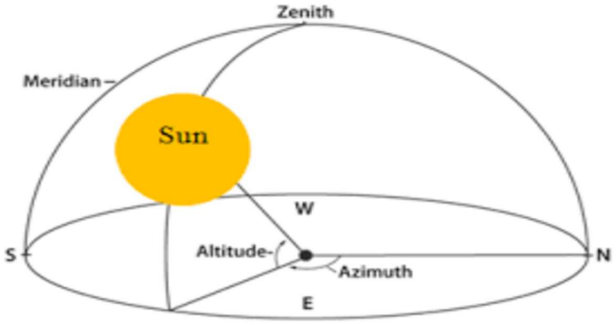
Review: Renewable Energy

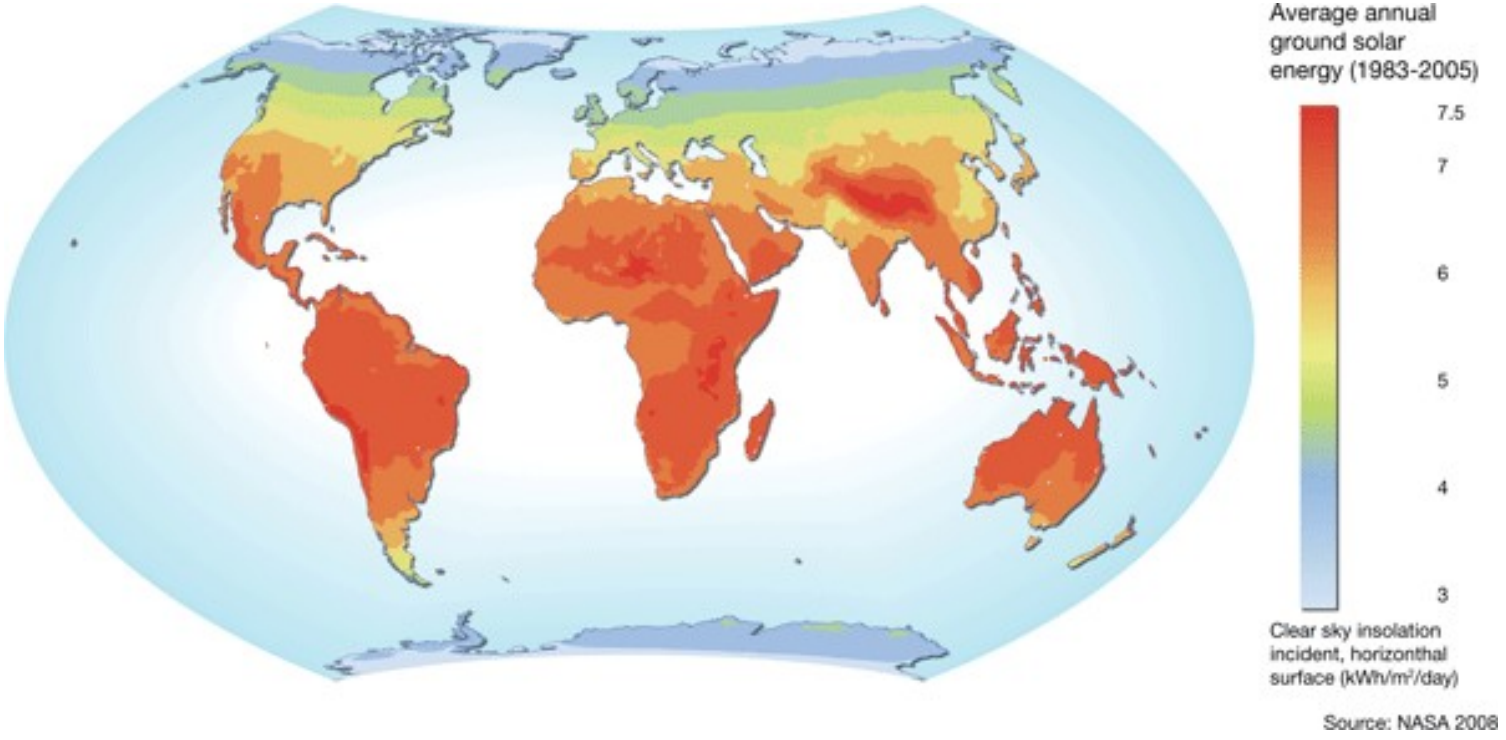
- Solar energy:
  - ➢enormous,
  - ➢nonpolluting,
  - ➢inexhaustible

