FCOE, The Full Cost of Energy

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Energy policy must meet three fundamental goals:

1. **energy security –sufficient, reliable, dispatchable**
2. **energy costs must be stable, affordable**
3. **environmental security must be maintained**

Energy policy today is focused on climate change, which is misguided, at best.

HOW TO COMPARE COSTS AMONG ENERGY PRODUCTION TECHNOLOGIES?

Primary energy is almost entirely - heat.
Our civilization runs on a variety of heat engines. We burn coal, NG, oil, fission uranium to produce heat to do work. That is fundamental.

Electricity is high quality energy, but is secondary- or even tertiary, energy. Electricity must be created, usually for immediate consumption. Limited storage is possible, e.g. in batteries or as pumped hydro-, but storage incurs losses of energy.

Variable renewable energy (VRE) primarily uses solar heat to produce electricity.
This leads to the waste of electricity: i.e. using heat to produce electricity to produce heat to boil water. It is better to burn NG to boil the water directly.

LCOE, the 'levelized cost of (electrical) energy', is often used to compare the costs of producing electricity or energy via VRE with base energy, but LCOE includes only selected components of the cost. LCOE, thus, avoids specifying the full cost of electricity (FCOE), just as the CPI avoids specifying the true cost of inflation.

Here, we will look at the Full Cost of Electricity (Energy) and define the variables .

Full Cost of Electricity must include:

Wind and Solar

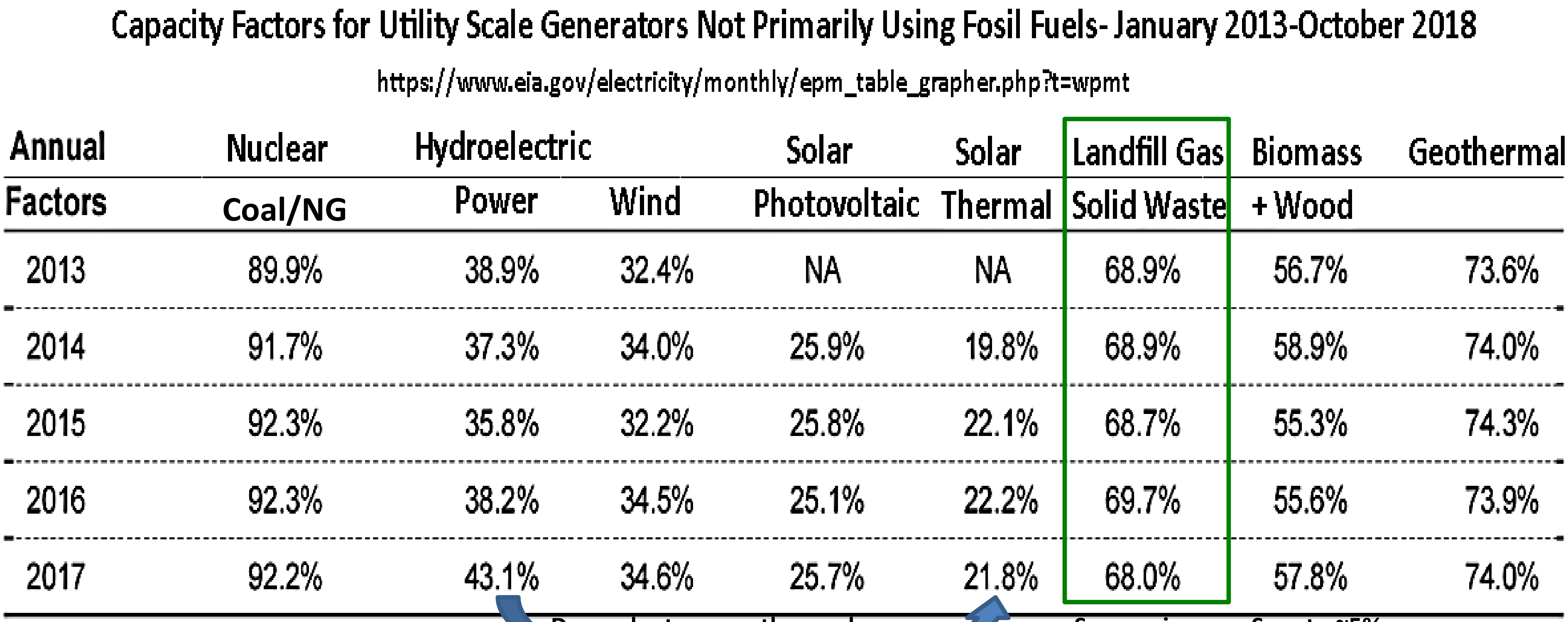
1.	Capacity factor & intermittency	Low-capacity factors due to site characteristics, intermittency and unpredictability of wind/solar.
2.	Energy density space requirement	Low energy densities, i.e., low availability of wind and solar irradiance per m^2 results in large space requirements increasing "Room Costs".
3.	Environmental damage	Environmental damage to plant and animal life, and negative affects on local and regional climate systems, such as warming, wind extraction, atmospheric changes.
4.	Energy efficiency	Low energy efficiencies and resulting economic losses from intermittency, power generation, conversion, conditioning, and transmission. Note, this statement applies to wind and solar electricity generation at grid scale.
5.	Correlated wind/solar resources	Continental sized areas of highly correlated wind speeds and solar availability.
6.	Lifetime	Short lifetime of wind and solar installations becoming shorter because of 'repowering'.
7.	Backup/storage	Critical requirement for and underutilization of backup power stations or long-duration backup energy storage systems that needs to equal essentially 100+% of wind and solar installed capacity because of intermittency and a.m. inefficiencies.
8.	Mineral resources	Natural resource and energy demand for mining, transportation, processing, manufacturing, and recycling of wind & solar installations and required backup/storage systems. Large geopolitical dependency on China.
9.	Recycling	Increased recycling challenges due to complex chemistry and short lifetime affecting economics and the environment.
10.	eROI and material efficiency	All the above translates to inadequate energy return on investment and low material efficiency, accounting for all embodied energy of the total energy system.

Source: Schernikau et al. 2022

1. Capacity factor & intermittency

Low-capacity factors due to site characteristics, intermittency and unpredictability of wind/solar.

Capacity Factor (CF) = measured output/nameplate capacity



Capacity Factors for Utility Scale Generators Not Primarily Using Fosil Fuels- January 2013-October 2018

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

Annual Factors	Nuclear Coal/NG	Hydroelectric Power	Wind	Solar Photovoltaic	Solar Thermal	Landfill Gas Solid Waste	Biomass + Wood	Geothermal
2013	89.9%	38.9%	32.4%	NA	NA	68.9%	56.7%	73.6%
2014	91.7%	37.3%	34.0%	25.9%	19.8%	68.9%	58.9%	74.0%
2015	92.3%	35.8%	32.2%	25.8%	22.1%	68.7%	55.3%	74.3%
2016	92.3%	38.2%	34.5%	25.1%	22.2%	69.7%	55.6%	73.9%
2017	92.2%	43.1%	34.6%	25.7%	21.8%	68.0%	57.8%	74.0%

Dependent on weather and season

Scavenging

Sum to ~5%

The measured CFs mean that 3-4X more nameplate PV/wind must be installed to meet average demand.

Result : multiply cost/area/number of components by 3-4 to get FCOE compared with LCOE.

2. Energy density space requirement

Low energy densities, i.e., low availability of wind and solar irradiance per m^2 results in large space requirements increasing "Room Costs".

USA total primary energy consumption 2021: 97 quads (1 quad equals 293 TWh) https://www.statista.com/topics/833/energy-consumption = 28,421 TWh/annum which equals (28,421/8766) TW = 3.25 TW.

The area of the USA is 8.1 x 10^6 km^2, or ~3 million mi^2 excluding Alaska, or 8.1 x 10^{12} m^2, This means:

Total USA power consumption/km^2 averages 0.4 MW/km^2 or 0.9 MW/mi^{2}of total area.

Data and analysis show that ~1 MW/km^2 can be achieved from wind and ~10 MW/km^2 can be achieved from PV, at the best sites.

