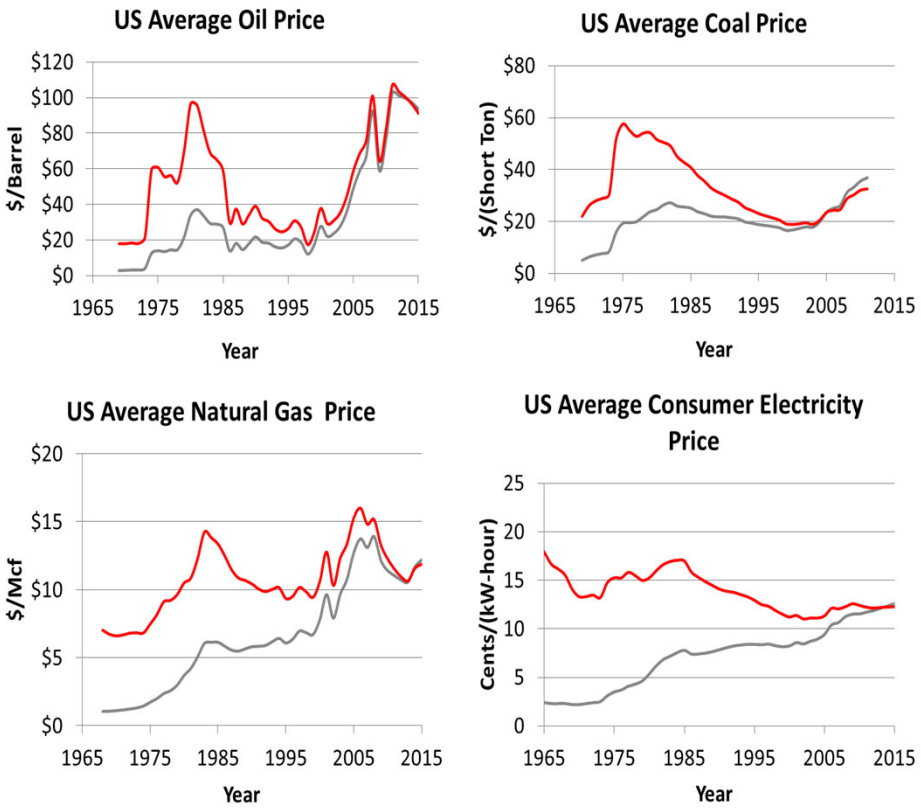
"Vladimir Putin-5 edit" by Kremlin.ru.

