HONR 229L: Climate Change: Science, Economics, and Governance

Discussion #12: Solar Energy

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Class Web Site: http://www.atmos.umd.edu/~rjs/class/honr229L

ELMS Page: https://myelms.umd.edu/courses/1269254

https://gigawattglobal.com/projects3/rwanda/

10 October 2019

Announcements

- First Paper (25% of overall grade)
  - **1 Nov (Fri)** deadline to guarantee comments on draft version
  - **14 Nov (Thurs**) midnight deadline for paper submission
  - 5 to 8 pages single spaced; must include references & can include figures, both of which are excluded from the page count
  - original work for this class, related to the themes of the class in some manner
  - Please submit via email, using HONR 229L in the subject

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Essay #1 on Longer and More Damaging Wildfire Seasons

Longer and more damaging wildfire seasons are a direct result of global warming, and a very present and costly one at that. As the global average temperatures rise, and humidity drops as a result, drier and hotter environments are being created. *The average temperature increase in the North American west (where wildfires are most common) has increased at about twice the global average since 1970*. Due to this average temperature increase, the average wildfire season in the area has increased in length by about 40%. The annual number of wildfires has increased by about 75%, a statistic which shows that *not only is the wildfire season getting longer, but also that the number of wildfires is increasing at a disproportionate rate*.

These wildfires are increasing as a direct result of global warming due to human greenhouse emissions. The cost of this is wrought in money, life, and land. Since 1985, the financial cost of eliminating forest fires has nearly quadrupled. This diverts significant portions of the Forest Service budget, taking away from the potential of other conservation-focused projects. Homes are also being lost at an alarming rate, as housing development is being allowed much closer to forests which carry the risk of wildfires than usual. In addition, the habitat of many species which thrive in forests are being lost as well, reducing our biodiversity in an alarming fashion.

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Los Angeles Times

CALIFORNIA

Californians fume over PG&E power outage: 'A humongous inconvenience'

By HANNAH FRY, PATRICK MCGREEVY, TARYN LUNA, MARIA L. LA GANGA, JACLYN COSGROVE

OCT. 9, 2019 | 6:25 PM

Millions of Californians could spend days without power as the state's largest utility continues shutting off electricity in a desperate attempt to avoid wildfires sparked by windblown power lines.

The first power cutoffs, affecting about 513,000 Pacific Gas & Electric Co. customers, began shortly after midnight Wednesday in several counties around Sacramento, including Placer and Yuba. Roughly five hours later, the outages had extended to Humboldt County to the north, Marin County to the south and Nevada County to the east, according to a map provided by the utility.

The second phase of the shut-off was expected to begin about noon in areas around Silicon Valley and the East San Francisco Bay Area, but the utility said those outages would be delayed until later in the day. About 234,000 customers in Alameda, Alpine, Contra Costa, Mariposa, San Joaquin, San Mateo, Santa Clara, Stanislaus, Tuolumne, and parts of Mendocino and Calaveras counties were expected to lose power by the evening.

https://www.latimes.com/california/story/2019-10-09/pg-e-cuts-power-across-northern-california-as-winds-bring-critical-fire-danger

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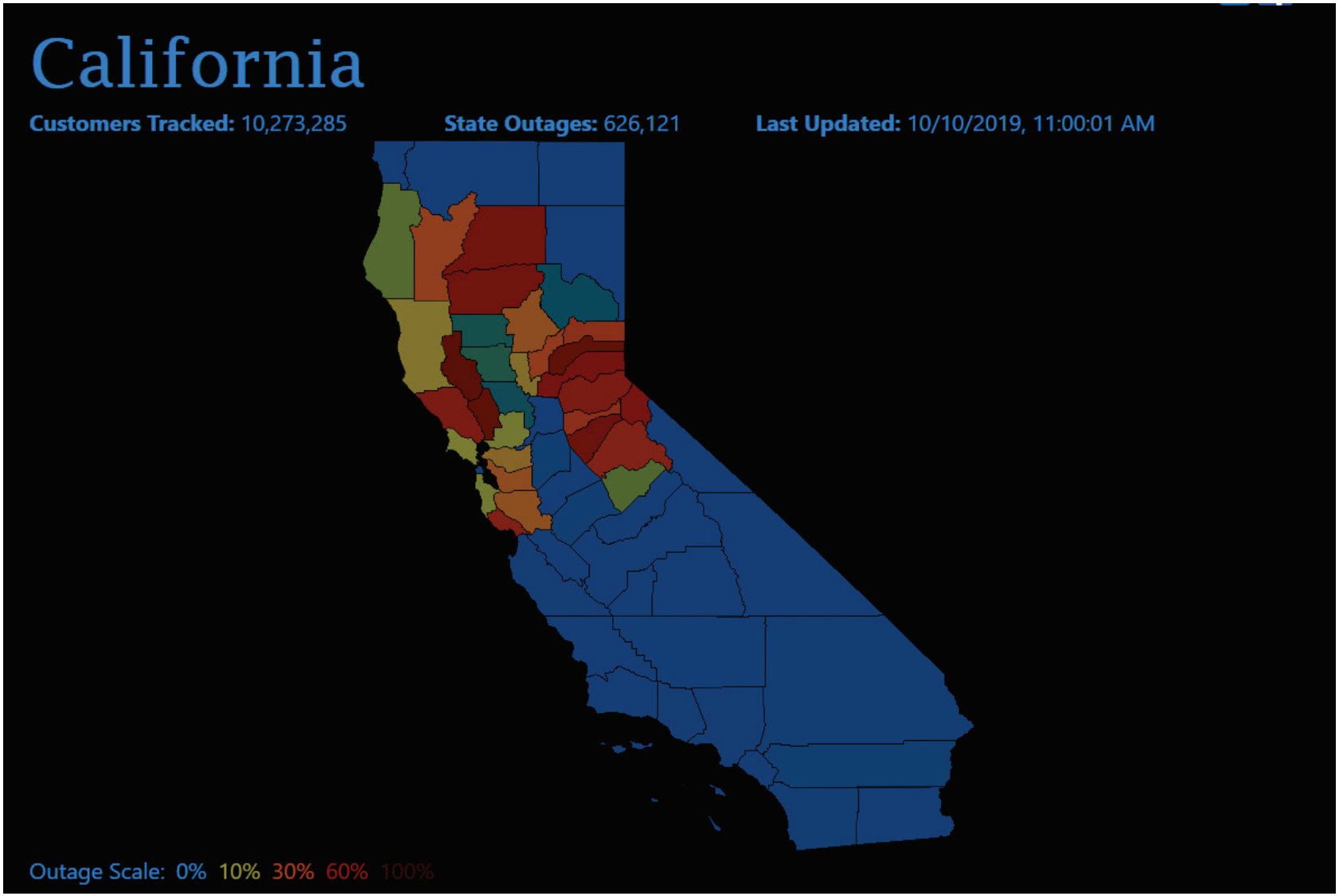

https://poweroutage.us/area/state/california

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BERKELEY'S NEWS
Thursday, October 10, 2019

THE DAILY CALIFORNIAN

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BREAKING NEWS UC Berkeley cancels classes for 2nd day because of power outage

NEWS / ALAMEDA COUNTY 10/10/19

UC Berkeley cancels classes for 2nd day because of power outage

PG&E began shutting down power in Alameda County about 11 p.m. Wednesday night, according to a tweet from the Alameda County Sheriff's Office, in accordance with its Public Safety Power Shutoff.

READ MORE...

CONCERTS

2019 Rolling Loud brings charisma, energy, hip-hop stars to Oakland Coliseum Grounds

https://www.dailycal.org/

Peter Gleick @PeterGleick

Dear California,
You realize if PG&E is permitted to cut power to millions of people whenever wildfire risk is high, it will mean no power for millions every year over and over and over again, just to save their corporate stability.

8:58 PM · Oct 9, 2019 · Twitter for Android

376 Retweets **1.1K** Likes

Jason @jhyu · 14h
Replying to @PeterGleick
Might encourage more people to install solar panels though.
3 1 26

Peter Gleick @PeterGleick · 13h
I have solar, but when the power is cut, I can't use my own solar. It's connected to PG&E. I'd have to also invest in battery storage... Which is looking better and better.
7 8 94

Jason @jhyu · 13h
Oh ok yeah that's what I was getting at e.g. Tesla Powerwall + Solar
1 1 21

https://twitter.com/PeterGleick/status/1182097939105234945

PG&E bankruptcy judge to consider allowing trial on utility's liability in Tubbs fire

JULIE JOHNSON
THE PRESS DEMOCRAT | August 12, 2019

Follow this story

Greg Wilson is not alone in his skepticism over what ignited the 2017 Tubbs fire that forced him and his wife to cower in their pool while flames destroyed their Mark West Springs home and neighborhood and thousands of other homes on its deadly path from northern Napa County to Santa Rosa.

Help For Wildfire Victims

People with losses from wildfires can find more information about the bankruptcy case and other matters, including filing a claim against PG&E, at www.pgefirevictimshelp.com.

Cal Fire's announcement early this year that private power equipment at a Bennett Lane home near Calistoga started the Tubbs fire and not Pacific Gas and Electric Co.'s power grid upended widely held beliefs that the utility was responsible for the deadly fire, as it was for other major fires during the 2017 October firestorm and the following year.

Wilson and others wanted to contest Cal Fire's findings before a civil jury and argue state investigators missed or disregarded key evidence that they believe shows a blown fuse on one of the utility's power poles dropped hot metal on parched grasses below. But their lawsuits were halted in January when PG&E filed for bankruptcy protection under pressure from upward of $30 billion in liability from wildfires ignited by the company's power equipment.

Wilson and other wildfire survivors may still get their chance. On Wednesday, they're asking U.S. Bankruptcy Judge Dennis Montali to consider lifting the stay in the civil case and allowing them to pursue a fast-tracked state court trial on PG&E's liability for the Tubbs fire.

https://www.pressdemocrat.com/news/9894734-181/pge-bankruptcy-judge-to-consider

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Essay on Ocean Acidification

To put it simply, the *world's oceans are becoming more acidic due to climate change*. This occurs due to the absorption of carbon dioxide. The carbon dioxide dissolves in the ocean water to form carbonic acid. The formation of carbonic dioxide inevitably raises the pH level of the ocean. Since the Industrial Revolution, the ocean's acidity has increased by 30%. This has a significant impact on the state and the health of the ocean and the millions of organisms who call the ocean their home. Furthermore, this has an outreaching impact on the billions of people who depend on the ocean for food and survival. Many organisms that reside in the ocean can only survive in specific pH ranges, and increasing levels of pH in the ocean make it more and more difficult for certain critical oceanic species to survive.

…

These increasing levels are caused by human activities, mainly the burning of fossil fuels. *Only by decreasing the use of fossil fuels will carbon dioxide levels drastically do down and the effects of climate change on the ocean be lessened*. If carbon dioxide levels continue to rise, the ocean will continue to absorb it and the ocean will eventually turn into acid. Acidic oceans mean the destruction of global reefs, and consequently the destruction of all ocean life. *The entire ocean ecosystem will collapse*, along with the fishing industry and tourism that supports many island economies. As a result, ultimately, *ocean acidification would cause entire human settlements to collapse* as well.

Sadly and strangely, ocean acidification is an often overlooked dire consequence of global climate change. The rapid acidification of the world's oceans does have the potential to cause a *collapse* of Earth's ocean ecosystem.

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Essay on Sea Level Rise

The sea level has risen about eight inches in the time between 1880 and 2009. This has been directly linked to human-caused global warming; the effect, which has increased the global temperature by 1.4 degrees in that same time period, has not only *warmed and expanded the ocean waters* along with the temperature but has also *increased the rate at which land ice melts*. The latter has become a more urgent issue since land ice melts to become water, which becomes part of the ocean. In addition, *with less land ice to reflect heat back into space, a positive feedback within global warming is created, further accelerating the melting of land ice and the warming/expansion of the ocean water*. Projections estimate that by 2100, the sea level [could] continue to rise by as much as 6 feet by 2100 unless action to stop greenhouse gas emissions is taken.

