Review: Energy

- **Wind**
- **Flowing water**

https://www.historyhttps://sailtraininginternational.org/vessel/eye-of-the-wind/.com/
Watermill of Braine-le-Château, Belgium (12th century)

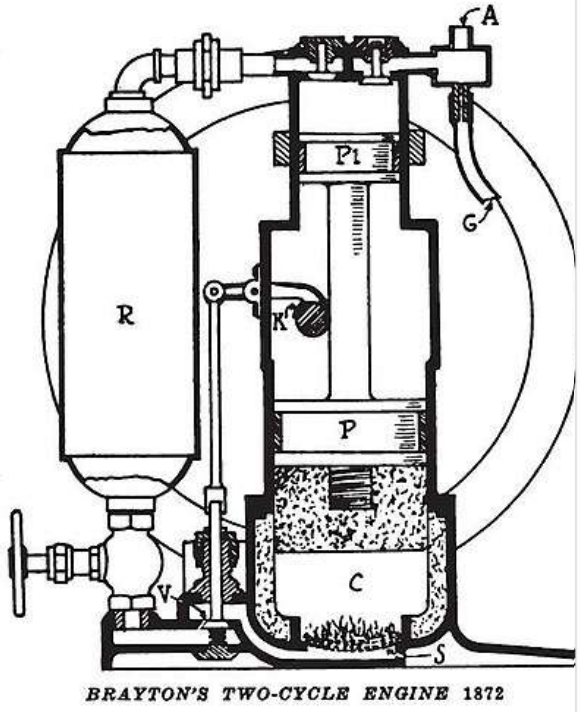
Review: Energy

- **Increased use of wood for heating, cooking, and metallurgy.**
- **Replaced by coal in late 19th century**

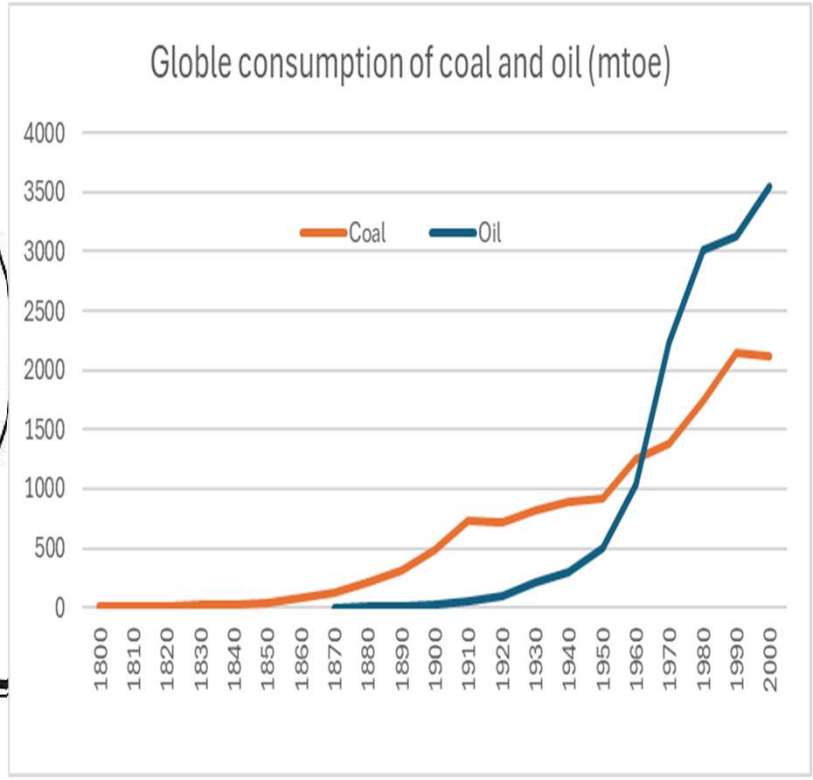
https://www.cozilogs.co.uk/

Review: Energy

- **1872, commercial liquid-fueled internal combustion engine was invented**
- **Replaced stream engines in the 1900s because of the higher thermal efficiency, lower weight, and more compact structure.**
- **Increased the production of Oil**



Brayton Gas engine 1872



Mtoe: Millions of tones of oil equivalent
https://www.encyclopedie-energie.org/

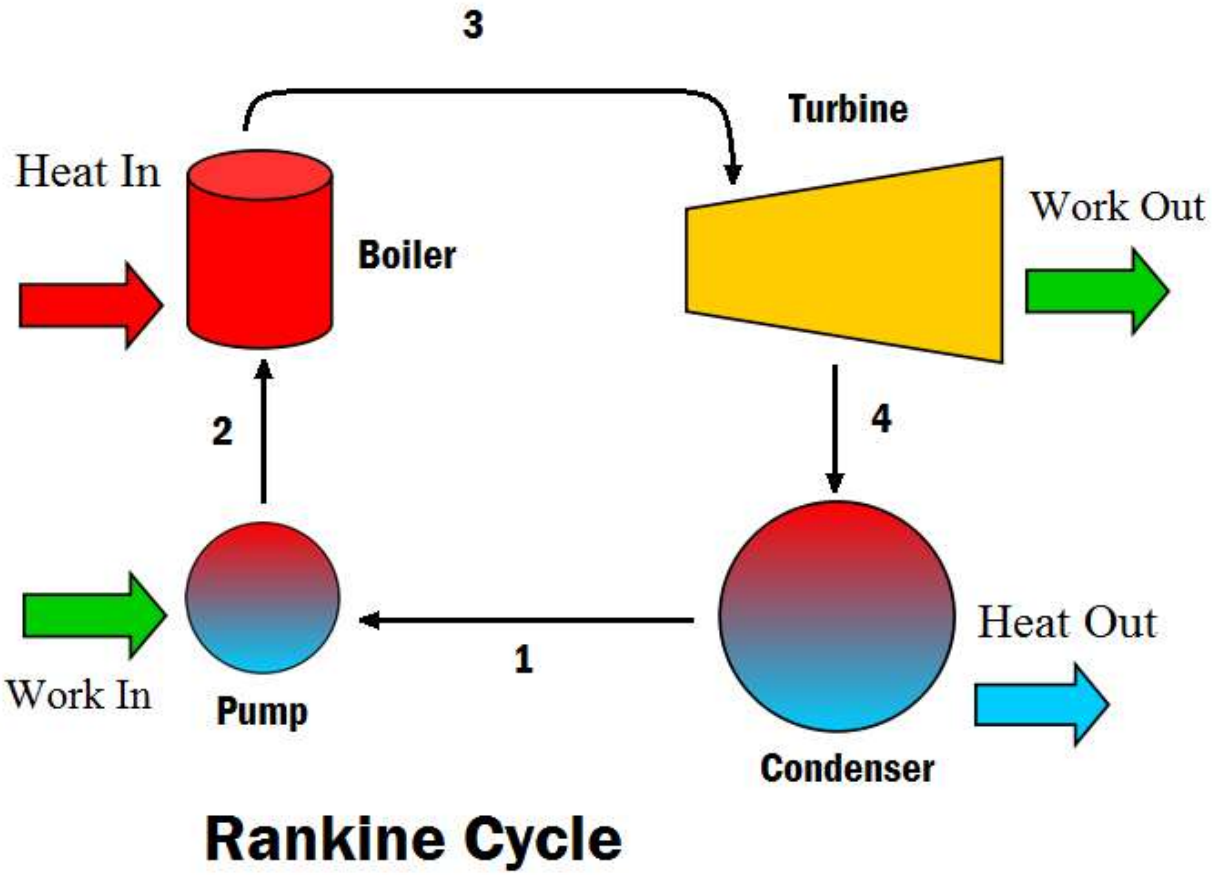
Review: Energy

- **Electric motors revolutionized industry, change power transmission**
- **Converting electrical energy into mechanical power**
- **Electric motors consume ≈50% of the world's electricity**
- **Residential use also increased quickly**

http://www.vem-group.cn/products/low-voltage-motor.html

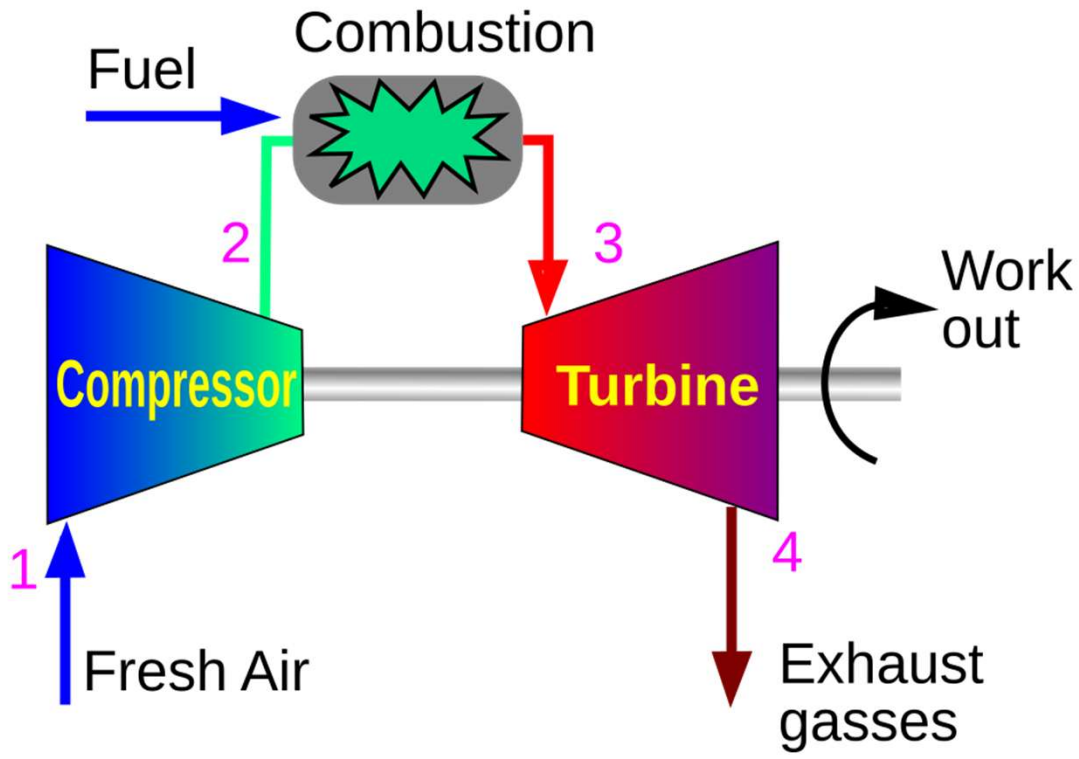
Review: Energy

- Combustion cycle that uses fuels to produce electricity
- Including 4 major steps: compress/heat water to vapor → expand the vapor through a turbine → generate mechanical energy



