Renewable Energy I:
Hydro, Wind and Solar

AOSC / CHEM 433 & AOSC / CHEM 633

Ross Salawitch

Class Web Sites:
http://www2.atmos.umd.edu/~rjs/class/spr2022
https://myelms.umd.edu/courses/137772

Next three lectures:
Challenge of meeting energy needs by means other than the combustion of fossil fuel

Today: Focus on three technologies with an emphasis on capacity factor, cost, growth, and an interesting adverse consequence of hydroelectricity

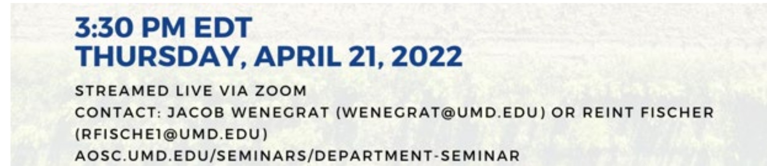
https://gigawattglobal.com/projects3/rwanda/

Lecture 19

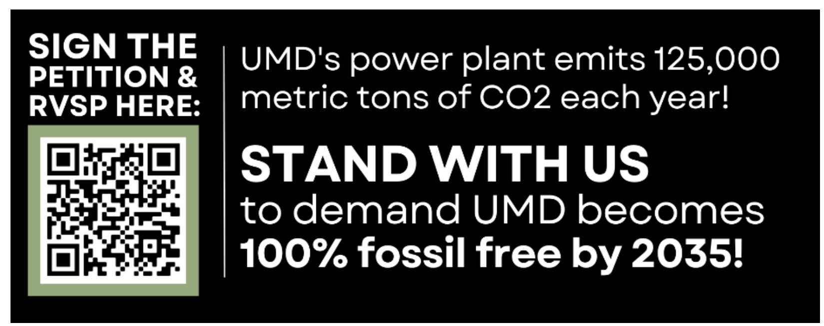
21 April 2022

Announcements

- AOSC Weekly Seminar: Today, 3:30 pm, virtual



- Review of Second Exam: Today, 7:30 pm, virtual:
  https://umd.zoom.us/s/9465565837
  Same link on class website and sent in class announcement
- Campus decarbonization protest Fri, 29 April, 3 pm:



Energy and Power

Simple equation connects energy and power:

Energy = Power $\times$ Time

Size of a ***power*** plant is commonly measured in units of power:

kW (kilo: 10^3 Watts): Home solar

MW (mega: 10^6 Watts) Industrial

GW (giga: 10^9 Watts): Massive Hydroelectric

TW (terra: 10^{12} Watts): Large Nation and/or Global

Most solar arrays are "sized" in terms of kW

Output of a **power** plant in units of ***energy***:

kWh (kilo: 10^3 W hour)

MWh (mega: 10^6 W hour)

GWh (gig: 10^9 W hour)

Output of most solar arrays are metered in terms of kWh

World Energy & Electricity Supply: units of Energy

World Energy

World Electricity

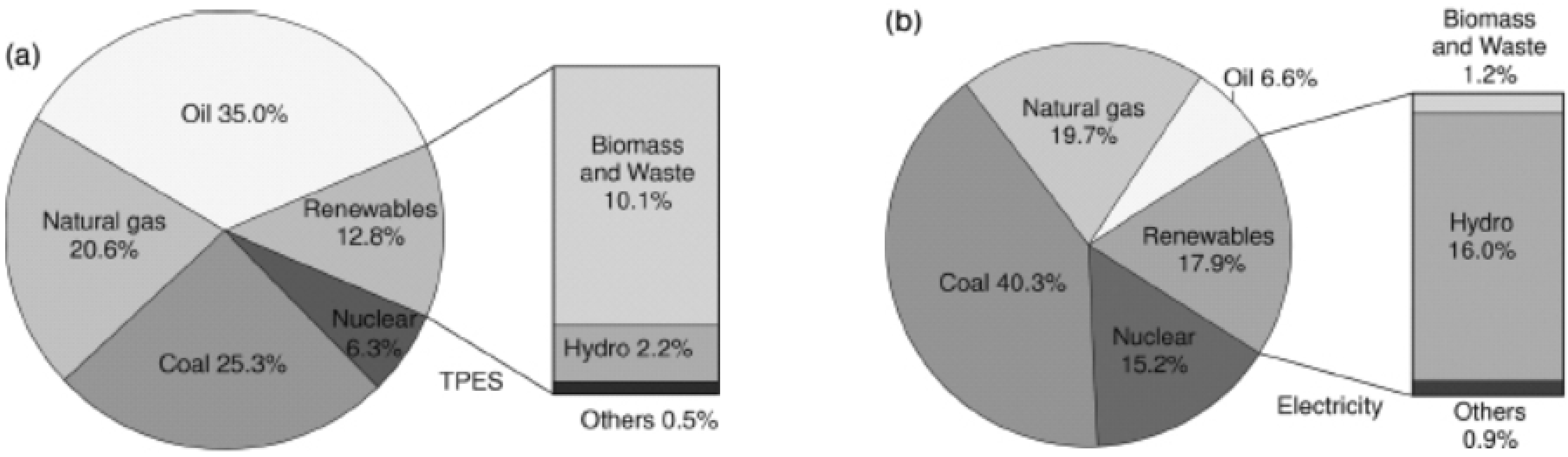


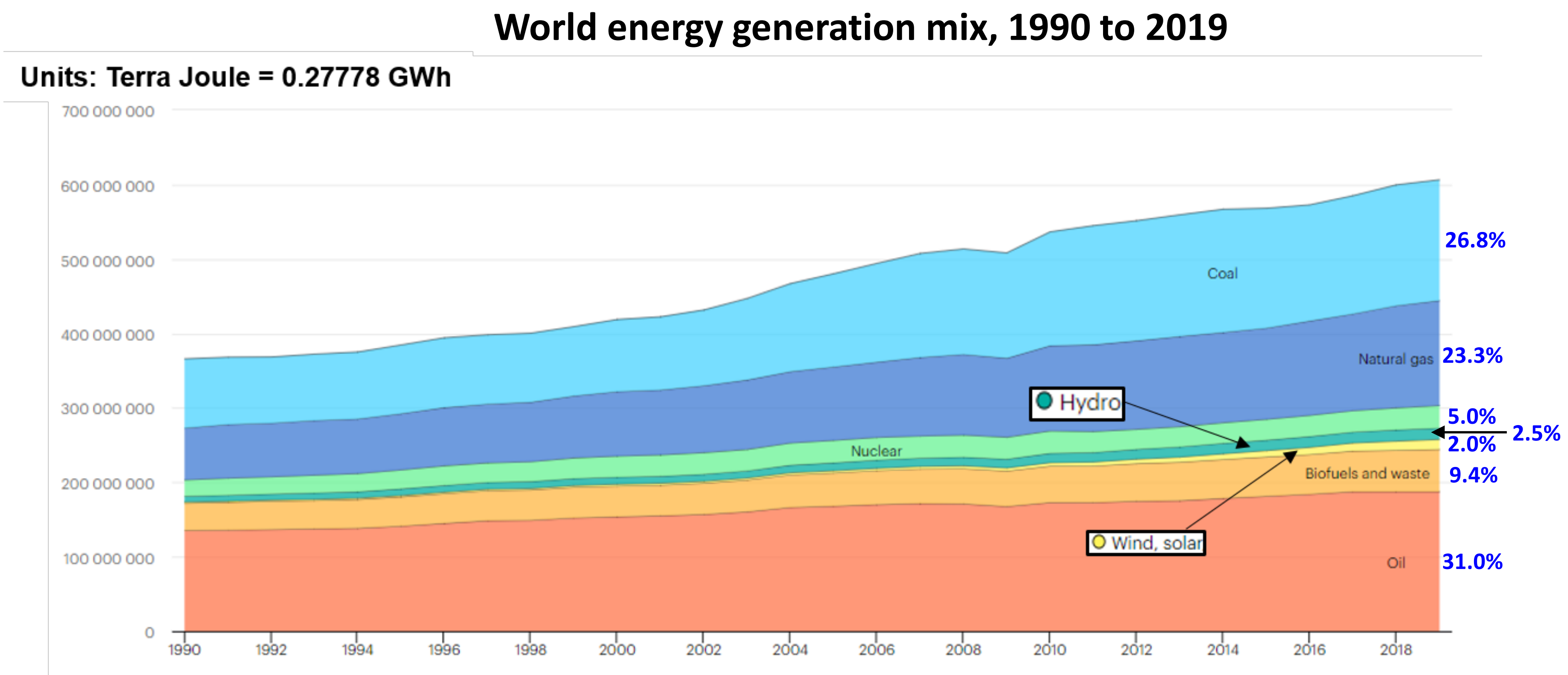
Figure 8.1 (a) Share of renewables in the world total primary energy supply (TPES) in 2005; (b) share of renewables in world electricity production in 2005. (Source: IEA Renewables Information 2007.)

Olah *et al.*, *Beyond Oil and Gas: The Methanol Economy*, 2009

In 2005, world obtained:
~81% of its **energy** &
~67% of its **electricity**
from combustion of fossil fuels

In 2005, world obtained:
~13% of its **energy** &
~18% of its **electricity**
from renewable sources

World Energy Update: units of Energy



In 2019, the world still obtained:

~81% of its **energy** (31.0+23.3+26.8=81.1%; this slide) &

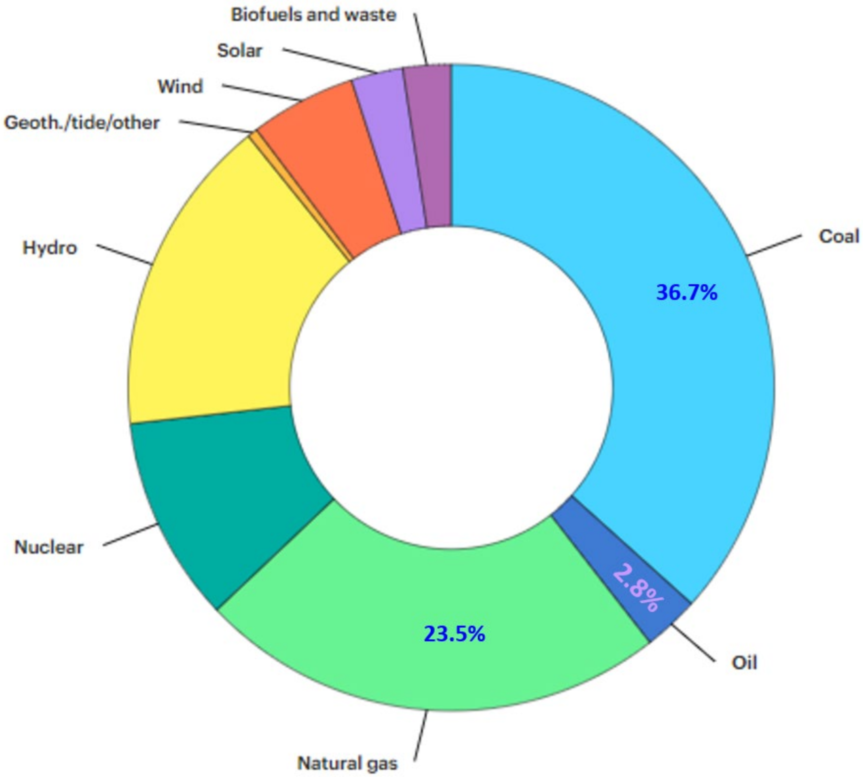
~63% of its **electricity** (next slide)