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

Review: Renewable Energy

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



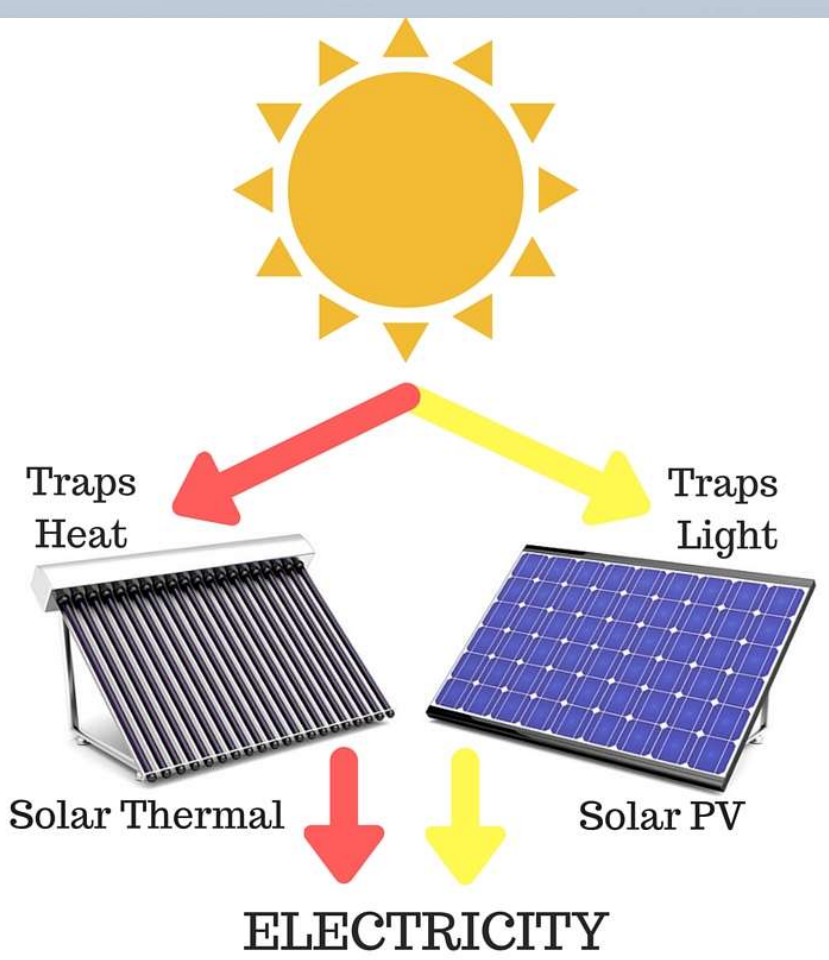


https://www.eia.gov/energyexplained/solar/where-solar-is-found.php

https://arka360.com/ros/solar-angles/

Review: Renewable 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/

Review: Renewable Energy

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

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

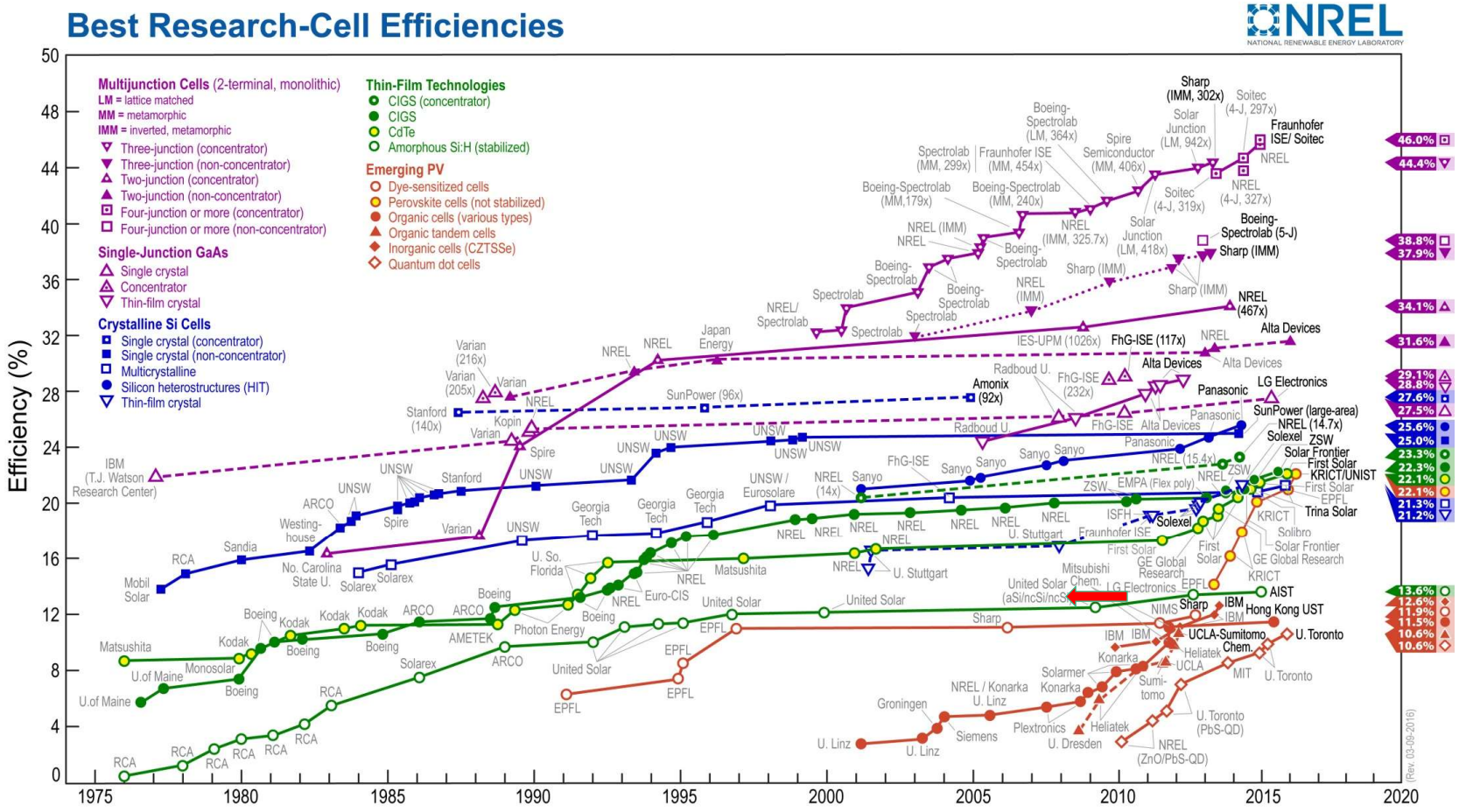
Review: Renewable Energy

- 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