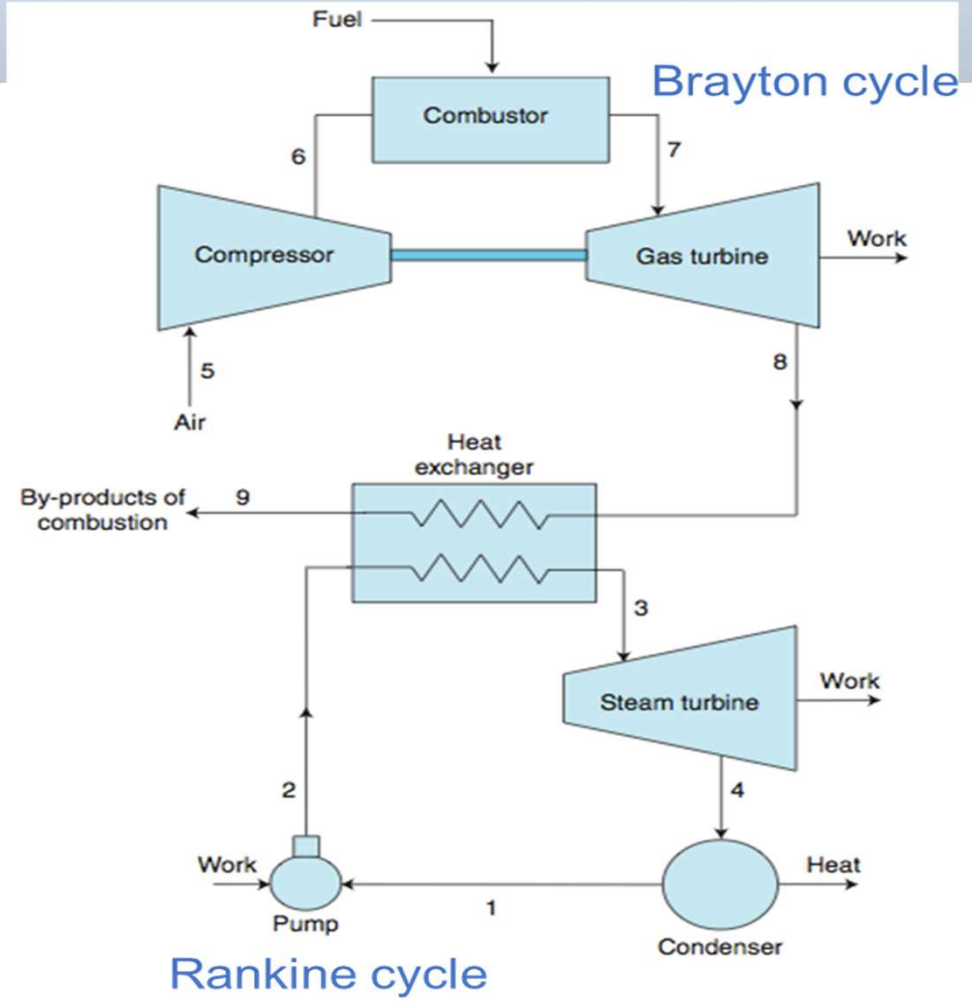
Rankine Cycle

- A gaseous working fluid is used in Brayton cycle
- Atmospheric air encounters isentropic compression to the max. system pressure
- Fuel is injected to the combustor and combusted at constant pressure to heat the gases to the highest temperature
- Isentropic expansion to create the output work



Review: Energy

- The remaining energy in the exhaust from the gas turbine can be put to reuse to increase overall system output



https://www.knick-international.com/zh/process-analytics

Review: Energy

- NO_X
- SO2
- Particulate
- Mercury and other heavy metals
- Ash
- Smog and acid rain

https://grist.org/climate-energy/coal-plant-pollution-can-be-deadly-even-hundreds-of-miles-downwind/

Review: Energy

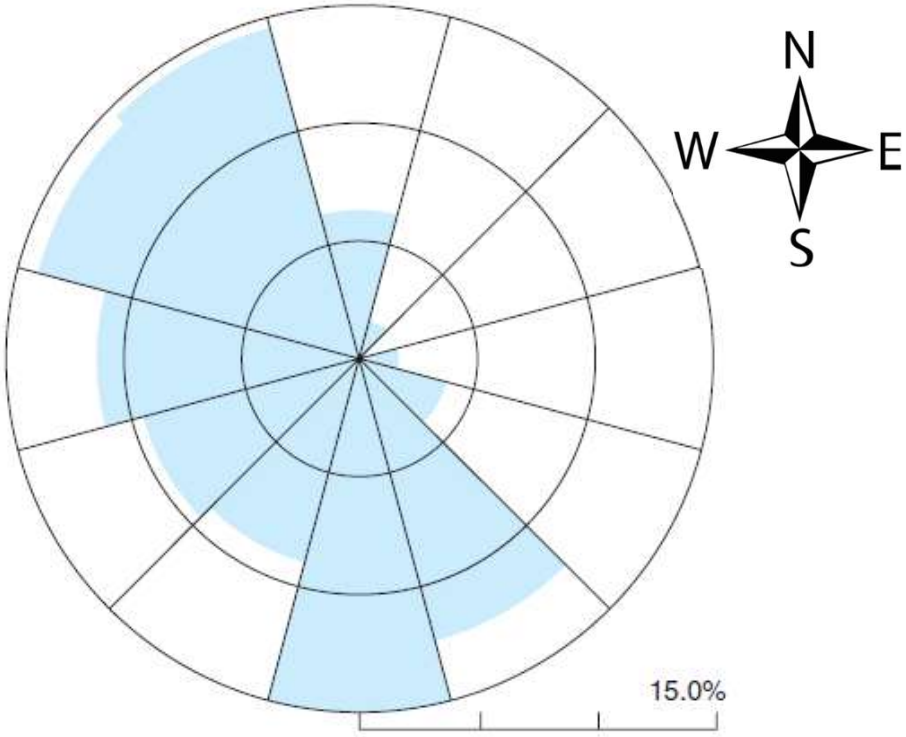
- **Wind**
- **Solar power**
- **Biofuel**

https://www.jasc.ch/the-top-5-renewable-energy-sources-for-homes

Review: Energy

- Varied wind direction
- Design wind turbine like a “sunflower”

Percentage time distribution of wind direction

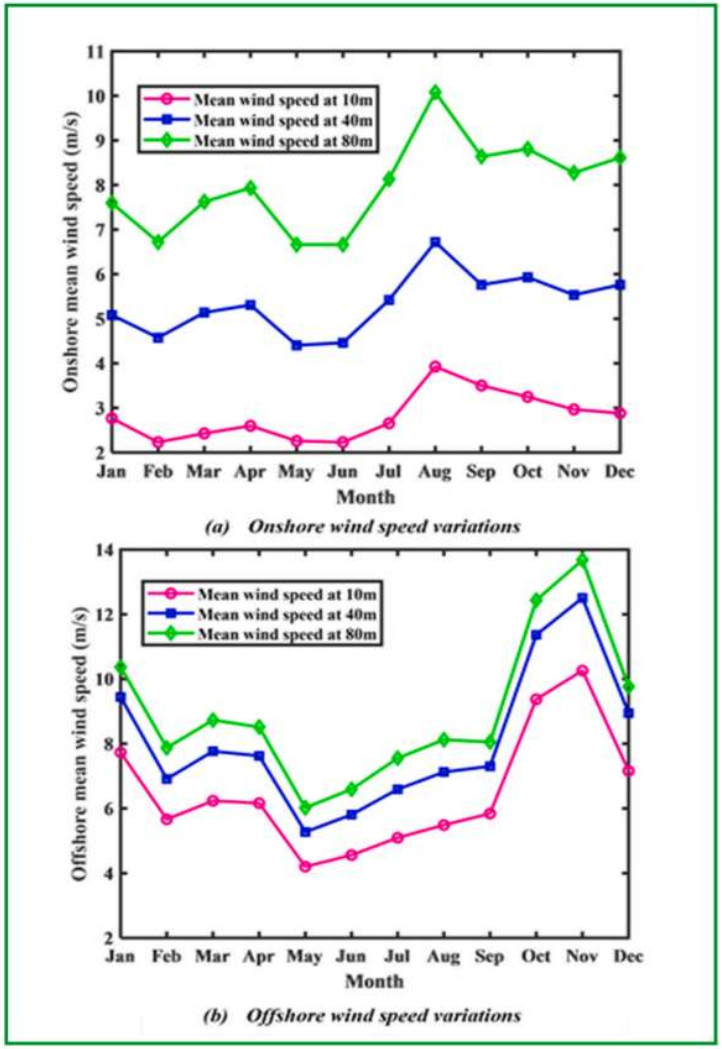


Credit to Prof. Yunlong Zi

Review: Energy

- Offshore sites have higher wind energy potential
- Most existing wind farms are onshore
- More offshore wind farms are being built

Desalegn, 2023



Year	I. Historical Data (GW)	
	(IRENA (2021), *Renewable Energy Statistics, 2021 The International Renewable Energy Agency, Abu Dhabi.*, n.d.; IRENA-International Renewable Energy Agency, 2023; Renewable Energy AgencyI, 2022)	
	Onshorc	Offshorc
2011	216.344	3.776
2012	261.579	5.334
2013	292.705	7.171
2014	340.816	8.492
2015	404.458	11.717
2016	452.515	14.342
2017	495.381	18.837
2018	539.888	23.626
2019	593.291	28.355
2020	698.043	34.367
2021	769.196	55.678
2022	836	63

Vocabulary of this lecture

- **Photovoltaic:** 光伏
- **Molten salt:** 熔盐
- **Perovskite：** 钙钛矿
- **Starch:** 淀粉
- **Cellulose:** 纤维素
- **Lignin：** 木质素
- **Glucose：** 葡萄糖
- **Algae:** 藻类
- **Ethanol :**乙醇

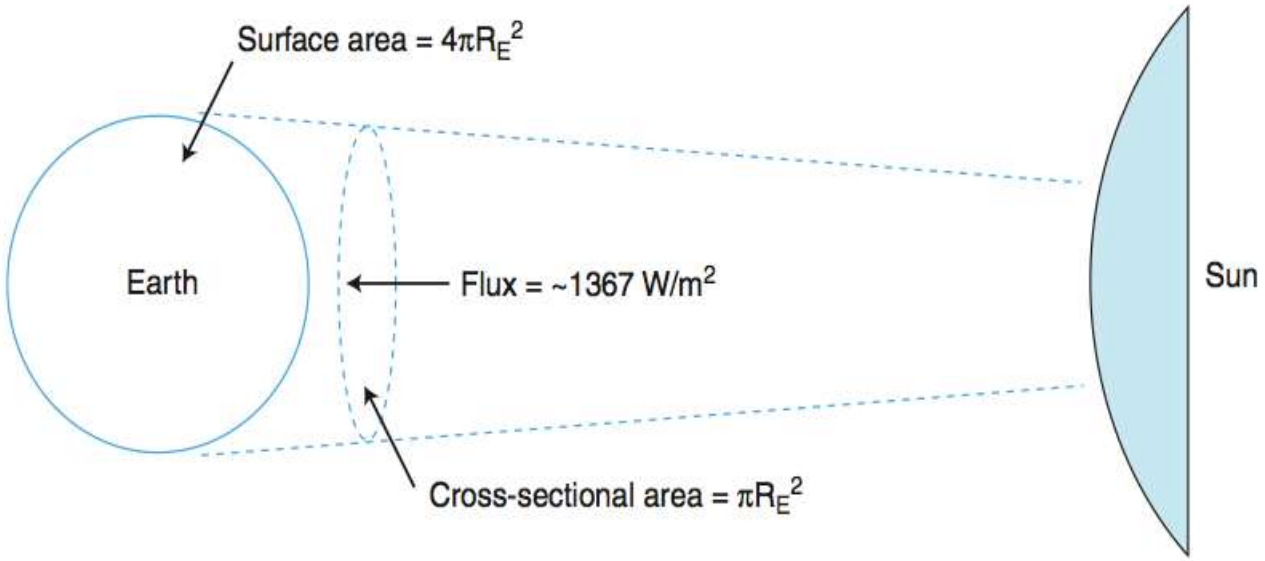
Solar Energy

- Solar energy:
  - ➢enormous,
  - ➢nonpolluting,
  - ➢inexhaustible

https://sempower.com/fun-facts-about-solar-energy/

Solar radiation

- Solar Constant: average intensity at the distance of the Earth 1367 W/m^2

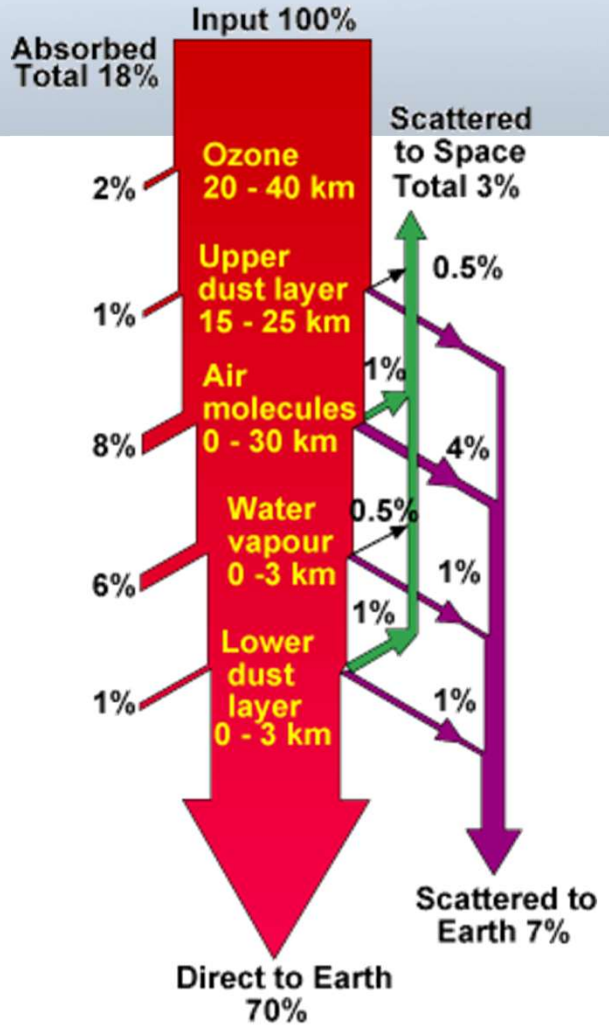


Credit to Prof. Yunlong Zi

Solar radiation

- Reduced by the air through absorption, scattering and reflection.