The total area required for wind farms to yield the average annual power demand of the USA then is: 3.25 million km^2 or (3.25 km^2 /2.72 km^2 /mi^2) = 1.2 million mi^2.

The total area required for PV parks to yield the average annual power demand of the USA is, correspondingly, 325,000 km^2, or 120,000 mi^2.

MEETING AVERAGE DEMAND GUARANTEES DAILY GRID COLLAPSES.

Measurements show peak power (PP) (https://www.eia.gov/todayinenergy/detail.php?id=15051) is 1.8X average power and a dynamic reserve (DR) of 20% is required for maintenance/failed system elements. The areas above must now be (1.8 x1.2) = 2.2 times larger, wind farms = 7.15 million km^2 or 2.64 million mi^2 and PV Parks = 715,000 km^2 or 264,000 mi^2.

This area is 3.1X the area of Utah - 85,000 mi^2


4. **Energy efficiency**

Low energy efficiencies and resulting economic losses from intermittency, power generation, conversion, conditioning, and transmission. Note, this statement applies to wind and solar electricity generation at grid scale.

Power has not reached the consumer yet. The power quoted above is power produced "at the power plant". Power must be conditioned and then transmitted to the grid/consumer.

For Wind, electricity generation is ac, but too poorly regulated to insert into the grid, so it is rectified at summing stations, then inverted at the proper phase and transformed to a high voltage for transmission. Typical rectification and inversion losses are 20% while transforming/transmission losses are typically 10%. The power plant must increase its output by 1.3X to meet these additional losses. The wind farms has now grown to 9.3 million km^2 or 3.4 million mi^2. The area of the USA is 3.1 million mi^2.

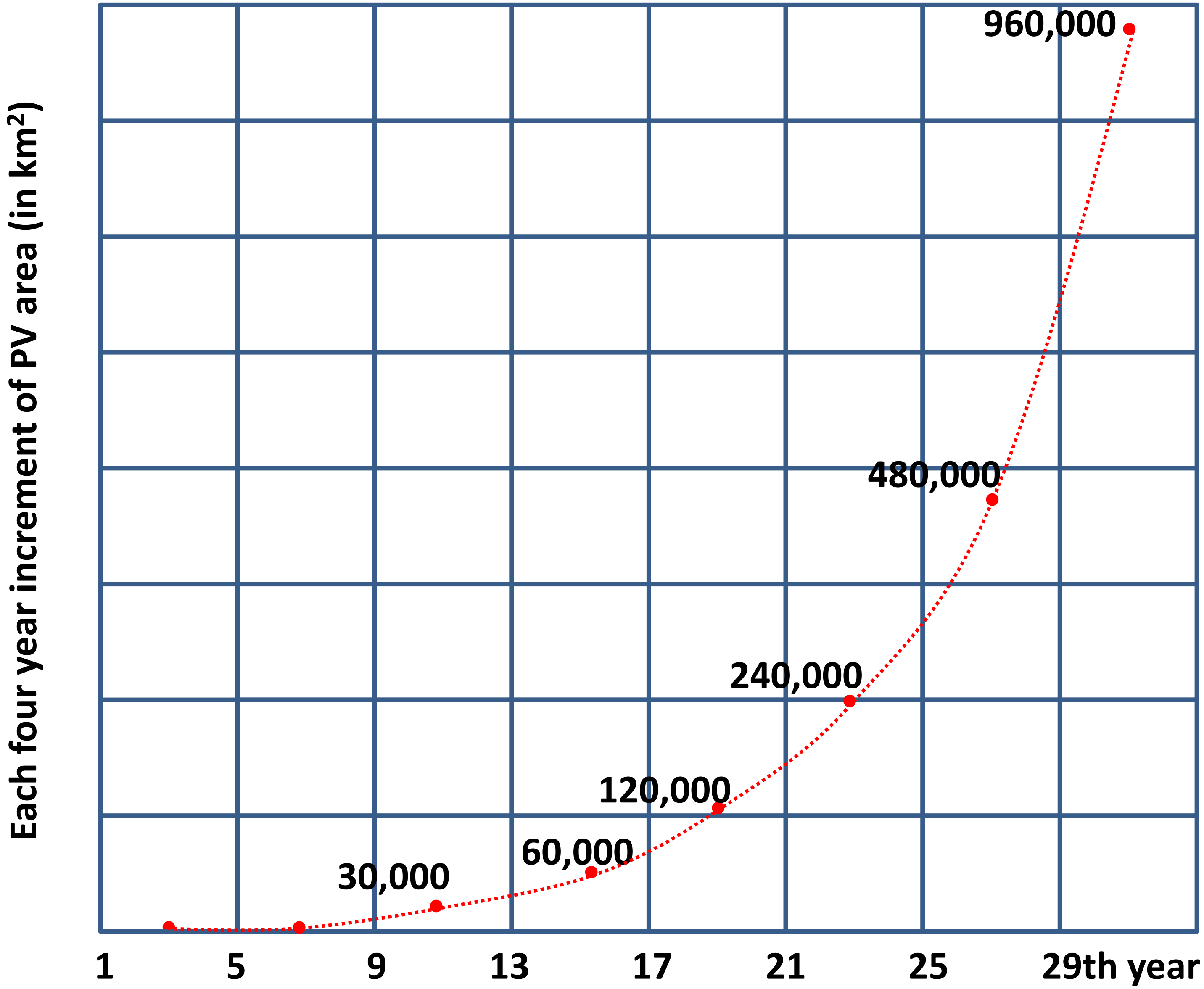
PV Parks area = 715,000 km^2 or 264,000 mi^2. For PV parks, electricity generation is dc. The output is inverted and voltage transformed for transmission, a loss factor of 0.3X.
The PV parks are now 930,000 km^2, or 342,000 mi^2 or 4X Utah

At these sizes, peak power demand and dynamic reserve are met.

BUT (there is always a but), efficiency degradations of wind and PV occur at known rates, and the backup requirements caused by the erratic and seasonal variability are NOT included.

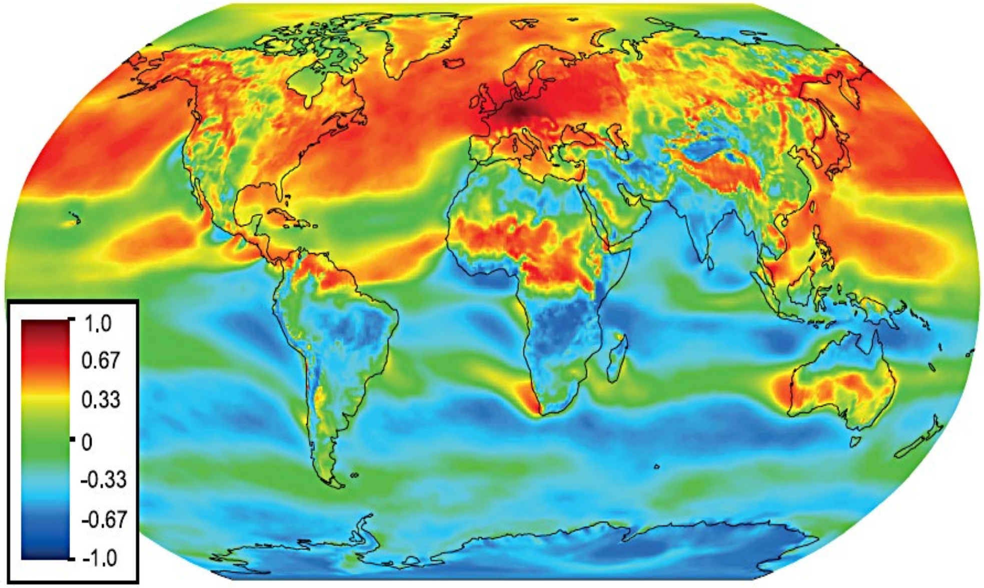
Additional electricity production (area) must be provided in both instances for storage, entailing further conversion losses of the backup to meet energy demand when the renewable energy is not available and to compensate for the decline in efficiency with time (see below).

USA Build out of PV to match PEAK + DR POWER by 2050; not including provision for backup. Total area = 4X area of Utah



5. Correlated wind/solar resources

Continental sized areas of highly correlated wind speeds and solar availability.