Review: Renewable Energy

- 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/

Review: Renewable Energy

Credit to Prof. Yunlong Zi

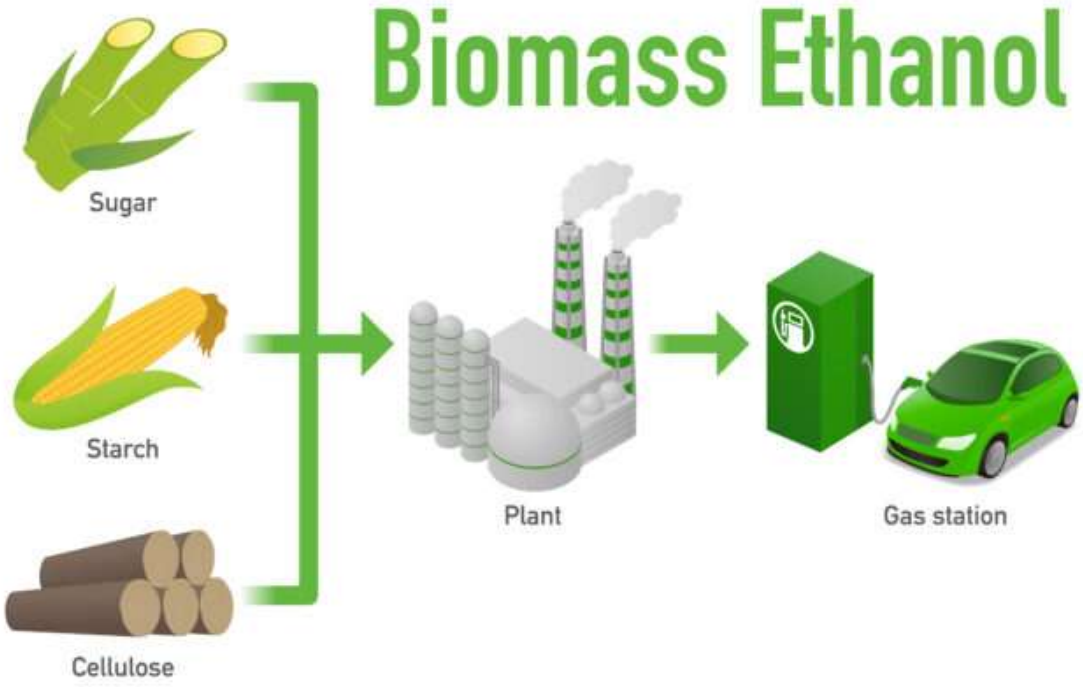
Review: Renewable Energy

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

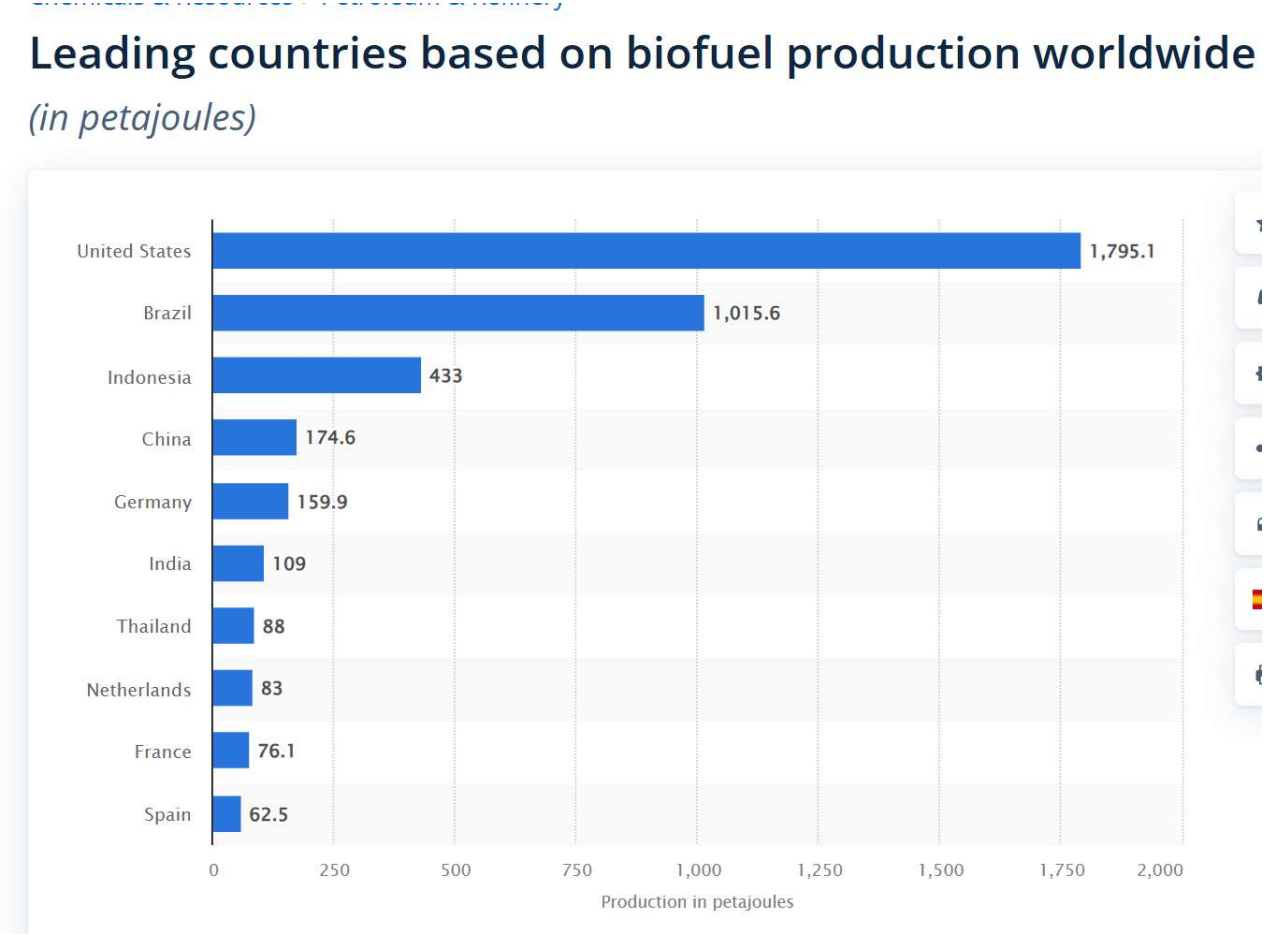
https://chariotenergy.com/chariot-university/solar-farms/

Review: Renewable Energy

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



Review: Renewable Energy



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

Review: Renewable Energy

- 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

Review: Renewable Energy

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

Have we produced enough solar/wind energy?

Too much wind energy in the UK

Excessive Solar Energy in California

Introduction to Function Hub For Sustainable Future

Lecture 9： Energy Storage

Qichun Yang

2024-11-11

香港科技大学(广州)
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY (GUANGZHOU)

Vocabulary of this lecture

- **Intermittent:** 不连续的
- **Seasonality:** 季节性
- **Dispatchable generation:** 可调度发电
- **Ramp rate:** 升降速率
- **Potential:** 势能
- **Gravitational potential:** 重力势能
- **Electromagnetic:** 电磁的
- **Sensible heat:** 感热
- **Latent heat:** 潜热
- **Insulation:** 隔热