- Solar energy received by Earth in less than 1 month = all the energy stored in coal, petroleum, and natural gas

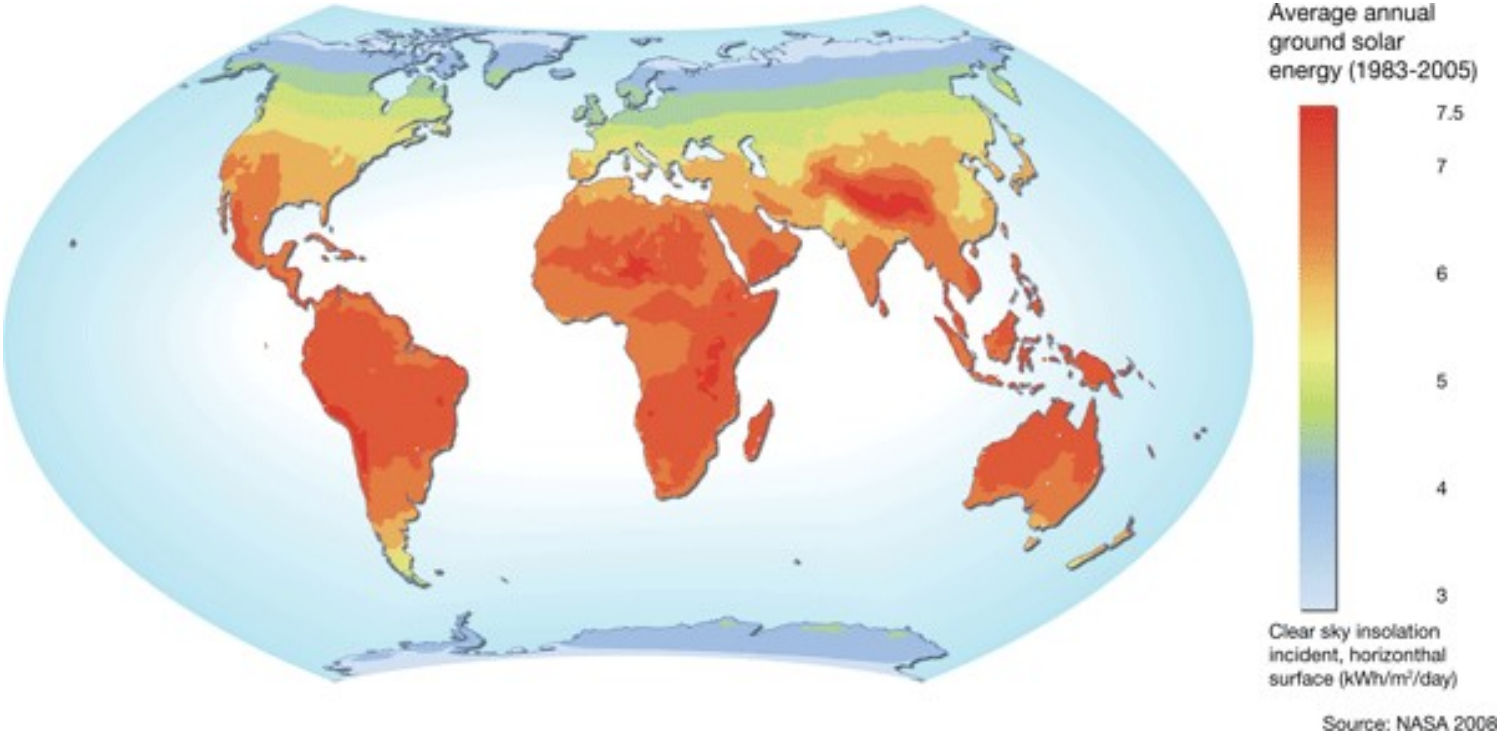


https://www.pveducation.org/pvcdrom/properties-of-sunlight/atmospheric-effects

Typical clear sky absorption and scattering of incident sunlight, Reflection accounts for ~30% of the total inputs

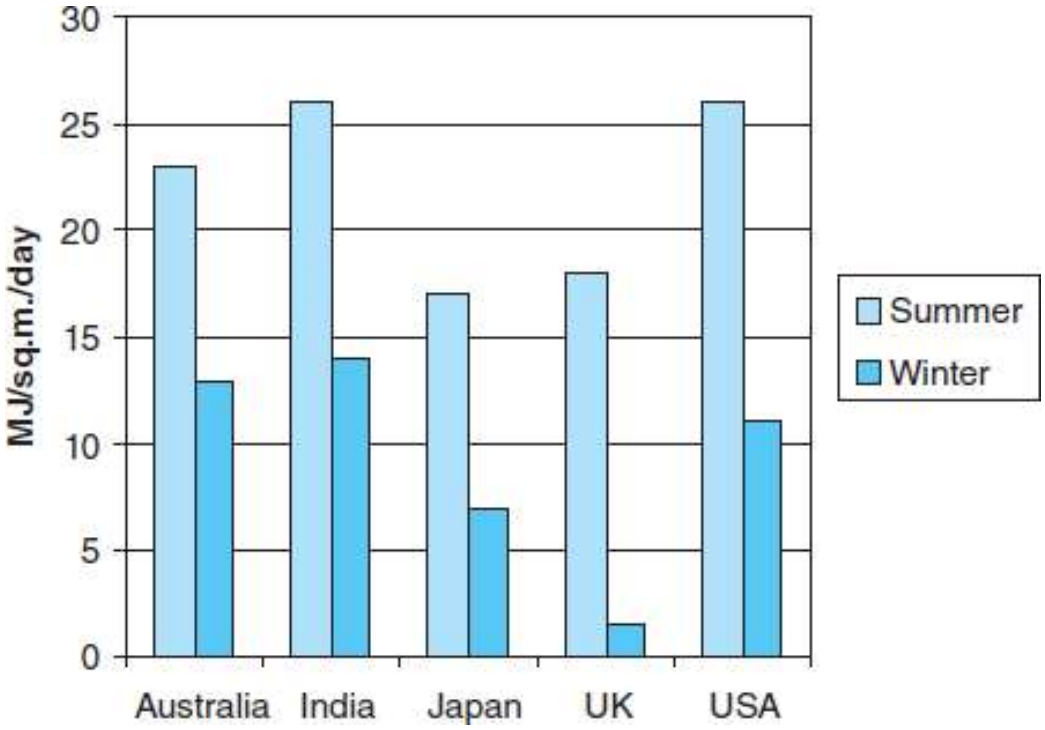
Factors affecting solar energy reaching land surface(Insolation)

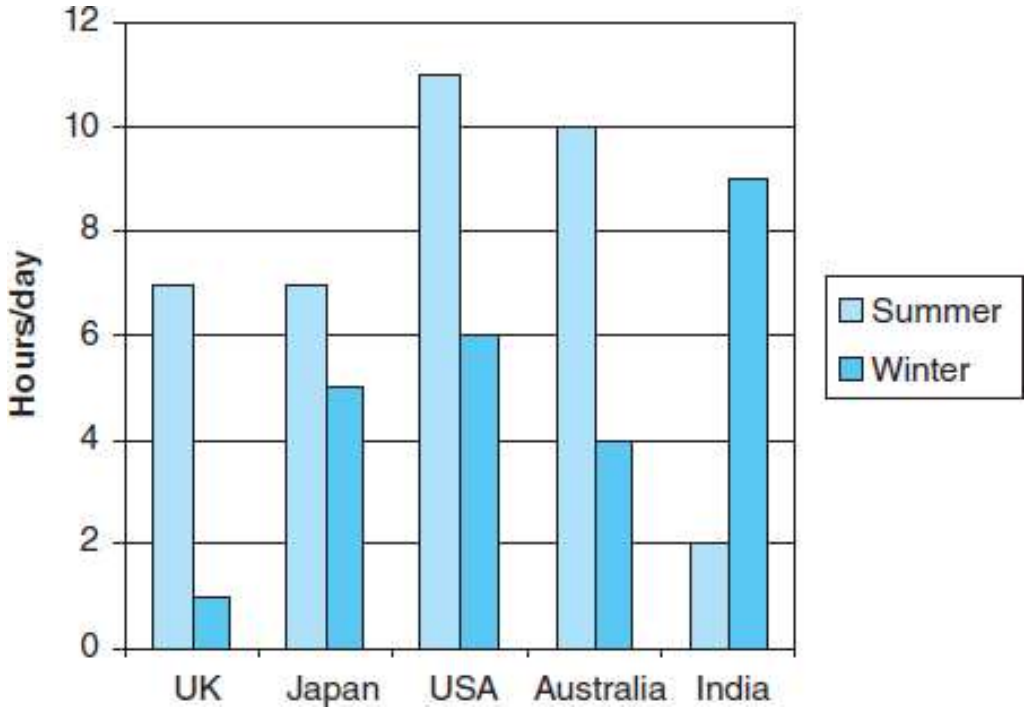
- Weather
- Season
- Solar time in a day
- Location