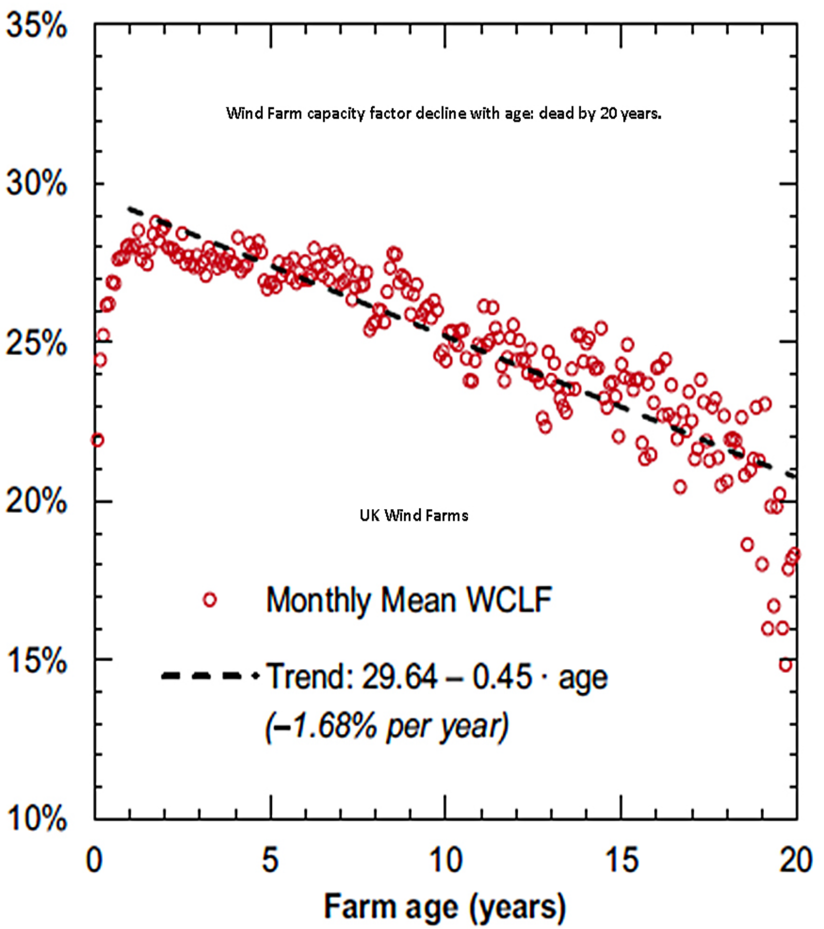
Correlation in 30-day mean wind speed to a grid point in Germany. 10 years of MERRA data was used.

The red-orange areas have a better than 3:1 chance of having too little or too much wind at the same time. Blue areas are anticorrelated and over 10,000 km distant (6000 miles). https://www.diva-portal.org/smash/get/diva2:721570/FULLTEXT01.pdf

For PV: http://dx.doi.org/10.1016/j.renene.2015.10.006

6. Lifetime

Short lifetime of wind and solar installations due to aging and wear.



Lifetime of Wind Turbines onshore is ~15 years: 25% decline of output in 15 years, http://dx.doi.org/10.1016/j.renene.2013.10.041

Wind turbines offshore decline ~50% in 15 years @ 4.5% per annum. https://www.manhattan-institute.org/dismal-economics-offshore-wind-energy

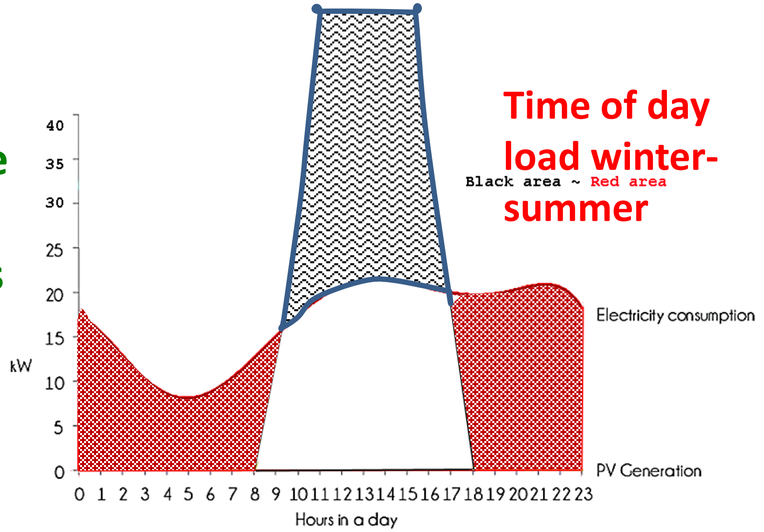
These declines require continual replacement of 7% of the wind fleet per year or ~240,000 mi^2 annually in perpetuity and proportionally faster offshore.

7. Backup/storage

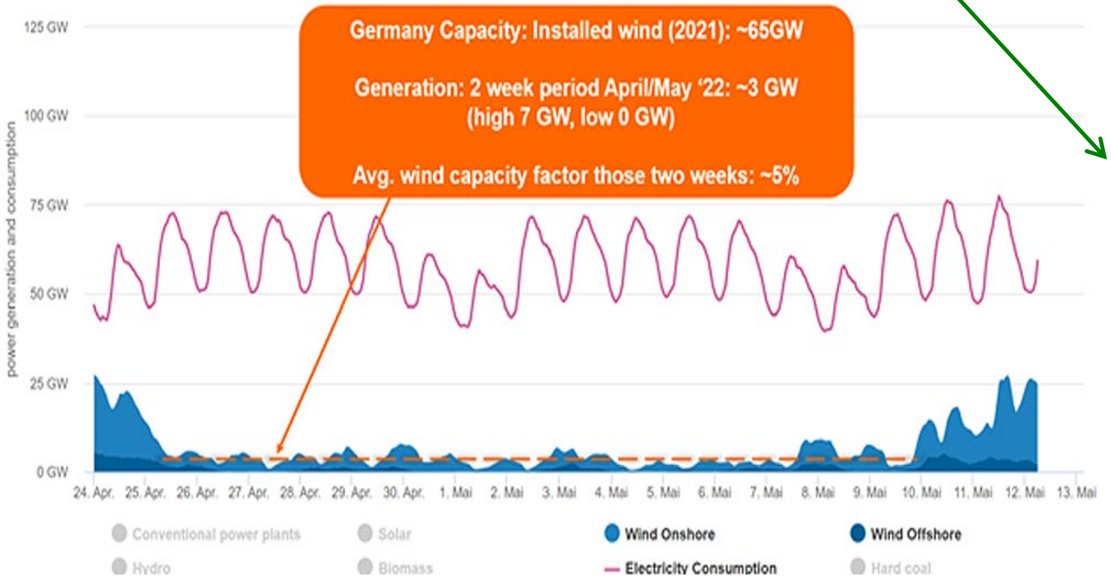
Critical requirement for and underutilization of backup power stations or long-duration backup energy storage systems that needs to equal essentially 100+% of wind and solar installed capacity because of intermittency and a.m. inefficiencies.

Backup is required for both wind and PV. The two renewable energy sources are somewhat anti-correlated, but not sufficiently to backup each other (Renewable Energy, 87, 96-110 (2016)).

Backup for PV is a diurnal, as well as a seasonal requirement. The power demand curve is shown at the right. The grey area is the PV area to provide for storage at night and is included above. This cost is in FCOE estimates, but not in LCOE. The PV area specified meets the peak and DR requirement for USA energy.