The impact of sea level rise on human society is grave. At best, coastal areas around the world will experience more frequent flooding - possibly a tripling of high-tide floods every year in the next 15 years; this will heavily damage and isolate communities in those areas. Other areas, though, will be completely submerged as the sea level increases, making them uninhabitable by humans. For instance, over 100 million people live in parts of states like Florida whose altitudes are not very high above sea level; should even the modest sea level rise projections come true, those people may be forced to permanently relocate before century's end.

Salt water incursion threatens agriculture in low lying areas throughout the world. Here is a link to an interesting research article that describes one attempt to mitigate the effect on agriculture of salt water incursion:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4336437

In 2012, at the request of the U.S. Climate Change Science Program, NOAA scientists conducted a review of the research on global sea level rise projections, and concluded that there is very high confidence (greater than 90% chance) that global mean sea level will rise at least 8 inches (0.2 meter) but no more than 6.6 feet (2.0 meters) by 2100.

https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

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Essay on Infectious Disease

The issue of infectious disease is affected by climate change in several ways. First, *rising temperatures increase water vapor making the environment more suitable for vectors such as mosquitos that carry malaria*. Additionally, these climbing temperatures could expand the area in which mosquitos can live, making more groups of people vulnerable to such diseases. However, scientists have not agreed on the true extent of the effects of climate change on malaria and other mosquito-carried diseases. While some areas will become more hospitable to the mosquito's needs, others will become too hot, resulting in a decline in malaria outbreaks. *Secondly, the rising oceanic temperatures promote an ideal climate for algal blooms which help carry diseases such as cholera. Cholera travels in water ways and already kills a large group of people every year*.

…

Both droughts and floods have the unfortunate effect of tarnishing sources of clean, drinkable water especially in third world countries, resulting in more diseases through consumption of unclean water. *Malaria is one instance of a major disease which will almost certainly spread to a larger demographic of people, many previously unexposed, as areas heat up to a level better accommodating mosquitoes carrying the sickness*. Other mosquito-borne illnesses hold true to this trend as well, and dengue fever, or *Lyme disease are also prone to increase due to climate change*.

The introduction of these new diseases into populations without resistance to them will have dire consequences. As the disease pool for mosquito-borne illnesses expands, more people are infected with malaria, dengue fever, Lyme disease, and yellow fever. It's especially tragic, at least to me, that many of these deaths and outbreaks will be swept under the rug as they occur in impoverished and developing countries without a media spotlight on them. Although, it is important to note that developed nations won't be immune to these effects, and the treatments for these new diseases will certainly act as a drag on the economy and quality of life for those afflicted.

…

This inequity can be seen in Shetty's article "Climate change and insect-borne diseases: Facts and figures," which states that 315,000 people have already lost their lives due to climate change, and that this number is 500 times higher in Africa when compared to Europe.

World Installed ***Electricity*** Generating ***Capacity***:

Power (Energy/Time)

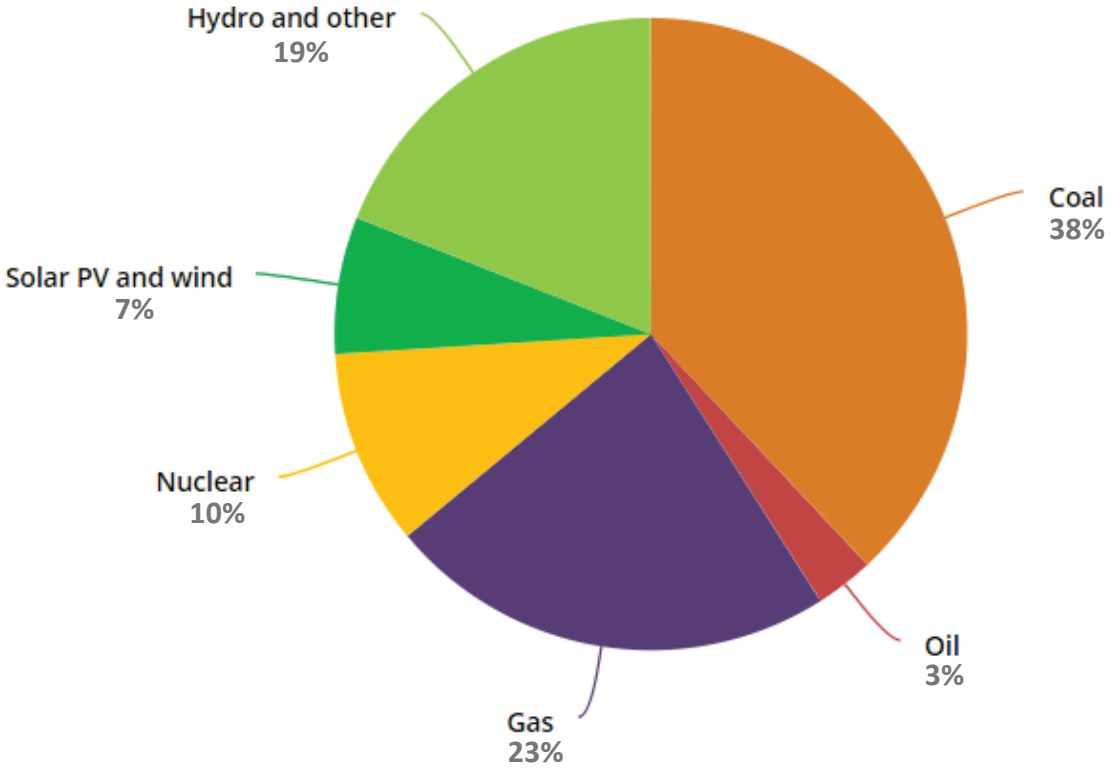
Total Source	GW (year 2018)
Coal	2,167
Natural Gas	1,769
Hydro-electric	**1140**
Wind	**524**
Liquid Fossil Fuel	381
Nuclear	374
Solar	**352**
Other Renewable (Biomass)	290
Geothermal	**19**
Total	7016

Source: https://www.eia.gov/outlooks/archive/ieo17/ieo_tables.php

In 2018, **38.4%** of global electricity generating capacity does not release prodigious GHGs to the atmosphere
33.1% involves hydro, wind, solar, biomass, and geothermal
12% involves solar energy and wind

World Electricity Generation Capacity

World electricity generation mix, 2018
26,700 TWh



https://www.iea.org/geco/electricity/

See also: https://renewablesnow.com/news/renewables-supply-25-of-global-power-in-2017-iea-606070

In 2018, world obtained ~36% of its **electricity** from sources that do not release prodigious amounts of GHGs to the atmosphere.

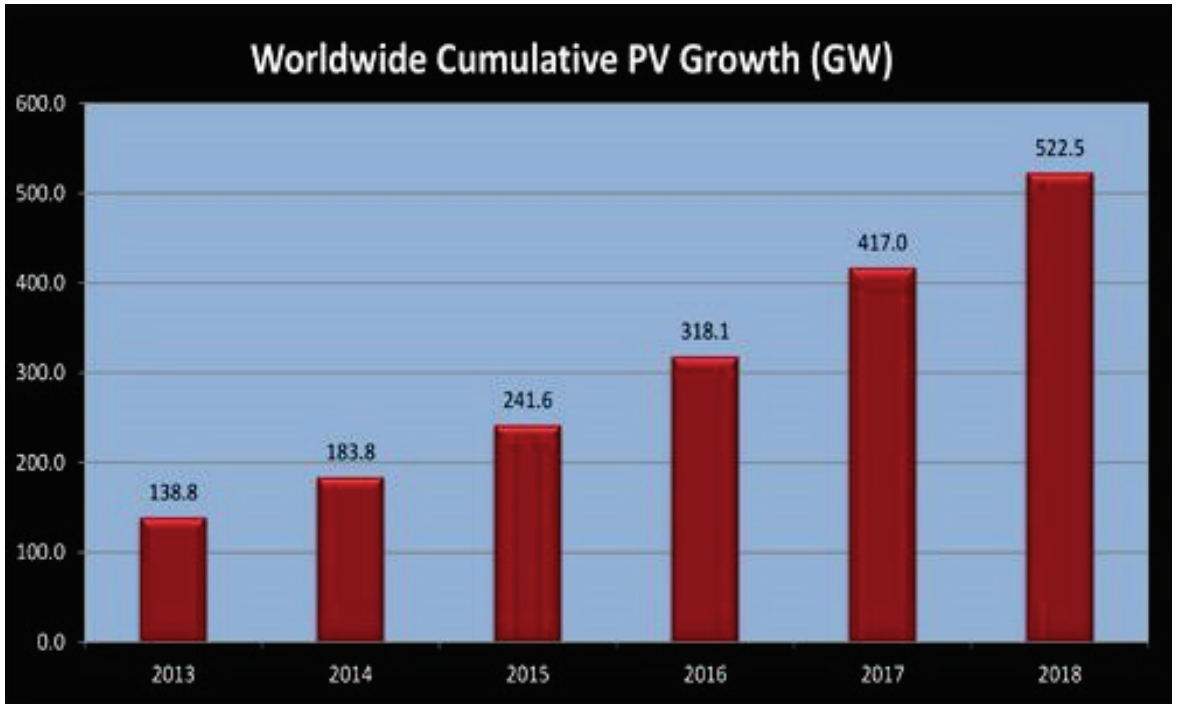
Only 7% involved solar and wind.

SOLAR ENERGY

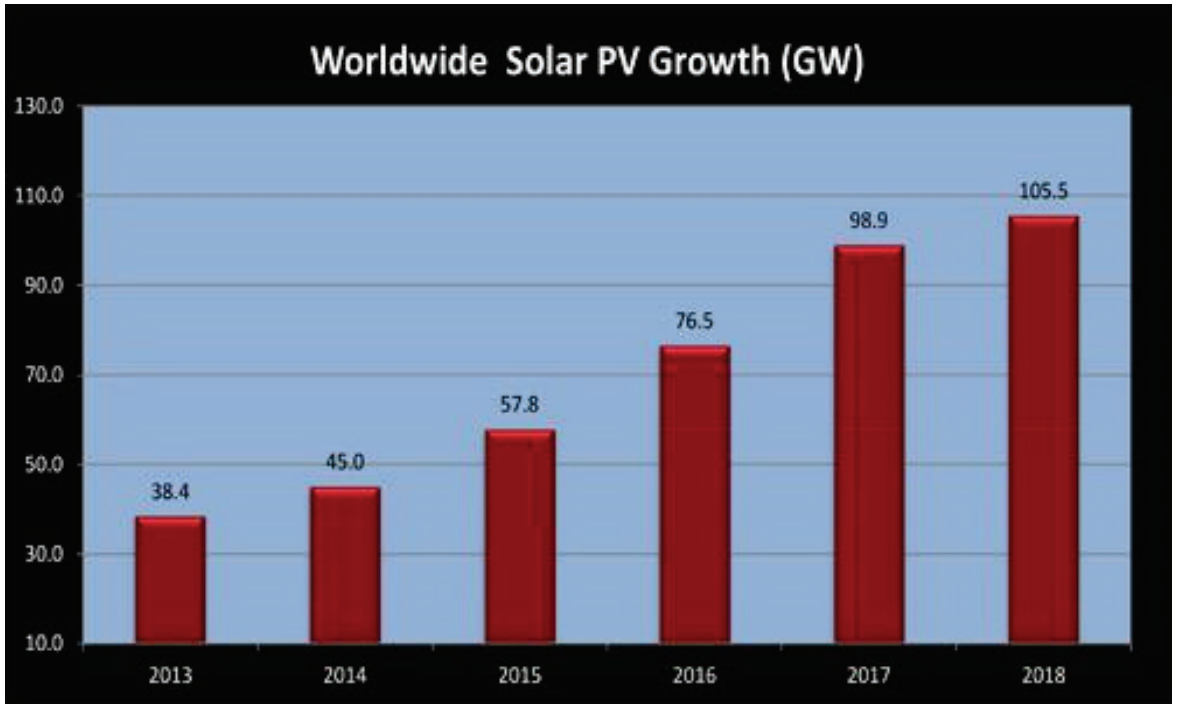
Abhay Patel

In the KH book, industry research firm Clean Edge makes a prediction of the total installed capacity for solar photovoltaics (PV) in year 2015.