https://www.eia.gov/energyexplained/solar/where-solar-is-found.php

Availability of solar radiation

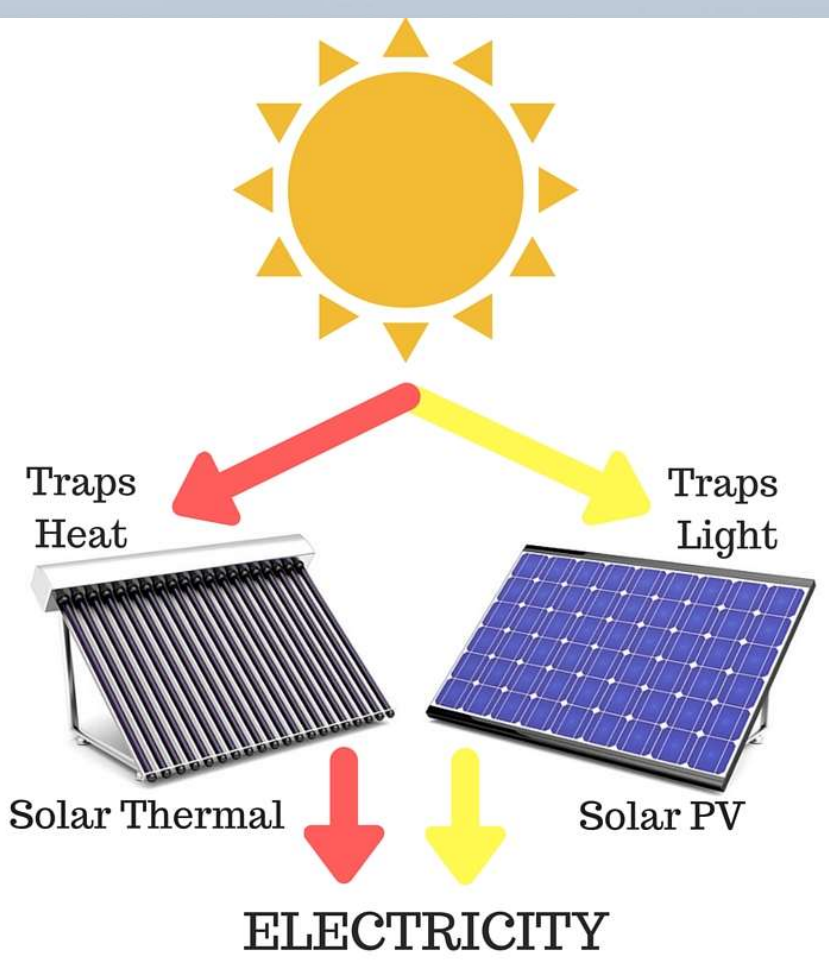




Credit to Prof. Yunlong Zi

Solar Energy

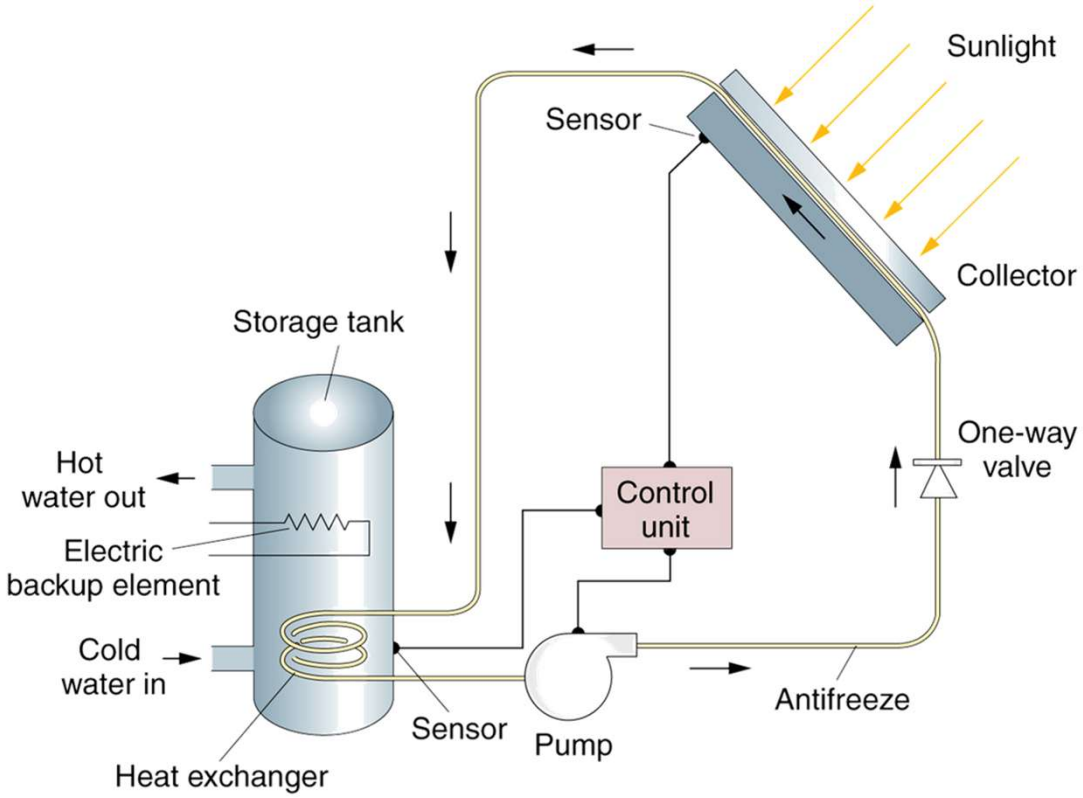
- Two technical routes:
  - ➢Solar energy to heat
  - ➢Solar energy to electricity



https://www.electricradiatorsdirect.ie/news/solar-thermal-is-our-favourite-renewable-energy-under-threat/

Solar Thermal Applications

- Two types of solar collectors:
  - ✓Flat-plate solar collector
  - ✓Concentrating collector



Credit to Prof. Yunlong Zi
https://www.e-education.psu.edu/eme811/node/685

Flat-plate solar collector

- Water or air as transport fluid
- Implemented at household scales

Credit to Prof. Yunlong Zi
https://www.edisonintegratedltd.com/

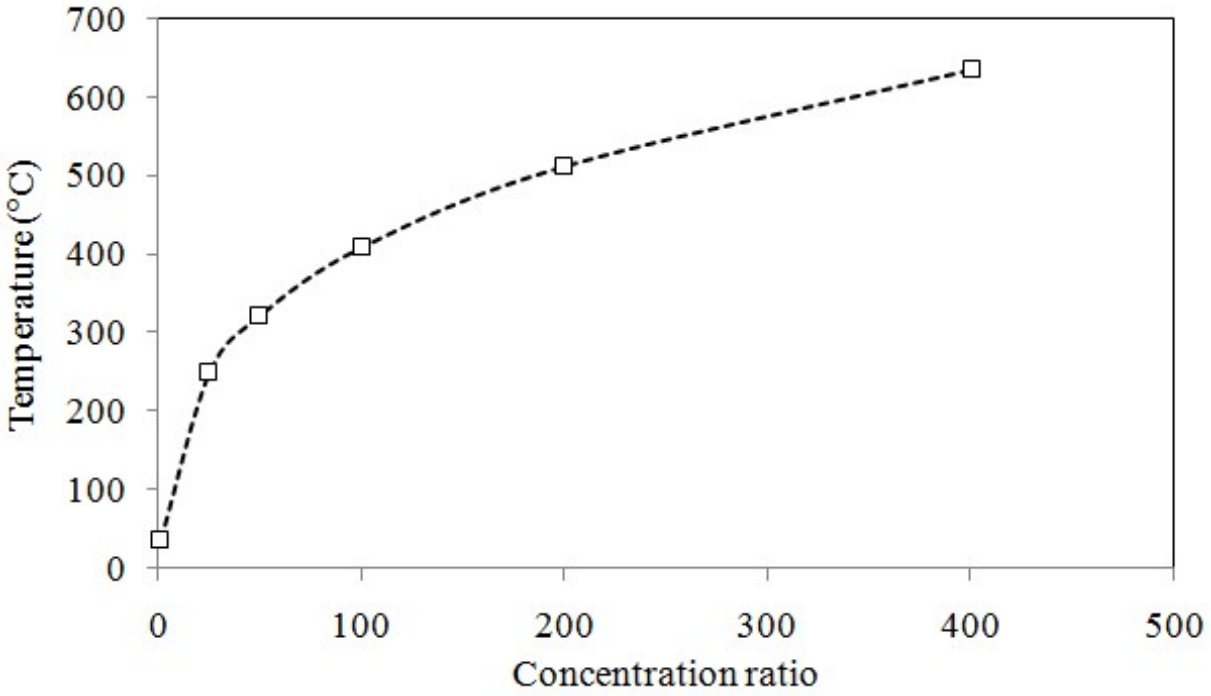
Concentrating Solar-thermal Power (CSP)

- The mirrors reflect, concentrate and focus natural sunlight, then convert into heat.
- Heat create steam, which drives a turbine to generate electrical power

https://www.brunel.net/en/blog/renewable-energy/concentrated-solar-power
https://www.solarpaces.org/

Concentrating Solar-thermal Power (CSP)

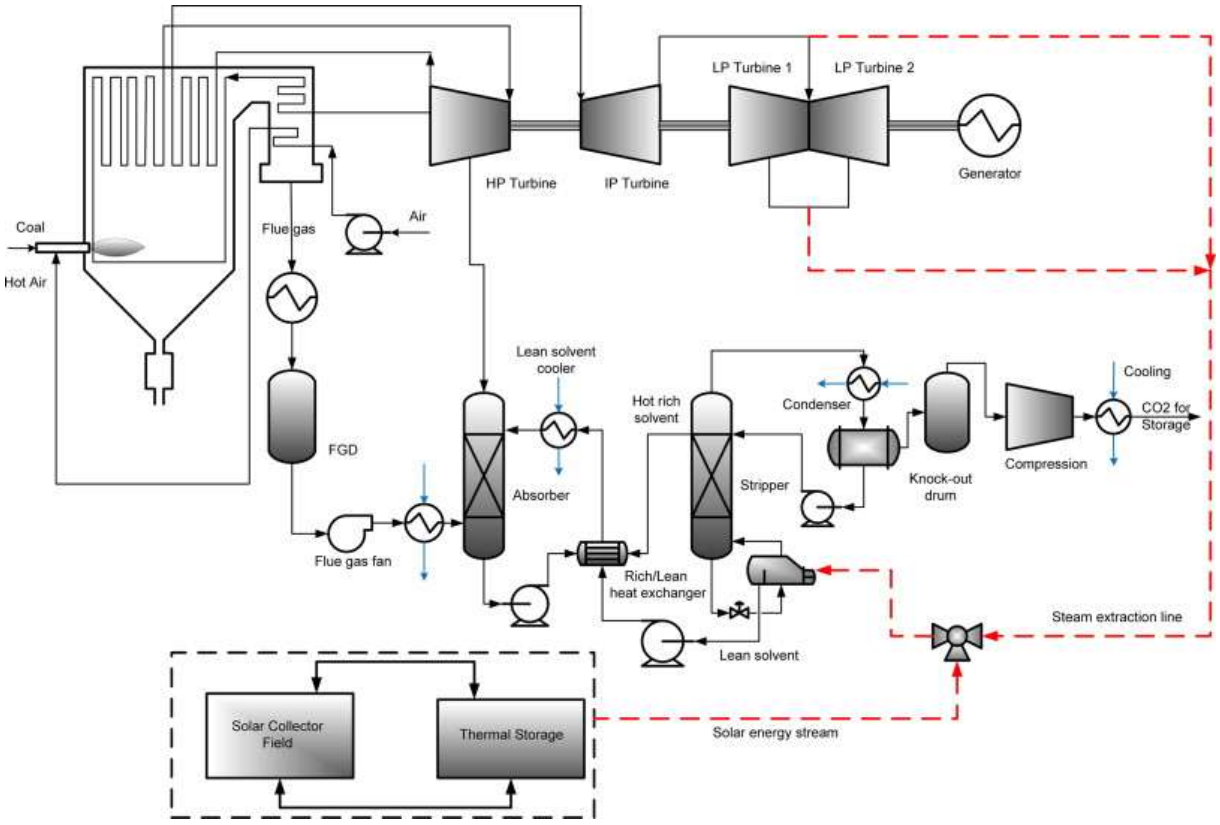
- Working fluid in the receiver is heated to 500–1000 °C
- Solar-to-electricity efficiencies are 7-20% for pilot power tower systems



Senthil et al. 2017

Advantages of CSP

- Relatively continuous, storing heat in transport fluid
- Can be integrated with other thermal plants (e.g., Rankine cycle)



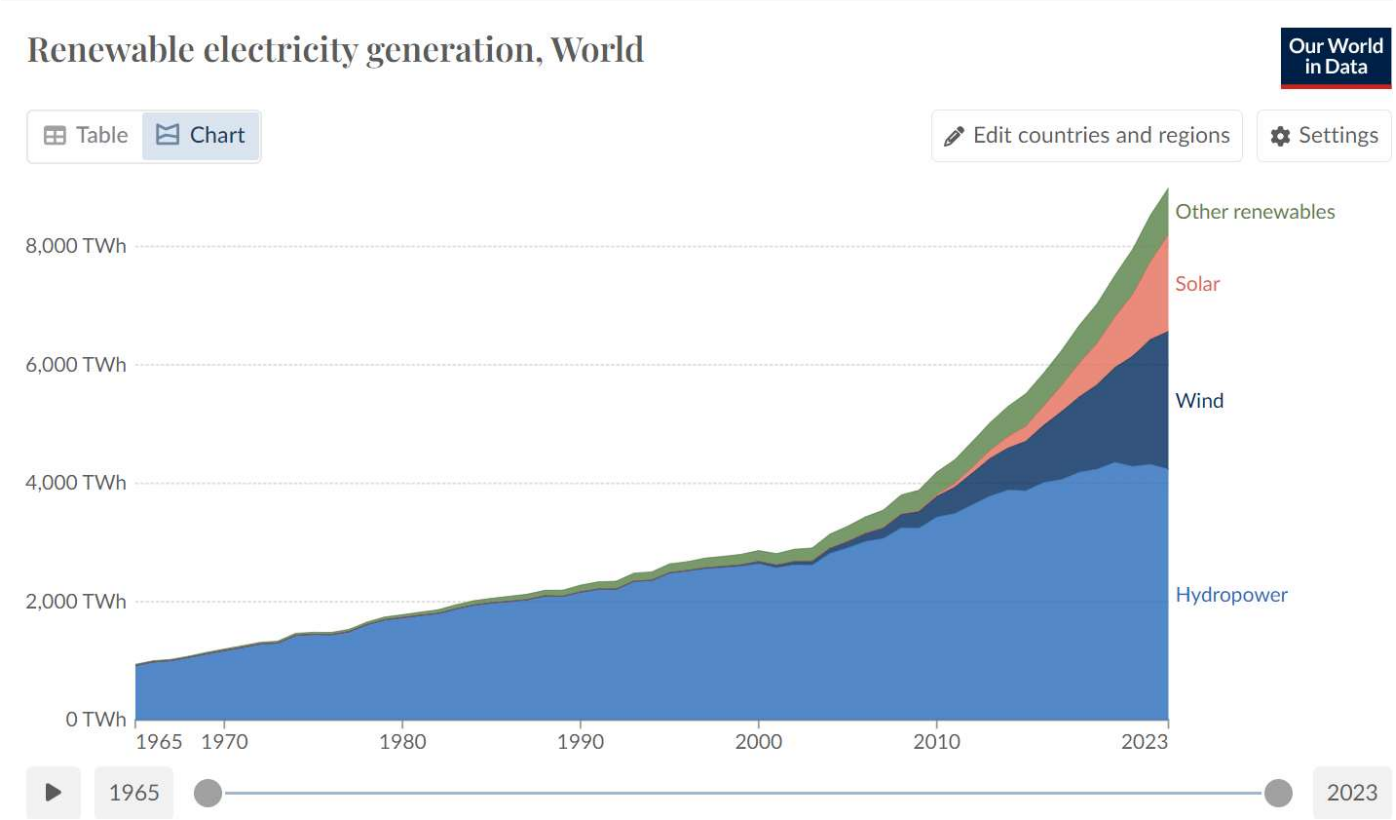
Parvareh et al., 2014. Renewable and Sustainable Energy Reviews

