Tuesday, 1/14/25

Introduction

"Photovoltaics" – definition: a method of converting solar radiation into DC electricity using semiconductors (or other materials) that exhibit the photovoltaic effect. "PV" is the abbreviation for "photovoltaics."

"Solar Energy" – definition: radiant light and heat from the sun that is harnessed by a variety of technologies:

(1) Photovoltaics

(2) Thermal systems to heat air, water, or other fluids/objects

(3) Thermal systems used to heat a fluid to pressurize it for rotating a turbine to produce electricity

(4) Indirect solar energy systems (more on this shortly)

World Energy Sources

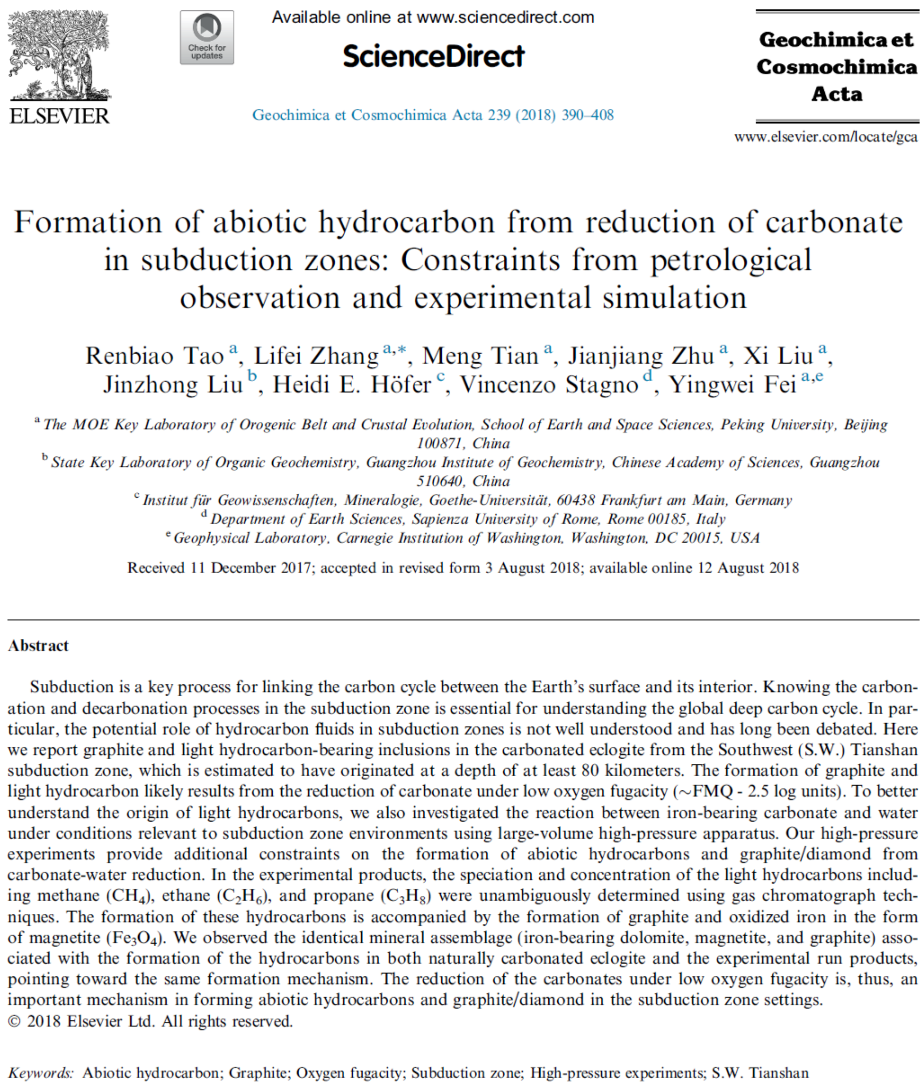
1) Fossil Fuels: coal, oil, oil shale, and natural gas

   NOTE: oil may be "slowly" renewable from carbonates being converted into petroleum in subduction zones along tectonic plate boundaries (see below)

2) Nuclear

3) Geothermal

4) Solar
   a. Direct Solar: thermal and photovoltaics
   b. Indirect Solar: bio-fuels, wind, hydro/hydroelectric, waves, and tidal