- 75 gigawatts
- Over 300 gigawatts



http://solarcellcentral.com/markets_page.html



http://solarcellcentral.com/markets_page.html

Why do you think the PV growth has been so rapid?

What countries are leading this growth?

PV Solar Installed by Country in Megawatts

Country	2015	2016	2017	2018
	17.0	34.5	53.0	45.0
	2.2	4.0	9.1	10.8
	8.0	14.6	10.6	10.6
	9.5	8.6	7.0	6.5
	.9	.8	1.3	3.8
	1.9	1.5	1.8	3.0
	18.3	12.5	16.1	25.8
Total Market	**57.8**	**76.5**	**98.9**	**105.5**

http://solarcellcentral.com/markets_page.html

PV Solar Installed by Country in Megawatts

Country	2015	2016	2017	2018
China	17.0	34.5	53.0	45.0
India	2.2	4.0	9.1	10.8
United States	8.0	14.6	10.6	10.6
Japan	9.5	8.6	7.0	6.5
Australia	.9	.8	1.3	3.8
Germany	1.9	1.5	1.8	3.0
ROTW	18.3	12.5	16.1	25.8
Total Market	**57.8**	**76.5**	**98.9**	**105.5**

http://solarcellcentral.com/markets_page.html

Paris Climate Agreement, Dec 2015:

Article 2, Section 1, Part a):

Objective to hold “increase in GMST to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels”

INDC: **I**ntended **N**ationally **D**etermined **C**ontributions to reduce GHG emissions

- Submitted prior to COP21-UNFCCC meeting in Paris
- Extend from present to year **2030**

GMST: Global Mean Surface Temperature

COP: Conference of the Parties

UNFCCC: United Nations Framework Convention on Climate Change

Nov 2014:

Presidents Obama & Xi announce:

U.S. will reduce GHG emissions to 27% below 2005 level by 2025

China will peak CO_2 emissions by 2030 with best effort to peak early

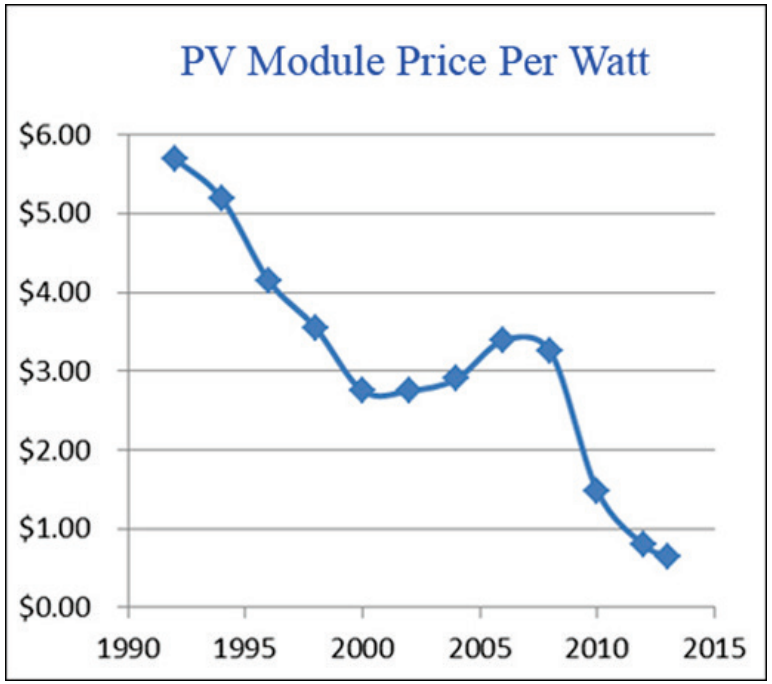
The KH book gives a numerical value for how much the price per peak watt for solar energy must be, for solar energy to be able to compete with "coal-fired electricity virtually everywhere". This number appears twice in the reading; also the wiki page provides the same price per peak watt cost for solar energy to achieve economic parity with the grid.

a) $1.00 per peak watt

b) ~2011

c) It would "require the next-generation photovoltaic technologies now emerging from the labs" to have solar-generated energy compete with coal-fired electricity.

http://solarcellcentral.com/markets_page.html



If the infrastructure is built using current and possibly inefficient solar technology, is it good practice to push out quantity or should we focus efforts on reducing costs further and making the technology more efficient?

Let's talk business:

MiaSolé®

A Hanergy Company

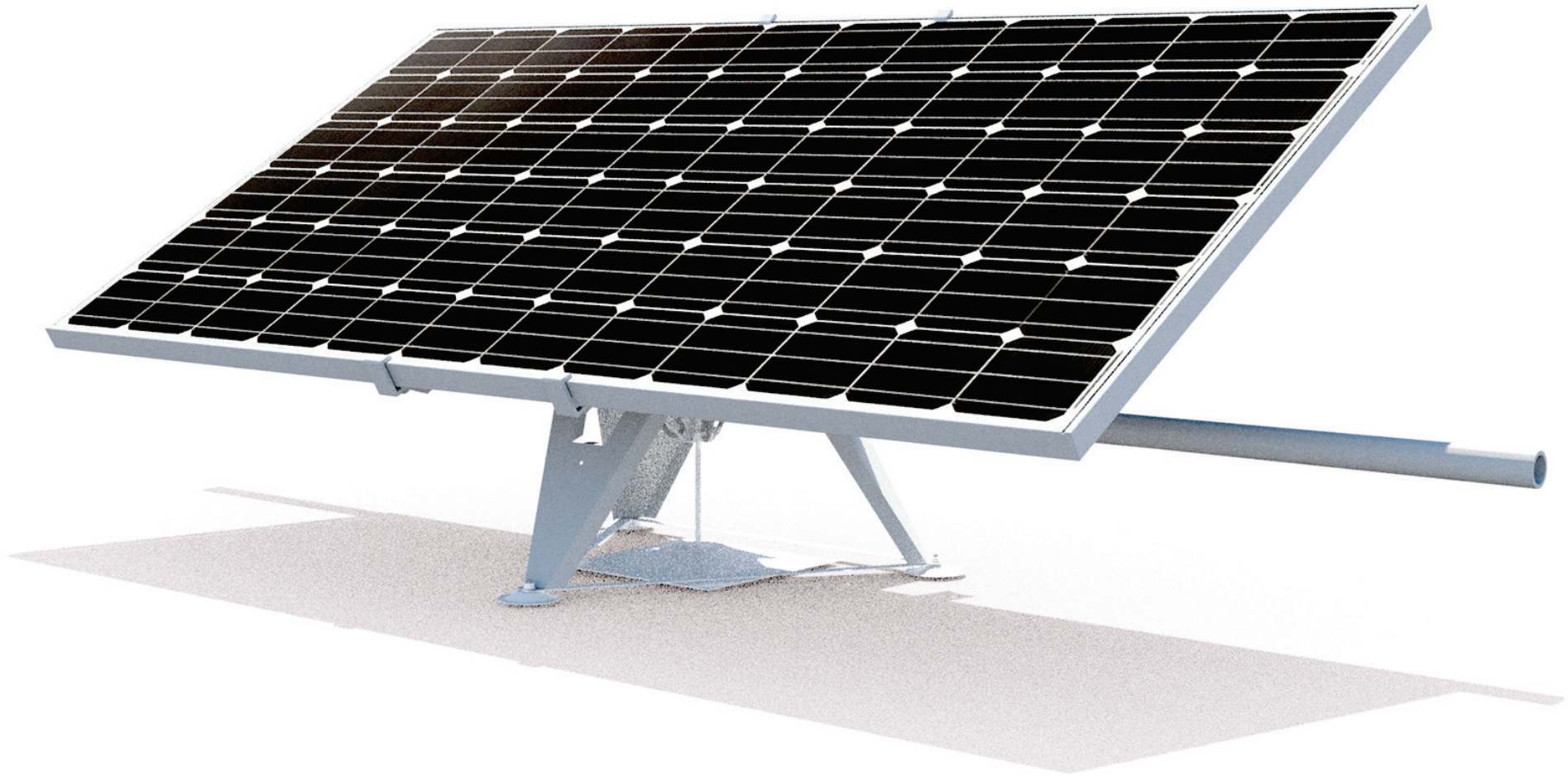
http://miasole.com/

innovaLIGHT

https://www.crunchbase.com/organization/innovalight

Edisun Microgrids™

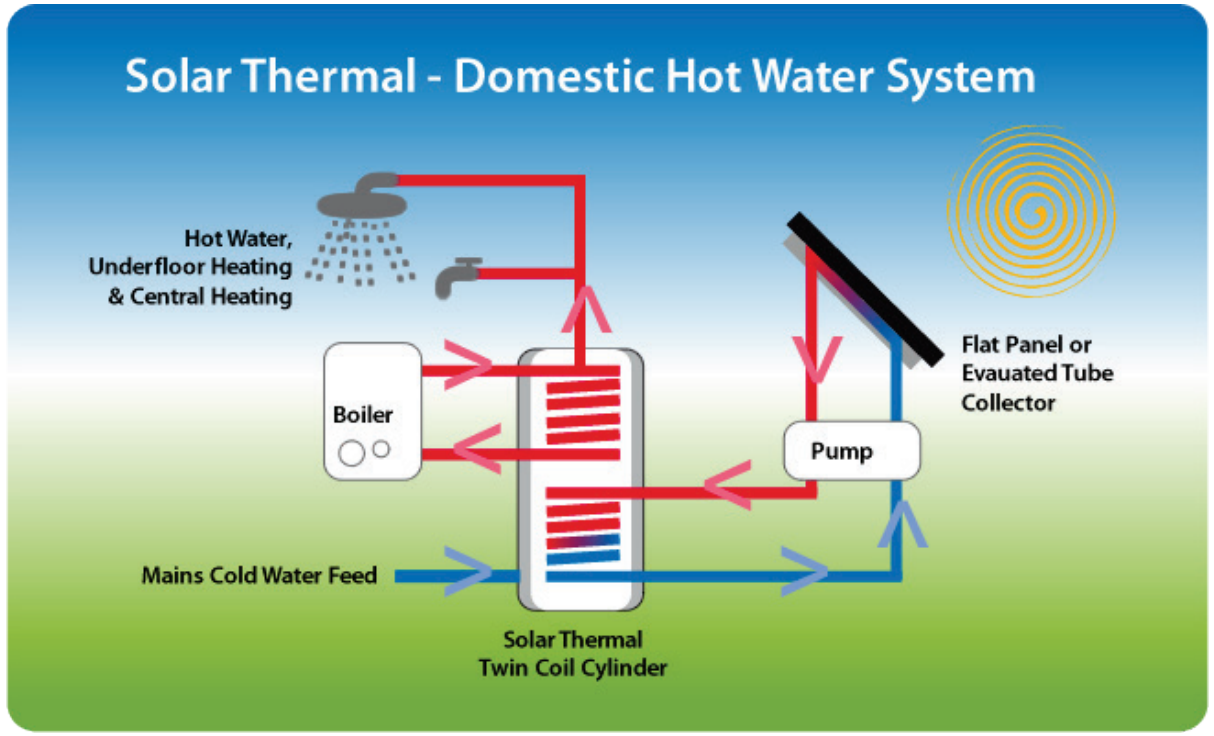
https://www.linkedin.com/company/edisun-microgrids