Disadvantages of CSP

- Needs large areas of land
- Cost is high
- Frequent maintenance needed

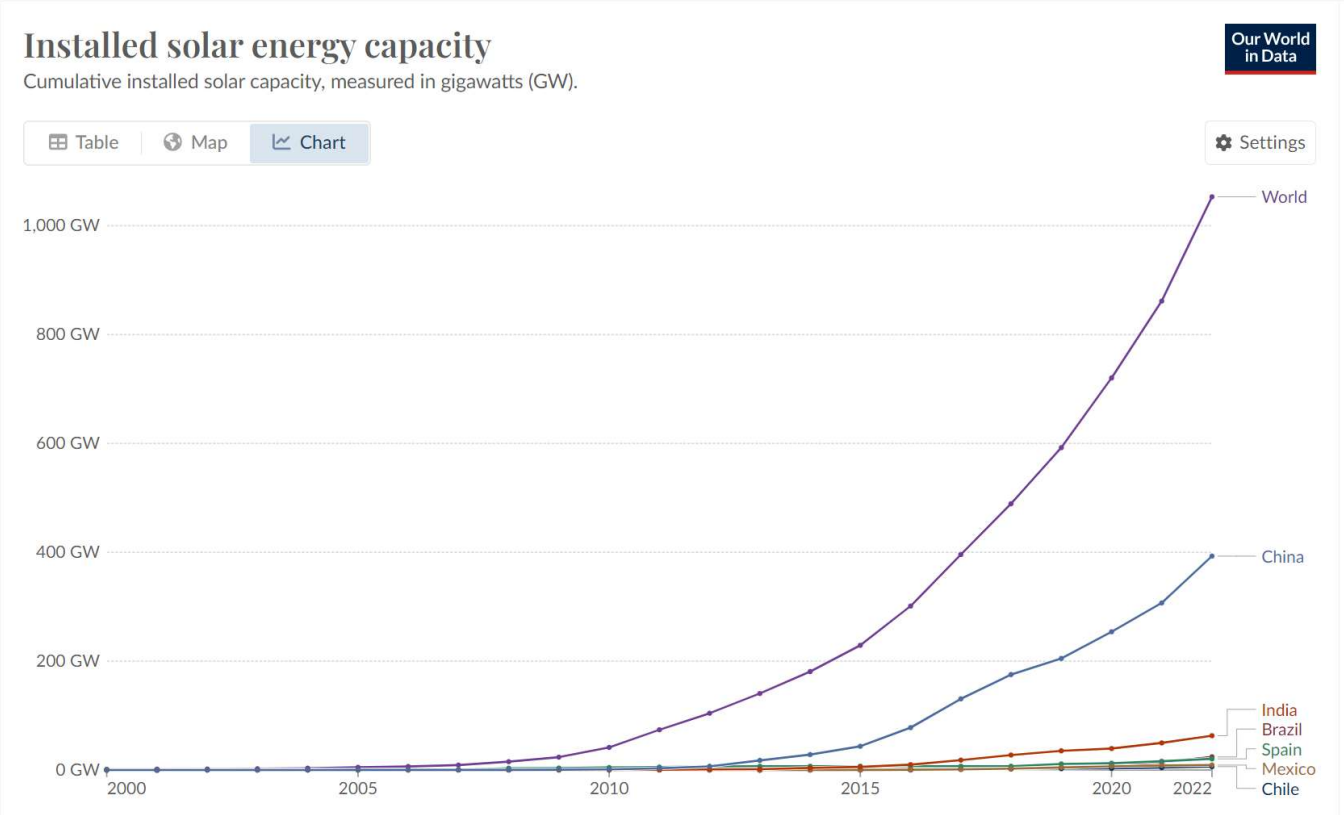
https://www.brunel.net/en/blog/renewable-energy/concentrated-solar-power

Photovoltaic (PV) Solar Energy



https://www.iea.org/energy-system/renewables

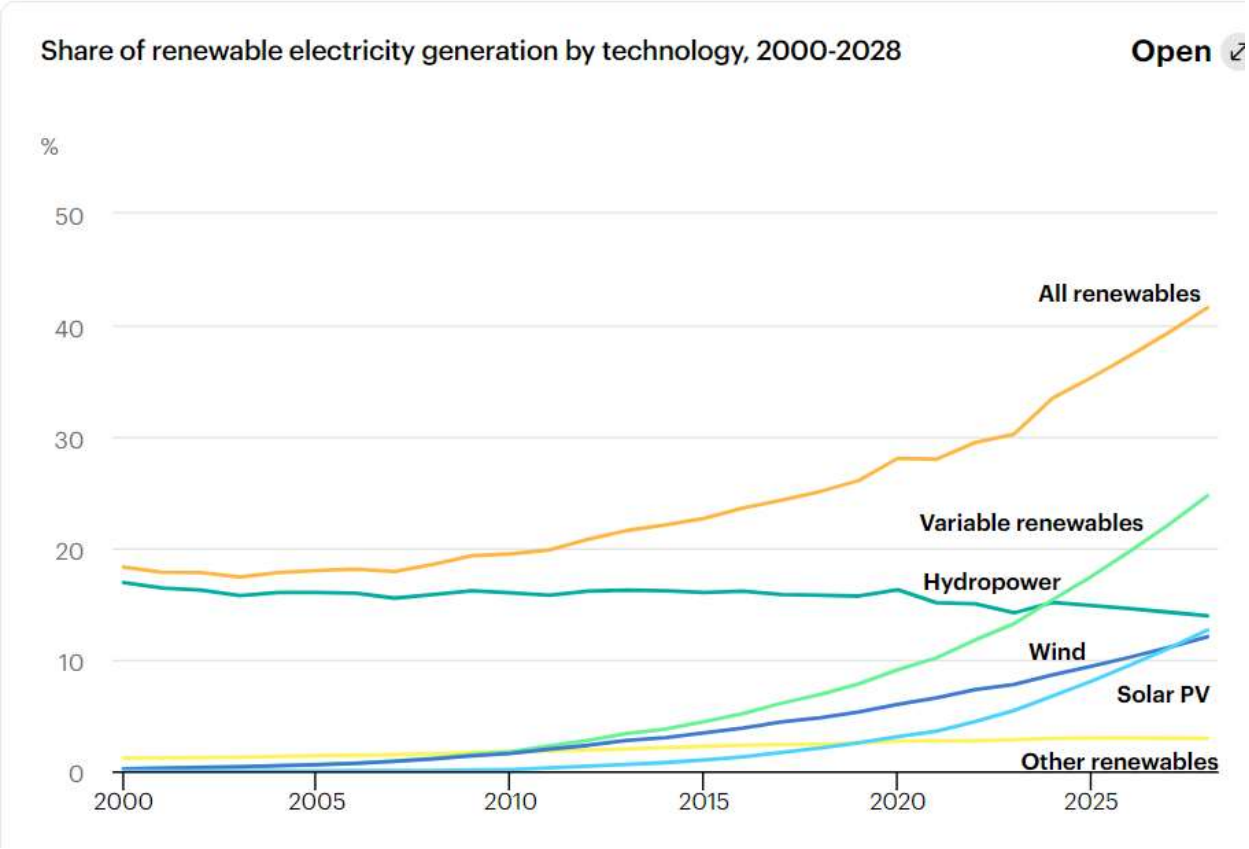
PV Solar Energy



https://ourworldindata.org/grapher/installed-solar-pv-capacity

PV Solar Energy

- In 2024, wind and solar PV together generate more electricity than hydropower.
- In 2028, renewable energy sources account for over 42% of global electricity generation, with the share of wind and solar PV doubling to 25%.



Installed solar energy capacity (ourworldindata.org)

PV technology

- Convert sunlight directly into electrical energy
- An individual PV cell is usually small, typically producing about 1 or 2 watts of power
- they are connected together in chains to form larger units

Credit to Prof. Yunlong Zi

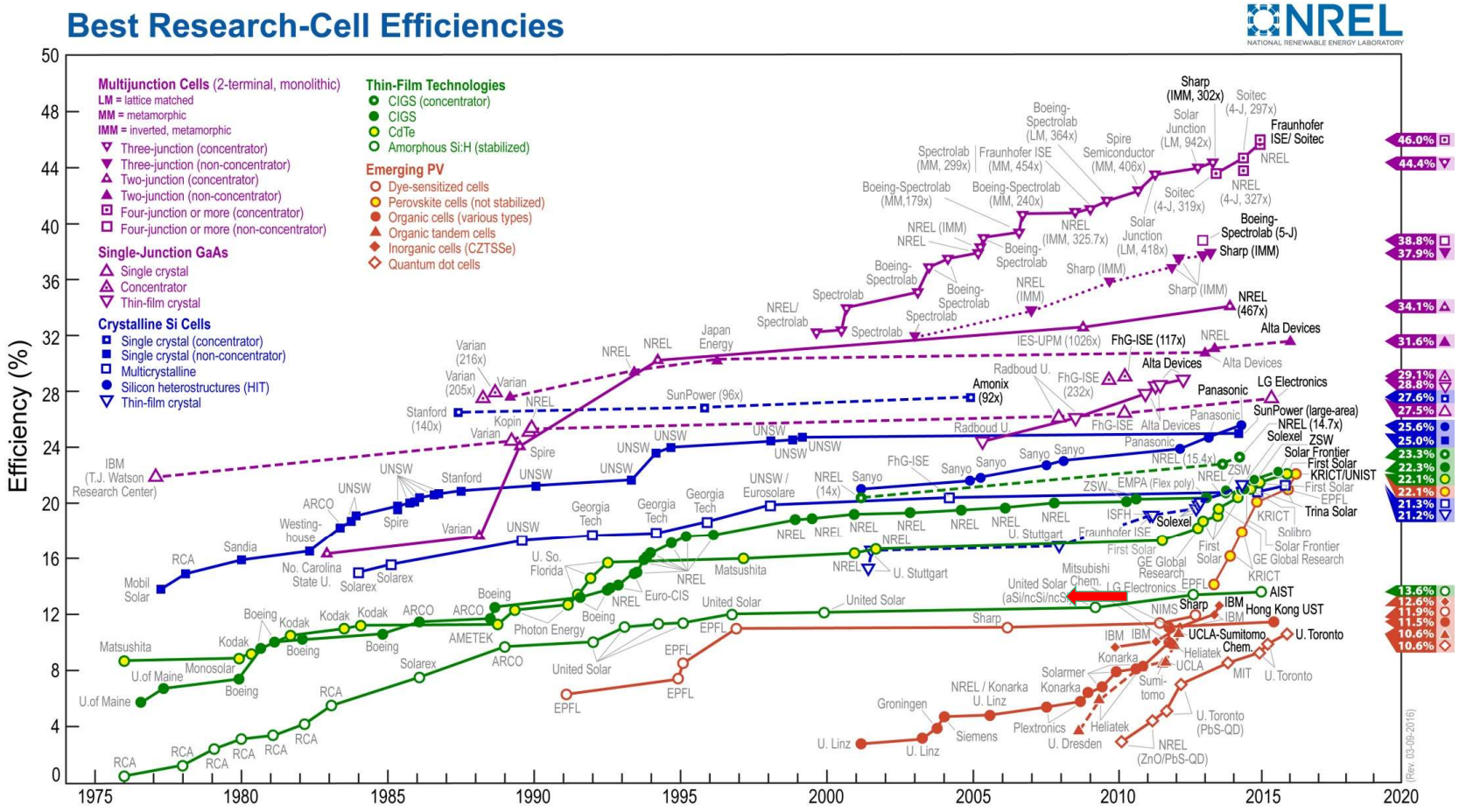
History of Photovoltaic System

- ✓1836 A.E. Becquerel observe photovoltaic effect
- ✓1883 Charles Fritts made the first solar cell based on selenium
- ✓1900 Planck postulates the quantum nature of light
- ✓1905 Einstein extended Planck's hypothesis to explain the photoelectric effect
- ✓1946 Russel Ohl applied the first patent for modern solar cell
- ✓1954 Chapin, Fuller and Pearson announce 6% efficient silicon solar cell
- ✓1958 First use of solar cells on an orbiting satellite Vanguard I
- ✓1970s start to use solar cells in civic applications
- ✓2023 1247 GW capacity installed worldwide