- **Lithium:**锂
- **Anode:** 阳极
- **Cathode:** 阴极
- **Electrolyte:** 电解质

Outline

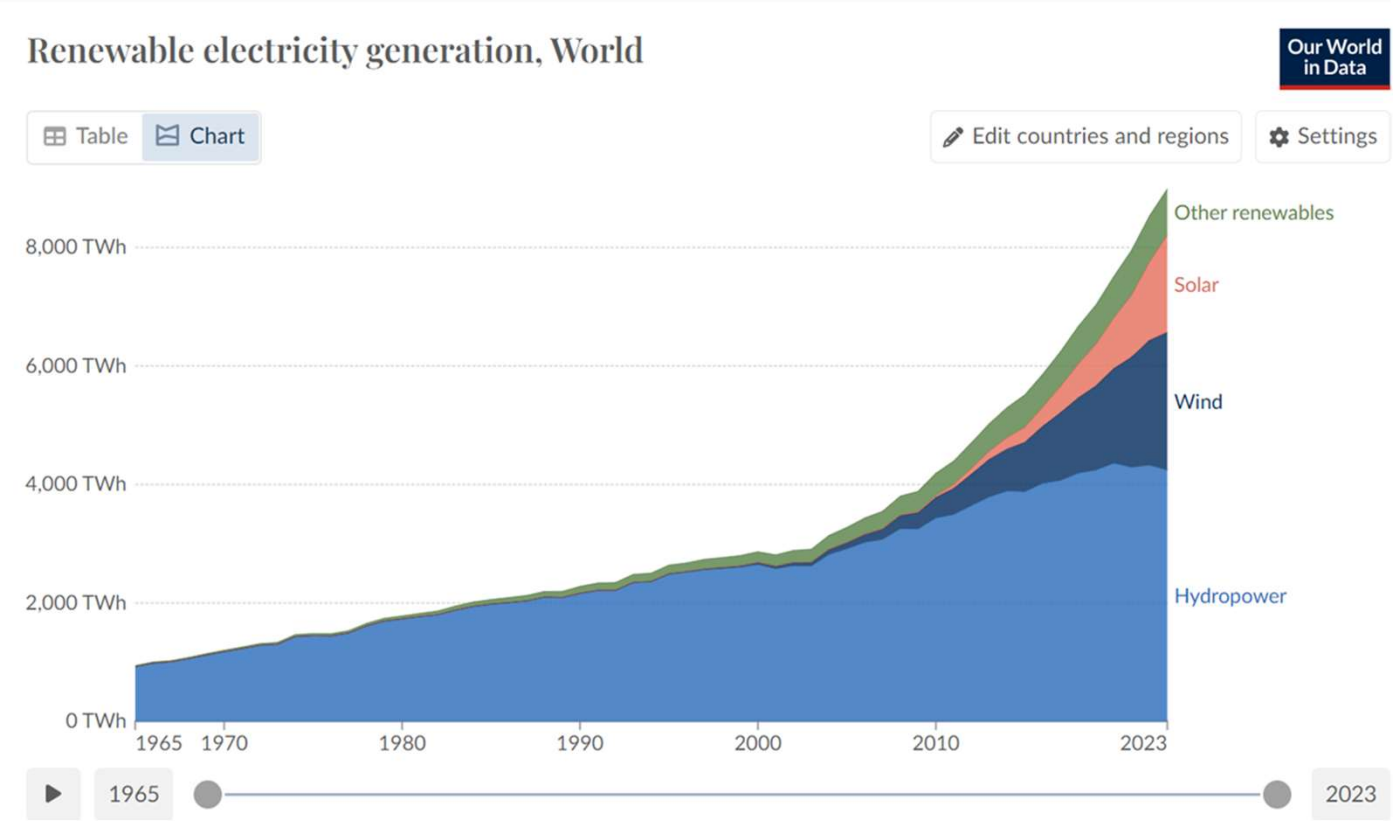
- Mismatches between electricity production and demand
- Energy storages
- Battery

Outline

- **Mismatches between electricity production and demand**
- **Energy storages**
- **Battery**

Cost of wind and solar energy

- For onshore wind the fall was 69 per cent to USD 0.033/kWh in 2022, slightly less than half that of the cheapest fossil fuel-fired option in 2022.
- The global weighted average cost of electricity from solar PV fell by 89 per cent to USD 0.049/kWh, almost one-third less than the cheapest fossil fuel globally.

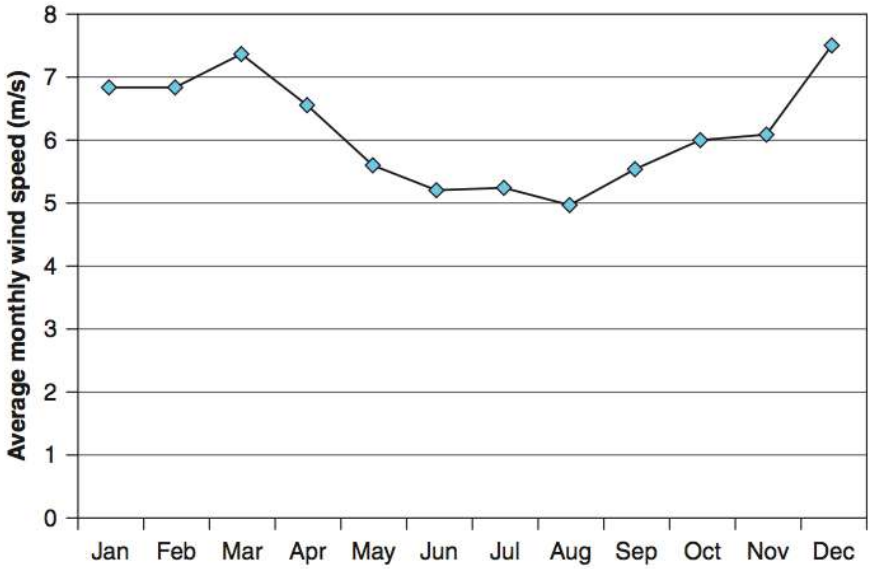


https://www.irena.org/News/pressreleases/2023/Aug/Renewables-Competitiveness-Accelerates-Despite-Cost-Inflation