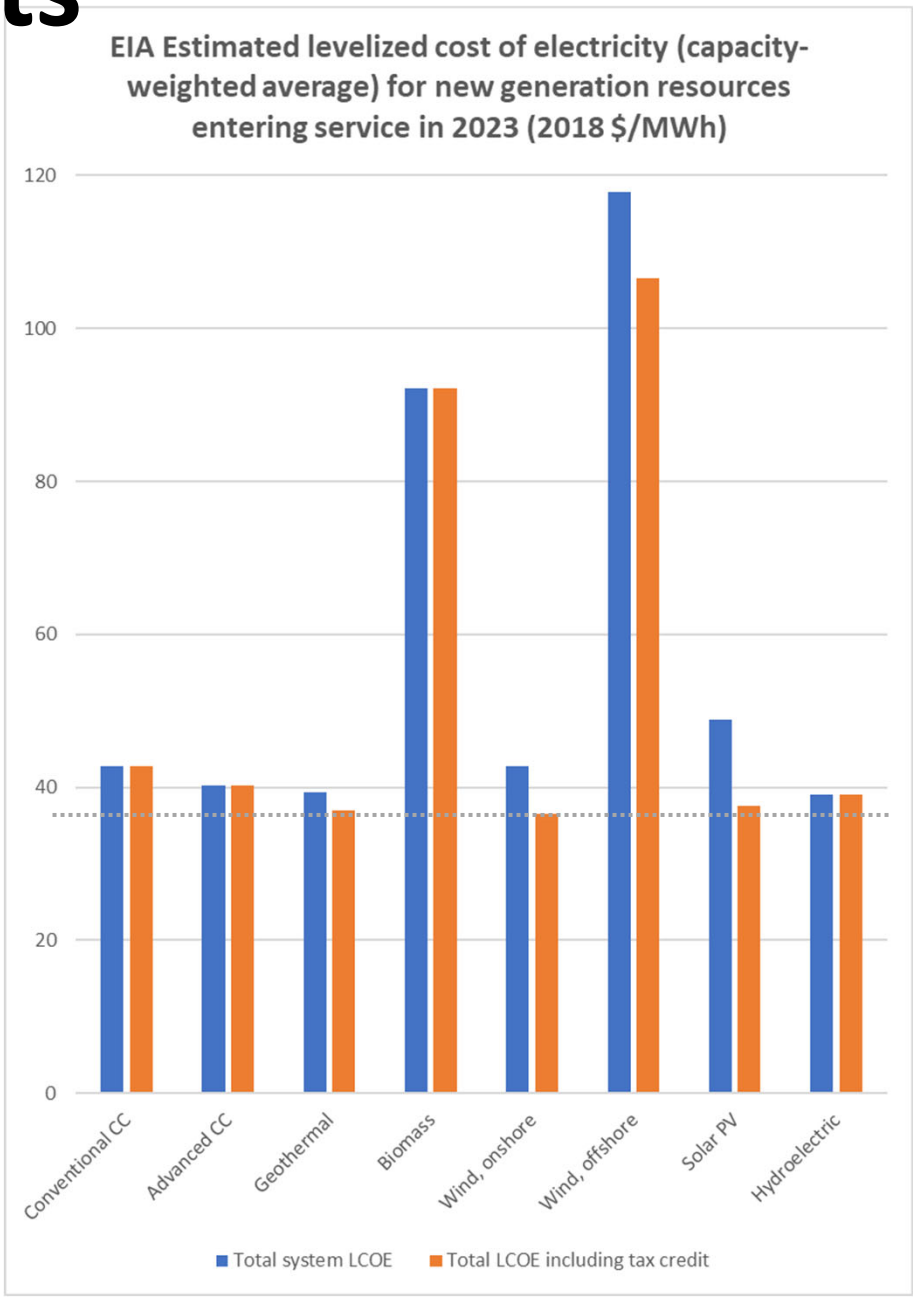
TVA Kingston Fossil Plant coal fly ash slurry spill Dec 22 2008 [http://www.tva.gov/emergency/ashslide_kingston.htm TVA