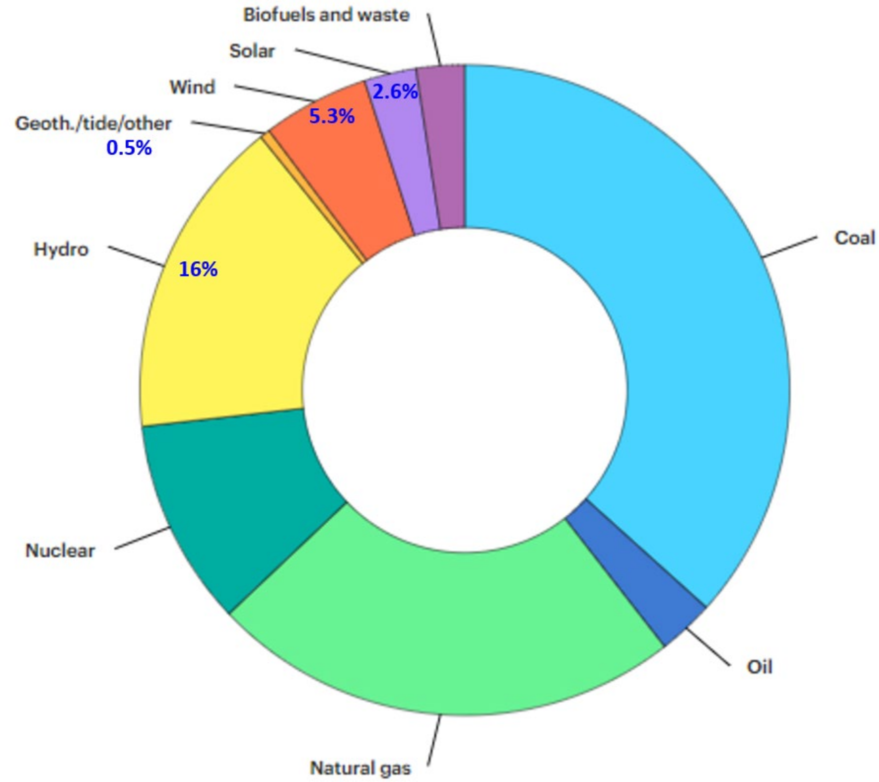
from the combustion of fossil fuels

https://www.iea.org/data-and-statistics/data-browser/?country=WORLD&fuel=Energy%20supply&indicator=TESbySource

World Electricity Update: units of Energy

World electricity generation mix, 2019





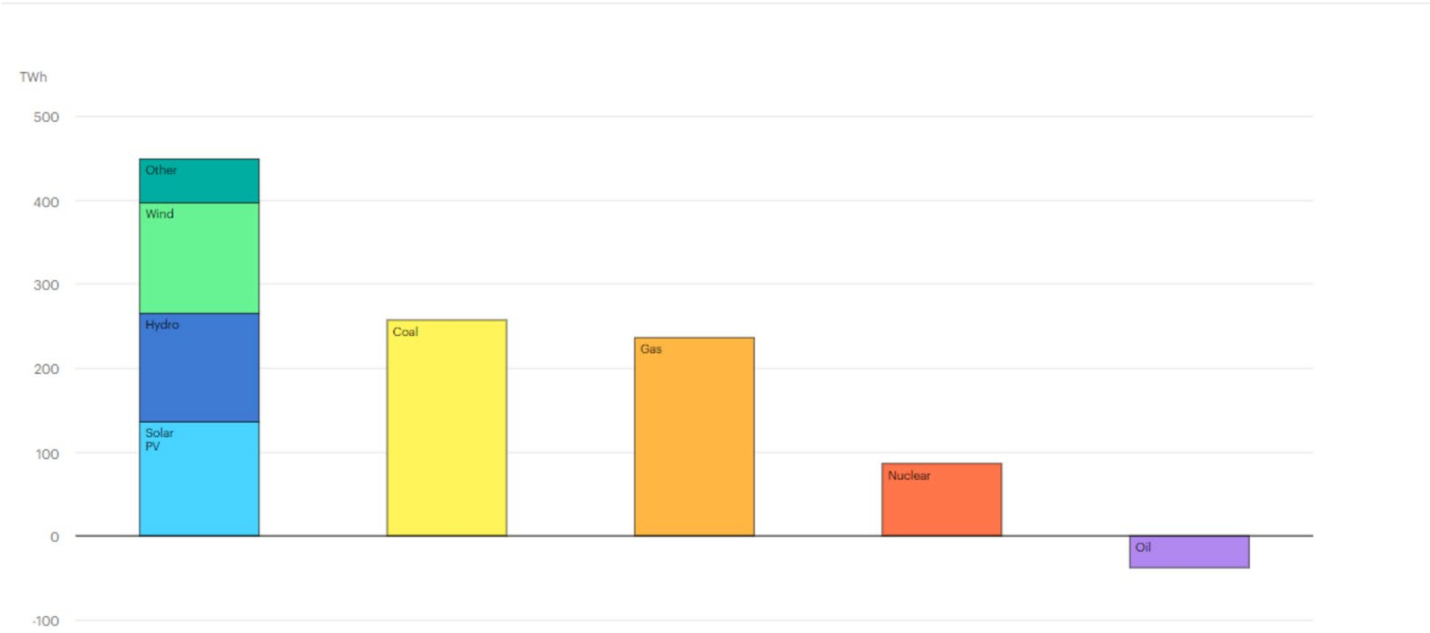
In 2019, the world still obtained:
~81% of its **energy** (prior slide) &
~63% of its **electricity** (36.7+23.5+2.8=63%; this slide)
from the combustion of fossil fuels (had been 81% & 67% in 2005)

In 2019, world obtained 24.4% (16+5.3+2.6+0.5%) of its **electricity** from renewables (had been 18% in 2005)

https://www.iea.org/data-and-statistics/charts/world-gross-electricity-production-by-source-2019

World Electricity Trend

Change in global electricity generation by source, 2018 versus 2017



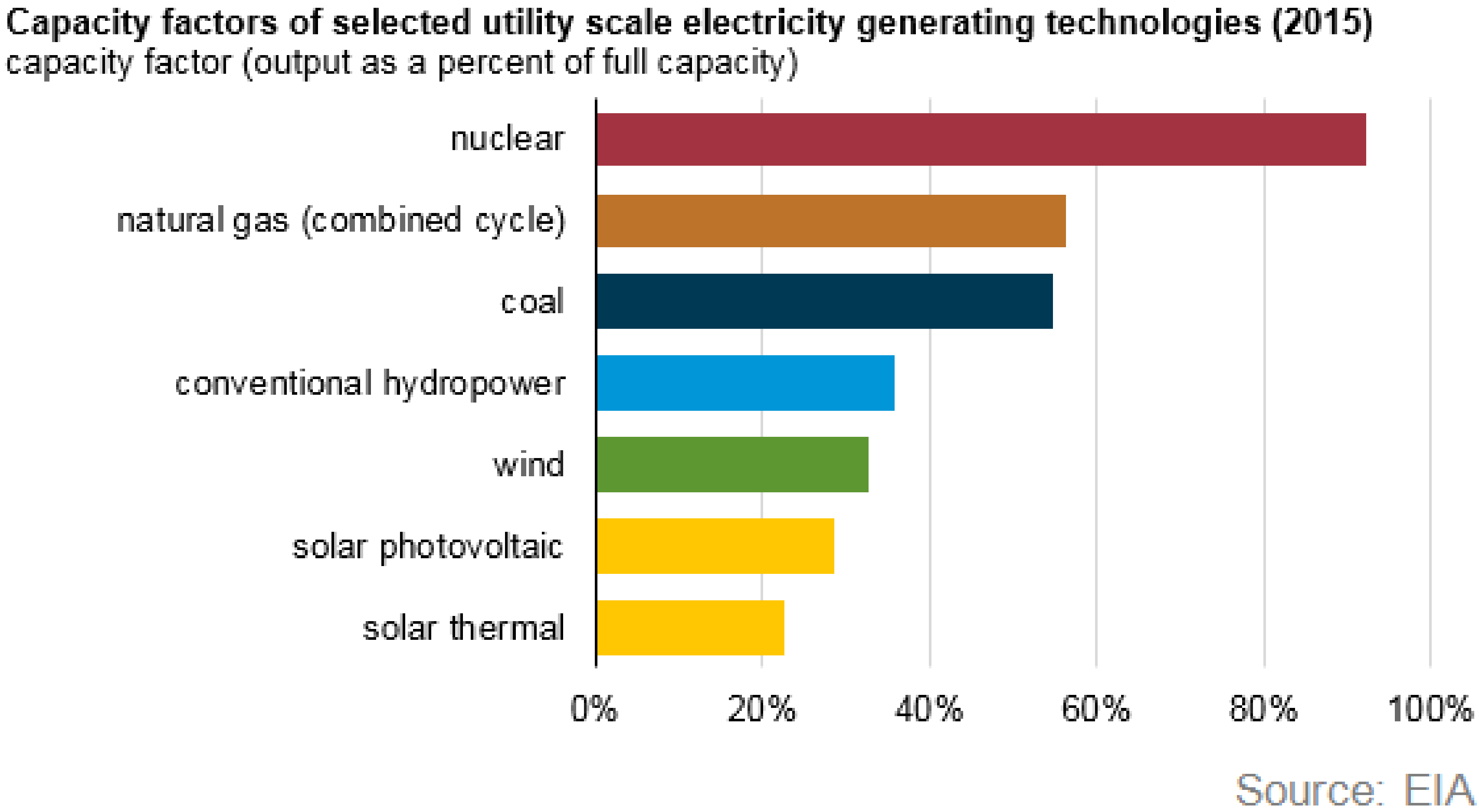
https://www.iea.org/data-and-statistics/charts/change-in-electricity-generation-by-source-2017-2018

Global electricity demand increased by 4%, about twice as fast as the overall demand for energy. **Together renewables & nuclear met a majority of the increase in power demand**.

However, electricity generation from coal and gas-fired power plants also rose to meet the increased demand for electricity, driving up CO_2 emissions from this sector by 2.5%.

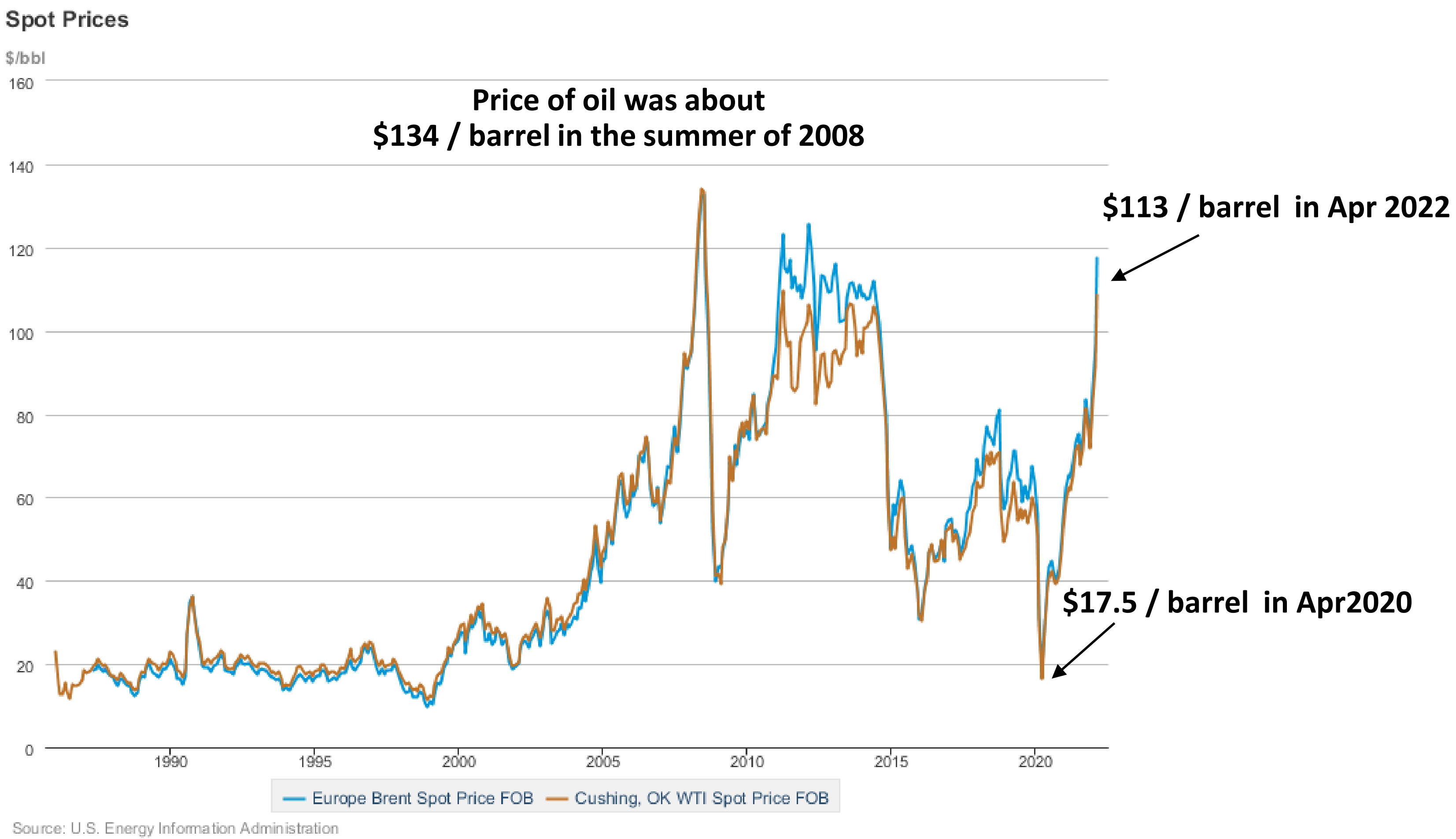
Half of the growth in global energy demand came from the power sector, in response to higher electricity consumption. ***About a fifth of the growth in electricity demand last year can be attributed to weather conditions*** :