Time of day load winter-summer



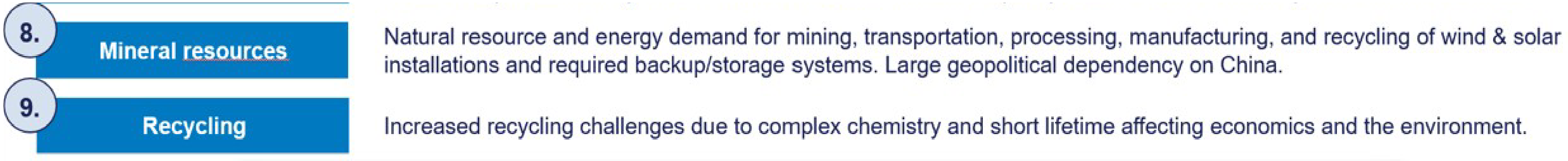
Germany Capacity: Installed wind (2021): ~65GW

Generation: 2 week period April/May '22: ~3 GW (high 7 GW, low 0 GW)

Avg. wind capacity factor those two weeks: ~5%

Over half the energy must be stored for use when the sun sets every day. In terms of Li-ion batteries, the annual output of 110 Gigafactories (GFs) is required for one night's storage, and an additional 220 GFs' output for each additional cloudy day.

As commonly occurs for Germany, two weeks of ~NO wind would require a backup of 45 TWh for electricity only, compared with a GLOBAL production presently of 0.5TWh of Li-ion batteries, today's best technology, or 10 Gigafactories. Such backup does not exist.



8.	Mineral resources	Natural resource and energy demand for mining, transportation, processing, manufacturing, and recycling of wind & solar installations and required backup/storage systems. Large geopolitical dependency on China.
9.	Recycling	Increased recycling challenges due to complex chemistry and short lifetime affecting economics and the environment.

The current global silicon production could yield 26,000 km^2 of solar panels annually (7.5x 10^6 kg silicon ÷ 0.29 kg/m^2). The full build out of PV-USA, alone, requires nearly twice the global annual production of silicon. Silver demand for PV has been reduced to a minimum, and no durable substitute is known. Over 3.5 tons of silver is required for PV panels per km^2, or nearly 3 million tons of silver is required for the PV-USA, or more than 100 years production at the current global rate of 27,000 tons annually. Neodymium for wind electric generators, copper for windings and transmission infrastructure, iron for towers, masts, balsa wood for turbine blades, and much more are completely unprecedented.

Then, as you see below, huge masses of worn out wind turbine blades (life of 6-8 years), PV panels, every component of the system should be recycled, but NO provision yet exists. These mining, fabrication, and recycling costs are missing from the LCOE estimates, but not from FCOE. Early leaders in renewable energy are paying a price for incomplete analysis.

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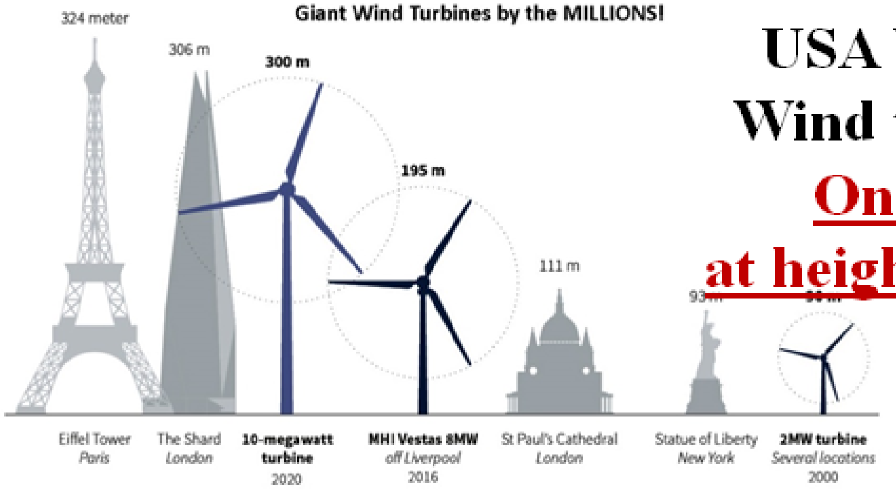
3. Environmental damage

Environmental damage to plant and animal life, and negative affects on local and regional climate systems, such as warming, wind extraction, atmospheric changes.



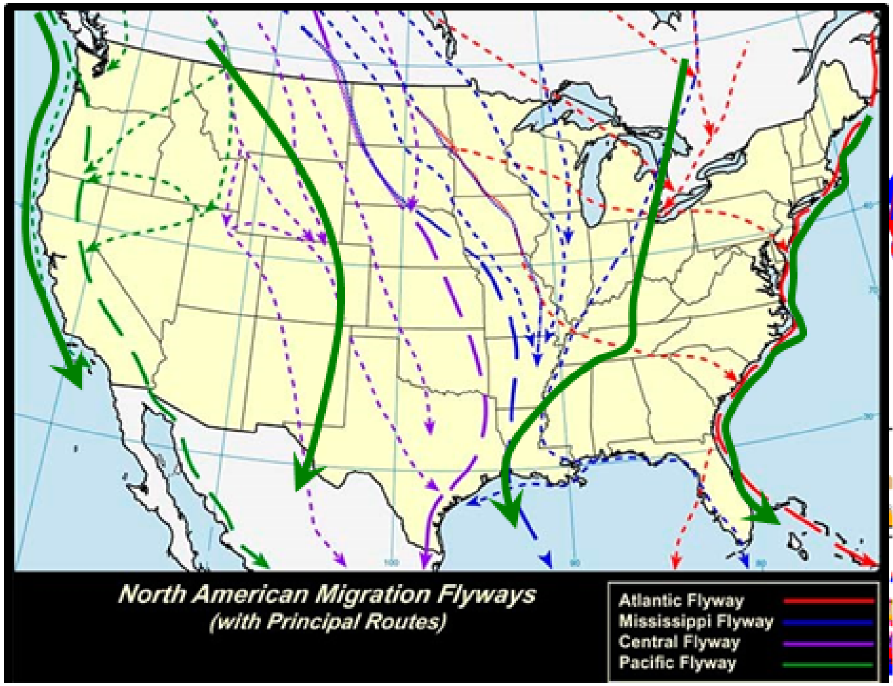
Sources: Dong Energy UK; Nextwind Inc.

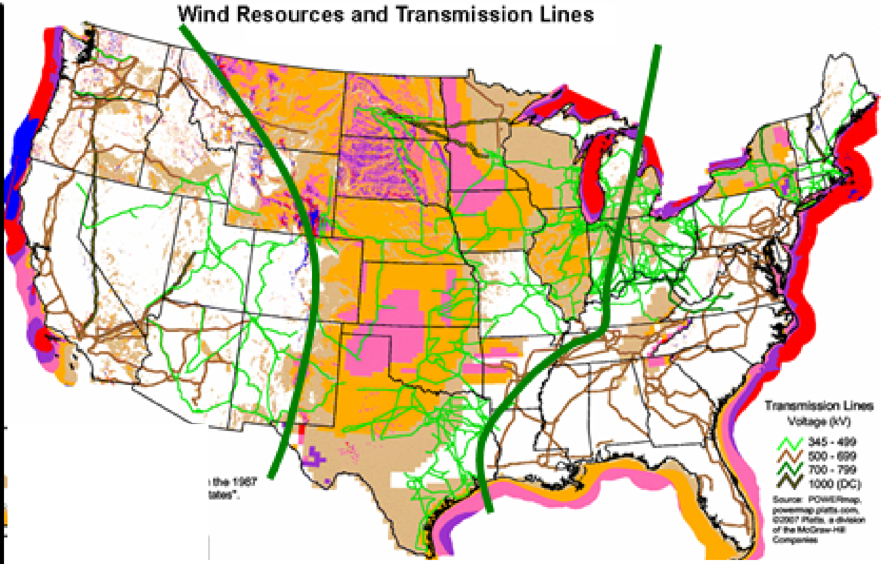
USA Wind Turbines in 2018 = 60,000

Wind turbines to power America 2040:

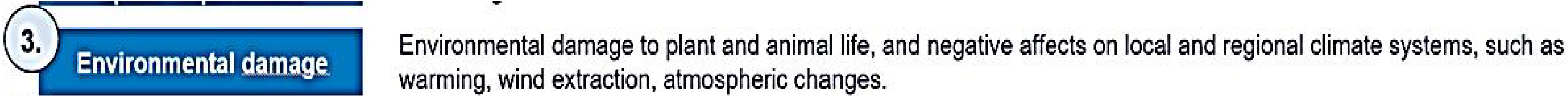
One hundred times MORE! and at heights 100-300 meters where birds fly

Wind turbines will destroy bird/bat populations





Source: POWERmap, powermap.platts.com, ©2007 Platts, a division of the McGraw-Hill Companies



3. Environmental damage	Environmental damage to plant and animal life, and negative affects on local and regional climate systems, such as warming, wind extraction, atmospheric changes.