Costs

Renewables->
Buy Now Earn Later

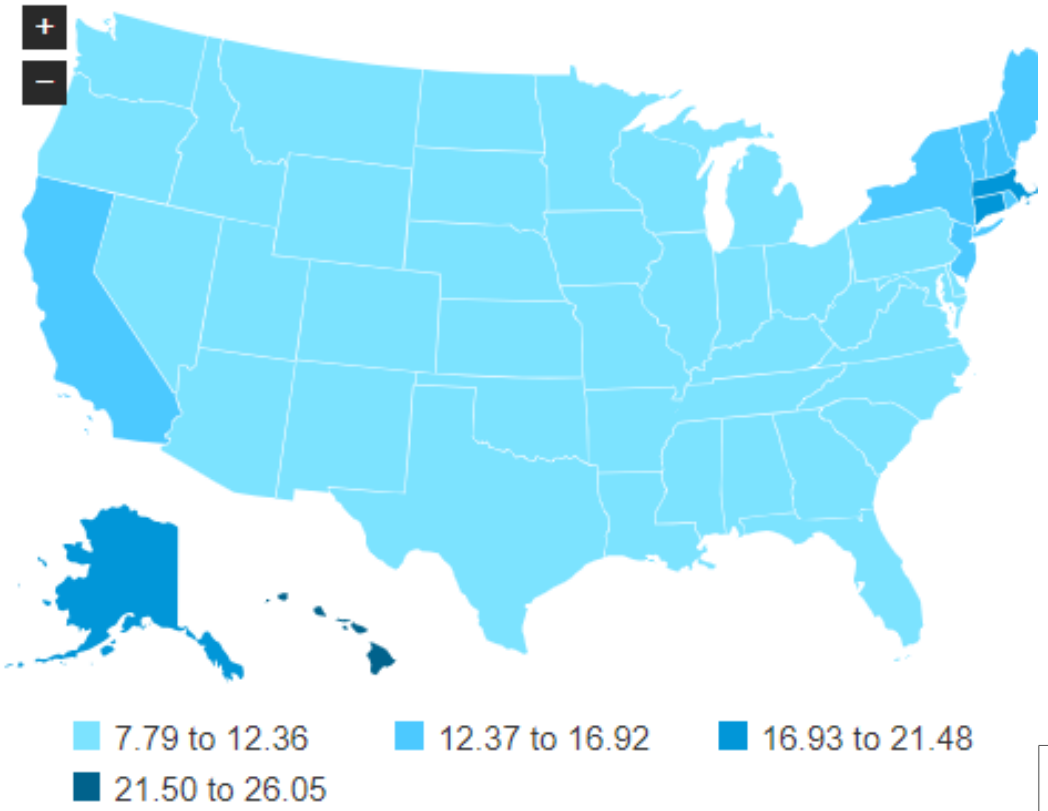
It's Difficult to Make Predictions, Especially About the Future