Credit to Prof. Yunlong Zi

Solar Cell Research

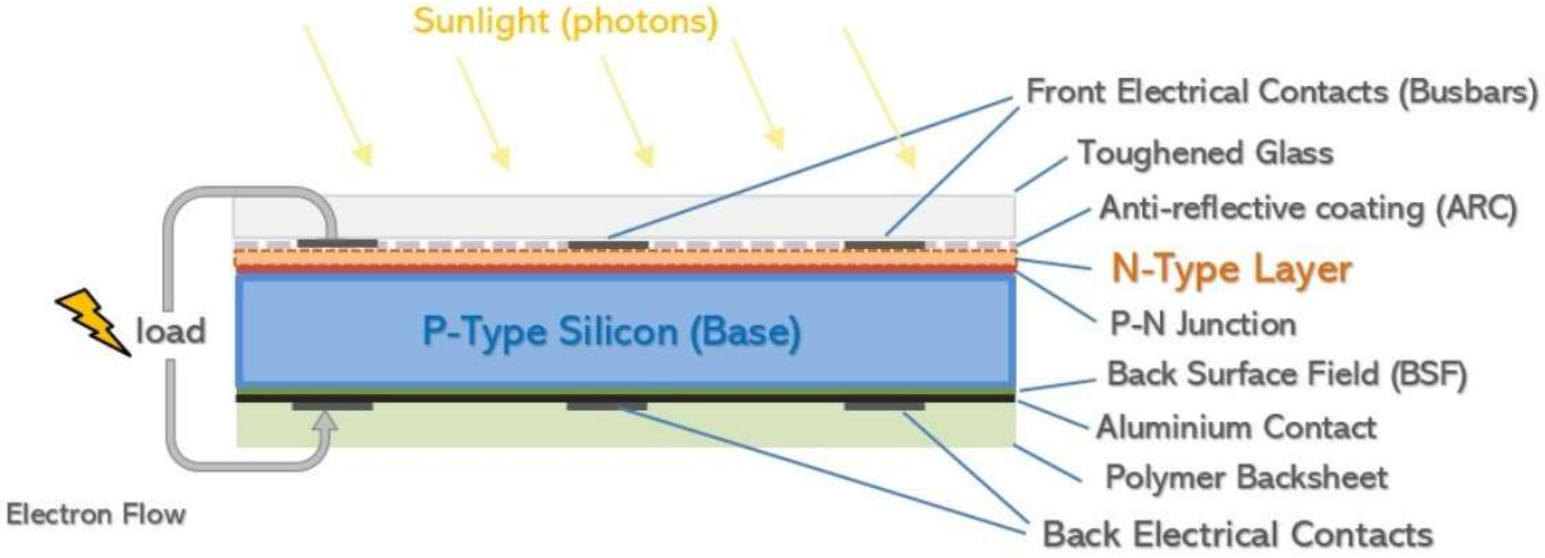
- Silicon based cells have the efficiency of ~25%
- Perovskite has a much higher efficiency of 35%-45%



Credit to Prof. Yunlong Zi
https://www.pv-magazine.com/2024/09/12/longi-achieves-34-6-efficiency-for-two-terminal-tandem-perovskite-solar-cell-prototype/

Silicon PV Cells

- N-Type – Negatively charged Silicon doped with Phosphorous
- P-Type – Positively charged Silicon doped with Boron

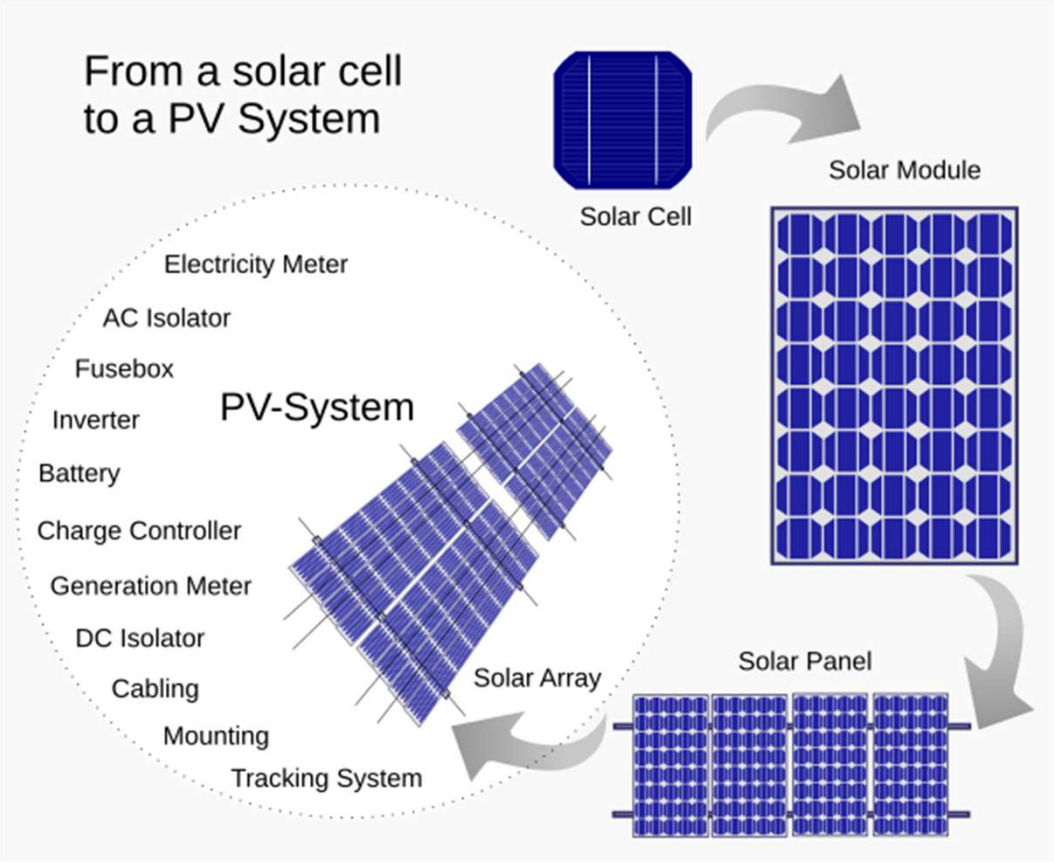


Basic construction diagram of a common P-type silicon cell

https://www.cleanenergyreviews.info/blog/solar-pv-cell-construction

Silicon PV Cells

- Silicon solar cells has a market share of 95%
- Multiple cells are integrated to form a panel, yielding higher current



Credit to Prof. Yunlong Zi
https://www.mouser.cn/blog/cn-new-pv-cells-benefit-energy-harvesting

Installation: Mounting of a few panels

Credit to Prof. Yunlong Zi

Solar farms

A solar farm is a large collection of photovoltaic (PV) solar panels that absorb energy from the sun, convert it into electricity and send that electricity to the power grid for distribution and consumption

https://chariotenergy.com/chariot-university/solar-farms/

Large solar farms

- The Xinjiang solar farm in China has just become the world's largest solar farm, with an installed solar capacity of 5GW，covering~800km^2 (Nansha district is 803km^2)
- The Golmud Solar Park in China is now the world's second largest solar farm, with an installed solar capacity of 2.8 GW

https://www.theecoexperts.co.uk/solar-panels/biggest-solar-farms

Challenges of solar energy

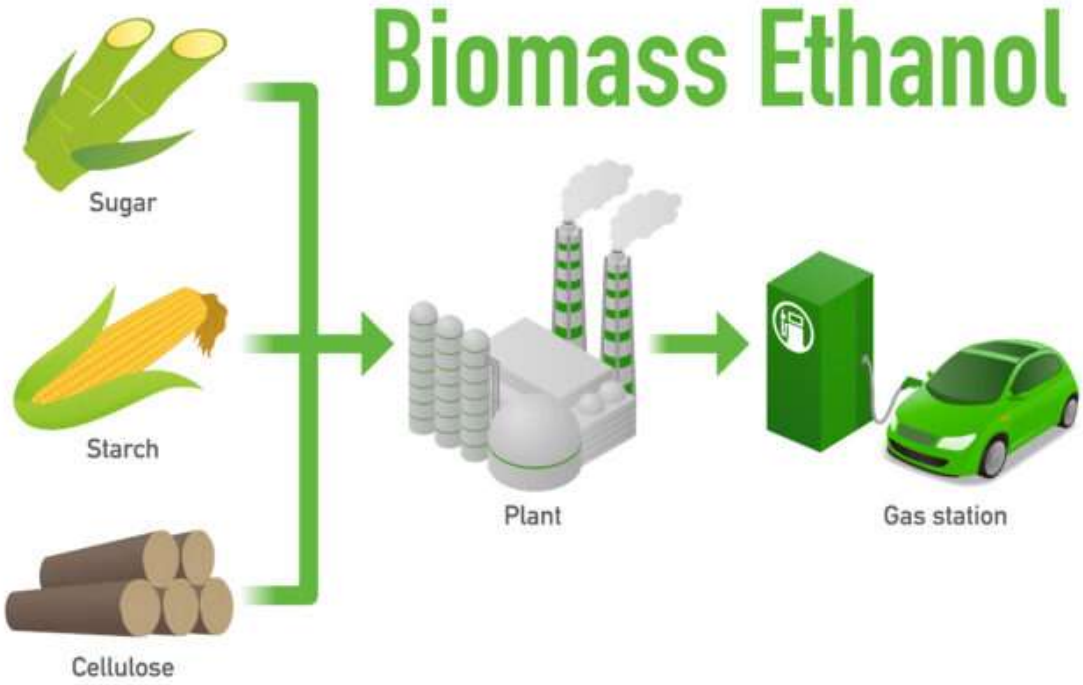
1. Economic and Financial Barriers
2. Technological Advancements and Efficiency
3. Mismatch between energy production and consumption patterns
4. Grid Integration