Many are concerned with destruction of birds and bats, but what of insects? It is the smaller species near the base of the food web which are often ignored, despite great potential damage to the ecology. Indeed, the greatest harm to the ecosystem and to humans may occur due to insect losses. Like birds, insects migrate to find favorable terrain to breed. Trieb (2018) estimated insect fatalities for Germany based on Sandia data for insect residues on wind turbine blades, see below. The quoted study estimates 25 trillion insects killed annually.

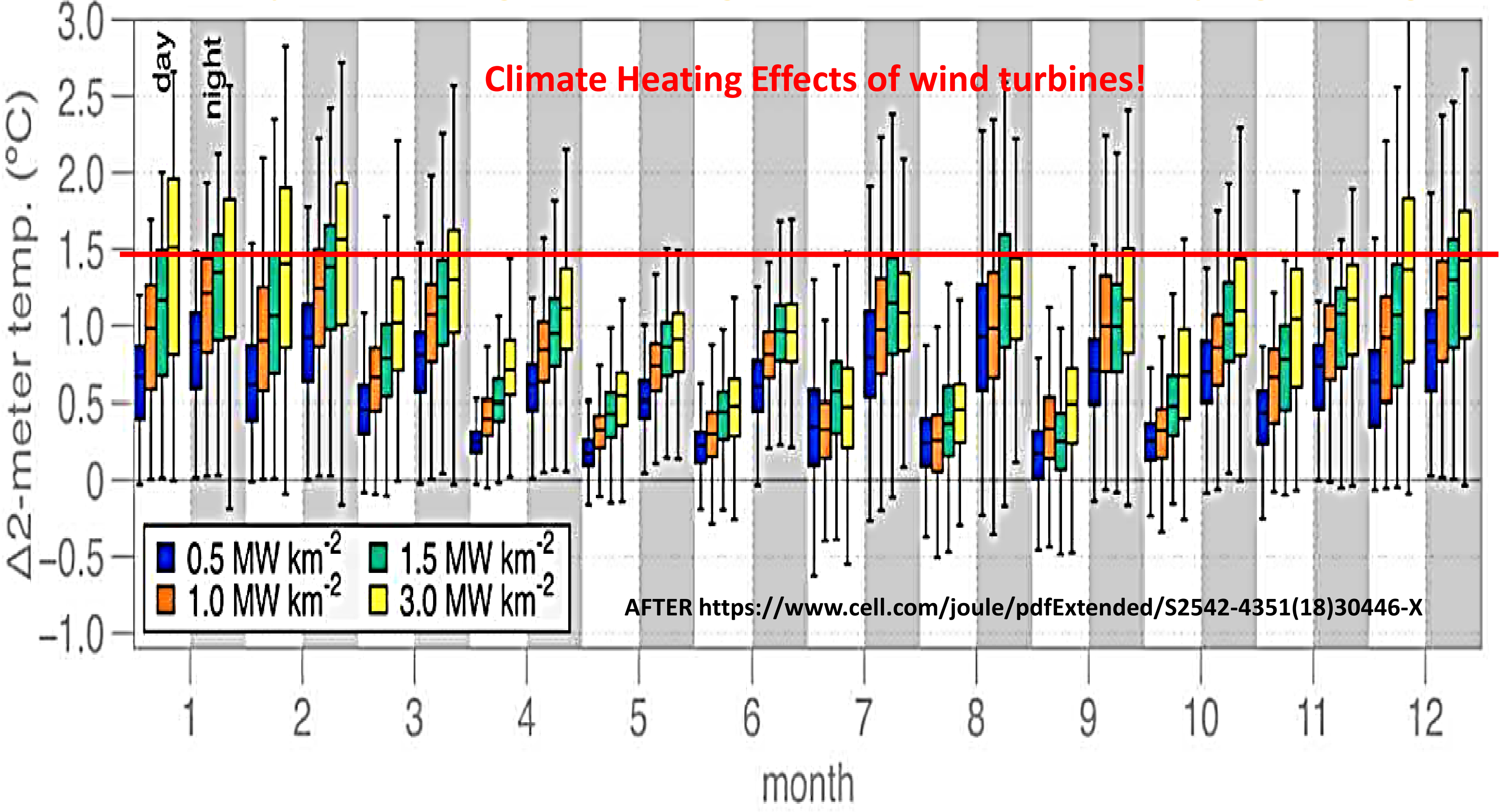
The analysis also concluded that WT efficiency losses due to insect residue on rotors would reach 50%. Insect erosion effect may contribute to the measured, but of 'unknown' origin, energy production deficit of 27% in German Wind farms. (https://doi.org/10.1371/journal.pone.0211028).

3. **Environmental damage**

Environmental damage to plant and animal life, and negative affects on local and regional climate systems, such as warming, wind extraction, atmospheric changes.

IPCC AR6 (2021) Warming Target is for 2100 AD 1.5°C, Such global warming could trigger multiple climate tipping points, according to https://doi.org/10.1126/science.abn7950-Sept.2022

Air temperature changes at 2 m height above the sea surface- day-night averages



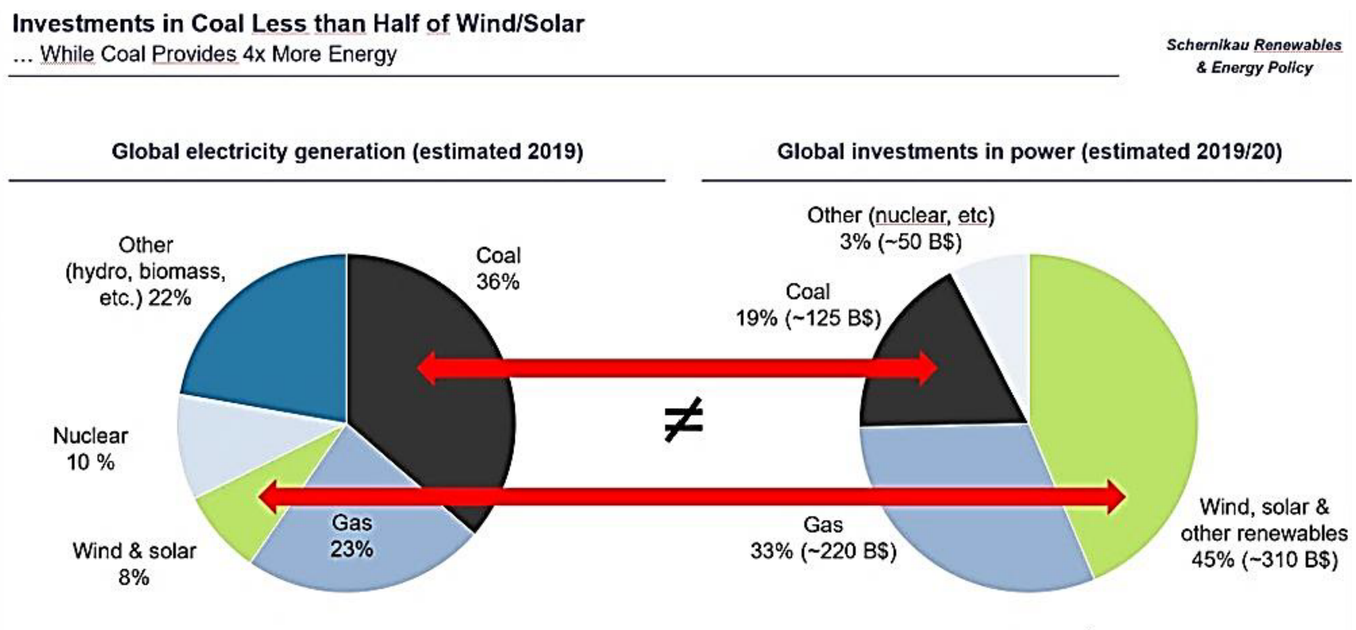
Climate Heating Effects of wind turbines!