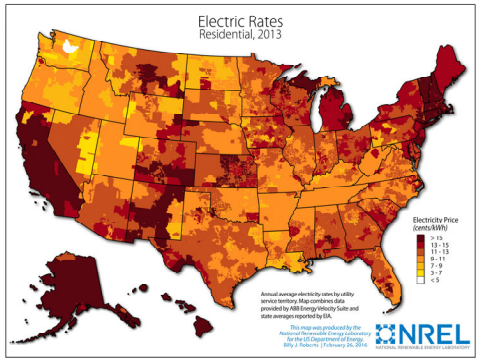


(health and environmental costs excluded)

Map of US Average Retail Electricity Prices by State 2017



US average=10.48
Iowa=8.7 (>35% wind)
MA=17.1
Hawaii=26



The All Electric Revolution

Change Sources

Wikimeida commons Dirk Ingo Franke

Wikimedia commons Gray Watson User:E090

Change Consumption

Wikimeida commons Mariordo (talk) - Roadster 2.5 windmills.jpg.

Wikimedia commons Mj-bird

public domain

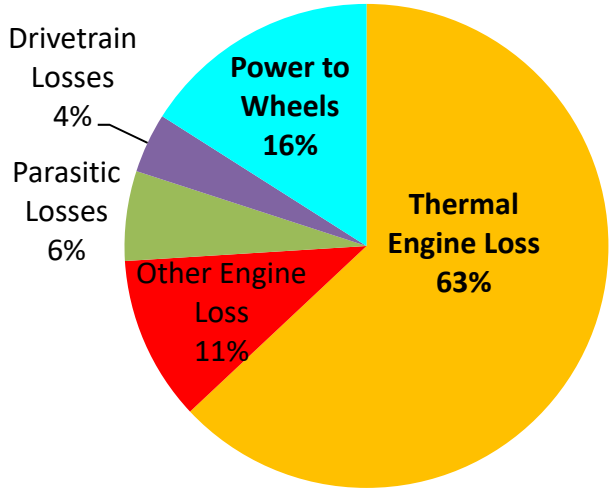
Wikimedia commons Piisamson

Wikimedia commons Dmitry_G

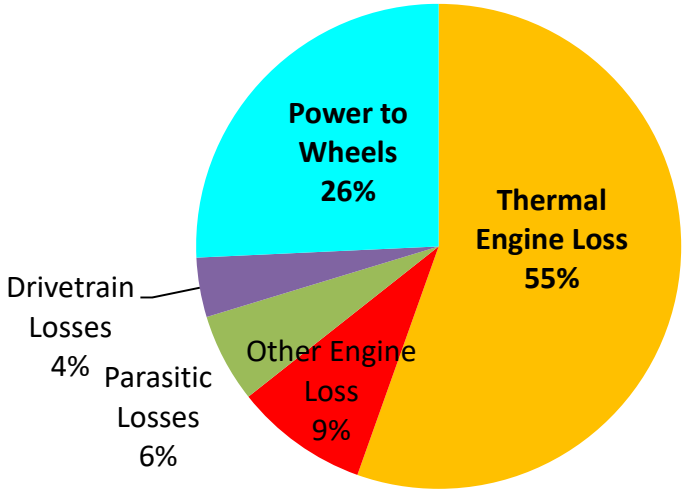
Cars and the Revolution

(analogy: regenerative braking to a child on a swing)