https://tamesol.com/solar-2024-challenges/

Comparison of CSP and PV

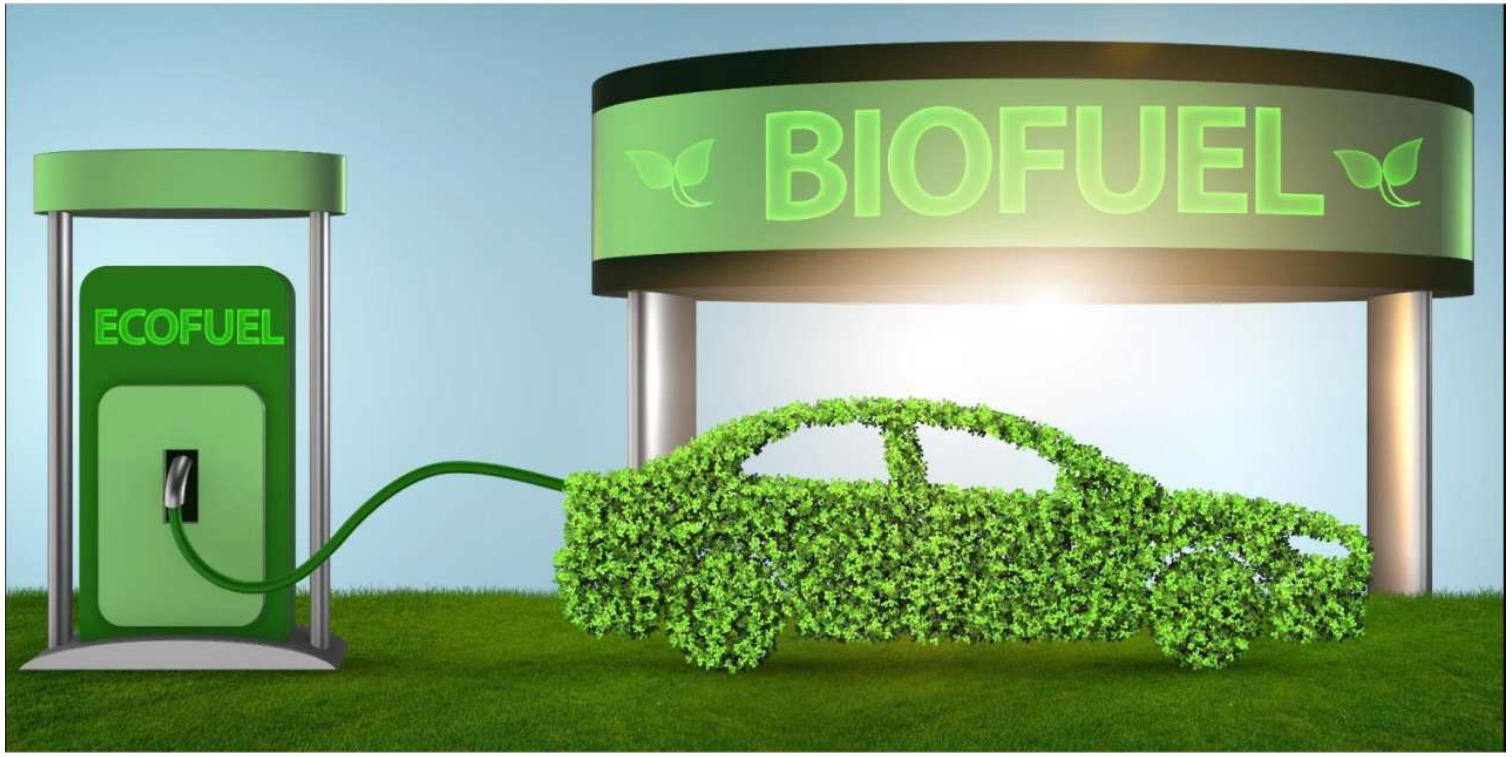
Biofuel

A fuel made from materials derived from living organisms: crops, grass, wood chips

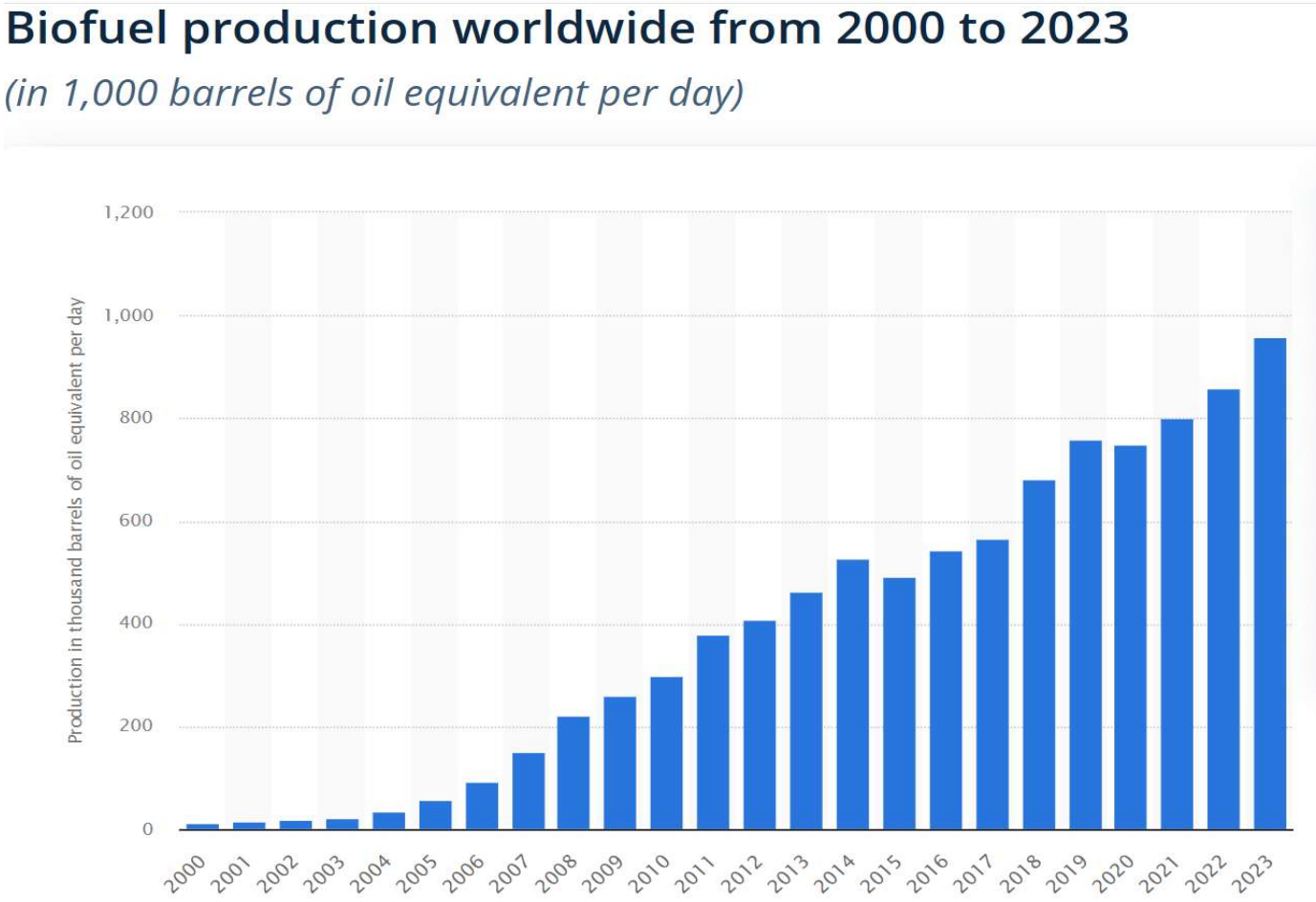


Biofuel

- Low emission
- Raw materials are abundant
- Mainly used to replace oil

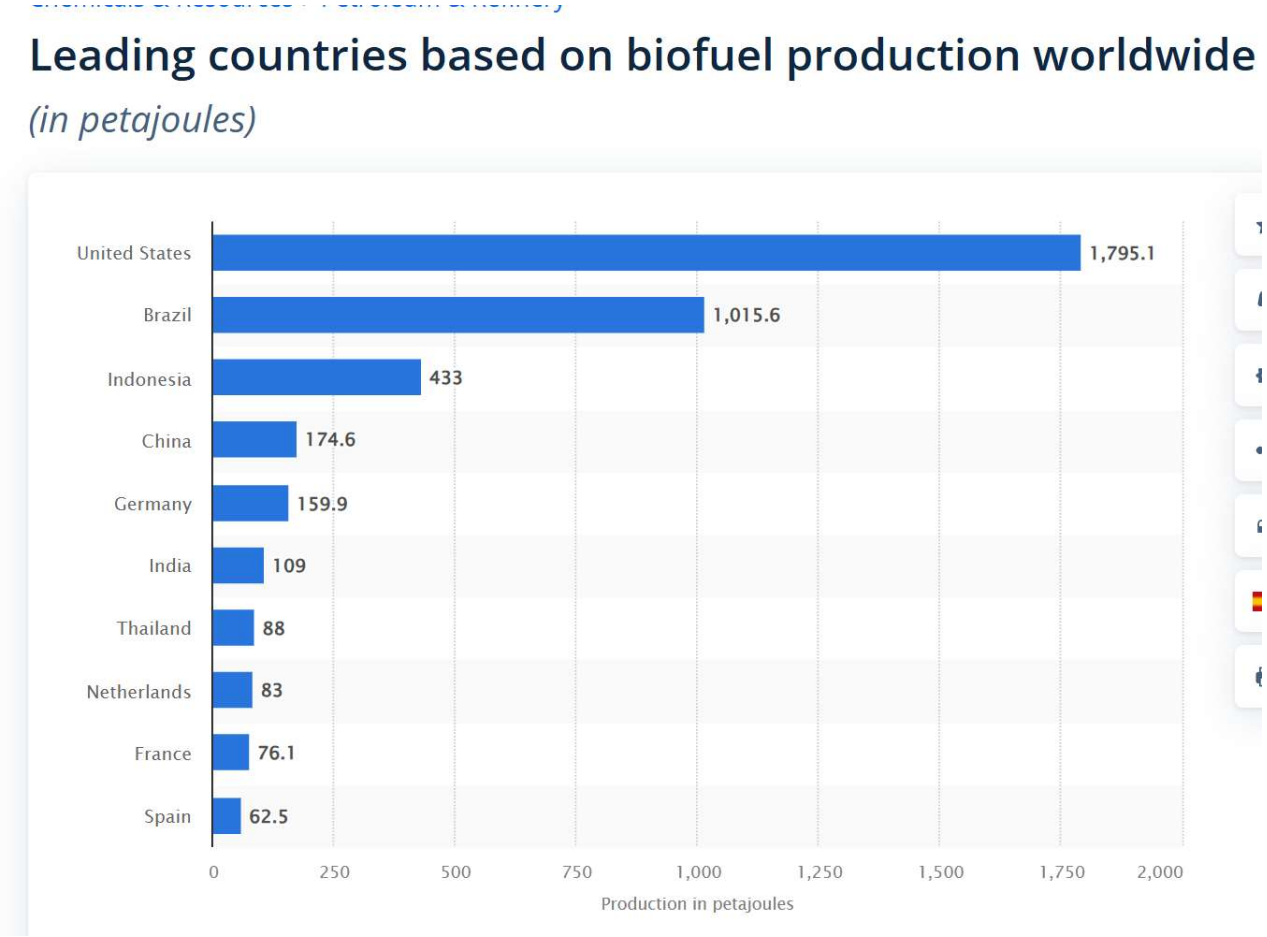


Global Biofuel Production



https://www.statista.com/statistics/274163/global-biofuel-production-in-oil-equivalent/

Global Biofuel Production in 2023



https://www.statista.com/statistics/274168/biofuel-production-in-leading-countries-in-oil-equivalent/

Bioenergy in the U.S.