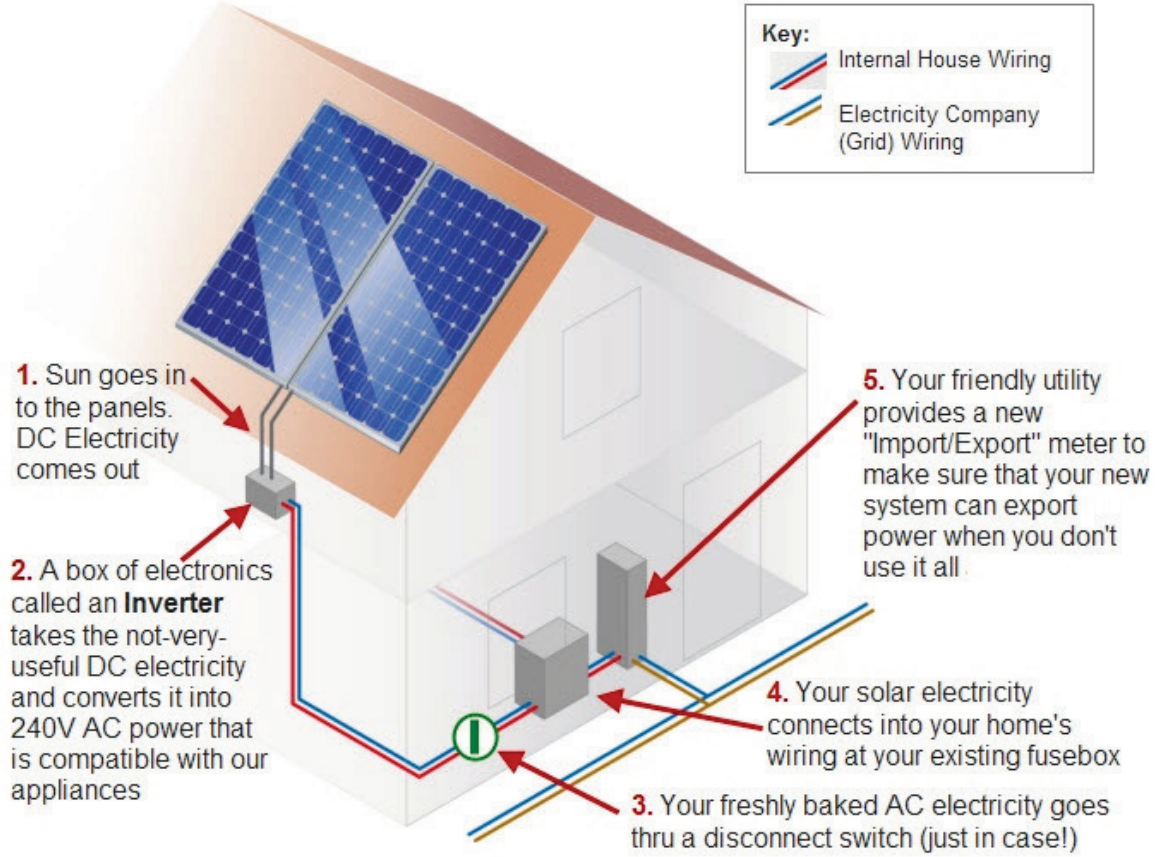
https://www.solarpowerworldonline.com/2018/12/editor-picks-for-the-top-solar-products-of-2018/

- 10 miles would be the side length
- This is at 10% efficiency
- At the Boeing Spectrolab highest efficiency, which was 40.7%, the length of the side would be 49.6 miles long