City Driving Energy Distribution



Highway Driving Energy Distribution



84% energy loss

Hybrid loss ~67%

(regenerative breaking helps)

Electric car loss ~ 40%

(regenerative breaking helps + burning bonus)

74% energy loss

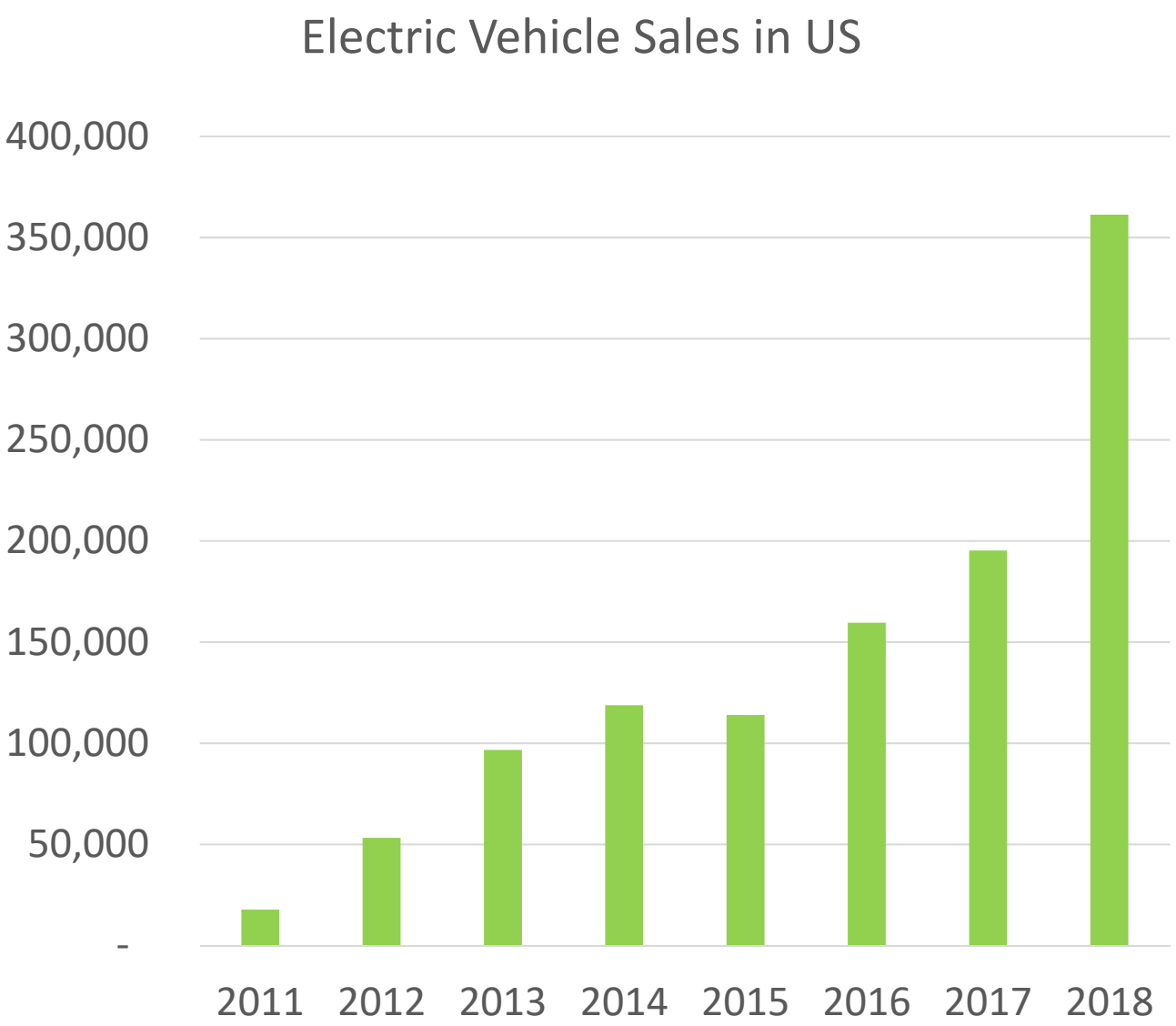
Hybrid loss ~67%

Electric car loss ~40%

Reduces Energy Use

Replaces Burning

Electric Car Sales are Increasing Rapidly



2018 ~ 2% of ~ 17,000,000 total light duty vehicle sales

Electric cars would provide enough daily storage

~ 268 million cars store more than total US energy per day

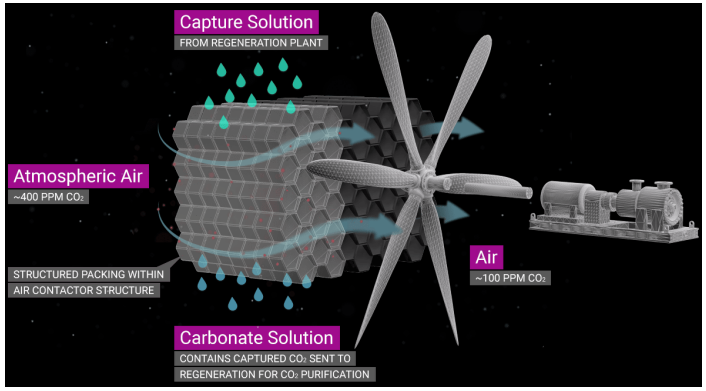
Now make them all electric…

Synfuels

$(n\ CO + (2n+1)\ H_2 \rightarrow C_n\ H_{2n+2} + n\ H_2O)$

Pearl GTL in Ras Laffan Industrial City, Qatar

140,000 barrels of GTL products each day~ 10% of US jet fuel consumption. Operation began in 2011. Cost $19 billion. Cleaner than petroleum.
https://www.shell.com/about-us/major-projects/pearl-gtl/pearl-gtl-an-overview.html



Carbon Engineering removes CO2 from air to make fuel. Projects 200 barrels per day in 2021.

http://carbonengineering.com/

More Consumption Revolutions

(beyond the “burning bonus”)