The source of bioenergy

- Photosynthesis converts solar → chemical energy
  - ✓ $nCO_2 + mH_2O + hv \rightarrow C_n(H_2O)_m + nO_2$
  - ✓ Average fixation ~0.42 W/m^2 (0.2% of solar insolation)
  - ✓ Photosynthesis **stores** ~300 EJ/yr, vs. human energy use ~400 EJ/yr

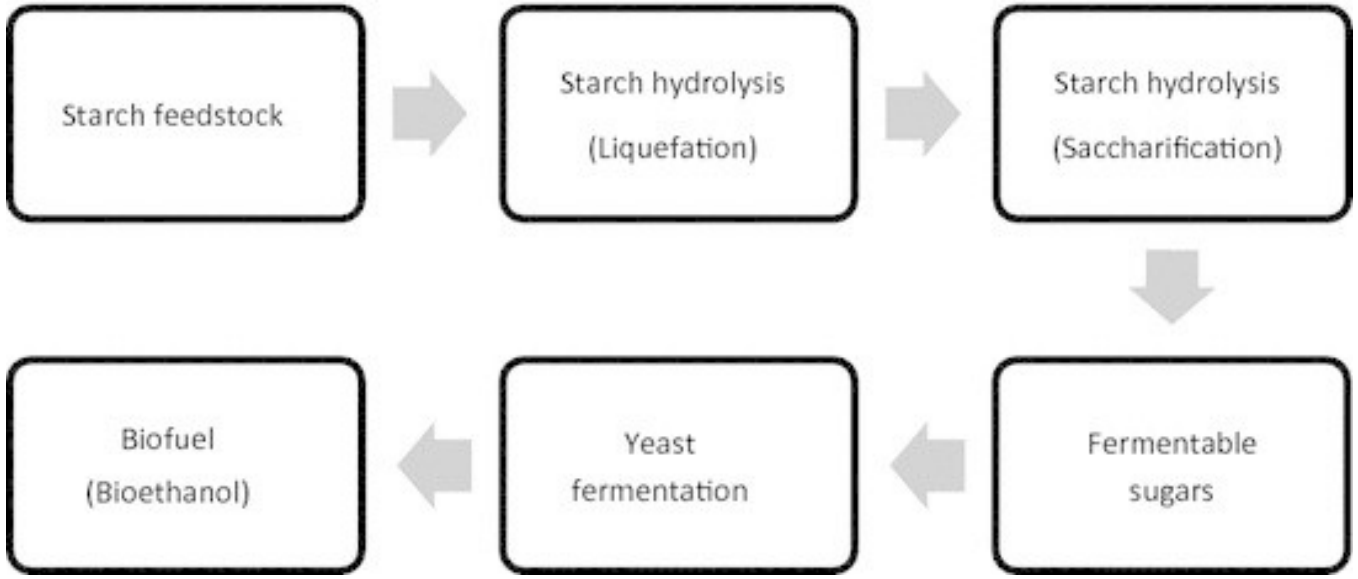
- Biofuel production reverses the above reaction

Credit to Prof. Yunlong Zi

The Source of bioenergy: Starch

Hydrolysis

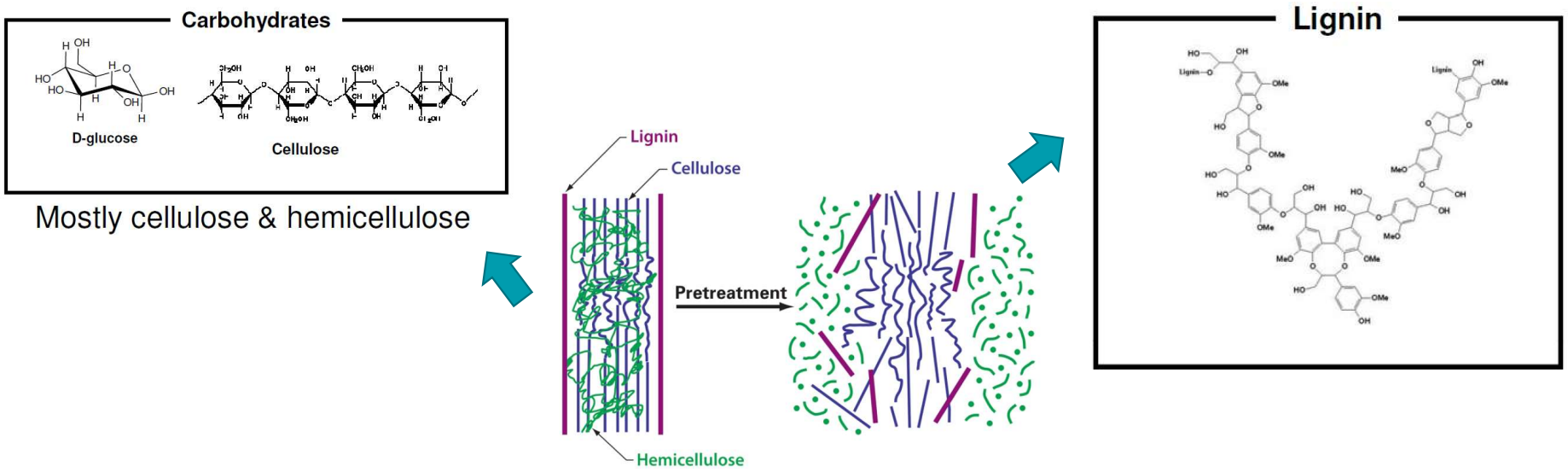
Starch	Water	Glucose
$n\ C_6H_{10}O_5$	$+\ n\ H_2O$	$\rightarrow\ n\ C_6H_{12}O_6$
162g	18g	180g



Woiciechowski et al., 2016
Feedstocks for Biofuels

The Source of bioenergy： Biomass

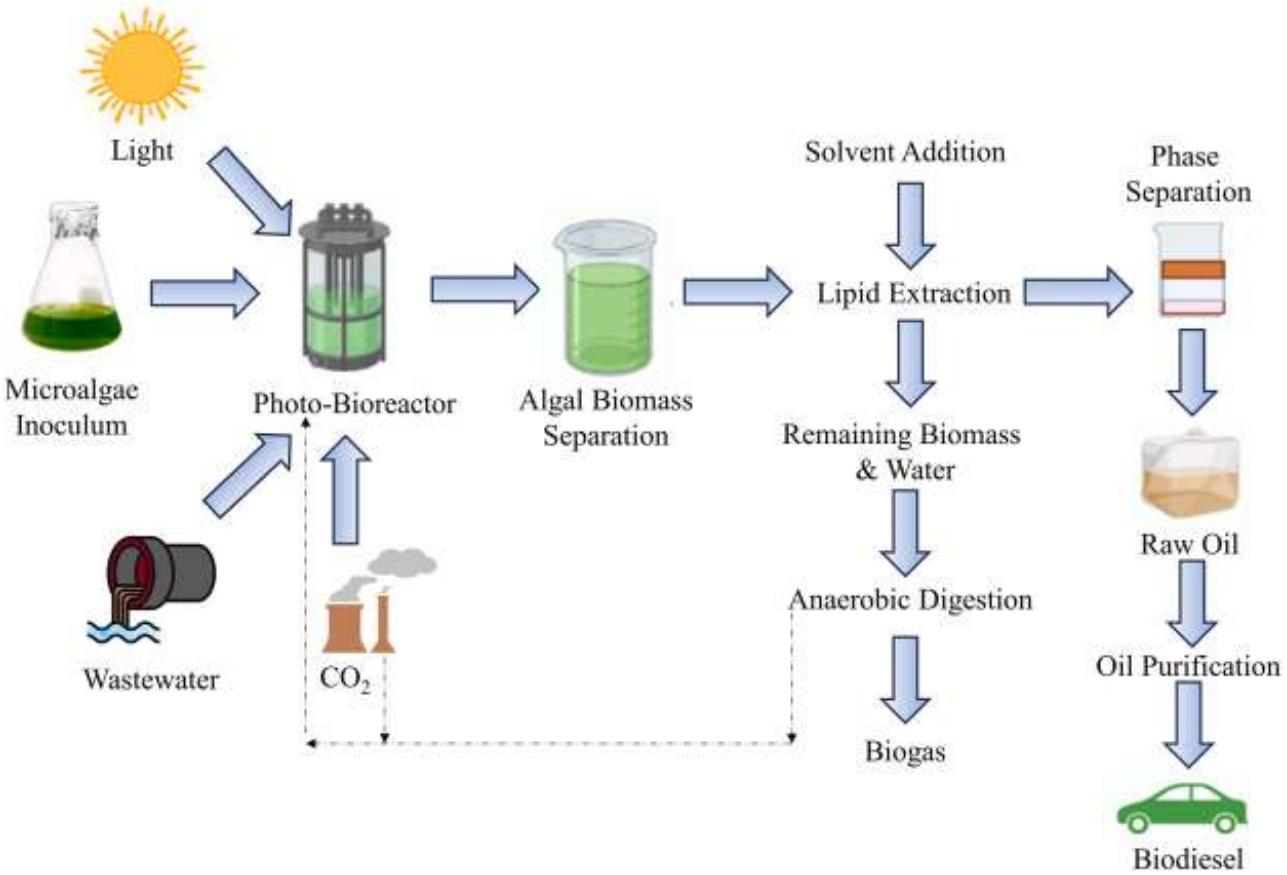
- Carbohydrates (cellulose) & lignin (+proteins, lipids)



from Wikimedia Commons

The Source of bioenergy： Algae

- The high lipid content, high growth rate and ability to rapidly improve strains and produce co-products, without competing for arable land, make algae an exciting addition to the sustainable fuel portfolio



Tomar et al., 2023. Biocatalysis and Agricultural Biotechnology

Ethanol-Gasoline Blends

- Ethanol added to gasoline
- E10 (10% ethanol, 90% gasoline)

Environmental Impacts

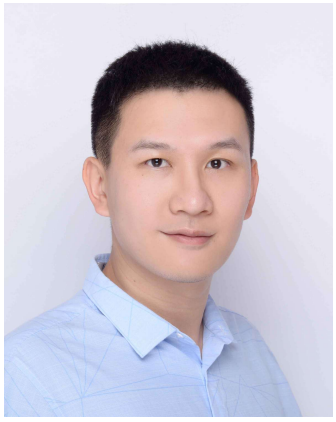
Technology	Land Required (km^2/exajoule-year)
Biomass	125,000 - 250,000
Large Hydro	8,300 - 250,000
Small Hydro	170 - 17,000
Wind	300 (turbines, roads); 17,000 (fetch area)
Photovoltaic	1,700 - 3,300
Coal	670 – 6,700
Natural gas	200 - 670

Tester et al. (data from Flavin & Lenssen, 1994)

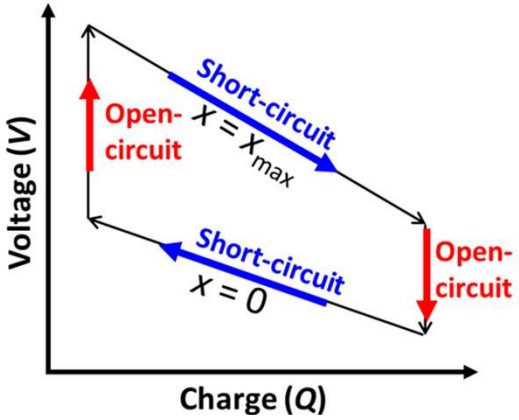
Energy production related Research in the SEE Thrust

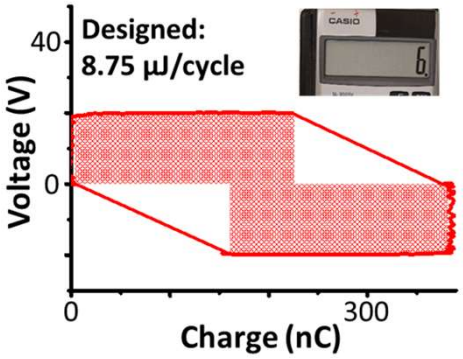
Yunlong ZI 訾云龙

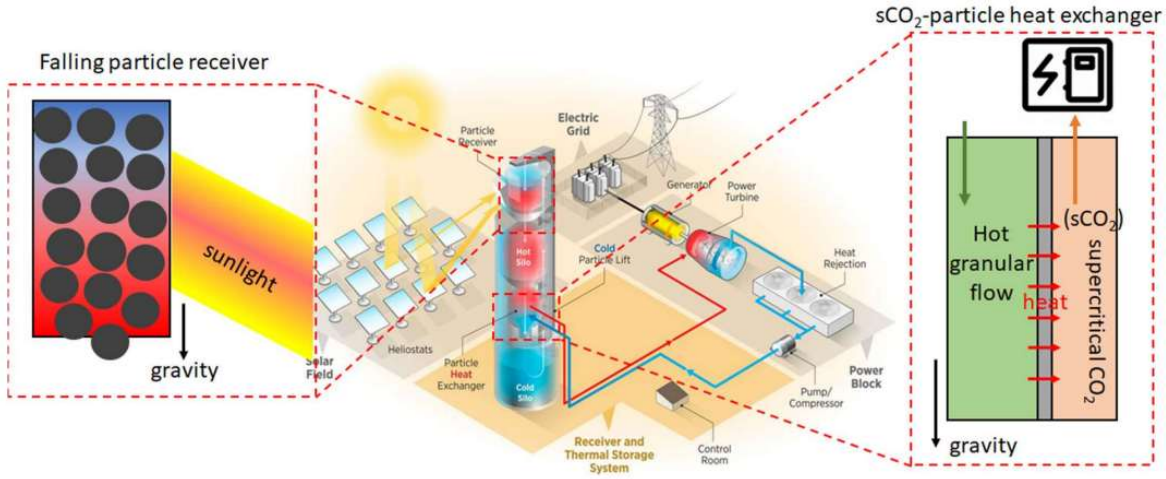
Jian ZENG 曾健



Chang Yan 颜畅







Research related to environmental impacts of energy production in the SEE Thrust

Junyu Zheng 郑君瑜

Shuncheng LEE 李顺诚

Ting Fang 方婷

Yutong LIANG 梁雨桐