- Demand for air-conditioning jumped during summer 2018, which ranked as the fourth hottest year on record.
- Likewise, colder-than-average winters in North America during 2018 increased electricity demand for heating.



https://marketrealist.com/2016/06/energy-sources-capacity-factor-capacity-additions

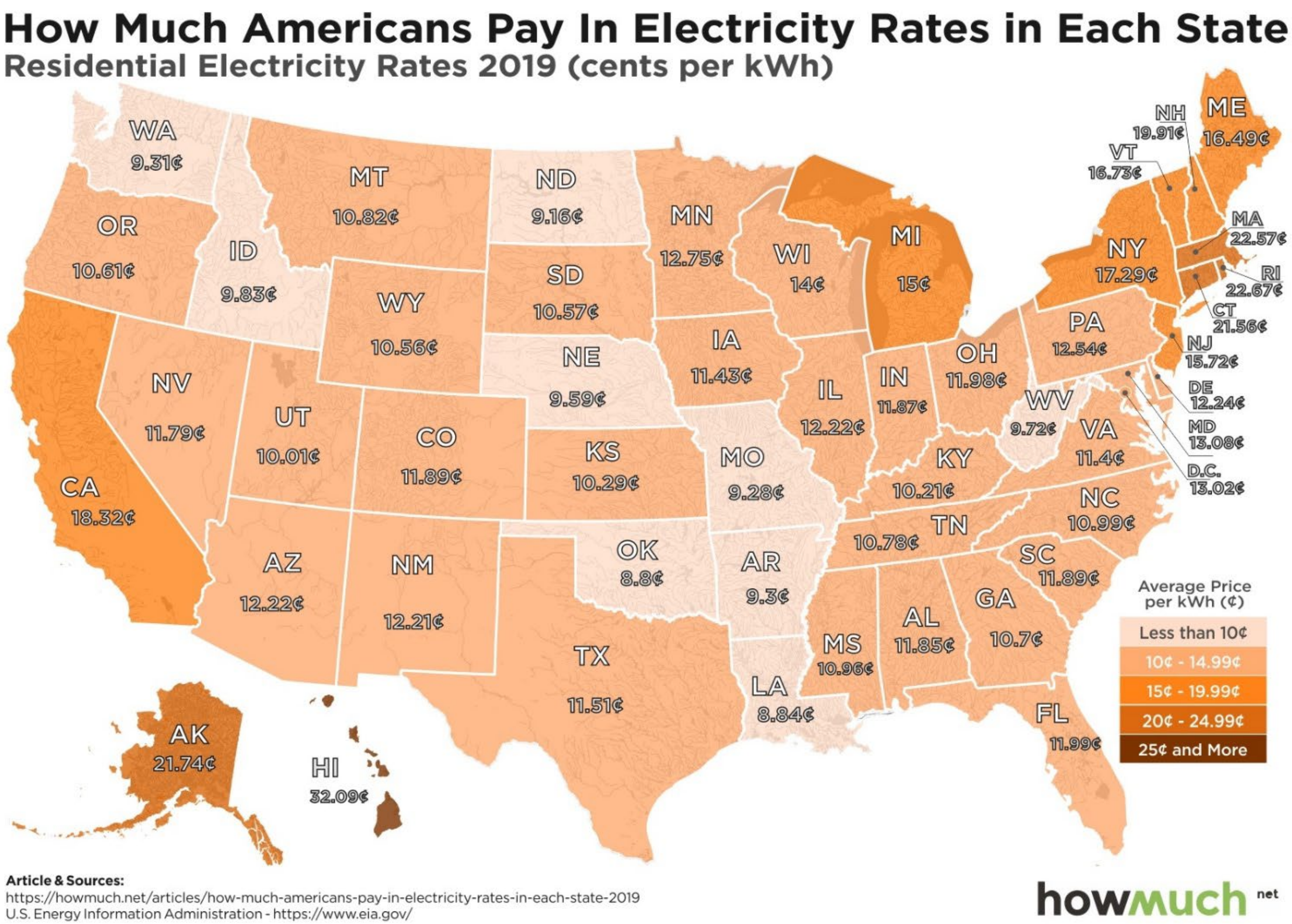
Market Force #1: Cost of Fossil Fuel



https://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm

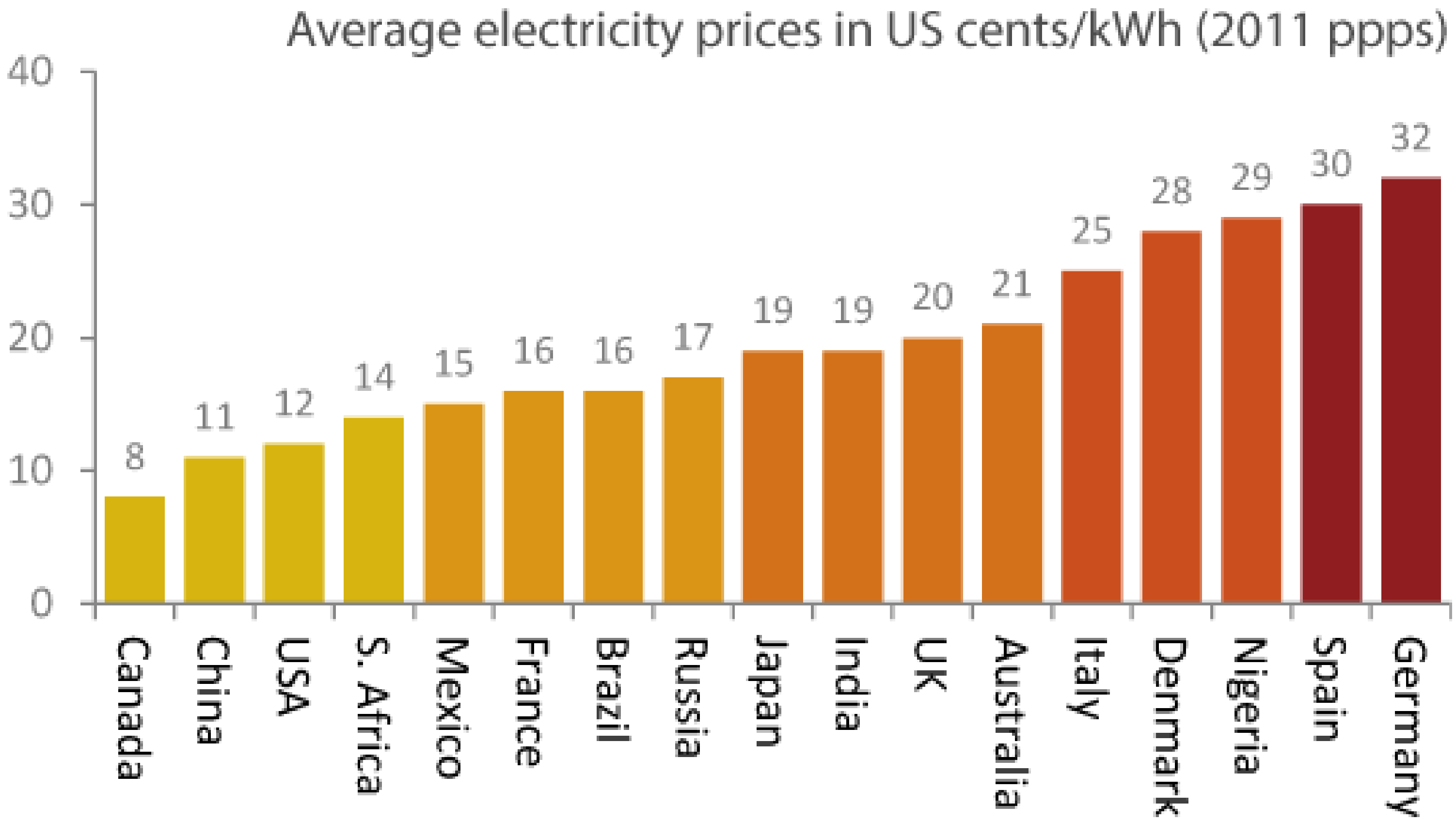
Market Force #2: Price of Electricity

U.S average residential retail price of electricity: 13 cents per kilowatt-hour in 2019



https://howmuch.net/articles/how-much-americans-pay-in-electricity-rates-in-each-state-2019
https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_03

Price of Electricity Varies A Lot Internationally



ppps: purchasing power parities

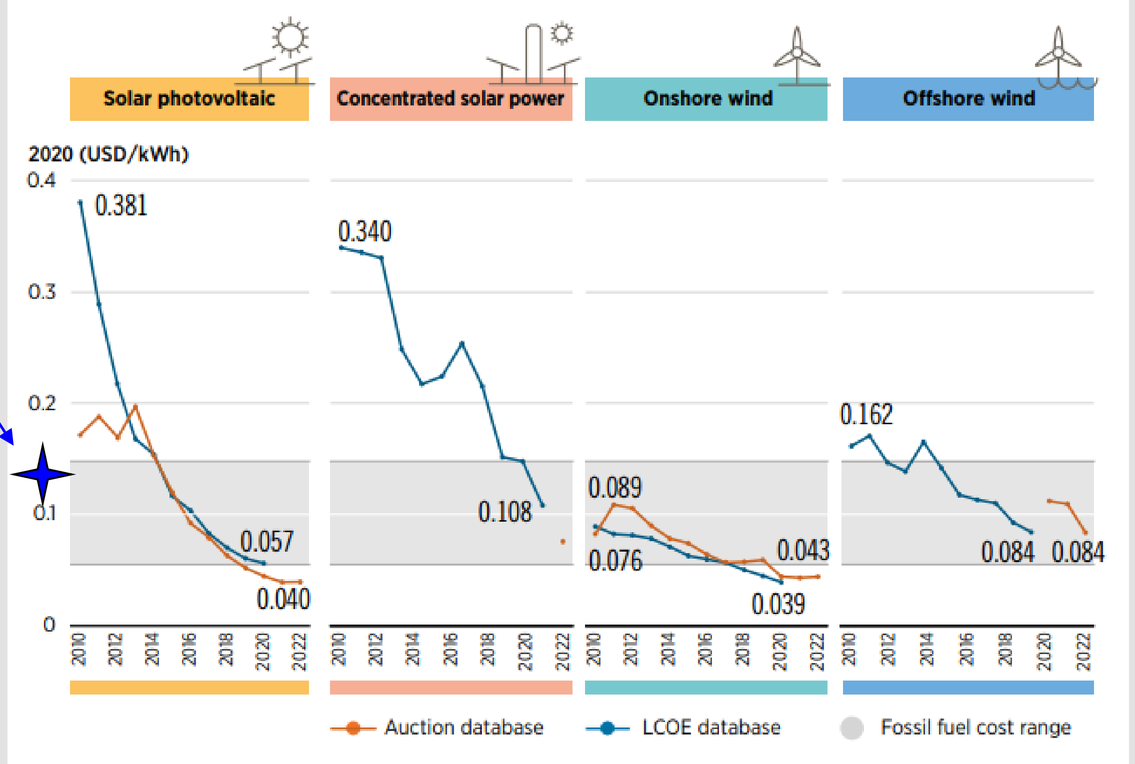
http://theenergycollective.com/lindsay-wilson/279126/average-electricity-prices-around-world-kwh

Market Force #3: Cost of Electricity from Renewables ↓

IRENA
International Renewable Energy Agency

2019 US Average Retail Cost of Electricity: ~13 cents per kw-hour

FIGURE 1.7 **The global weighted-average LCOE and PPA/auction prices for solar PV, CSP, onshore wind and offshore wind, 2010–2023**



https://www.irena.org/publications/2022/Mar/World-Energy-Transitions-Outlook-2022

4 Data for February 2022 futures contracts.

Good news: solar and wind are cost competitive with fossil fuels!
Bad news: solar and wind require large up-front costs.