Wikimedia commons Mj-bird

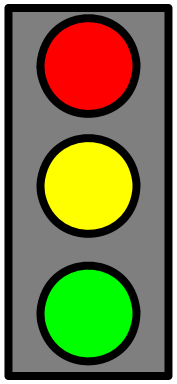
Reduces Energy Use

public domain

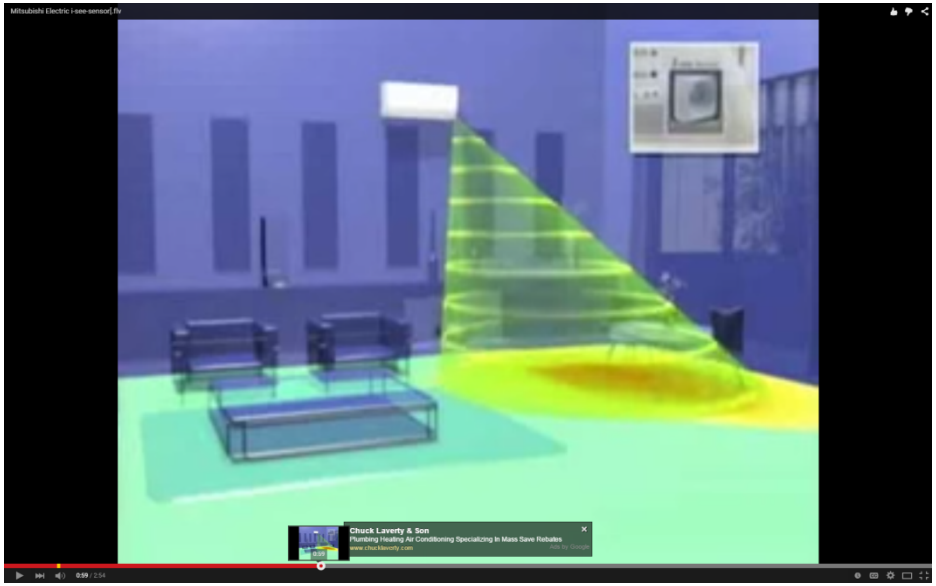
Wikimedia commons Piisamson

>300% efficient
Reduces Energy Use
Replaces Burning
Reduces Peak January Demand

Be Smart



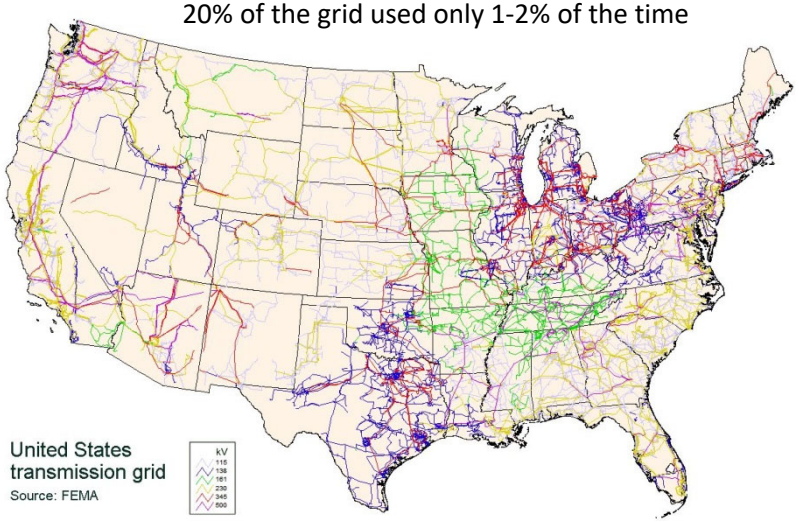
http://www.bbc.com/autos/story/20150317-how-smart-traffic-signals-may-ease-your-commute



https://www.youtube.com/watch?v=QKF3PYmSTFU

Redistribute Supply and Demand

20% of the grid used only 1-2% of the time



Public domain by Rolypolyman at wikimedia commons

Critical periods occur only 1-2% of the hours per year, yet the infrastructure must be maintained to supply it. “About 20 percent of the entire grid capacity exists only to manage a few hours a year of peak load. http://www.floridaenergy.ufl.edu/wp-content/uploads/FESC_Smart_Grid_final_12-08-011.pdf