Solar Thermal & Solar Photovoltaic

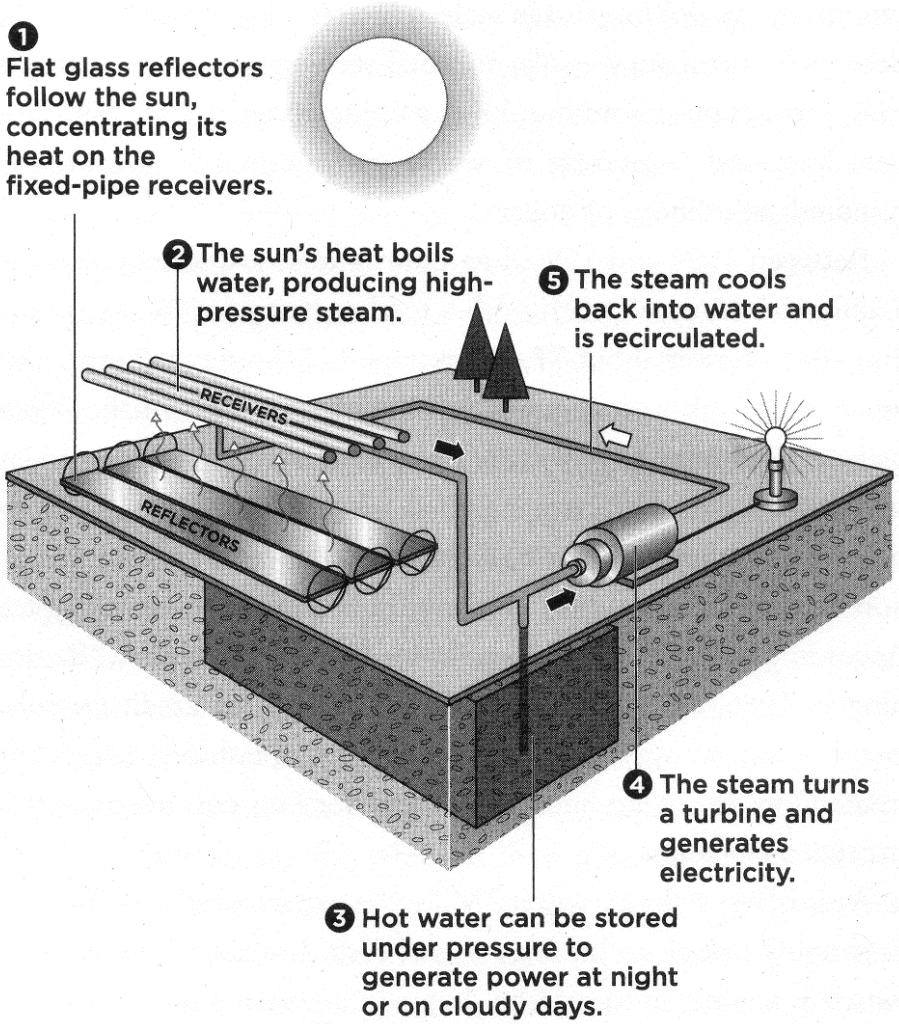


http://www.somersetrenewables.co.uk/solar_thermal/systems.php

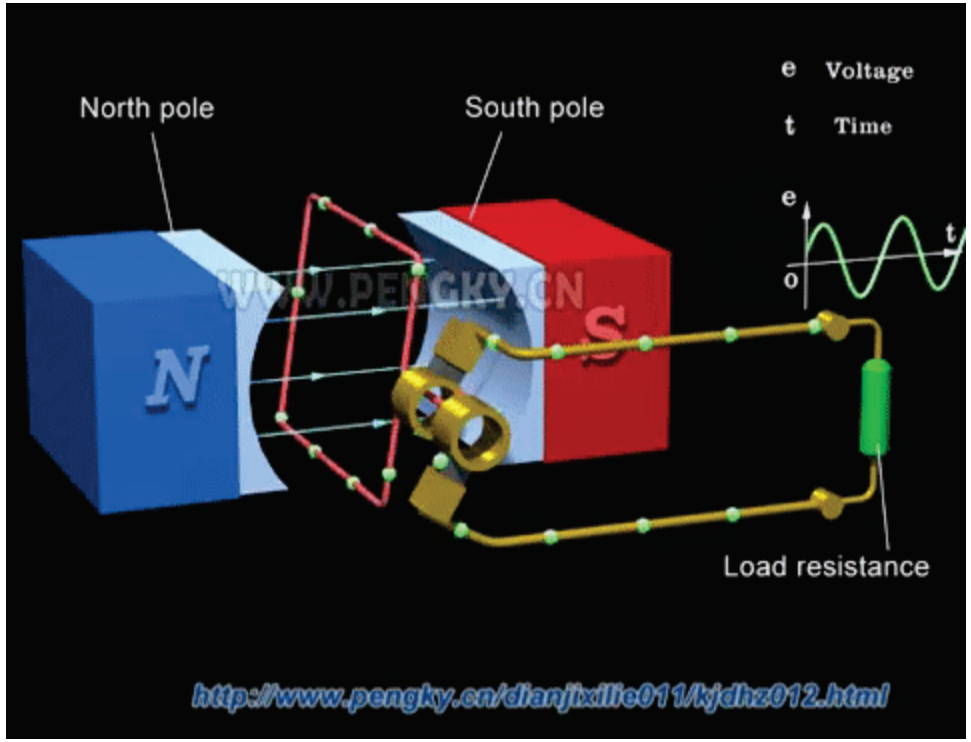


https://www.solarquotes.com.au/how-does-solar-power-work/solar-power-diagram/

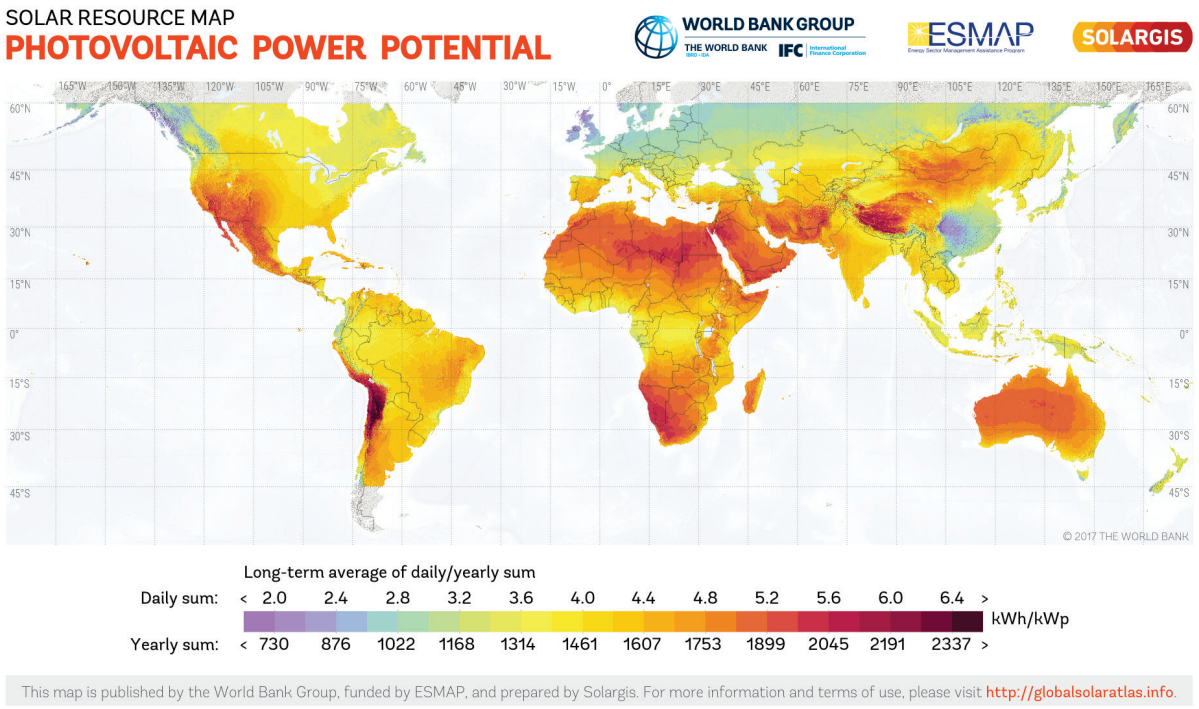
Harnessing the Sun's Heat

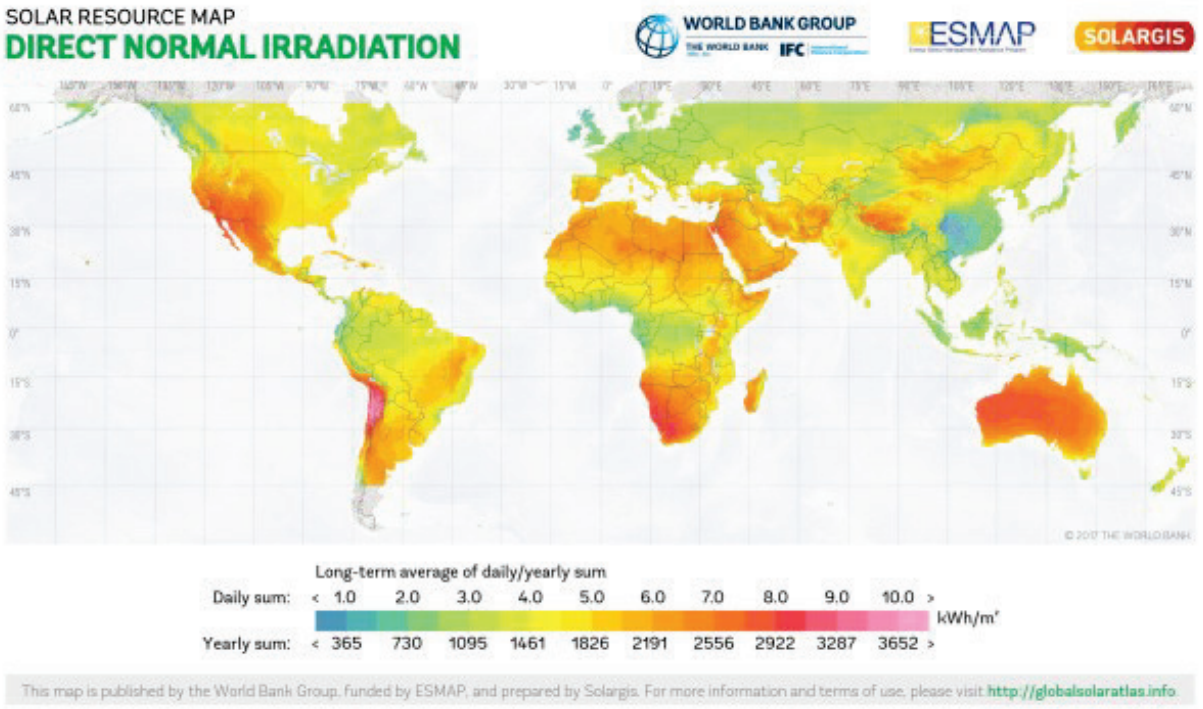


This low-cost approach is just one of the solar thermal technologies now under development to generate electricity from the sun's heat. Another approach puts the receivers at the top of a tall tower, achieving higher efficiencies at a higher capital cost.



https://gfycat.com/deliriousparallelbug

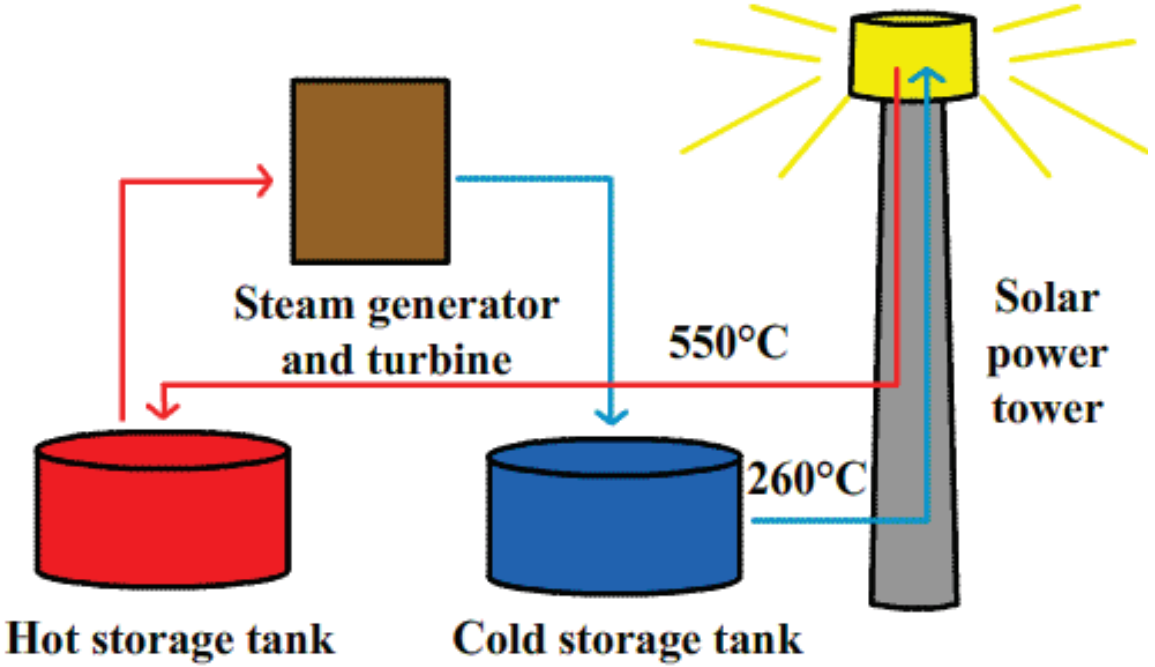




https://solargis.com/maps-and-gis-data/download/world

Notice how similar these are
What does this tell us?

The KH book notes “a key advantage of solar thermal over solar PV”. What is this key advantage and how, possibly, might this key advantage play a role in overcoming a major shortcoming of renewable energy?



http://large.stanford.edu/courses/2010/ph240/barile2/

Solar thermal is much easier to store

The KH books quotes John O' Donnell as stating financing is 'the last big obstacle to large-scale renewable energy deployment". The book then goes on to name three additional obstacles.

1. Access to the regional transmission grid
2. Cost of renewable technologies
3. Reliability of renewable energies

Which of these three obstacles do you think is truly the hardest to overcome and how do you think it could possibly by overcome?

Renewable Portfolio Standard: requires utilities to buy a set percentage of their total power from clean sources

Feed-In Tariff: requires utilities to buy electricity from renewable-energy producers, including owners of rooftop systems, at above market rates.

Spain

Feed-In Tariffs

https://en.wikipedia.org/wiki/Solar_power_in_Spain#Installed_capacity

National CSP capacities in 2018 (MW_p)

Country	Total	Added
Spain	2,300	0
United States	1,738	0
South Africa	400	100
Morocco	380	200
India	225	0
China	210	200
United Arab Emirates	100	0
Saudi Arabia	50	50
Algeria	25	0
Egypt	20	0
Australia	12	0
Thailand	5	0

Source: REN21 Global Status Report, 2017 and 2018[68][69][8]

https://en.wikipedia.org/wiki/Solar_power_in_Spain#Installed_capacity

https://www.acciona.us/projects/energy/concentrating-solar-power/nevada-solar-one/

Solar Photovoltaics: The Last Word

Ross Salawitch

Concentrated Solar Power (CSP)

- Parabolic mirrors heat fluid that drives Stirling engine
  - Fluid is permanently contained within the engine's hardware
  - Converts heat to energy
  - Theoretical efficiencies often challenging to achieve

    http://en.wikipedia.org/wiki/Stirling_engine
- Highest electrical efficiencies for solar → lowest costs!

  http://www.powerfromthesun.net/Book

  http://www.oilcrisis.com/us/ca/CaliforniaCSP_Benefits200604.pdf

Kramer Junction, Calif

Fully operational in 1991: 350 MW capacity

Low output in 1992 due to Pinatubo aerosol!

Present operating cost: ~11 ¢ / kWh

Nevada Solar One

Output: 64 MW capacity : 134,000 MWh / year

Construction cost: $266 million or

~$2 / kWh for one year's prod

Nevada Solar One

Project capacity: **64 MW** (power = energy / time)

Project output for 2008 to 2018: **1,313,500 MWh** (energy, or power × time)

Number of hours in year = 365×24 = 8760 h

Capacity Factor = 1,313,500 MWh / (64 MW × 8760 h/yr × 11 yrs) = **0.21**

Nevada Solar One

Output: 64 MW capacity

Could supply all of US electricity needs in 2017
if built over a 144 mile × 144 mile area

Construction cost: ~$2 / kW-hr for one yr's prod

Generation (MW·h) of Nevada Solar One

Nevada Solar One's production is as follows (values in GW·h).[20]

Year	Solar	Fossil	Total
2007	41.21	0.38	41.59
2008	122.69	0.91	123.31
2009	120.65	2.43	123.07
2010	133.00	1.16	134.16
2011	128.26	1.99	130.26
2012	128.94	1.39	130.33
2013	112.79	2.31	115.10
2014	116.23	2.58	118.80
2015	105.65	2.14	107.79
2016	116.89	2.24	119.13
2017	118.03	2.58	120.60
2018	110.38	2.57	112.95

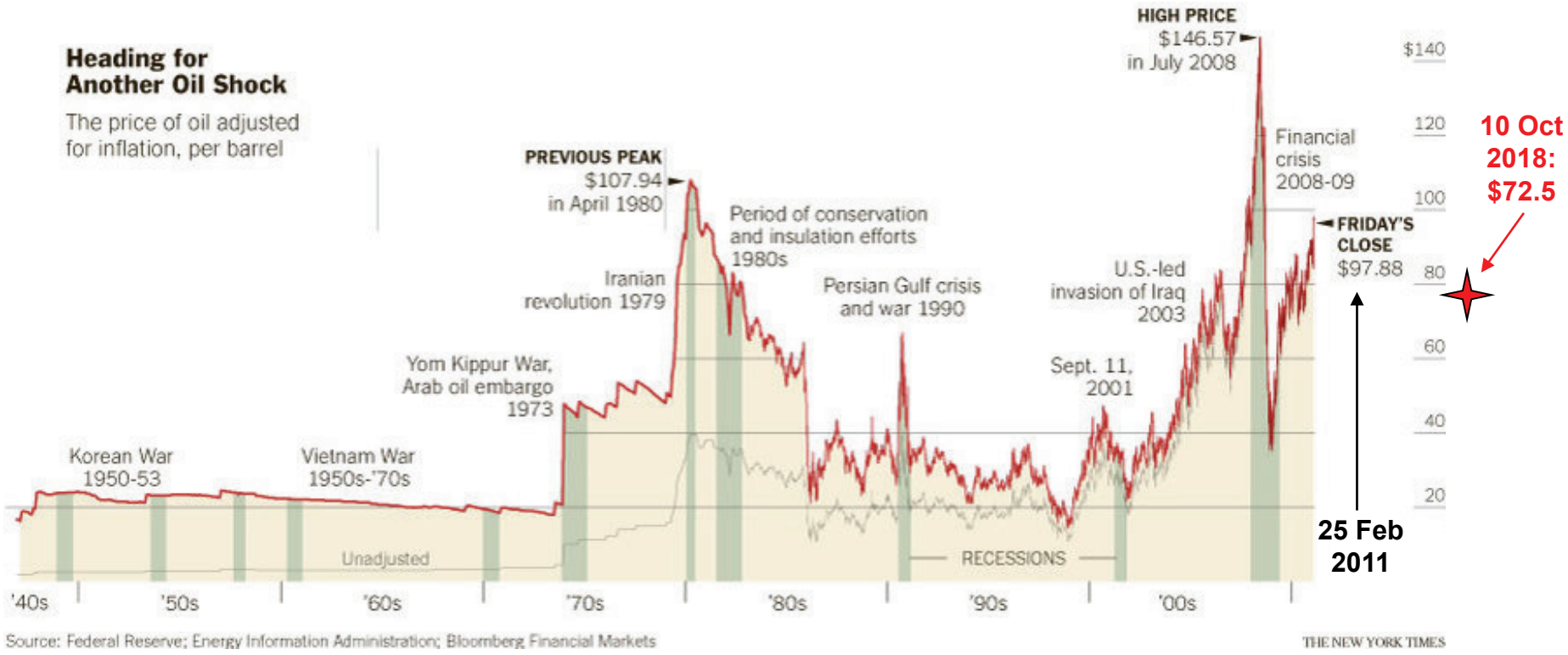
Note: 1 GWh = 1000 MWh

2018 was 17% lower than 2010 peak

http://en.wikipedia.org/wiki/Nevada_Solar_One#Production

Fossil backup, night time preservation, and morning pre-heating, is provided by natural gas and provides up to 2% of total output.