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

Hydro

- World's largest renewable energy source for production of electricity
  - 17% of world's electricity needs
  - Nearly 100% of electricity in Norway, Uruguay, and Paraguay
  - Canada: nearly 50% US: ~7% in 2005 as well as today
- Technology very mature
- Only ~20% of world overall potential being tapped

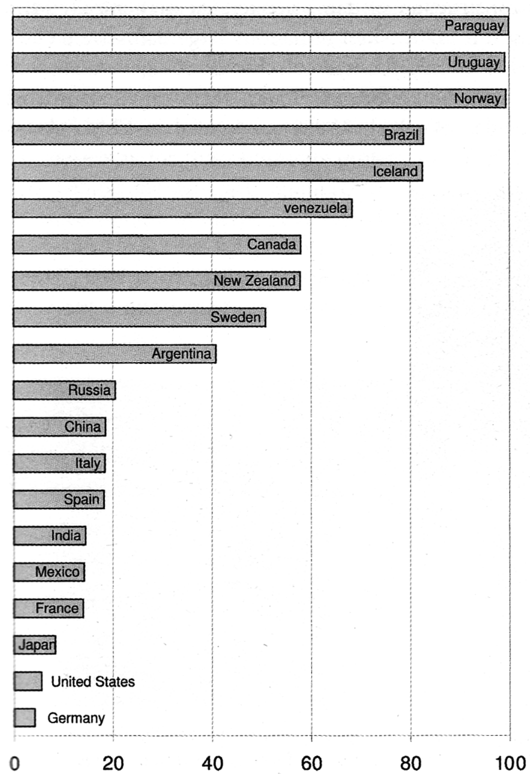


Figure 8.2 Percentage of electricity produced from hydropower in different countries. (Source: CIA World Factbook, December 2003.)

Hydro: 16 % of world electricity capacity

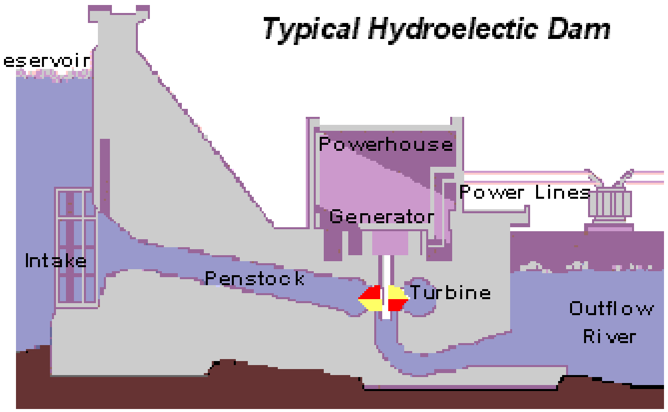
Total Source	GW (year 2020)
Coal	2154
Natural Gas	1662
Hydro-electric	**1162**
Solar	716
Wind	736
Nuclear	395
Liquid Fossil Fuel	297
Other Renewable (Biomass)	136
Geothermal	14
Total	7272

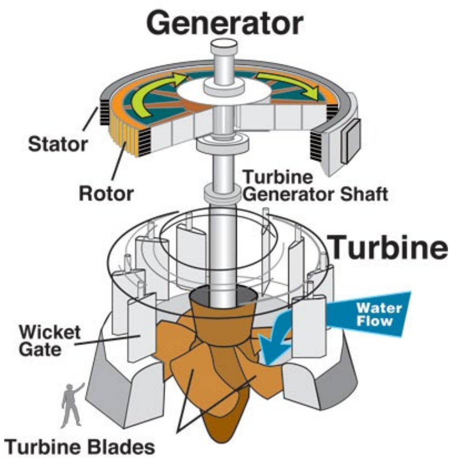
Olah *et al.*, *Beyond Oil and Gas: The Methanol Economy*, 2009.

Hydro

Environmental Ledger

- Positive:
  - No NO_x and SO_x during operation
  - CO_2 release only during construction (page 90, Olah et al.)





http://ga.water.usgs.gov/edu/hyhowworks.html

- Negative:
  - Flooding: **over 1 million people displaced by Three Gorge Dam**
  - Soil fertility: High Aswan Dam in Egypt has resulted in fertile silt collecting at bottom of Lake Nassar, necessitating use of 1×10^6 tons of fertilizer
  - GHG emissions from lost forest and decaying biomass under dammed water

    http://www.springerlink.com/content/k30639u4n8pl5266/

    http://www.newscientist.com/article.ns?id=dn7046

Hydro

GREENHOUSE GAS EMISSIONS FROM A HYDROELECTRIC RESERVOIR (BRAZIL'S TUCURUí DAM) AND THE ENERGY POLICY IMPLICATIONS

PHILIP M. FEARNSIDE
Department of Ecology, National Institute for Research in the Amazon (INPA), Av. André Araújo, 2936, C.P. 478, 69011-970 Manaus, Amazonas, Brazil

Brazil as a whole emitted 53×10^6 t of carbon annually from fossil fuels in 1990 (La Rovere, 1996). The 7.0–10.1 $\times 10^6$ t emission of CO_2-equivalent C from Tucuruí in 1990 therefore represents 13–19% of the fossil fuel emission from the entire 170 million Brazilian population. The Tucuruí emission is 1.3–1.9 times that of the fossil fuel burned by the 17 million population of Brazil's largest city, São Paulo (10% of Brazil's population).

The above-water wood that produced 25–36% of the emission from Tucuruí in 1990 will eventually disappear. The methane emission that makes up the remainder of the dam's global-warming impact will decline to a lower plateau, but a poorly quantified part of this will continue as a permanent source. A São Paulo-sized emission source may therefore be permanent. These impacts consider the 100-yr global warming potentials without discounting (currently used by the Kyoto Protocol); were discounting or other time-preference weighting mechanisms to be applied, the relative impact of hydroelectric dams could be higher than those calculated here by a factor of two or more (Fearnside, 1997a).

Water, Air, and Soil Pollution 133: 69–96, 2002.

– **GHG emissions from lost forest and decaying biomass under dammed water**

http://www.springerlink.com/content/k30639u4n8pl5266/

http://www.newscientist.com/article.ns?id=dn7046

Hydro

Typical coal plant: 670 MW
Typical nuclear plant: 1000 MW

Largest Capacities:

- Itaipú, Paraná River, South America: 14,000 MW
  - Built 1975 to 1991
  - Volume of iron and steel: enough to build 380 Eiffel Towers
  - Volume of concrete :15 × that of Channel Tunnel between France and England

Itaipú Dam, Paraguay/Brazil. The world's largest hydroelectric facility.
Credit: Itaipu Binacional

second

http://ga.water.usgs.gov/edu/hybiggest.html

- Three Gorges Dam, Yangtze River, China: 22,500 MW
  - Fully operational in 2012
  - Cost: $22.5 billion or 1 million $ / MW
  - Largest construction project in China since Great Wall
  - 1 million people displaced
  - In 2011, provided _____ of China's electricity demand

Source: http://en.wikipedia.org/wiki/Three_Gorges_Dam

Hydro

Annual Production of Electricity, Three Gorges Dam

Year	Number of installed units	TWh
2003	6	8.607
2004	11	39.155
2005	14	49.090
2006	14	49.250
2007	21	61.600
2008	26	80.812
2009	26	79.470
2010	26	84.370
2011	29	78.290
2012	32	98.100
2013	32	83.270
2014	32	98.800
2015	32	87.000
2016	32	93.500
2017	32	97.600
2018	32	101.600
2019	32	96.880
2020	32	111.800
2021	32	103.649

Size (power) of all 32 units is 22,500 MW

If Three Gorges could run at full capacity for 24/365:
22,500 MW x 8760 hr = 1.97 x 10^8 MWh =
1.97 x 10^8 MWh x TWh/(10^6 MWh) =
197 TWh output per year

Therefore, the Capacity Factor of Three Gorges Dam is 97.2 TWh / (197 TWh) = 0.49

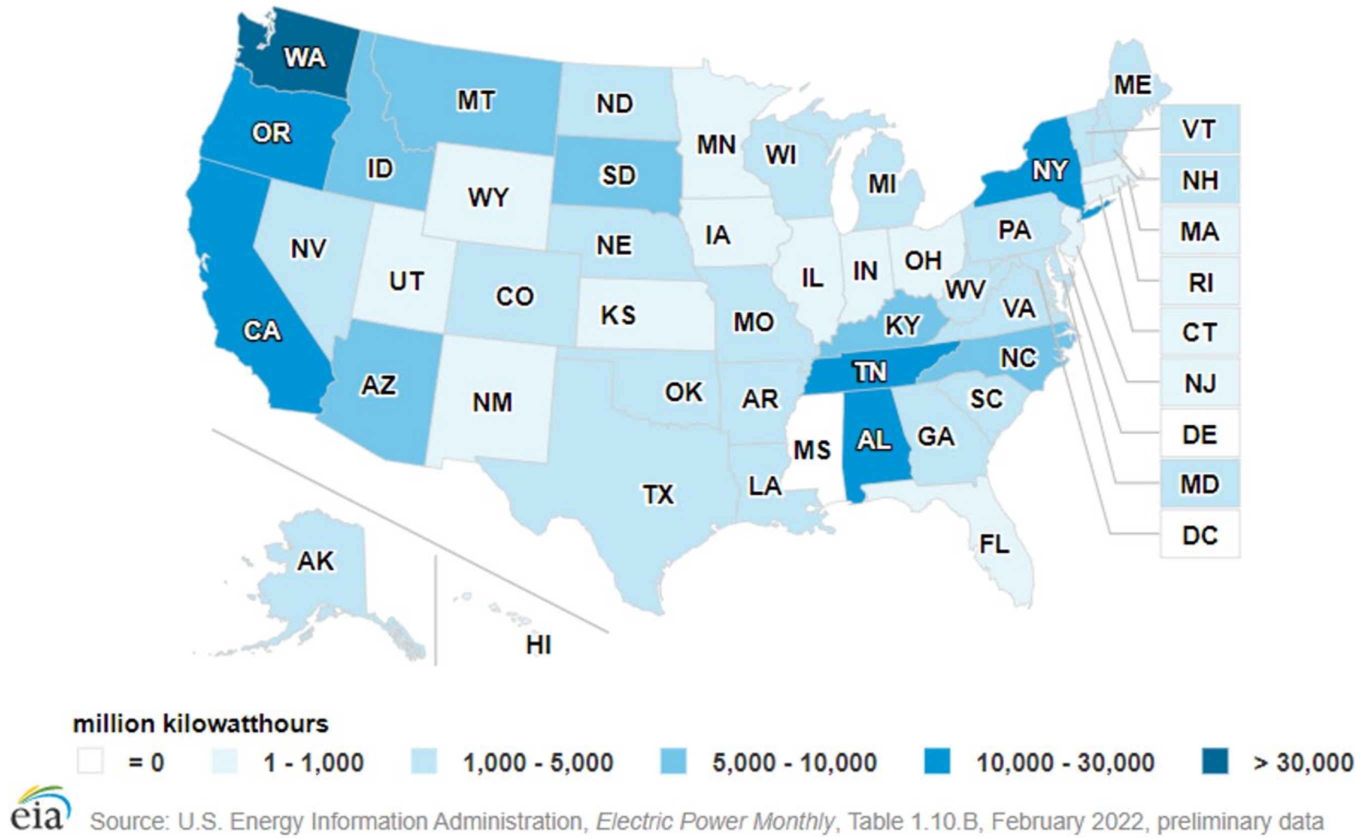
In 2012, the Three Gorges Dam in China took over the #1 spot of the largest hydroelectric dam (in electricity production), replacing Itaipú hydroelectric power plant in Brazil & Paraguay.