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Formation of abiotic hydrocarbon from reduction of carbonate in subduction zones: Constraints from petrological observation and experimental simulation

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Abstract

Subduction is a key process for linking the carbon cycle between the Earth's surface and its interior. Knowing the carbonation and decarbonation processes in the subduction zone is essential for understanding the global deep carbon cycle. In particular, the potential role of hydrocarbon fluids in subduction zones is not well understood and has long been debated. Here we report graphite and light hydrocarbon-bearing inclusions in the carbonated eclogite from the Southwest (S.W.) Tianshan subduction zone, which is estimated to have originated at a depth of at least 80 kilometers. The formation of graphite and light hydrocarbon likely results from the reduction of carbonate under low oxygen fugacity (~FMQ - 2.5 log units). To better understand the origin of light hydrocarbons, we also investigated the reaction between iron-bearing carbonate and water under conditions relevant to subduction zone environments using large-volume high-pressure apparatus. Our high-pressure experiments provide additional constraints on the formation of abiotic hydrocarbons and graphite/diamond from carbonate-water reduction. In the experimental products, the speciation and concentration of the light hydrocarbons including methane (CH_4), ethane (C_2H_6), and propane (C_3H_8) were unambiguously determined using gas chromatograph techniques. The formation of these hydrocarbons is accompanied by the formation of graphite and oxidized iron in the form of magnetite (Fe_3O_4). We observed the identical mineral assemblage (iron-bearing dolomite, magnetite, and graphite) associated with the formation of the hydrocarbons in both naturally carbonated eclogite and the experimental run products, pointing toward the same formation mechanism. The reduction of the carbonates under low oxygen fugacity is, thus, an important mechanism in forming abiotic hydrocarbons and graphite/diamond in the subduction zone settings.

Keywords: Abiotic hydrocarbon; Graphite; Oxygen fugacity; Subduction zone; High-pressure experiments; S.W. Tianshan

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Energy from the Sun

The solar "power" reaching the earth's outer atmosphere is approximately 10^{17} W, or 10^8 GW!

Solar Constant: the density of solar power reaching the earth's atmosphere: 1366 W/m^2 = 1.366 kW/m^2.

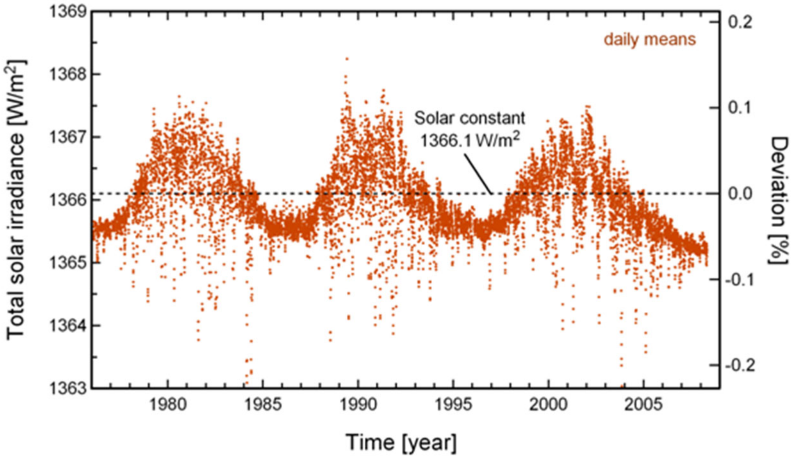
About 30% of the sun's energy is "lost" passing through the earth's atmosphere, yielding an insolation at the earth's surface of about 1000 W/m^2.

"Insolation" – definition: the amount of solar radiation reaching a given area.

This level of insolation is defined for the condition of being at sea level on a clear day, and it is the accepted standard for "strong sunshine."