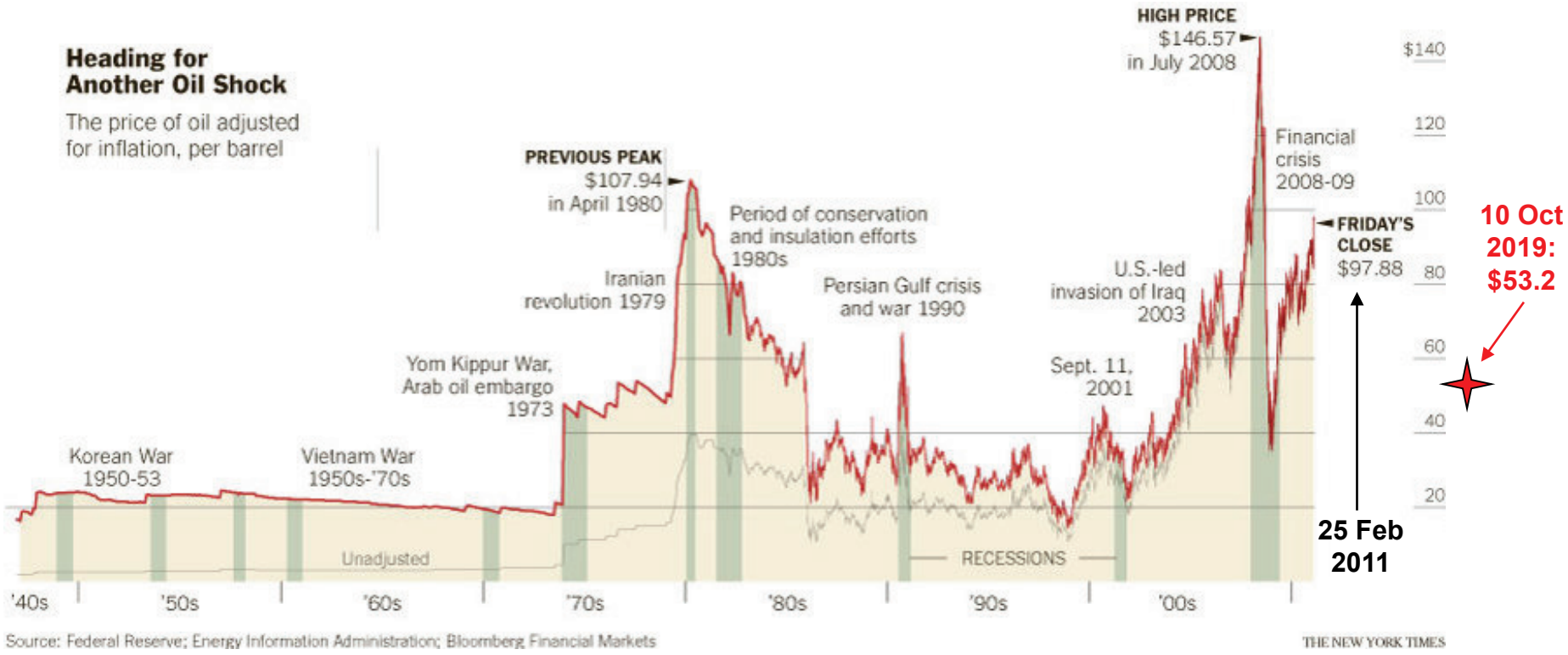
Market Force #1: Cost of Fossil Fuel



http://www.nytimes.com/2011/02/28/business/global/28oil.html

Graph shows cost of a barrel of oil

Market Force #1: Cost of Fossil Fuel



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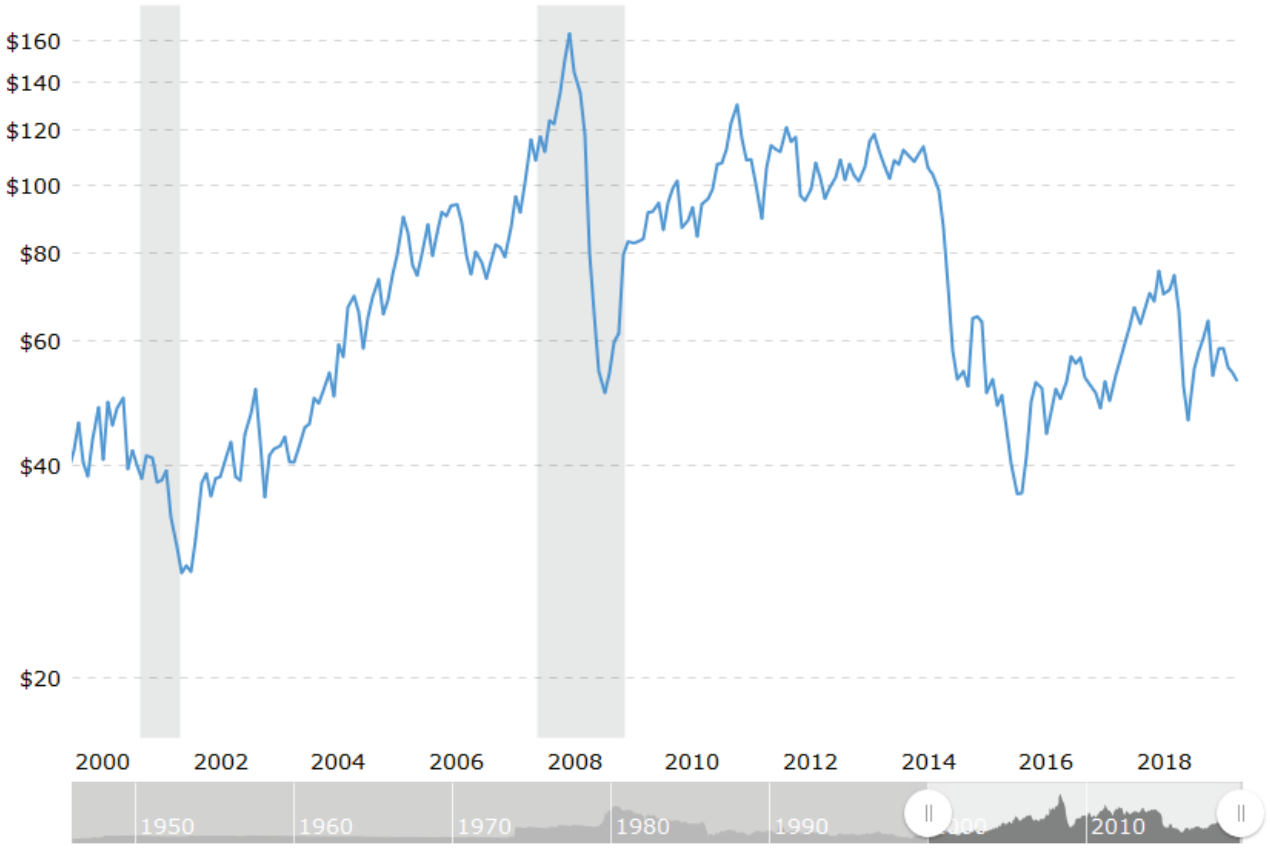
Graph shows cost of a barrel of oil