AFTER https://www.cell.com/joule/pdfExtended/S2542-4351(18)30446-X

10. eROI and material efficiency

All the above translates to inadequate energy return on investment and low material efficiency, accounting for all embodied energy of the total energy system.

Source: Schernikau et al. 2022



Investments in Coal Less than Half of Wind/Solar
… While Coal Provides 4x More Energy

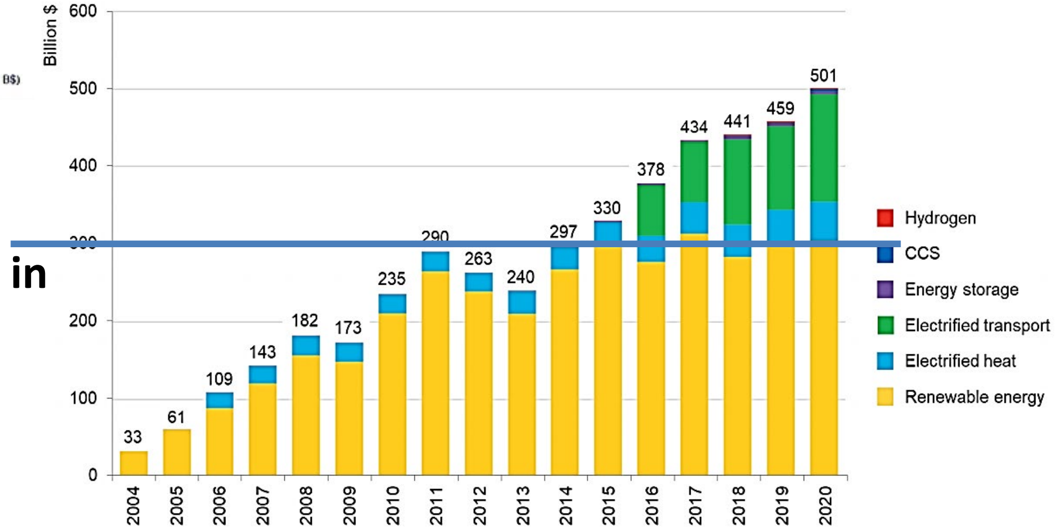
Schernikau Renewables & Energy Policy

∑ = 27.000 TWh

Note: Right side includes investments in fuel supply and power; for Gas it is assumed that 50% of total "oil & gas" fuel supply investments went into gas (511 B$ x 0,5 = 255 B$)
Sources: Schernikau Research & Analysis based no IEA and BNEF Data; Fuel supply – World Energy Investment 2020 – Analysis - IEA

Investment in coal produced 8X the return compared with investment in renewable energy

Investment in renewable energy stopped increasing in 2010. The increases are seen in energy consumption: bEVs and heat pumps… Graph from Bloomberg, 2021



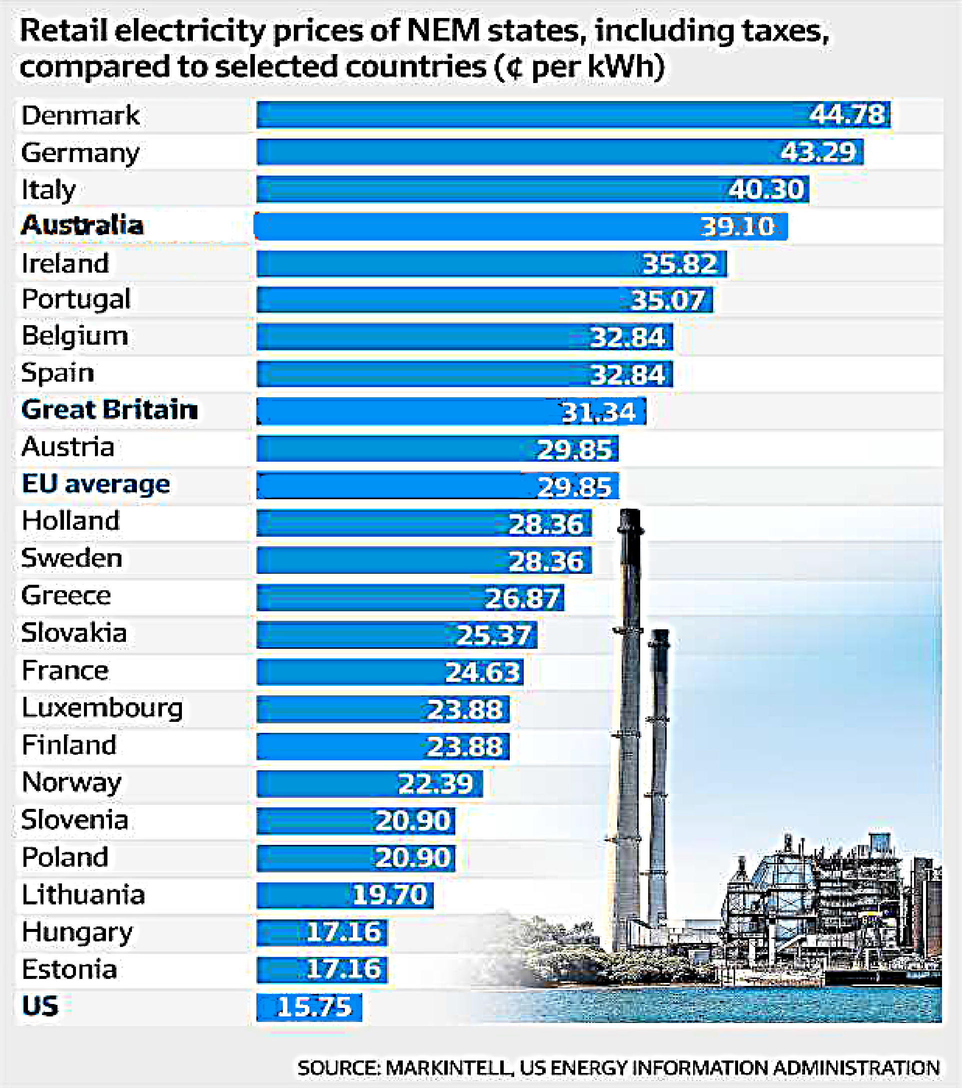
Fossil fuel/nuclear power plants produce 1000 MW/km^2.

This is 100-1000 times more power per square kilometer than erratic renewable energy provides.

Which means the citizens can have space in which to recreate, enjoy nature, and not be in thrall to an inadequate energy production technology.