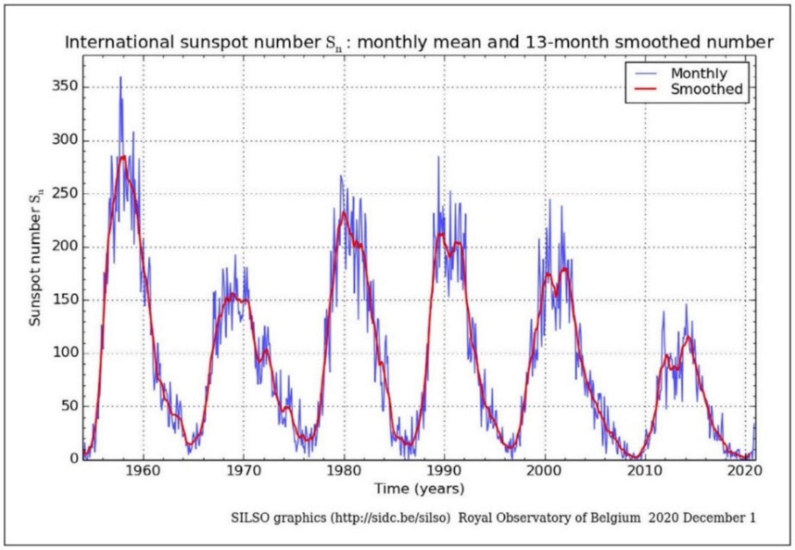
The "solar constant" varies a small amount over a year as the earth revolves about the sun, due to its slightly elliptical orbit, as well as over the 11 year sunspot cycle:

Natural Fluctuation in the Solar Constant



https://www2.pvlighthouse.com.au/resources/courses/altermatt/The%20Solar%20Spectrum/Measurement%20of%20the%20solar%20constant.aspx

Also, sunspot cycles vary from cycle to cycle too:



https://www.carolina.com/teacher-resources/Interactive/essentials-sunspot-activity/tr52801.tr

For more information: www.spaceweather.com

Are solar irradiance and insolation the same thing? Solar irradiance is an instantaneous measurement; insolation is a cumulative measurement over time.

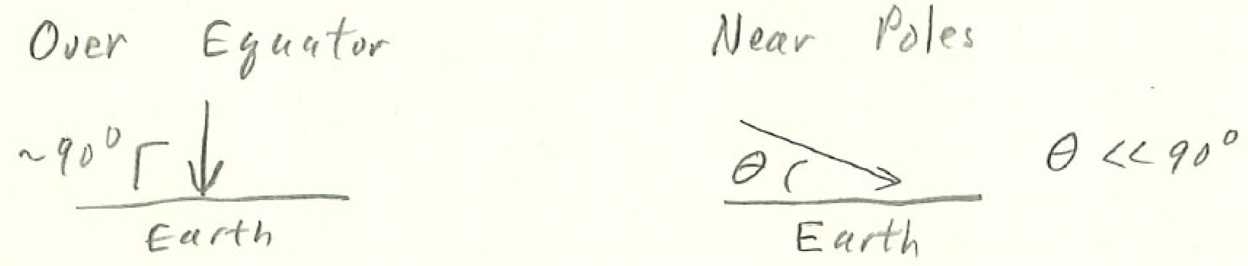
Annual Mean Insolation

Earth is approximately a sphere, with a “circular” solar footprint.

For a circle: $A = \pi R^2$, where R is earth’s radius.

The surface area for a sphere is: $SA = 4\pi R^2$, and the earth is a spinning “sphere.”

Therefore, the annual mean isolation above the atmosphere is then approximately: 1366/4 = 342 W/m^2. However, it is shared very unequally:



a. Atmospheric Losses

Sunlight has to travel through more atmosphere near the poles than near the equator.

Atmospheric losses reduce the isolation by about 30%, and come from:

(1) Absorption by atmospheric gases (wavelength dependent)

(2) Scattering by dust and other molecules

(3) Clouds

NOTE: (2) and (3) above vary with local climates.