Market Force #1: Cost of Fossil Fuel

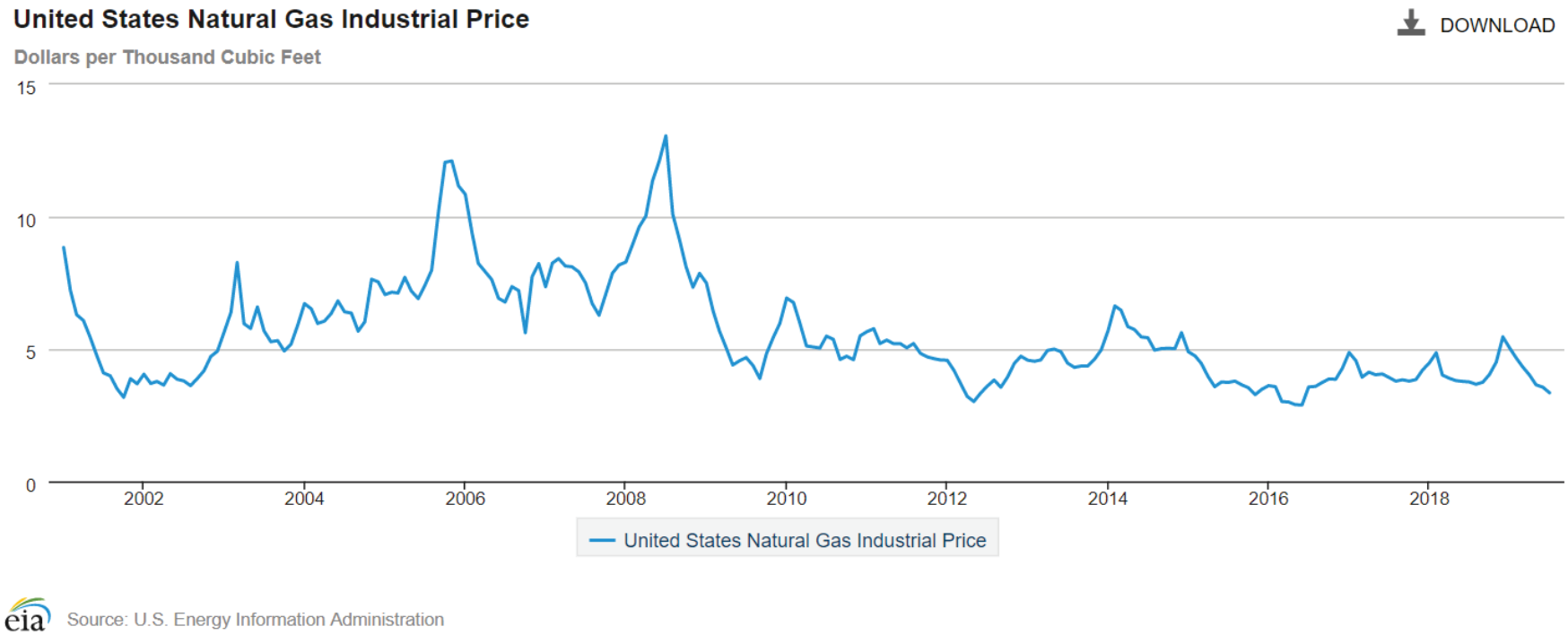
Graph shows cost of a barrel of oil



https://www.macrotrends.net/1369/crude-oil-price-history-chart

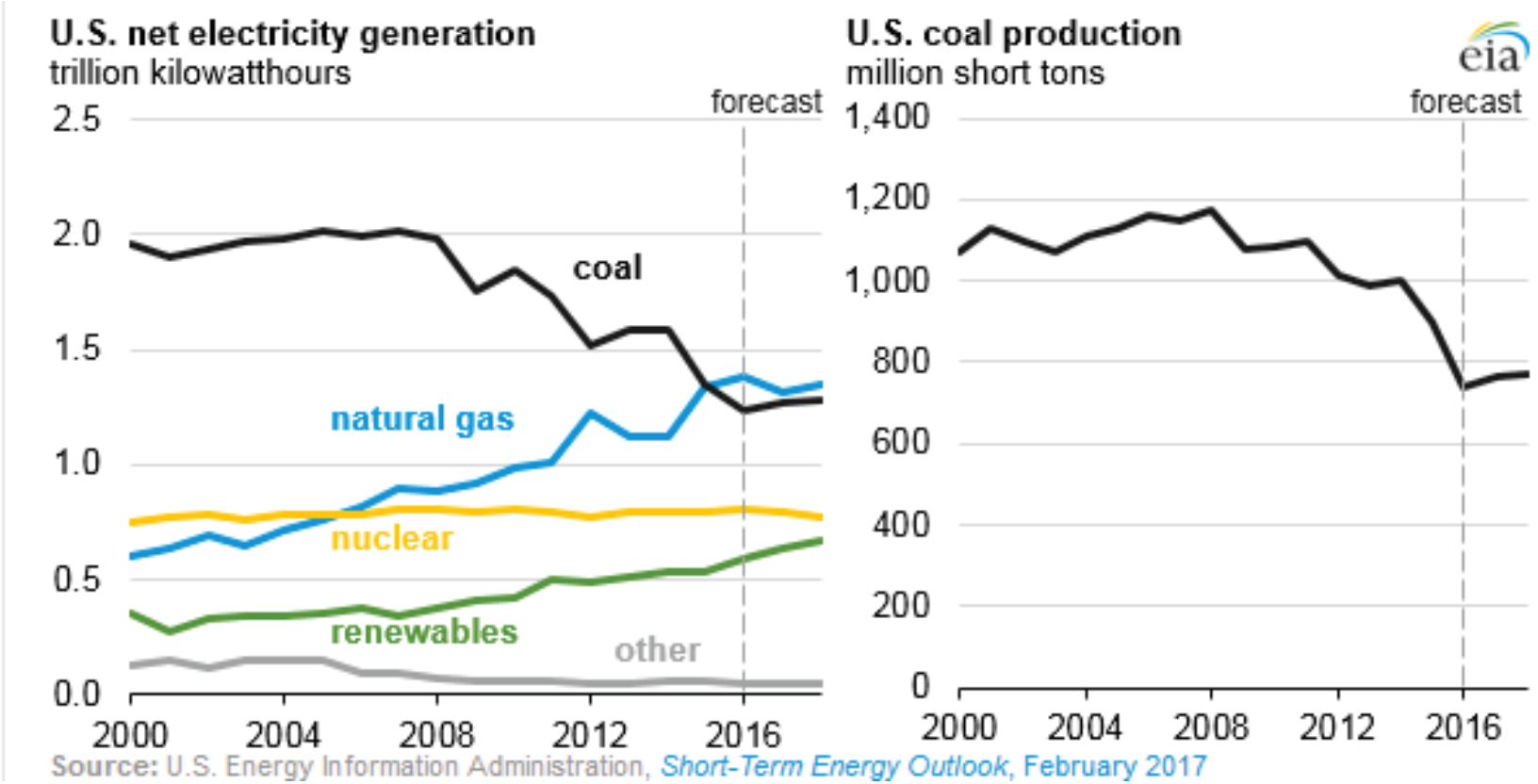
Market Force #1: Cost of Fossil Fuel

Graph shows cost of 1000 cubic feet of natural gas



https://www.eia.gov/dnav/ng/hist/n3035us3m.htm

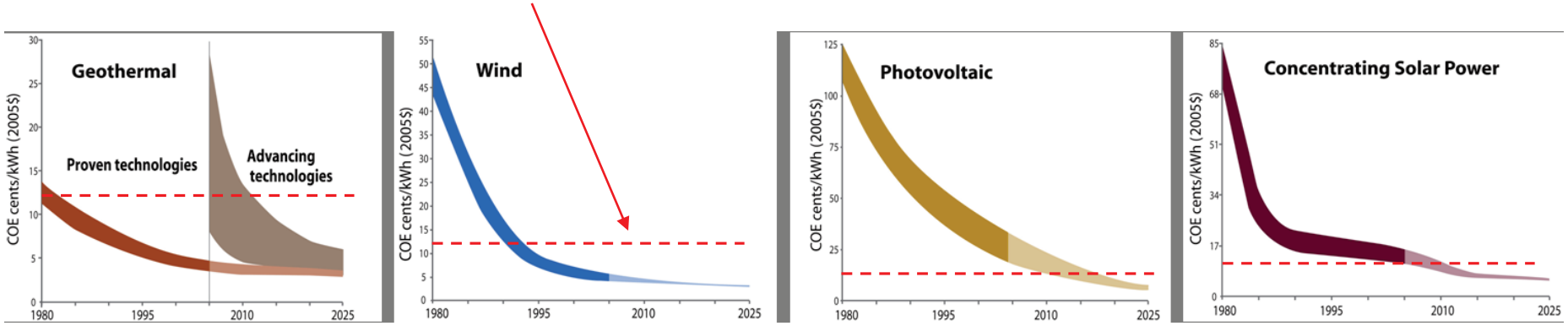
Market Force #1: Cost of Fossil Fuel



https://www.eia.gov/todayinenergy/detail.php?id=29872

Market Force #2: Cost of Electricity from Renewables ↓

2016 US Average Cost of Electricity: ~12.55 cents per kw-hour

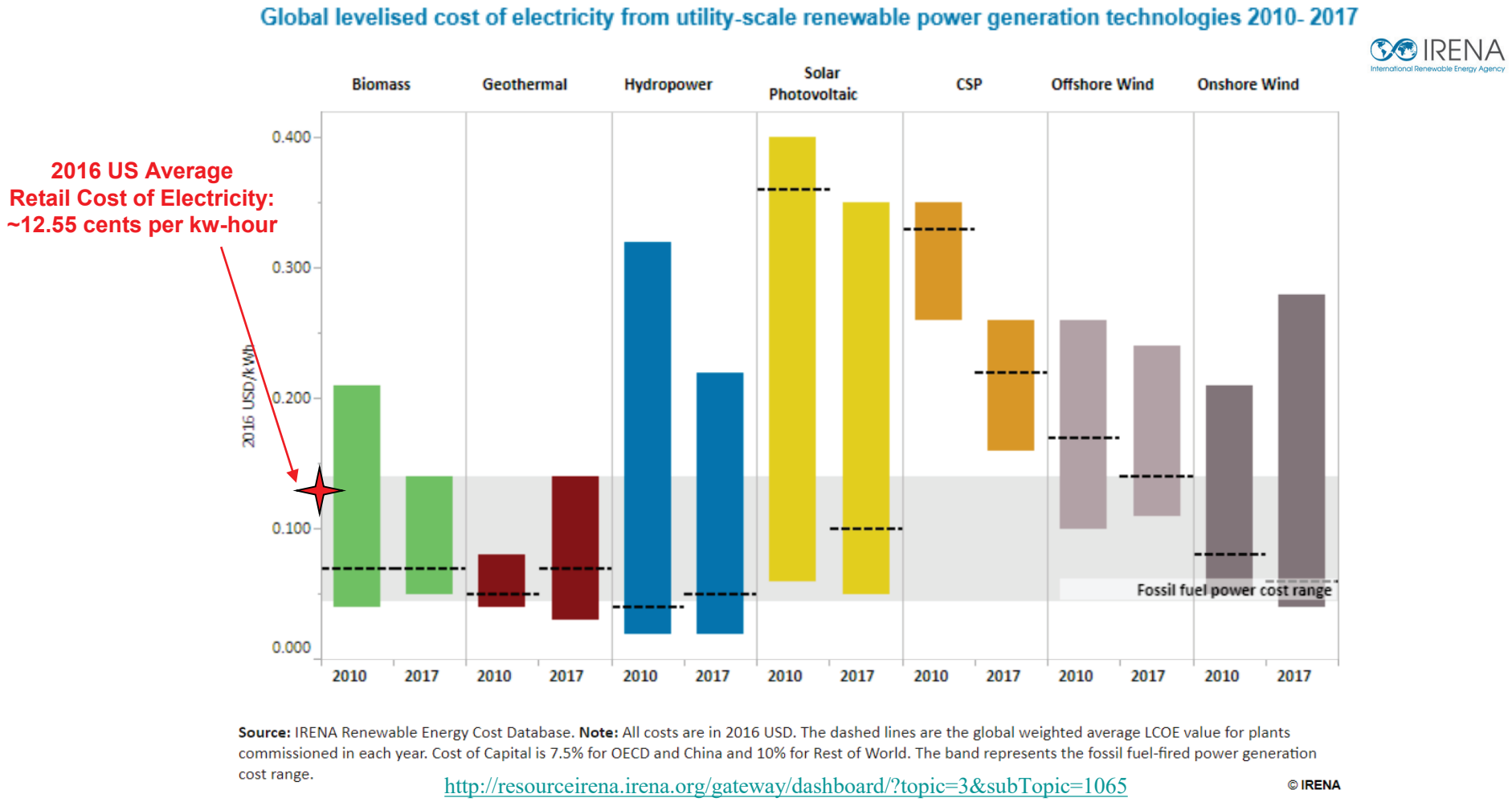


National Renewable Energy Lab: http://www.nrel.gov/analysis/docs/cost_curves_2005.ppt

The notational view "back in the day" was the cost of generating electricity from renewables would drop due to innovation, and the cost of generating electricity from fossil fuels would rise due to scarcity.

Alas, abundant natural gas (methane, CH_4) from fracking (the f-word in climate) has stabilized if not lowered the cost of generating electricity from fossil fuels.

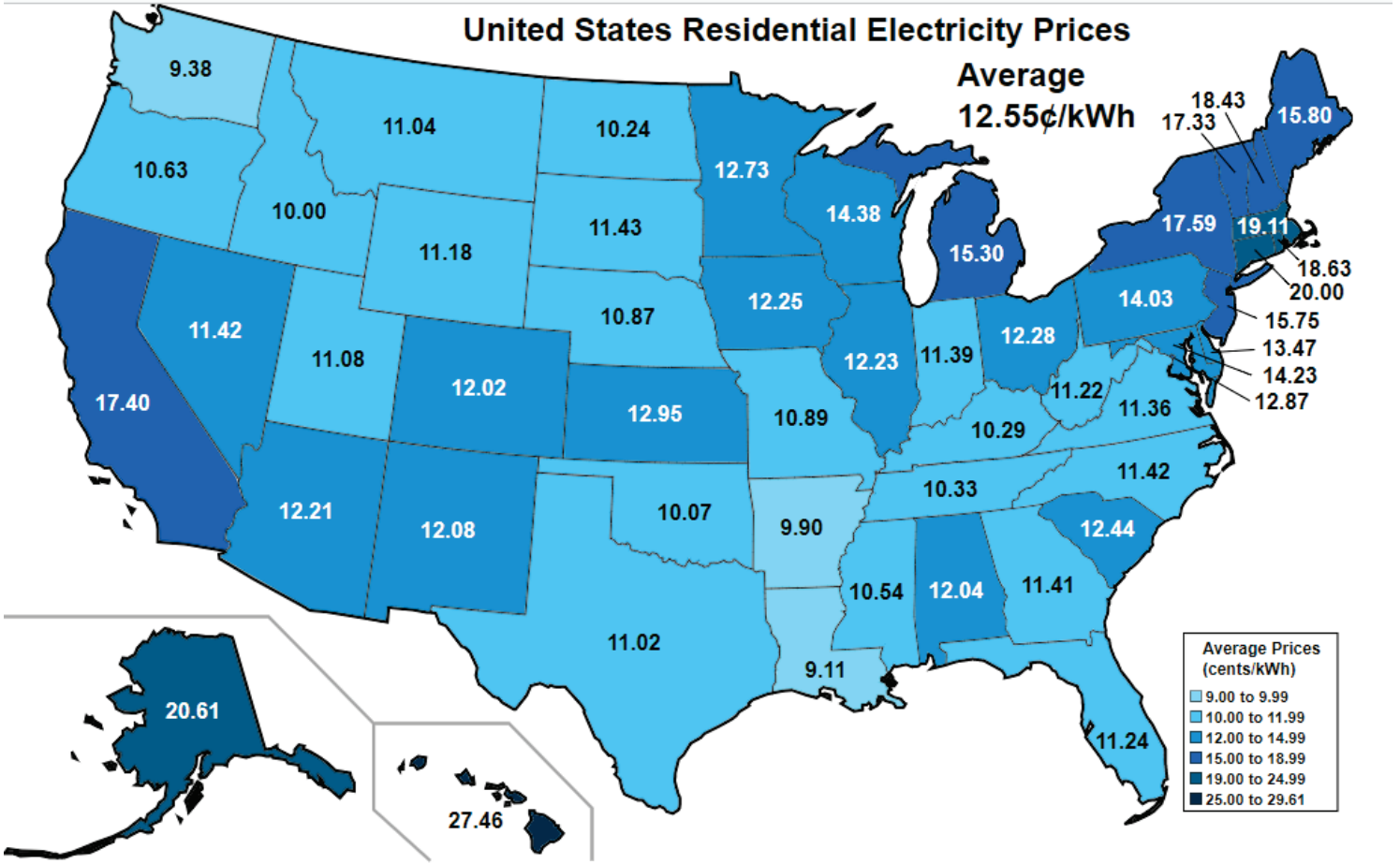
Market Force #2: Cost of Electricity from Renewables ↓