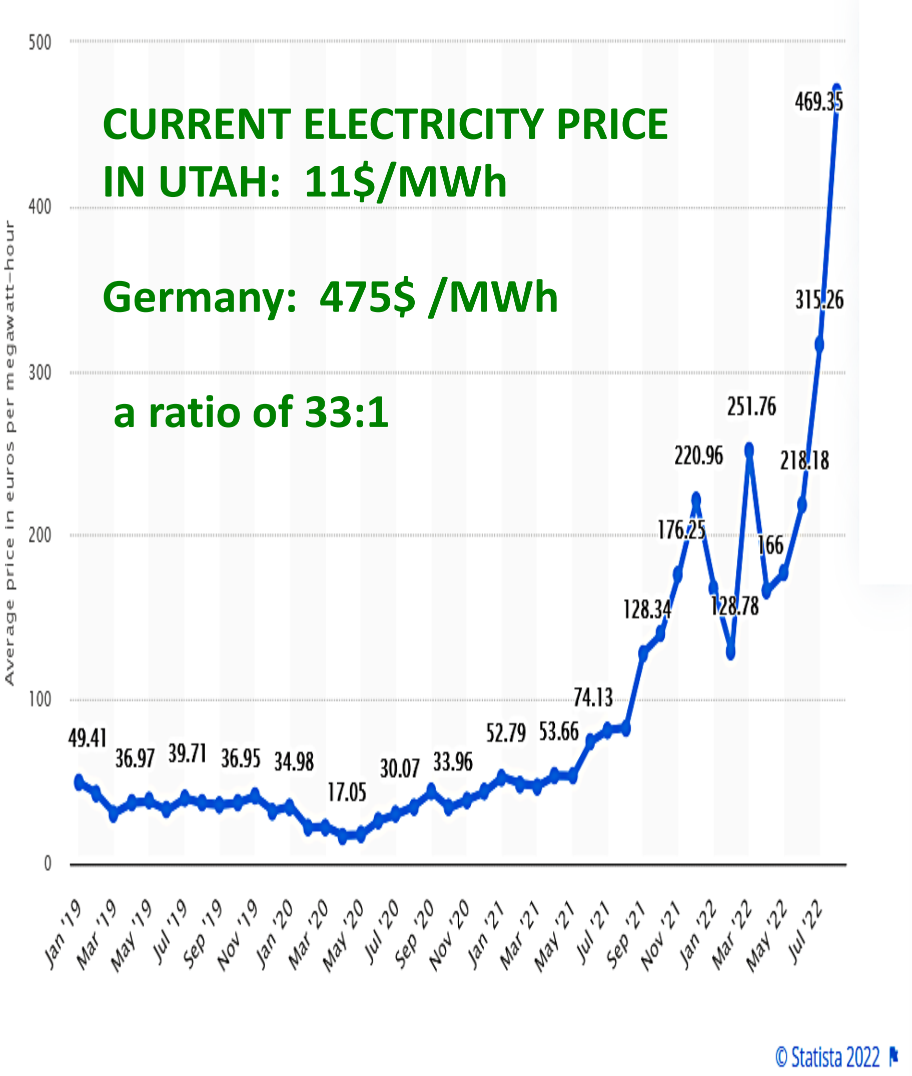
The following slides were added in response to questions posed by the committee

What is the likely cost to a Utah customer for electricity and the total cost of NetZero 2050?



Retail electricity prices of NEM states, including taxes, compared to selected countries (¢ per kWh)

SOURCE: MARKINTELL, US ENERGY INFORMATION ADMINISTRATION



CURRENT ELECTRICITY PRICE
IN UTAH: 11$/MWh

Germany: 475$ /MWh

a ratio of 33:1

Bullet 10, above, showed that over 5 $trillion was expended to produce 3% of global primary energy. The total cost for NetZero 2050, then would be 33X larger:165 $Trillion-or more!

Decarbonization means carbon capture utilization and sequestration (CCUS). Does that make sense?

The total mass of Earth's atmosphere (dry air 29 gm/mole) is about 5.1 x10^{15} tons.

1 ppm of CO$_2$ (gm/mole is 44) represents about 7.7 x10^{9} tons of CO$_2$.

If humans have added 130 ppm, then very nearly 1x 10^{12} tons of CO$_2$ have been added.

The cost to sequester is estimated to be at least $130/ton; a total cost of

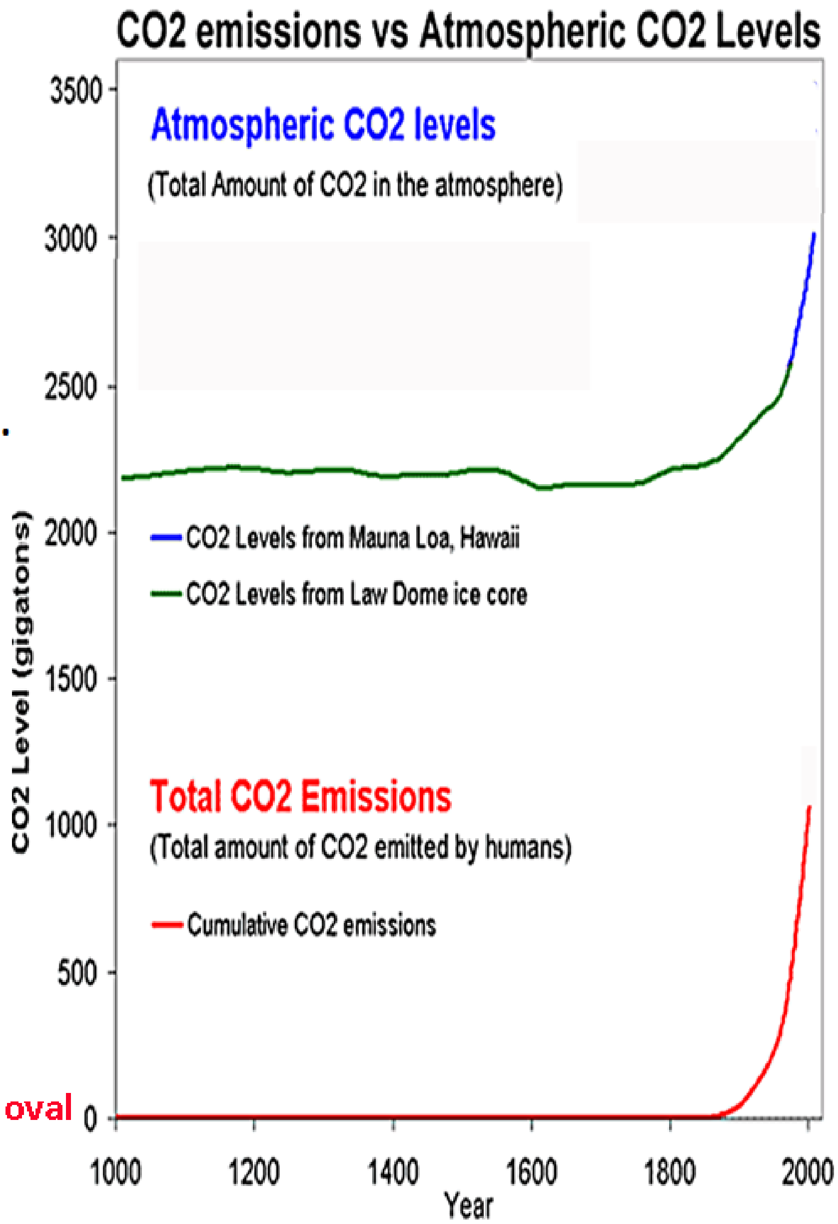
130 $Trillion.

The **GLOBAL** GDP is

~76 $Trillion.

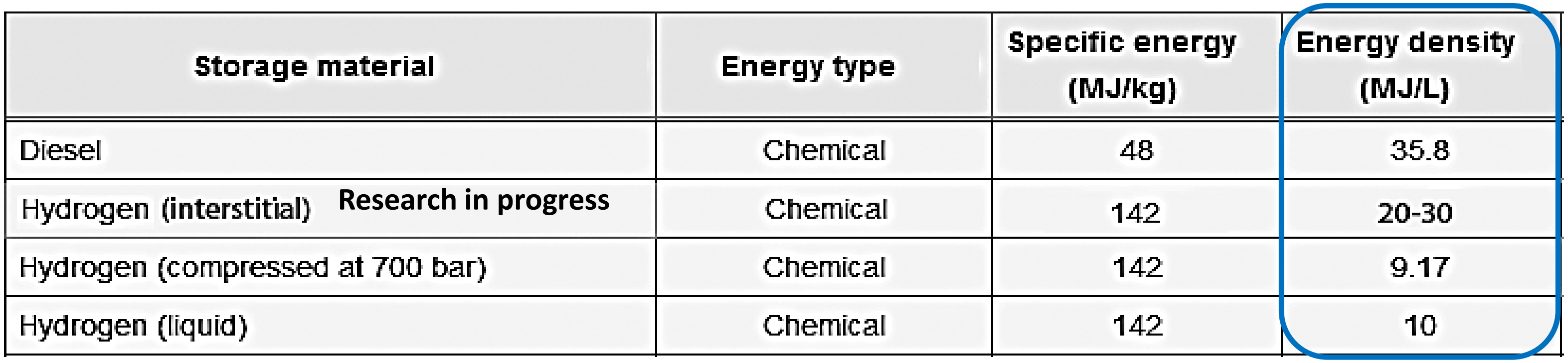
Thus, nearly two years of the total production of the planet is required to remove the CO$_2$ added already.

The CO$_2$ addition annually is 2 ppm, or a cost of 2 $TRILLION, every year for removal


CO2 emissions vs Atmospheric CO2 Levels

Can H_2 replace hydrocarbon fuels?