Examples: Average insolation at the earth’s surface:

Sahara Desert ~ 300 W/m^2

Neal the Poles ~ 80 W/m^2

b. Total Energy Received Per Year

If the average insolation for a location is known, use 8760 hours to estimate the total solar energy received over one year:

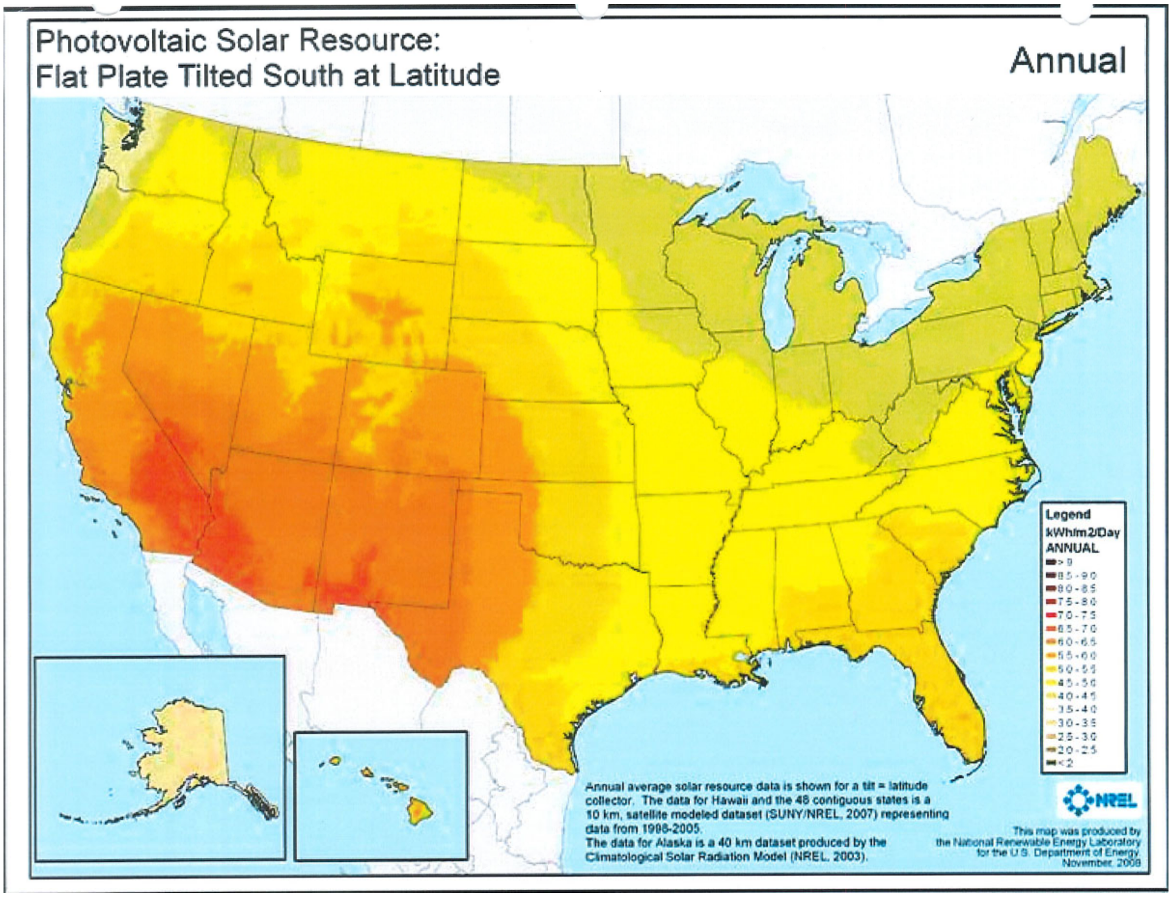
Examples:

(1) London/Berlin: avg. insolation = 120 W/m^2 → 1050 kWh/m^2

(2) Sydney Australia: avg. insolation = 200 W/m^2 → 1750 kWh/m^2

NOTE: use these estimates with caution, since they are averaged over night/day and spring/summer/fall/winter, and they may vary from year to year.