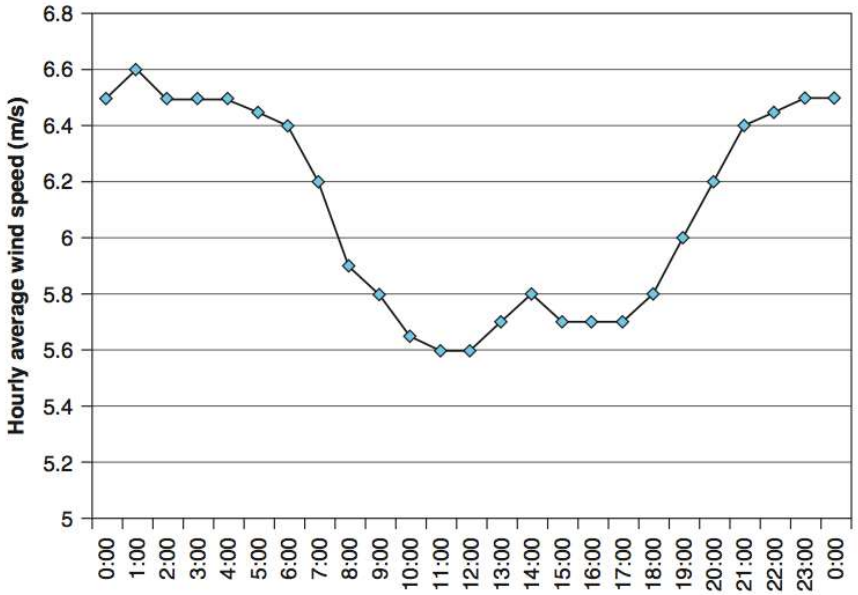
Temporal variability of wind speed

Enfield, New York, wind farm site (height =58m)