Three Gorges Dam has a generating capacity of 22,500 megawatts (MW) compared to 14,000 MW for the Itaipú Dam.

But, over a year-long period, both dams generate about the same amount of electricity because *seasonal variations in water availability on the Yangtze River in China limit power generation at Three Gorges Dam for a number of months during the year*.

Source: http://en.wikipedia.org/wiki/Three_Gorges_Dam

Hydroelectricity Generation By States, 2021



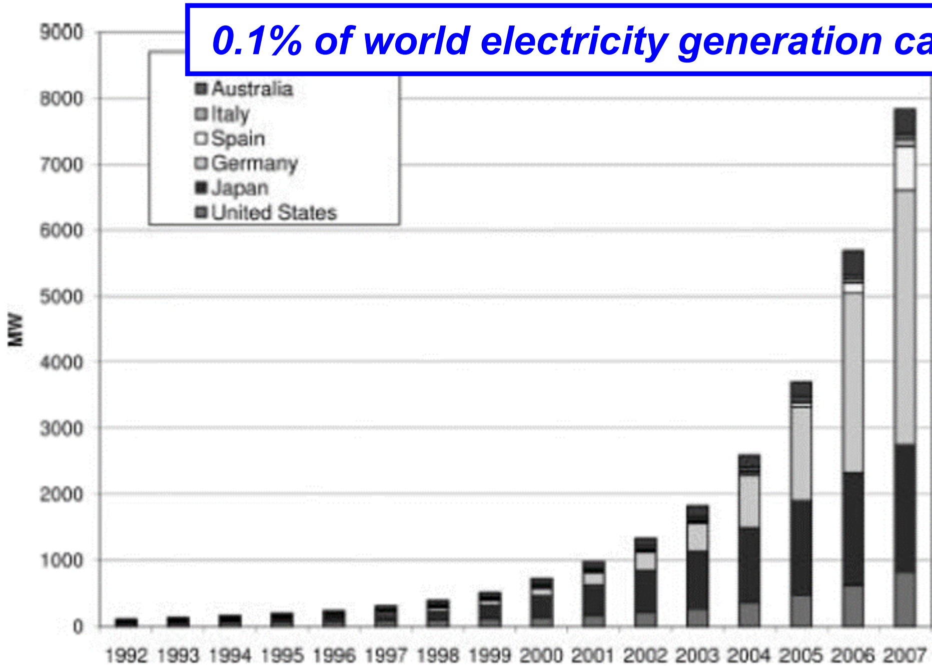
- About half of the total U.S. hydroelectric capacity for electricity generation concentrated in three States: Washington (27%), California (13%), and Oregon (10%)
- Largest hydroelectric facility is Grand Coulee Dam, in Washington

https://www.eia.gov/energyexplained/hydropower/where-hydropower-is-generated.php

Solar PV

- Sun delivers about 10,000 times more energy than world consumption
- Photovoltaic: converts solar energy into electricity
  - photovoltaic effect: Nobel Prize in 1921 went to __________
  - solar cells developed in 1960s for military and satellites
  - crystals from silicon, cadmium, copper, arsenic, etc
  - efficiency increased from 15% in mid-1970s to ~25% today
- PV capacity increased **30% per year from 1997 to 2007**:

0.1% of world electricity generation capacity



Year	Solar MW
2005	**5,681**
2010	40,070
2015	224,860
2020	**716,000**

10% of world electricity generation capacity 009.

Solar PV Efficiency

A second challenge is that the direct conversion of sunlight into electricity is not very efficient. A photovoltaic cell could, in principle, transform up to 31% of the radiant energy to which it is sensitive into electricity.

Page 357, *Chemistry in Context*

- Known as the Shockley–Queisser limit due to pioneering study by William Shockley and Hans-Joachim Queisser in 1961.
- Refers to the maximum theoretical efficiency of a solar cell using a ***single p-n junction***.
- Energy limit due to:

Physics: Absorption of a photon creates an electron-hole pair, which could potentially contribute to the current. However, the reverse process must also be possible; an electron and a hole can meet and recombine, emitting a photon

Radiation: At least about 7% of the incoming energy will be converted to heat and radiated

Enthalpy: Since moving an electron from the valence band to the conduction band requires energy, only photons with more than that amount of energy will produce an electron-hole pair. Simply put, a single junction will be preferentially tuned to photons of a specific wavelength; more energetic light can contribute (albeit, with diminished efficiency) whereas less energetic light not displace any electrons.

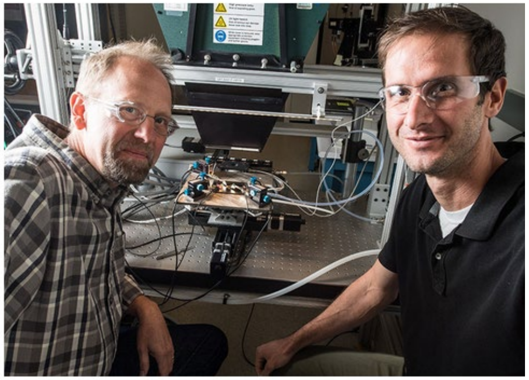
https://en.wikipedia.org/wiki/Shockley–Queisser_limit

Solar PV Efficiency

Six-junction III–V solar cell with 47.1% efficiency

A U.S. research group has developed a new solar cell, based on six active photoactive layers, to capture light from a specific part of the solar spectrum. The scientists claim that they could potentially reach a 50% efficiency rate with the new cell.

APRIL 14, 2020 **EMILIANO BELLINI**



NREL scientists John Geisz (left) and Ryan France.

Researchers from the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) have developed a six-junction III–V solar cell with a 47.1% conversion efficiency rate under 143 Suns concentration.

They said that they have achieved an efficiency rate of 39.2% under one-sun illumination. The cell is based on six different photoactive layers fabricated with alloys of III–V semiconductors, which can each capture light from a specific part of the solar spectrum.

"The device contains about 140 total layers of various III-V materials to support the performance of these junctions, and yet is three times narrower than a human hair," the scientists said.

https://www.pv-magazine.com/2020/04/14/six-junction-iii-v-solar-cell-with-47-1-effiency/

Solar PV Efficiency

Material	Laboratory Efficiency	Production Efficiency
Monocrystalline Silicon	24 %	14 to 17 %
Polycrystalline Silicon	18 %	13 to 15%
Amorphous Silicon	13 %	5 to 7 %

Efficiency Limited By:

Spectral range of effective photons (depends on material used)

Surplus energy transformed into heat

Optical losses from shadowing and/or reflection

https://web.archive.org/web/20170728233529/http://www.solarserver.com/knowledge/basic-knowledge/photovoltaics.html

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

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)

Solar output for 2008 to 2020: **1,531 GWh** (energy, or power × time)

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

Capacity Factor = 1,531 GWh x 1000 MW/GW / (64 MW x 8760 h/yr x 13 yrs) = **0.21**

Nevada Solar One

Output: 64 MW capacity; **covers 1.6 km^2**

Could supply all of US electricity needs in 2021 if built over a 144 mile × 144 mile area

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

Generation (MW·h) of Nevada Solar One

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

Note: 1 GWh = 1000 MWh

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
2019	110.24	n.a.	n.a.
2020	107.37	n.a.	n.a.

Solar output peaked in 2017 and has since dropped

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.

Ivanpah

Project capacity: **392 MW** (power = energy / time)

Project output for 2014 to 2020: **4,919,755 MWh** (energy, or power × time)

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

Capacity Factor = 4,919,755 MWh / (392 MW x 8760 h/yr x 7 yrs) = **0.20**

Net electricity production (all) [MWh]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Sun	NG	Total
2014	10,485	9,630	19,959	24,833	44,784	64,275	35,967	44,070	43,751	56,013	47,177	18,141	**419,085**	**0**	**419,085**
2015	21,888	30,273	57,090	75,304	47,956	77,534	61,681	72,806	66,147	36,971	60,474	44,998	**627,161**	**25,961**	**653,122**
2016	25,439	67,254	58,409	38,449	43,436	65,721	98,849	65,631	82,215	61,312	62,052	34,272	**670,575**	**32,464**	**703,039**
2017	38,305	33,828	50,642	40,589	87,013	97,677	66,664	67,642	75,241	77,805	40,801	43,931	**686,899**	**33,239**	**720,138**
2018	48,873	43,963	59,181	62,060	76,438	115,737	63,197	78,754	91,706	62,396	57,871	35,860	**761,489**	**34,367**	**795,856**
2019	35,211	27,203	48,252	59,345	64,707	101,999	97,520	101,399	72,734	84,848	53,478	25,518	**739,481**	**32,733**	**772,214**
2020	35,348	41,830	33,378	66,895	107,822	96,616	113,893	101,134	86,025	81,562	58,688	33,110	**815,817**	**40,484**	**856,301**
Total													**4,720,507**	**199,248**	**4,919,755**

Ivanpah was advertised as designed to produce 940,000 MWh of electricity per year, based on its nameplate capacity and assumed capacity factor.[85] In its second year of operation, Ivanpah's production of 653,122 MWh of net electricity was 69.5 percent of this value, ramping up from 44.6 percent in the first year. The commissioning of a new thermal plants requires up to four years to achieve 100% operating level, from the first grid connection to full production.[86] In its seventh year (2020), the annual production was 91.1% of its advertised value.

https://en.wikipedia.org/wiki/Ivanpah_Solar_Power_Facility

Ivanpah

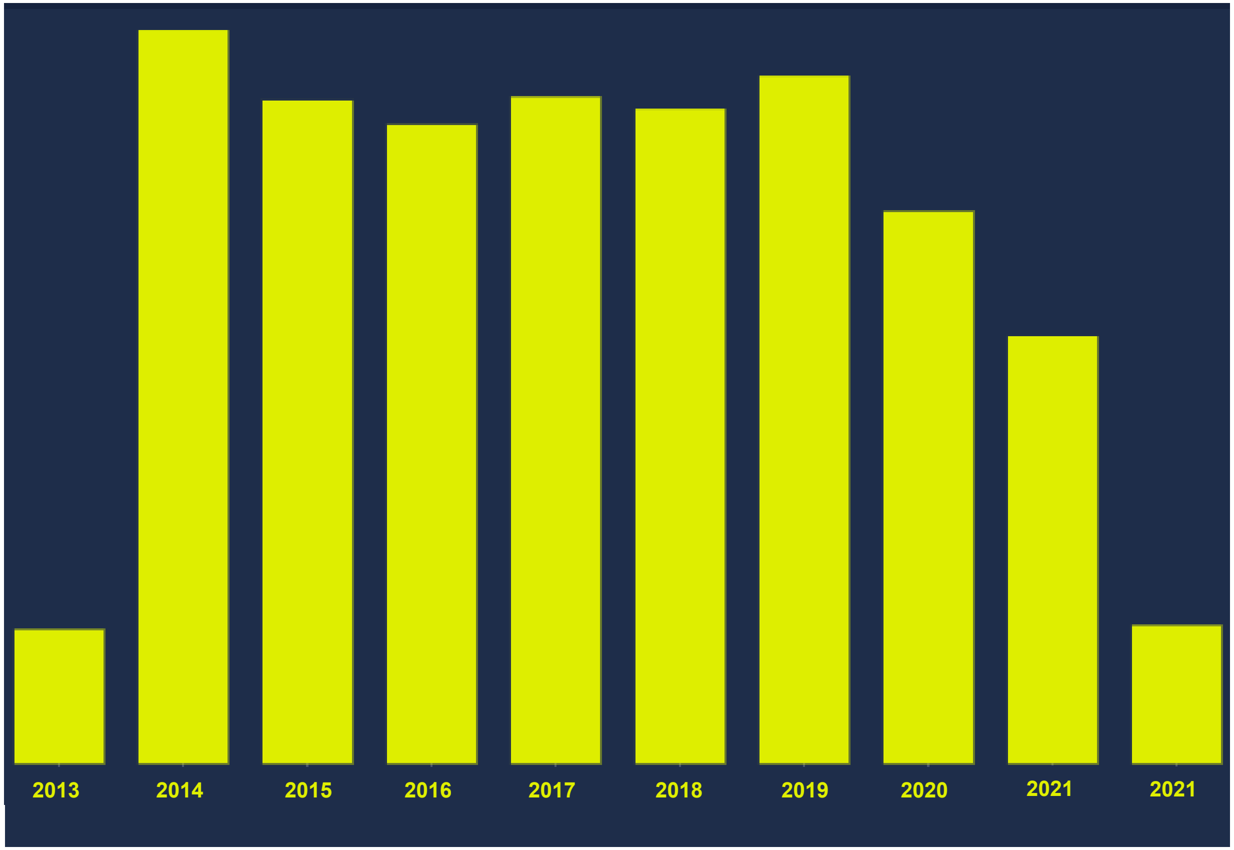
Output: 392 MW capacity

Could supply all of US electricity needs in 2019
if built over a 176 mile × 176 mile area