Graphic showing the average kWh/m^2/day in the USA:



c. Some additional average insolation data (from a different source), in MJ/m^2/day:

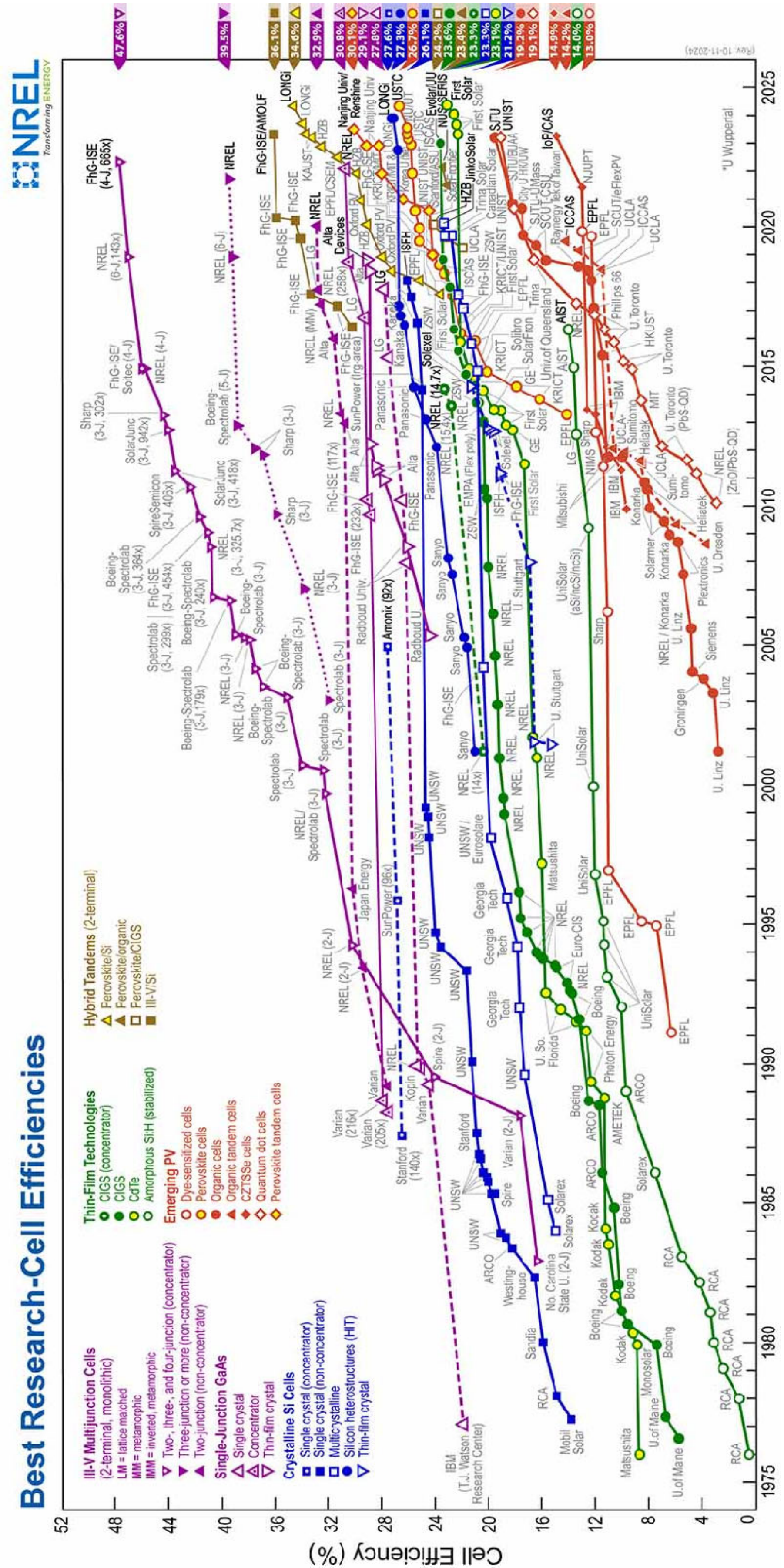
(1) Montgomery, AL → Dec: 8.16, June: 22.38