Seasonal distribution of wind speed in m/s



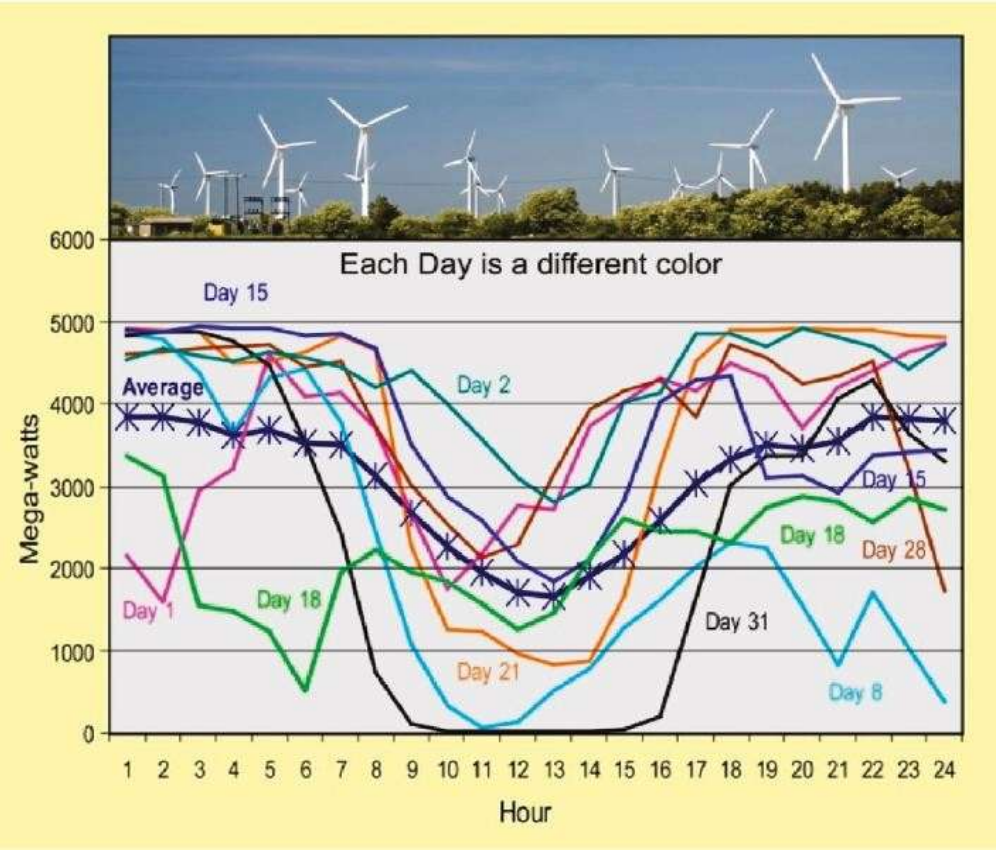
Hourly distribution of wind speed



Credit to Prof. Yunlong Zi

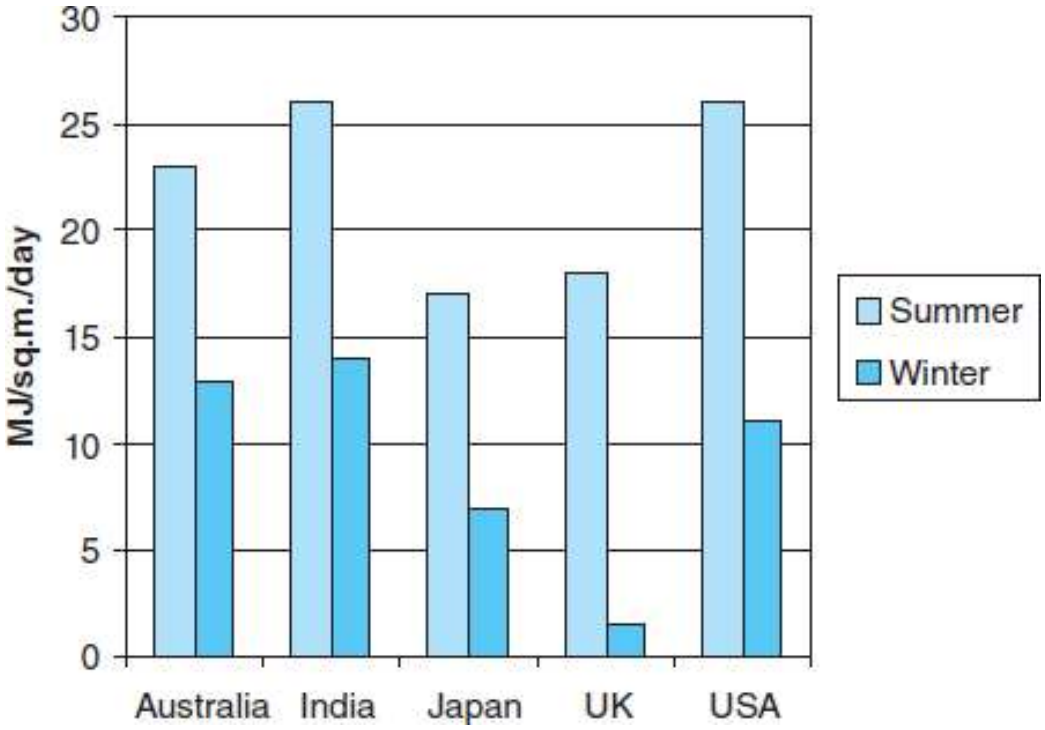
Intermittency of wind energy

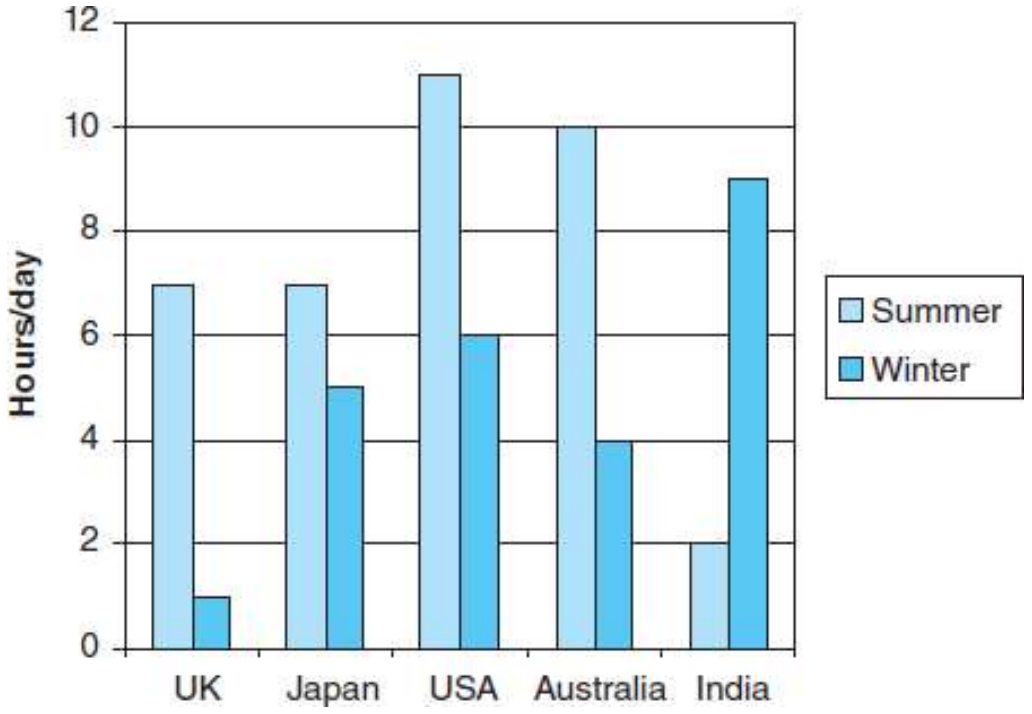
- Daily profiles of wind power projected in April 2005 for the year 2011 in Tehachapi, California