Construction cost: ~$48 / kW-hr for one yr's prod

Fossil backup, night time preservation, and morning pre-heating, is provided by natural gas and provides up to 4% of total output.

Solar: University Park Elementary School



http://kiosk.datareadings.com/elkWdi6e/overview?granularity=total&slideshow=true

Capacity Factor:

Actual Output / Theoretical Output Nonstop Operation =

64.8 kW x (76 + 8 x 365 + 110) days x 24 hrs / day= 4.83 x 10^6 kWh = 4830 MWh =

569 MWh / 4830 MWh = **0.12**

Solar Energy

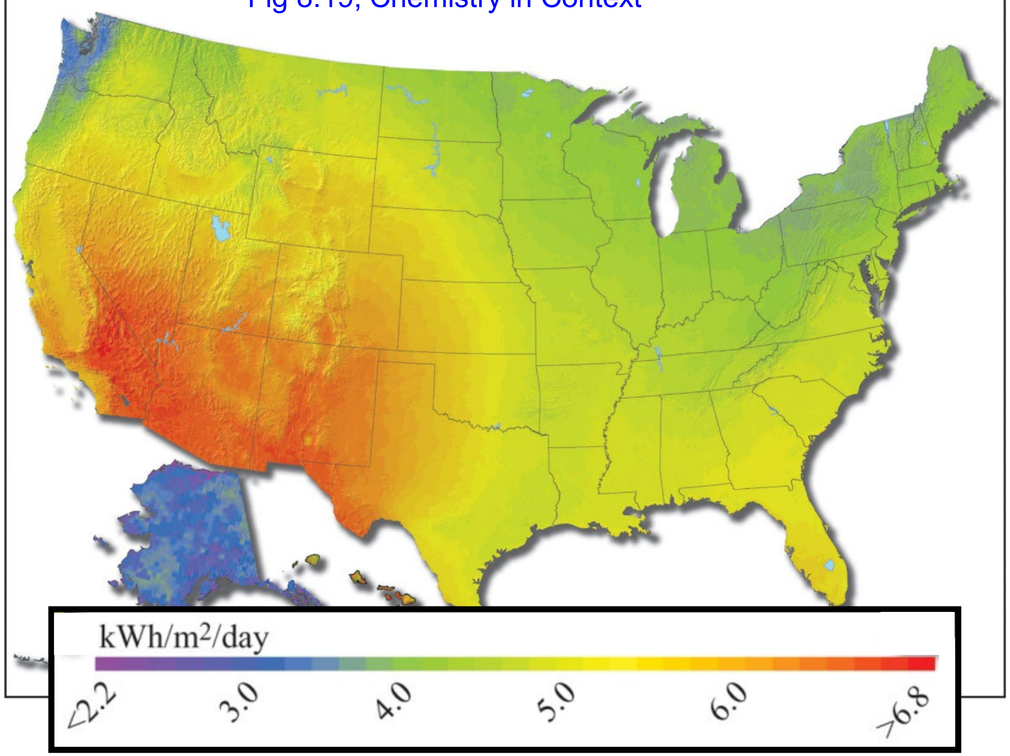
At currently attainable levels of operating efficiency, the electricity needs of the United States have been estimated to require a photovoltaic generating station covering an area of 136 x 136 km, roughly the size of New Jersey.

Page 358, *Chemistry in Context*

Using the current solar technology, an area of 160 x 160 km in this region [the Mojave Desert] could generate as much electricity as the entire U.S currently consumes.

Page 123, *Olah et al.*

Fig 8.19, Chemistry in Context



Olah et al. state:

On a ***perfectly clear day***, Earth receives about 1000 W m^{-2} at noon

In the U.S., the highest *daily* solar insolation is about 6800 Wh m^{-2} or 6.8 kWh m^{-2}

Let's assume 5 kWh m^{-2}

In 2021, U.S. used 3795×10^9 kWh of electricity

https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_01

Would need an area of:

$\{3795 \times 10^9 \text{ kWh} / (5 \text{ kWh m}^{-2} \times 365)\}^{1/2}$ = 46 km by 46 km

if we could capture the full 5 kWh m^{-2}

Area needed becomes about 5 times as large, or 100 km x 100 km with 21% capacity factor

Nevada Solar One / US Electricity Needs

US Electricity Consumption in 2021: 3795×10^9 MWh x GWh / 1000 MWh = 3795×10^6 GWh

https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_01

Nevada Solar One annual output averaged over past 5 years: **112.6 GWh**

Nevada Solar One size = 1.6 km^2

To meet total U.S. electricity demand, would need an area of:

(3796 x 10^6 GWh / 112.6 GWh) x 1.6 square km = 5.4 x 10^4 square km

(5.4 x 10^4 square km)$^{1/2}$ = 232 km by 232 km (or 144 miles by 144 miles)

Cost

US Electricity Consumption in 2021: 3795×10^9 MWh x GWh / 1000 MWh = 3795×10^6 GWh

https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_01

Nevada Solar One annual output averaged over past 5 years: **112.6 GWh**

Nevada Solar One size = 1.6 km^2

To meet U.S. Energy Needs, would need an area of:

$(3796 \times 10^6$ GWh / 112.6 GWh$) \times 1.6$ square km = 5.4×10^4 square km

$(5.4 \times 10^4 \text{ square km})^{1/2}$ = 232 km by 232 km (or 144 miles by 144 miles)

Cost: \$2 / KWh x 3795 TWh x (10^9 KW/TW) = \$ 7.6×10^{12} or **\$7.6 trillion dollars**

Wind

- Fastest growing renewable resource: 30% per year from 1992 to 2007

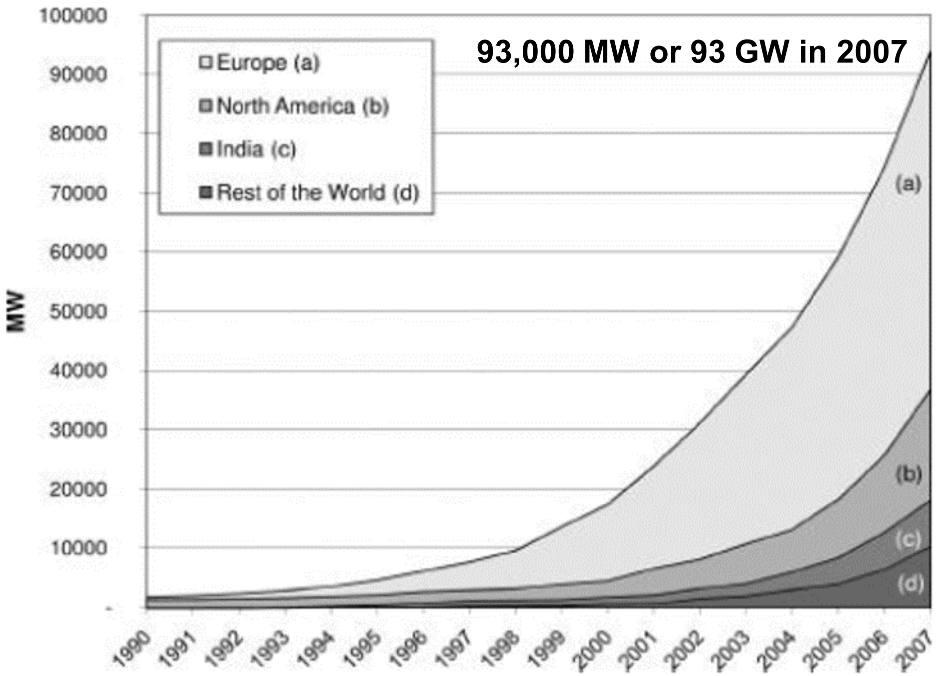


Figure 8.8 World wind power installed capacity. (Source: Global Wind Energy Council, European Wind Energy Association, IEA.)

Total Source	GW (year 2020)
Coal	2154
Natural Gas	1662
Hydro-electric	1162
Solar	716
Wind	**736**
Nuclear	395
Liquid Fossil Fuel	297
Other Renewable (Biomass)	136
Geothermal	14
Total	7272

- Germany: 44,470 MW capacity, generating 13.3% of country's electricity in 2015
  - Europe dominates wind energy turbine market
- Turbine capability has increased dramatically past 20 years:
  - Went from 20 m diameter generating 20-60 kW to 100 m diameter generating 2 MW

About 10% of world electricity production capacity right now

Wind Power Potential, World

- Wind power varies as [Wind Velocity]^3 :
  - Betz law: http://en.wikipedia.org/wiki/Betz%27_law
  - Installation benefits from accurate knowledge of wind fields