(2) Phoenix, AZ → Dec: 10.58, June: 31.09

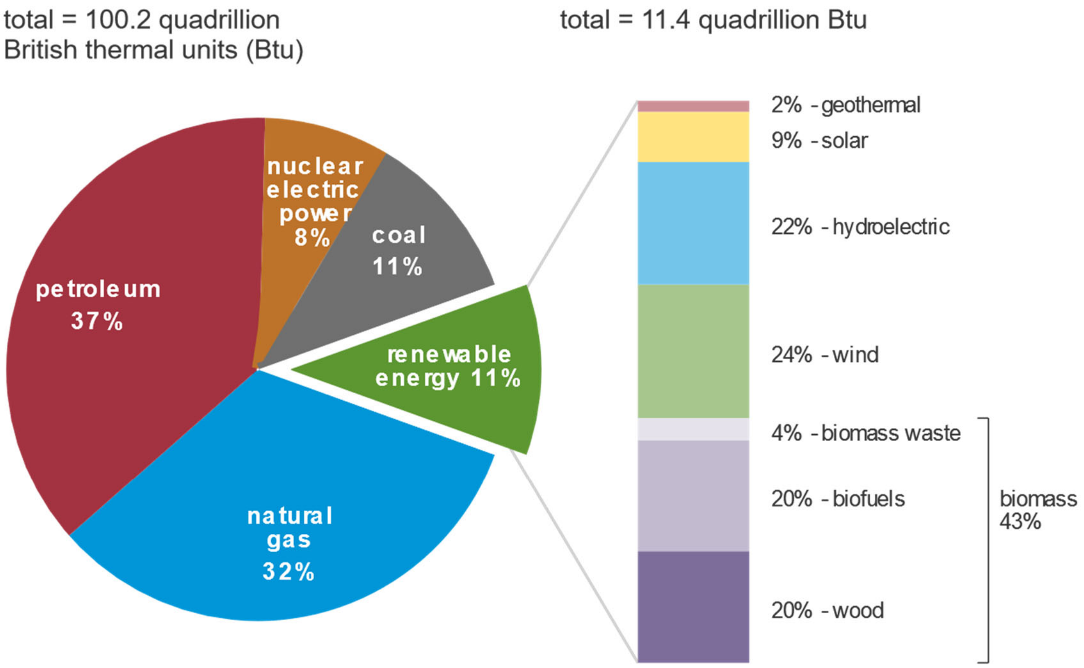
(3) NY, NY → Dec: 4.58, June: 19.41

PV Cell Efficiencies

PV cell efficiencies have been slowly increasing as technology advances:


Best Research-Cell Efficiencies
NREL Transforming ENERGY
III-V Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Two-, three-, and four-junction (concentrator)
Three-junction or more (non-concentrator)
Two-junction (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Emerging PV
Dye-sensitized cells
Perovskite cells
Organic cells
Organic tandem cells
CZTSSe cells
Quantum dot cells
Perovskite tandem cells
Hybrid Tandems (2-terminal)
Perovskite/Si
Perovskite/organic
Perovskite/CIGS
III-V/Si
Cell Efficiency (%)
0
4
8
12
16
20
24
28
32
36
40
44
48
52
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
47.6%
39.5%
36.1%
34.6%
32.9%
30.8%
30.1%
29.1%
27.8%
27.6%
27.3%
26.7%
26.1%
24.2%
23.6%
23.4%
23.3%
23.1%
21.2%
19.2%
19.1%
14.9%
14.2%
14.0%
13.0%
(Rev. 10-11-2024)

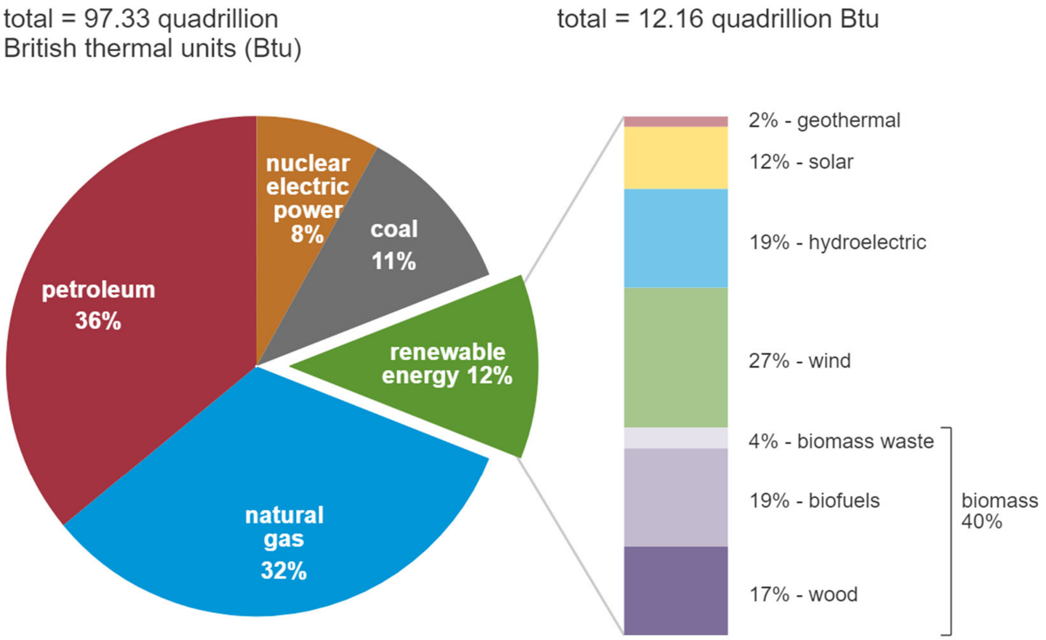
U.S. primary energy consumption by energy source, 2019