Biomass, Geothermal, Hydro, Solar PVs, and Onshore Wind cost competitive with fossil fuels. Utility-scale renewable options of Concentrated Solar and Offshore Wind still lag.

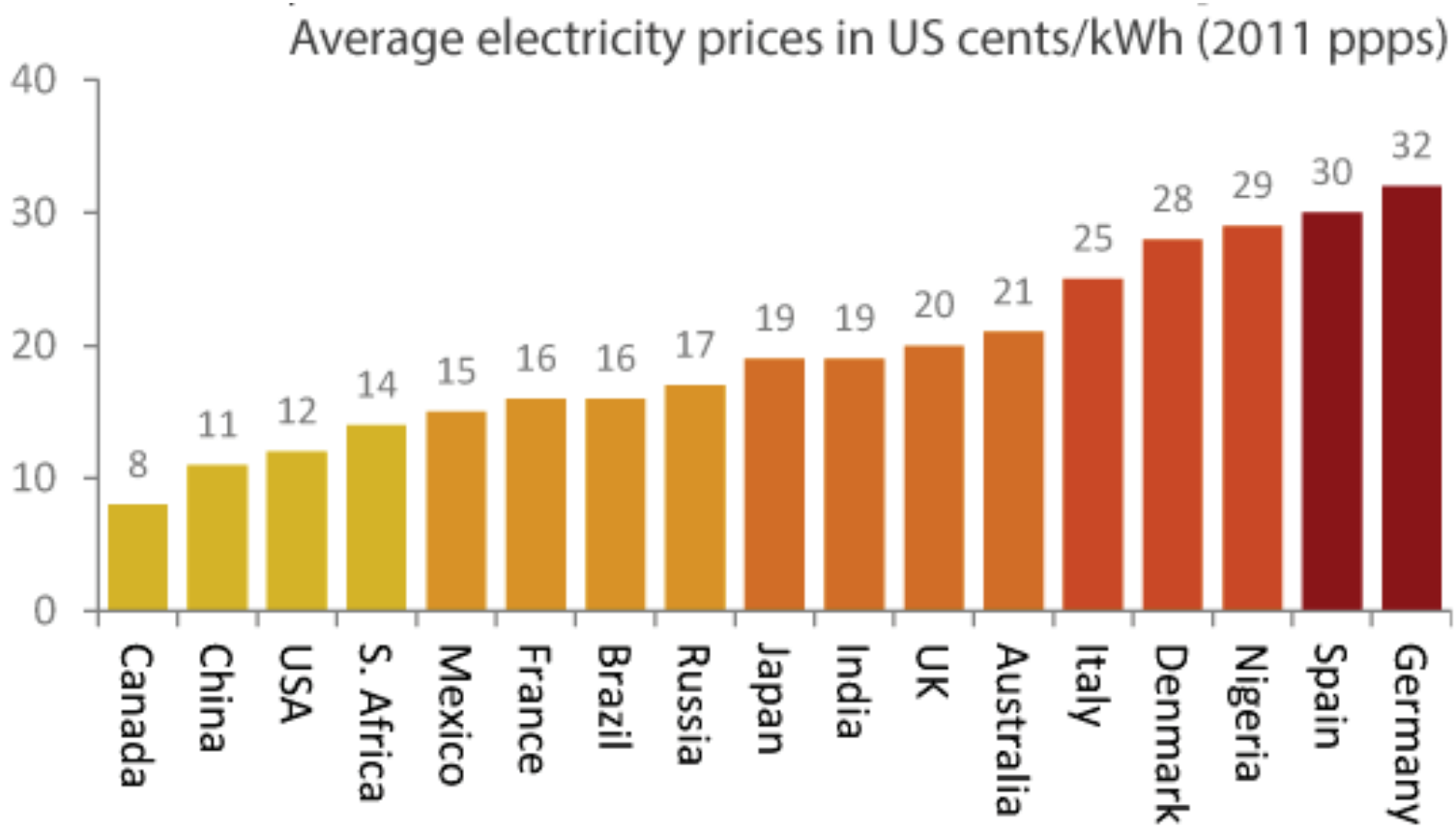
LCOE: Levelized Cost of Electricity https://en.wikipedia.org/wiki/Cost_of_electricity_by_source

U.S average residential retail price of electricity: 12.55 cents per kilowatt-hour in 2016



https://commons.wikimedia.org/wiki/File:Average_Residential_Price_of_Electricity_by_State.svg

Price of Electricity varies a lot Internationally

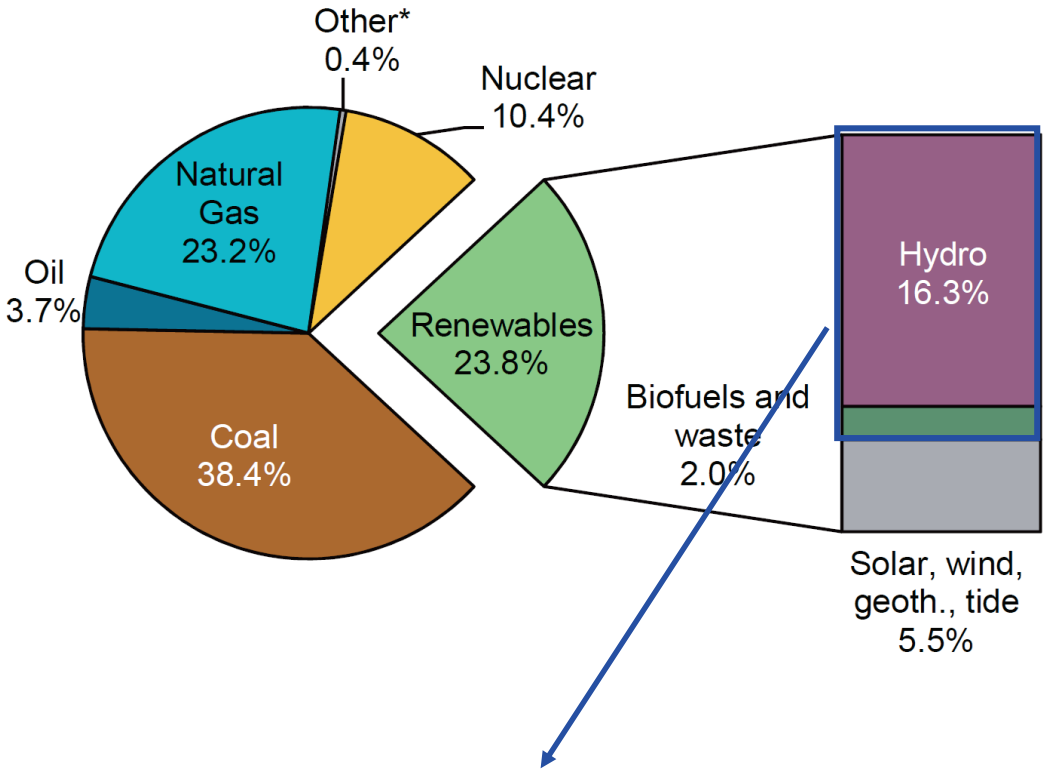


ppps: purchasing power parities

http://theenergycollective.com/lindsay-wilson/279126/average-electricity-prices-around-world-kwh

World Electricity Supply, 2016

Figure 7: Fuel shares in world electricity production in 2016

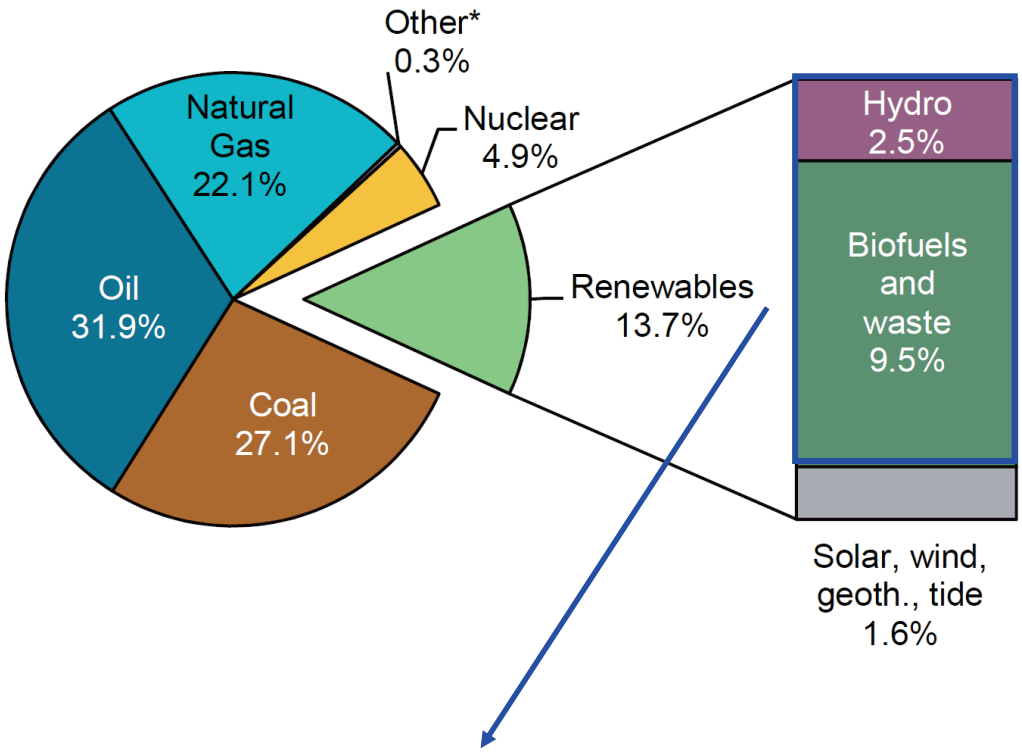


We'll discuss biofuels on Tues & hydroelectricity on Thurs

https://webstore.iea.org/download/direct/2260?fileName=Renewables_Information_2018_Overview.pdf

World Energy Supply, 2016

Figure 1: 2016 fuel shares in world total primary energy supply



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