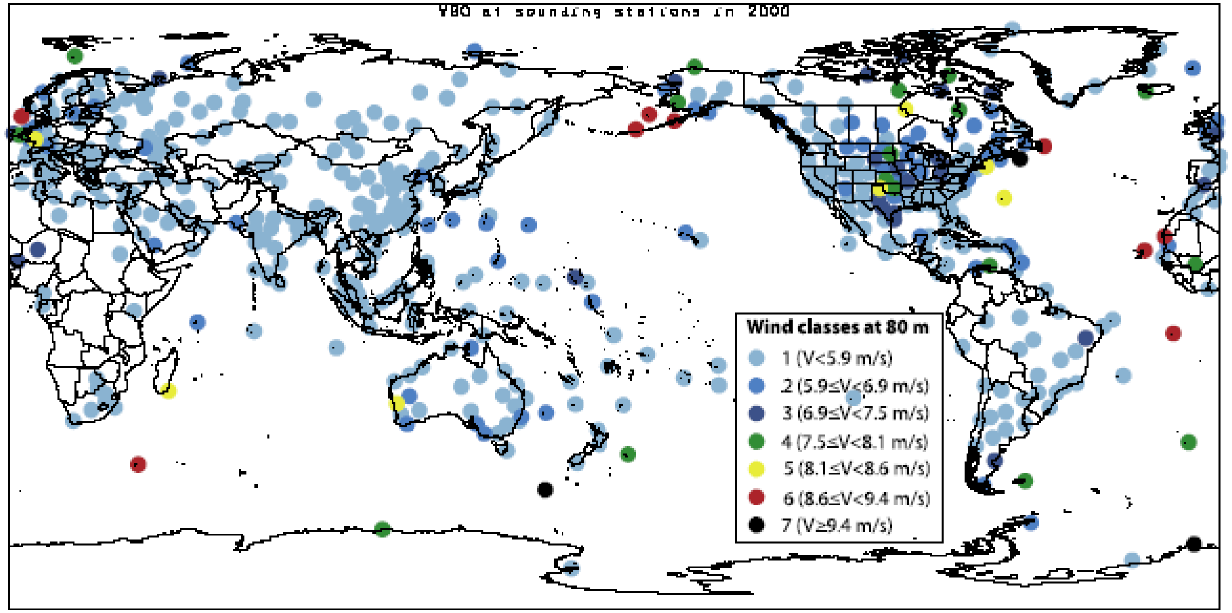


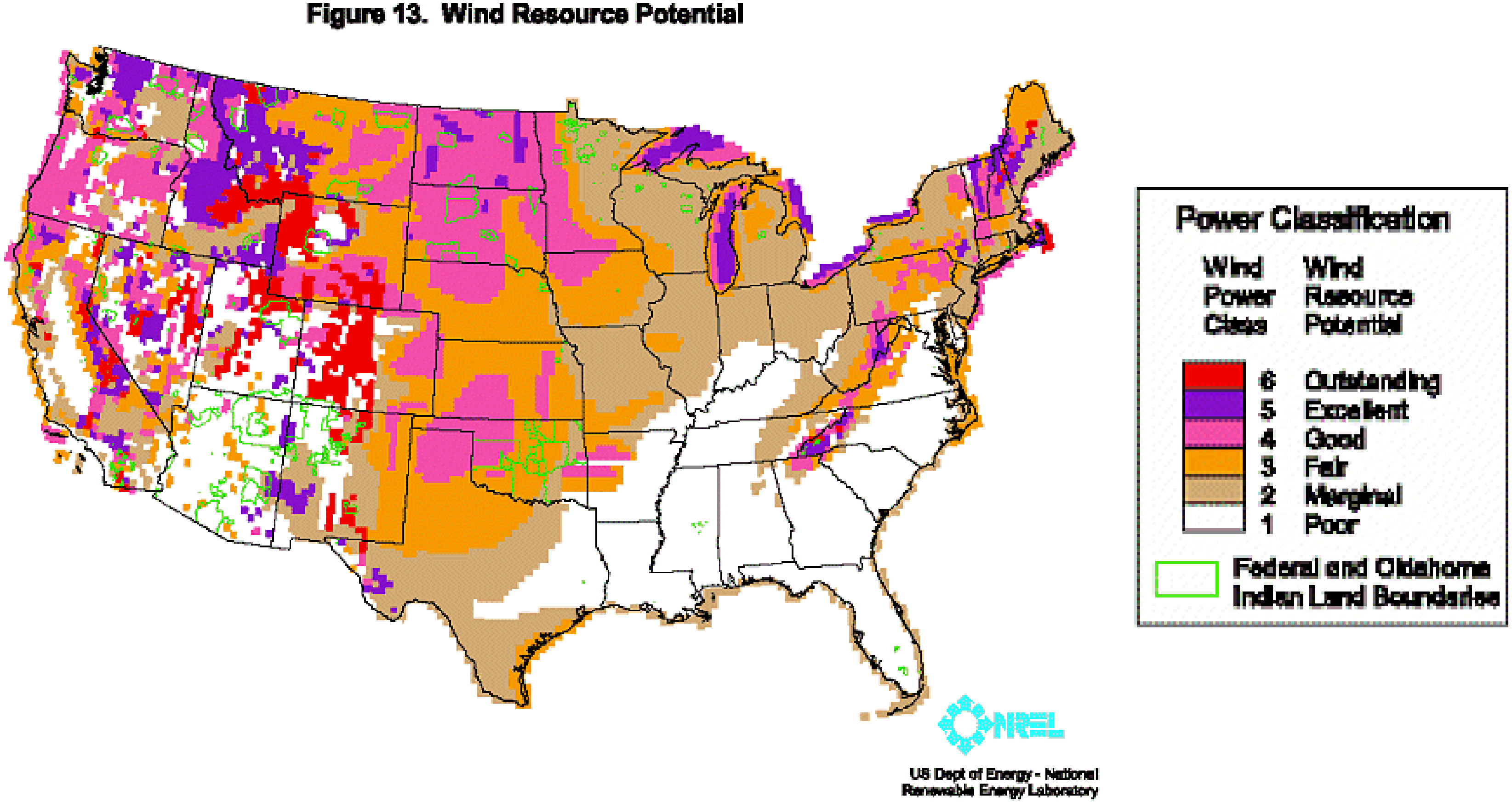
Figure 2. Map of wind speed extrapolated to 80 m and averaged over all days of the year 2000 at sounding locations with 20 or more valid readings for the year 2000.

Archer and Jacobson, *JGR*, 2006

- Potential electricity generation from "sustainable Class 3 winds" is 72 Terawatts!
- Installation of ~5 Terawatts (current global electricity capacity) requires harnessing only a fraction of this potential with current turbine technology

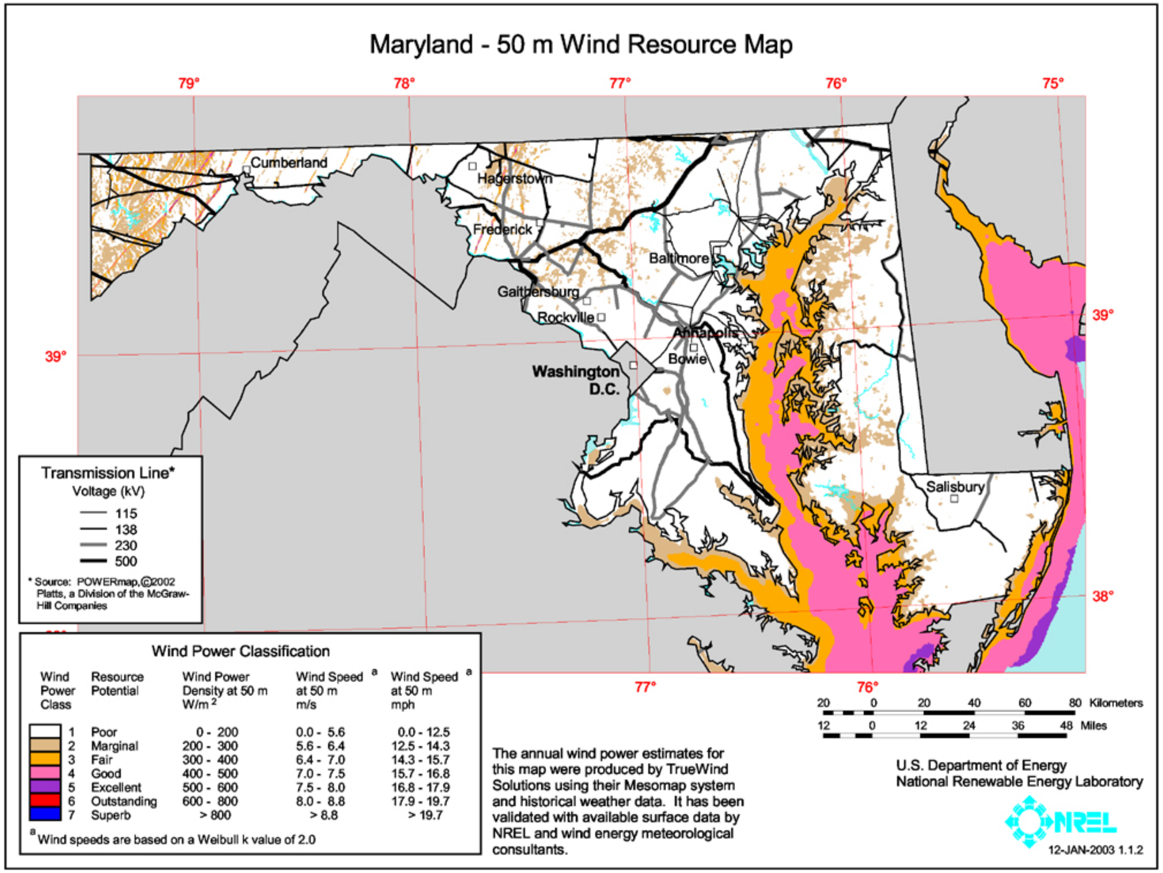
Wind

- Wind power varies as [Wind Velocity]^3 :
  - Betz law: http://en.wikipedia.org/wiki/Betz%27_law
  - Installation benefits from accurate knowledge of wind fields



http://www.eia.gov/cneaf/solar.renewables/ilands/fig13.html

Wind Power Potential, Maryland



http://www.eere.energy.gov/windandhydro/windpoweringamerica/images/windmaps/md_50m_800.jpg

Wind Power, Pros & Cons

Environmental Ledger

- Positive:
  - No emissions
  - Land on wind farm can be used for agriculture or livestock

- Negative:
  - Lightning strikes, turbine break / failure, or leaking fluid can lead to fire
  - Long-term performance of turbines not well established
  - Public resistance to visual impact or noise:

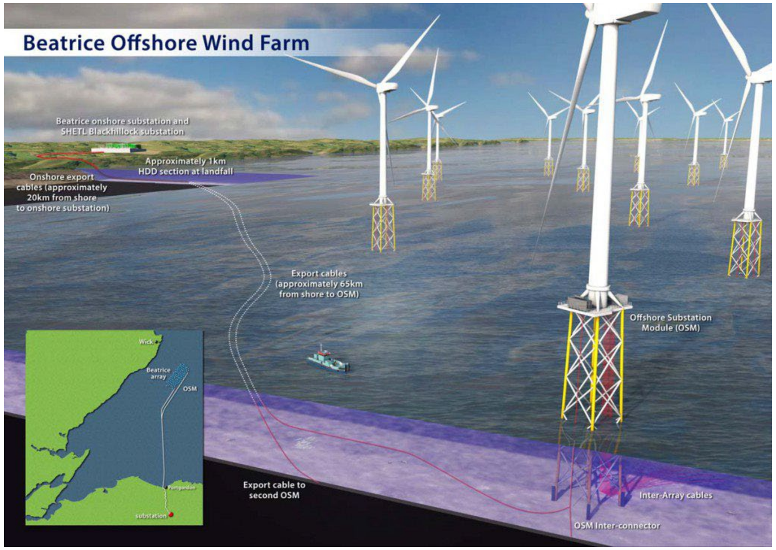
    June 29, 2003 - After a wind project was proposed several miles off the coast of Cape Cod, some environmentalists raised objections, as did U.S. Senator Ted Kennedy who owns a summer home in the area

    http://www.cbsnews.com/stories/2003/06/26/sunday/main560595.shtml

Offshore Wind, Scotland

List of countries by cumulative installed offshore wind power capacity (MW)

Rank	Country	2016[12]	2017[12]	2018[12]	2019[13]	2020[147][14]	2021[148]
1	China	1,627	2,788	4,588	6,838	9,996	19,747
2	United Kingdom	5,156	6,651	7,963	9,723	10,428	12,281
3	Germany	4,108	5,411	6,380	7,493	7,689	7,701



https://en.wikipedia.org/wiki/Offshore_wind_power

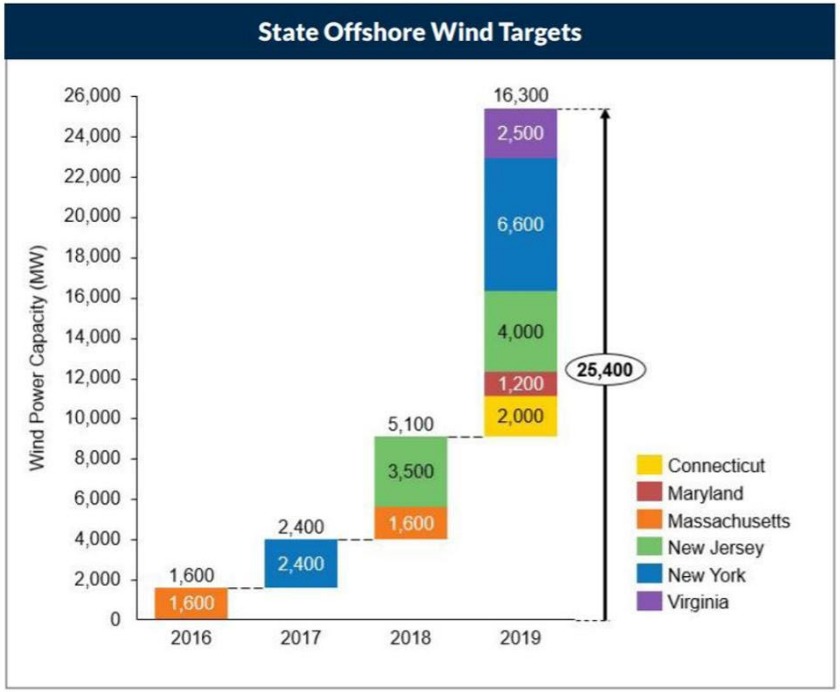
https://www.offshorewindindustry.com/sites/default/files/field/image/offshoreb_beatrice_offshore_wind_farm.jpg