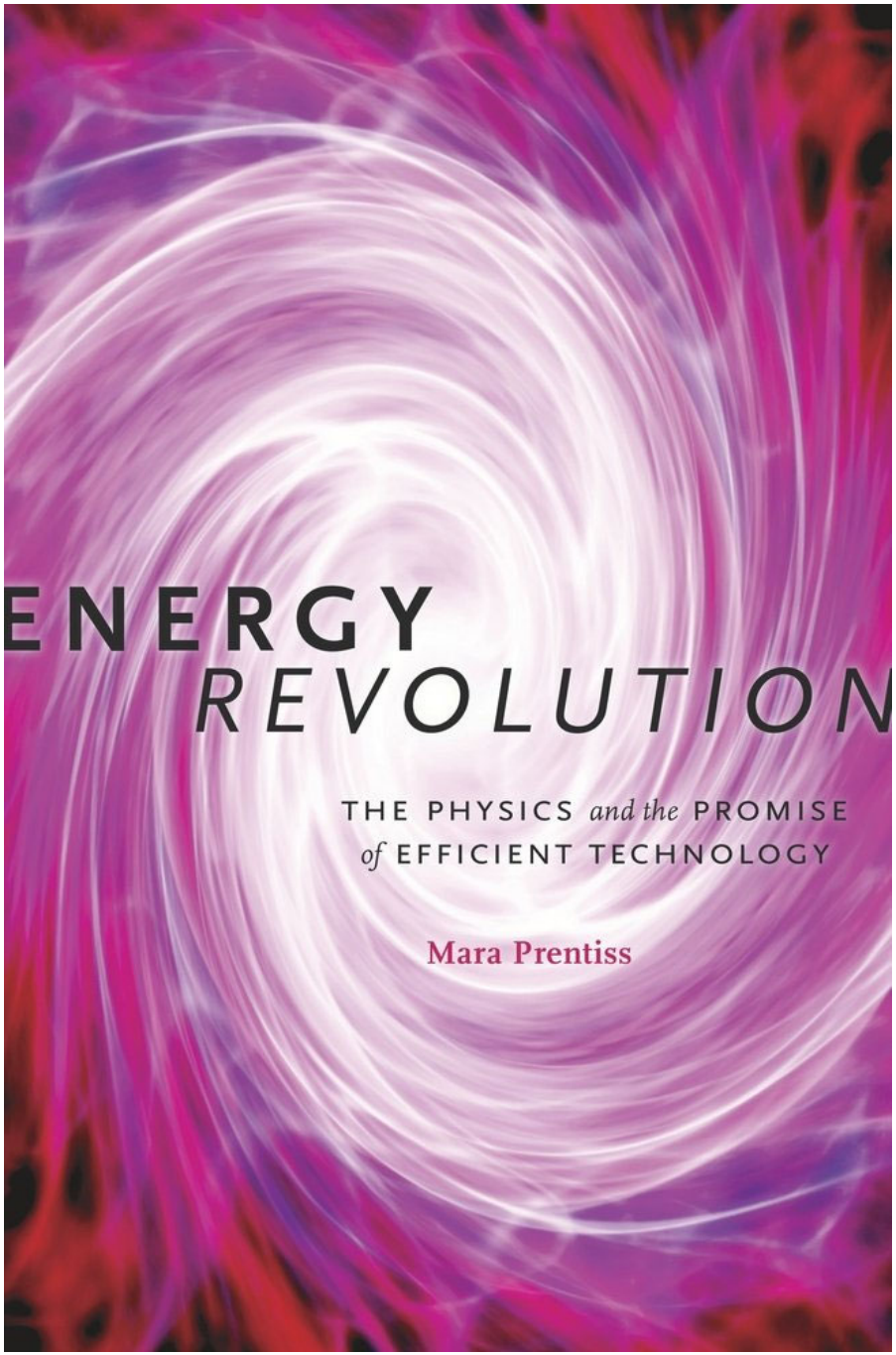
Just Park

All Together

Quistnix from Wikimedia commons

Port of Rotterdam

- Electric powered robots with computer optimization
- Renewable energy sources
  - (170 MW of wind inside port)
- Excess heat redirected to climate control
- Favorable pricing for greener vessels


ENERGY
REVOLUTION
THE PHYSICS and the PROMISE
of EFFICIENT TECHNOLOGY
Mara Prentiss

The End

Quantity	Value
seconds/year	31536000
US surface area km^2 including water	9,833,517
US surface area m^2 including water	9.83352 E+12
US surface area m^2 excluding water	9,158,022E+12
EIA Projected Total Energy Use 2013 in Quads	96.26
US total energy consumption in Joules (1 Quad = 1.05 10^18 joules)	1.01074E+20
Average US total energy consumption in watts	**3.205E+12**
watts/m^2 for total us energy consumption	**0.326**
Average US total energy consumption in watts without losses	**1.60E+12**
Watts/m^2 for Energy Used after 50% losses which are largely thermal	**0.163**
EIA Projected Energy required to generate electricity in 2013 in Quads	38.4
EIA Projected Electricity Consumed 2013 in Quads	12.4
EIA Projected Electrical Energy Consumed 2013 in Joules	4.02843E+19
US electricity consumption in billion kiloWatt-hours	3,856
Average US electricity consumption in watts	**4.4121E+11**
Watts/m^2 for total us electric consumption	**0.045**
Average US Electricity End Use in kW/capita	**1.500 kW/capita**
US GDP Billions of $	$15,685