Wind/PV → electricity → electrolysis of H_2O → H_2 → electricity for many purposes

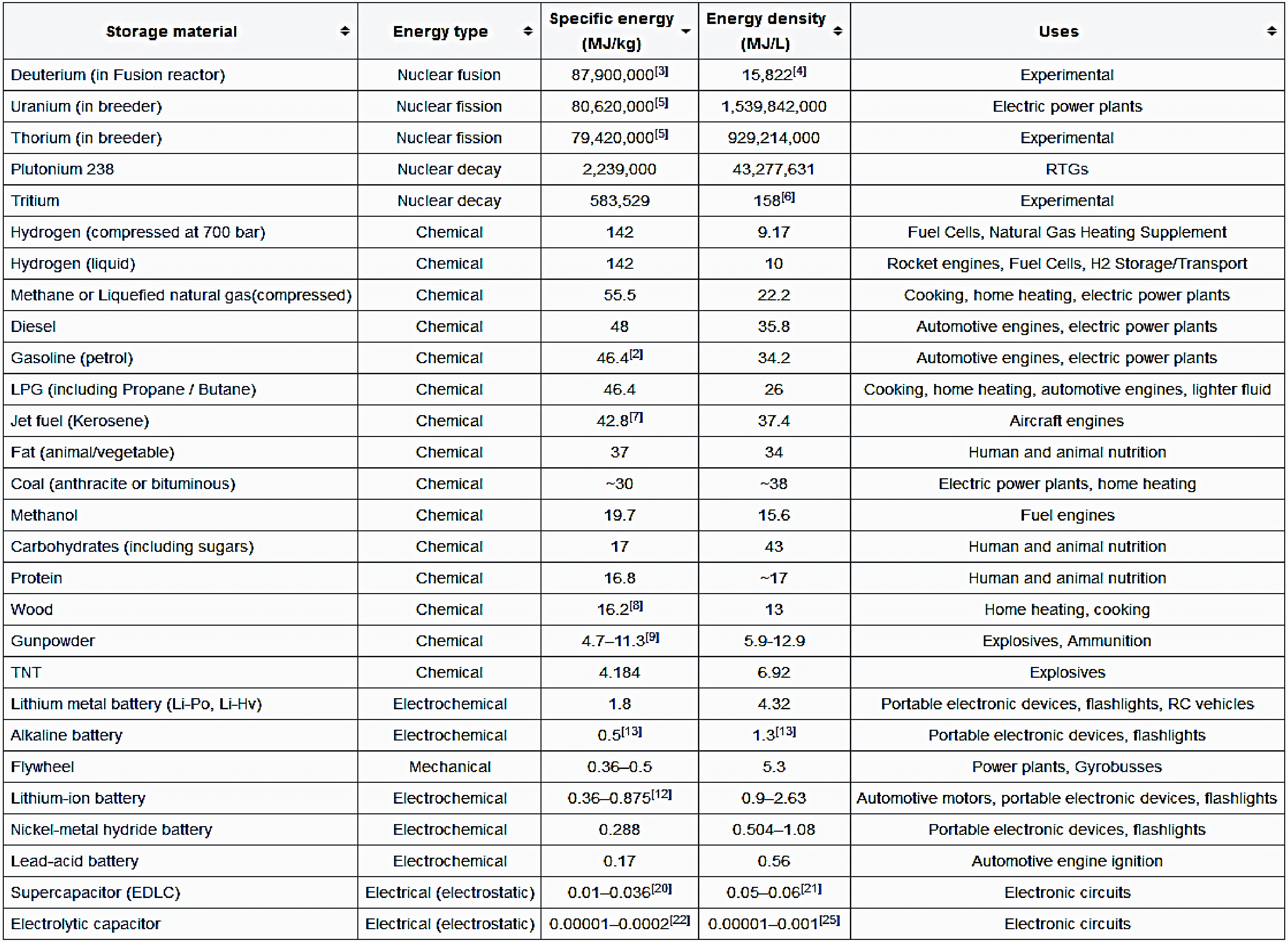


Storage material	Energy type	Specific energy (MJ/kg)	Energy density (MJ/L)
Diesel	Chemical	48	35.8
Hydrogen (interstitial) Research in progress	Chemical	142	20-30
Hydrogen (compressed at 700 bar)	Chemical	142	9.17
Hydrogen (liquid)	Chemical	142	10

Diesel and H_2 must be extracted, processed, stored, transported, and consumed.

1. Extraction - diesel→ pumped crude oil ; - H_2 → electrolysis from $H_2$0 (~70%)
2. Processing –diesel→ refinement ; H_2 → compression/liquefaction –energy intensive
3. Storage-Shipping → long term- diesel – tanker-freighter ;
   short term only- H_2 → cryogenic tanker with loses.
4. Consumption: ICE – 56% efficiency best today; H_2 → fuel cell 60-70% efficiency
5. The NetZero 2050 schedule calls for 435 Mt of H_2 by 2045, equal to ~3BTOe, but in 2021 global fossil fuel consumption was ~12 BTOe (Our World in Data), This constitutes 75% shortfall in primary energy and approximates the medieval energy intensivity and its standard of living.

The following unit conversions may be helpful when considering the data in the table: 3.6 MJ = 1 kWh ≈ 1.34 HPh.



Storage material	Energy type	Specific energy (MJ/kg)	Energy density (MJ/L)	Uses
Deuterium (in Fusion reactor)	Nuclear fusion	87,900,000[3]	15,822[4]	Experimental
Uranium (in breeder)	Nuclear fission	80,620,000[5]	1,539,842,000	Electric power plants
Thorium (in breeder)	Nuclear fission	79,420,000[5]	929,214,000	Experimental
Plutonium 238	Nuclear decay	2,239,000	43,277,631	RTGs
Tritium	Nuclear decay	583,529	158[6]	Experimental
Hydrogen (compressed at 700 bar)	Chemical	142	9.17	Fuel Cells, Natural Gas Heating Supplement
Hydrogen (liquid)	Chemical	142	10	Rocket engines, Fuel Cells, H2 Storage/Transport
Methane or Liquefied natural gas(compressed)	Chemical	55.5	22.2	Cooking, home heating, electric power plants
Diesel	Chemical	48	35.8	Automotive engines, electric power plants
Gasoline (petrol)	Chemical	46.4[2]	34.2	Automotive engines, electric power plants
LPG (including Propane / Butane)	Chemical	46.4	26	Cooking, home heating, automotive engines, lighter fluid
Jet fuel (Kerosene)	Chemical	42.8[7]	37.4	Aircraft engines
Fat (animal/vegetable)	Chemical	37	34	Human and animal nutrition
Coal (anthracite or bituminous)	Chemical	~30	~38	Electric power plants, home heating
Methanol	Chemical	19.7	15.6	Fuel engines
Carbohydrates (including sugars)	Chemical	17	43	Human and animal nutrition
Protein	Chemical	16.8	~17	Human and animal nutrition
Wood	Chemical	16.2[8]	13	Home heating, cooking
Gunpowder	Chemical	4.7–11.3[9]	5.9-12.9	Explosives, Ammunition
TNT	Chemical	4.184	6.92	Explosives
Lithium metal battery (Li-Po, Li-Hv)	Electrochemical	1.8	4.32	Portable electronic devices, flashlights, RC vehicles
Alkaline battery	Electrochemical	0.5[13]	1.3[13]	Portable electronic devices, flashlights
Flywheel	Mechanical	0.36–0.5	5.3	Power plants, Gyrobusses
Lithium-ion battery	Electrochemical	0.36–0.875[12]	0.9–2.63	Automotive motors, portable electronic devices, flashlights
Nickel-metal hydride battery	Electrochemical	0.288	0.504–1.08	Portable electronic devices, flashlights
Lead-acid battery	Electrochemical	0.17	0.56	Automotive engine ignition
Supercapacitor (EDLC)	Electrical (electrostatic)	0.01–0.036[20]	0.05–0.06[21]	Electronic circuits
Electrolytic capacitor	Electrical (electrostatic)	0.00001–0.0002[22]	0.00001–0.001[25]	Electronic circuits