Note: Sum of components may not equal 100% because of independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2020, preliminary data

https://www.e-education.psu.edu/ebf301/node/457

U.S. primary energy consumption by energy source, 2021



Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2022, preliminary data
Note: Sum of components may not equal 100% because of independent rounding.

Observe that in the figure above for 2021 (latest data available), solar represents just 1.44% of energy use in the USA. That's up from 0.99% in 2019 and 0.66% in 2017. Also notice that the total energy usage actually decreased from 2019 to 2021 (possibly COVID related?).

Suppose that all the USA's energy was obtained from PV, how much land area would that take?

1 Quadrillion = $1\text{x}10^{15}$.

1000 BTUs = 0.293071 kWh

97.33 Q-BTUs = $2.852\text{x}10^{13}$ kWh

For the PV system, assume:

1000 W/m^2 insolation for 6 hrs/day equivalent

These conditions for 365 days/yr

10% system efficiency → reasonable, which we will see over the semester

Therefore: $\left({}^{E}/_{m^2}\right)_{T_{yr}} = \frac{0.1(1000)(6)(365)}{1000} = 219\ kWh/m^2/yr$ → energy density.

Land area required: $\frac{2.852\times10^{13}}{219} = 1.34\times10^{11}\ m^2 = 130{,}249\ km^2$

Area of Alabama = 50,645.33 mi^2 = 131,170.8 km^2.

Therefore, the land required is almost as large as all the land in Alabama.

However, there are several issues to consider:

(1) Conversion of the DC PV output to AC for use with the current AC power system

(2) Energy storage (batteries), for nighttime and cloudy days

(3) Removal of the land from its current use (agriculture, housing, businesses, schools, hospitals, roads, wild lands, etc.)

(4) Environmental (a PV desert, no $CO_2 \rightarrow O_2$ photosynthesis, effects on weather/climate, severe weather issues, rainwater issues, effects on wildlife, end-of-life issues with the PV system components, etc.)

(5) Additional land needed for system support (roads, buildings, workers, storage, maintenance equipment, etc.)

(6) COVID effects aside, energy use should continue to grow as the population grows

(7) Actual insolation would be less (maybe much less), so much more land would be required to account for periods when the insolation is less

So, is converting the USA to all-PV energy production feasible?

Consider this:

Phoenix, AZ in June, a 1 m^2 PV array for one sunny day: 31.09 MJ

One gal of gasoline (10% ethanol): 125.6 MJ – about 2.84 kg

One kg of wood: 16 MJ

One kg of coal: 24 MJ

One kg of uranium (U-235): 3,900,000 MJ

Or: 1 m^2 PV array in June in Phoenix for a full day receives the energy equivalence of 0.25 gal of gasoline, or 1.3 kg of coal, or 1.94 kg of wood, or 8 mg of U-235.

Note, this is the energy input into the system, not the energy out:

Coal power plant: 33% to 45% efficiency

Gasoline power automobile: 20% to 35% efficiency

Nuclear power plant: 34% to 36% efficiency

PV system efficiency: 10% to 20% efficiency

So, is converting the USA to all-PV energy production feasible at this time?