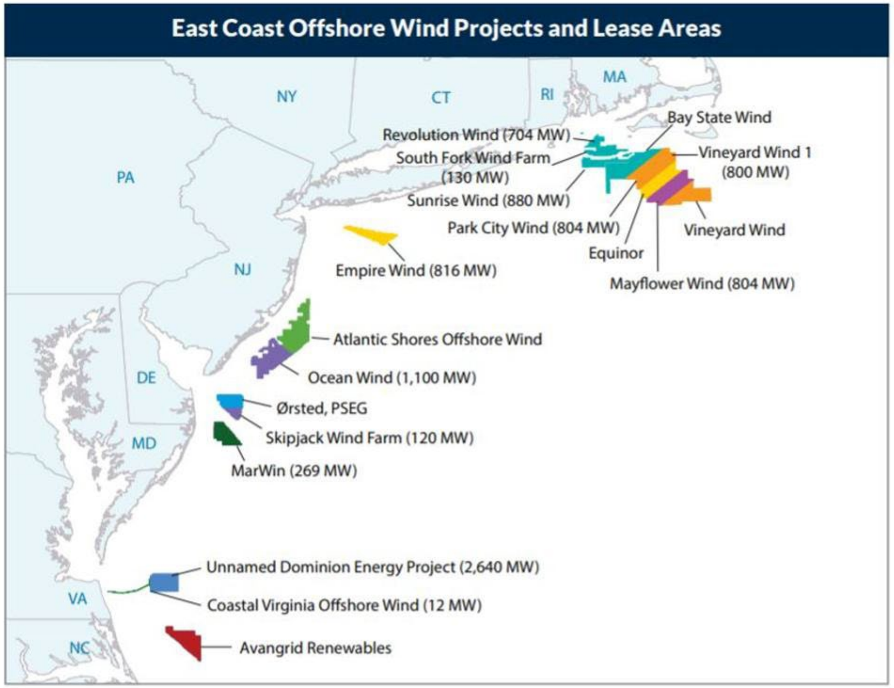
Offshore Wind, U.S.

Mar 24, 2020, 07:30am EDT

Four Federal Policies Could Help Offshore Wind Jump Start Our Coronavirus Economic Recovery

Silvio Marcacci Contributor





https://www.forbes.com/sites/energyinnovation/2020/03/24/these-federal-policies-could-help-offshore-wind-jump-start-americas-economic-recovery/#132693e578cc

Offshore Wind, MD

Offshore Wind in Maryland!

Initial phase completed for Maryland's first offshore wind staging centre

By: Tom Russell In: Windfarms 17/03/2021 Skipjack Wind Farm

Ørsted has announced the completion of the initial phase of Maryland's first offshore wind staging centre at Tradepoint Atlantic, the 3,300-acre global logistics centre in Baltimore County, Maryland.

Ørsted has now completed $13.2 million in port infrastructure upgrades, establishing a lift-on/lift-off and a roll-on/roll-off berth within Tradepoint Atlantic's port facility for handling offshore wind components such as wind turbine blades, foundations, nacelles, and towers. This includes strengthening the ground bearing capacity at the port to allow heavy-lift cranes and specialised transporters to move wind turbine components, some weighing as much as 2,000 tons, from ships onto the site. Ørsted provided funding to drive hundreds of heavy steel pilings over 150 feet into the ground so that these heavy components can be safely handled.

Ørsted and Tradepoint Atlantic are now beginning preparations for the second phase of the staging centre, which is the development of 50 additional acres of land for the laydown, storage, and assembly of offshore wind components.

https://www.4coffshore.com/news/initial-phase-completed-for-maryland92s-first-offshore-wind-staging-centre-nid21174.html

Offshore Wind, MD

Offshore Wind in Maryland!

Initial phase completed for Maryland's first offshore wind staging centre

"Tradepoint Atlantic is a world-class Maryland asset with a storied legacy of serving the needs of the United States and the world," said Governor of Maryland, Larry Hogan. *"This Baltimore institution is once again positioned to serve as a critical piece in supporting our country's clean and renewable energy transformation for generations to come. Now is the time to invest in the kind of infrastructure that supports the development of new industries—like offshore wind—and the creation of thousands of new jobs. Ørsted has an established track record as the global leader in this noble effort, and we're proud to call them a partner in achieving our climate and renewable energy goals."*

The Skipjack project is a 120 MW offshore wind farm under development 19 miles off the Maryland-Delaware coast. It was awarded offshore wind renewable energy credits by the Maryland Public Service Commission in 2017 and is expected to generate enough energy to power 35,000 homes in the region.

The centre also advances Ørsted's commitment to create 1,400 jobs in Maryland as part of the Skipjack Wind Farm, including 913 jobs measured in full-time equivalents during development and construction and 484 jobs during operation.

https://en.wikipedia.org/wiki/Skipjack_Wind_Farm & https://en.wikipedia.org/wiki/Wind_power_in_Maryland

https://www.4coffshore.com/news/initial-phase-completed-for-maryland92s-first-offshore-wind-staging-centre-nid21174.html

Geothermal

- Temperature of source critical:
  - dry steam (T > 220°C) most profitable
  - hot water (150 to 300°C) can generate electricity using "flash steam" (depressurization and boiling)
  - low temperature (T < 150°C) used for heat (Iceland) or to extract H_2 from H_2O or fossil fuels

Where will favorable conditions for geothermal most likely be found?

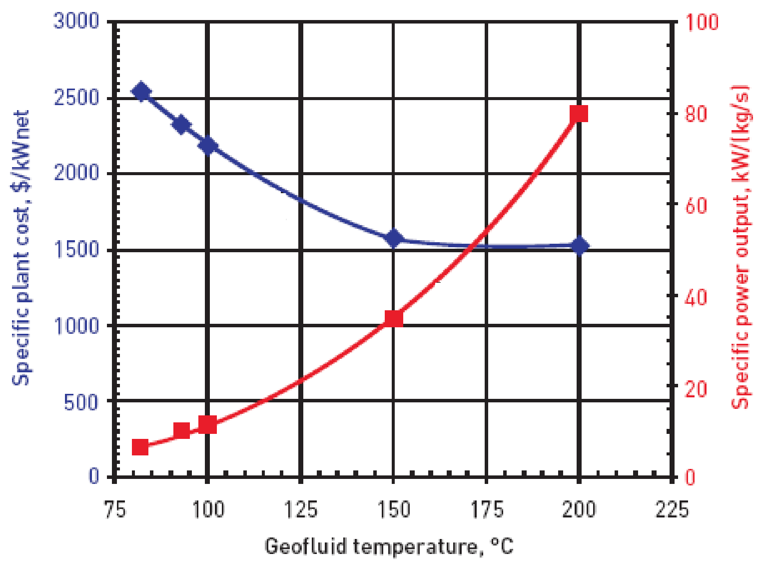
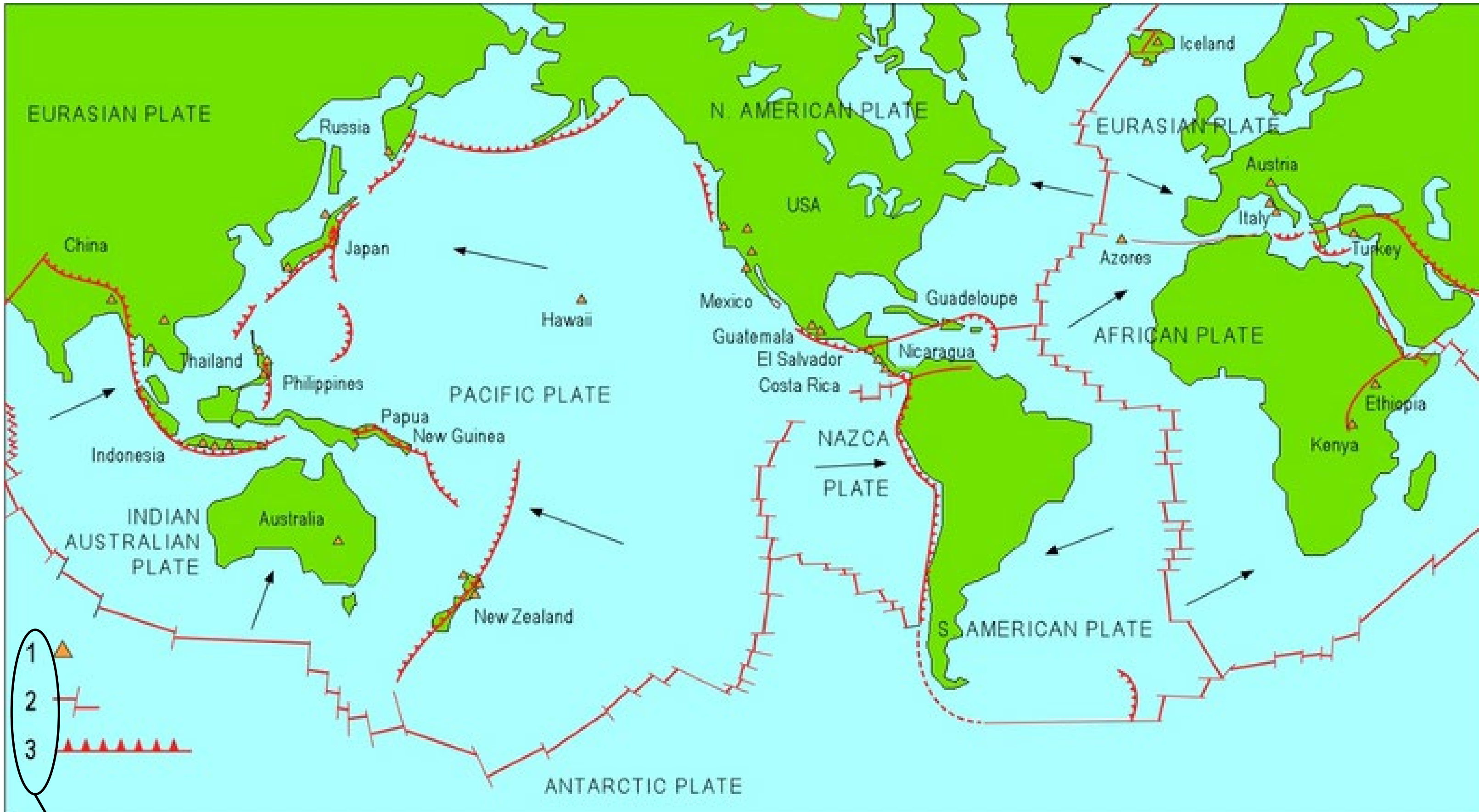


Figure 7.4 Cost and performance of 1 MW binary power plants as a function of geofluid temperature in degrees Celsius (°C).

http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

Geothermal

- **Margins of tectonic plates most favorable**



(1) Geothermal fields producing electricity

http://iga.igg.cnr.it/geo/geoenergy.php

(2) mid-oceanic ridges crossed by transform faults (long transversal fractures)

(3) subduction zones, where the subducting plate bends downwards and melts in the asthenosphere (~100 to 200 km below surface)

Great YouTube Video: https://www.youtube.com/watch?v=dFLX6oySYcc