Chem. Rev. 2011, 111, 3577–3613

Availability of solar radiation

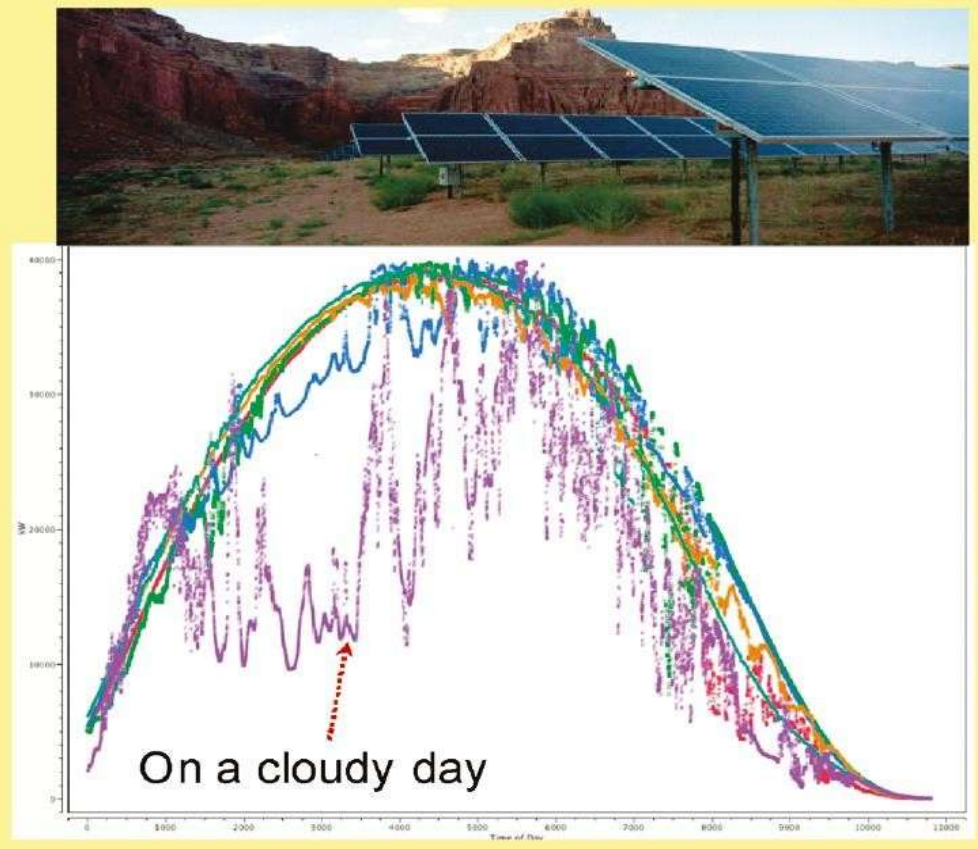




Credit to Prof. Yunlong Zi

Intermittency of solar energy

- 5 MW PV power over a span of 6 days in Spain (Courtesy of AES).

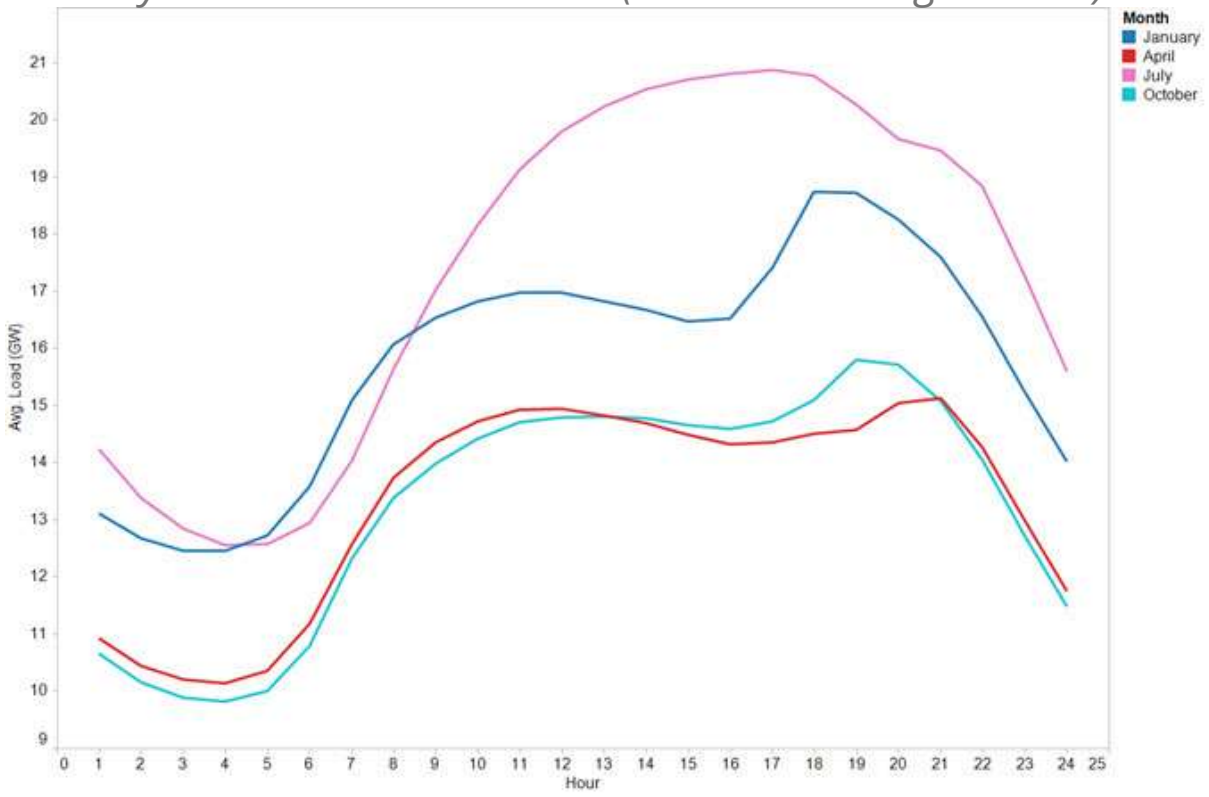


Chem. Rev. 2011, 111, 3577–3613

Electricity demand

- The energy demand on the gird varies by the time of day
- As instant energy generation must follow instant demand, the shape of the daily energy demand is fairly critical.

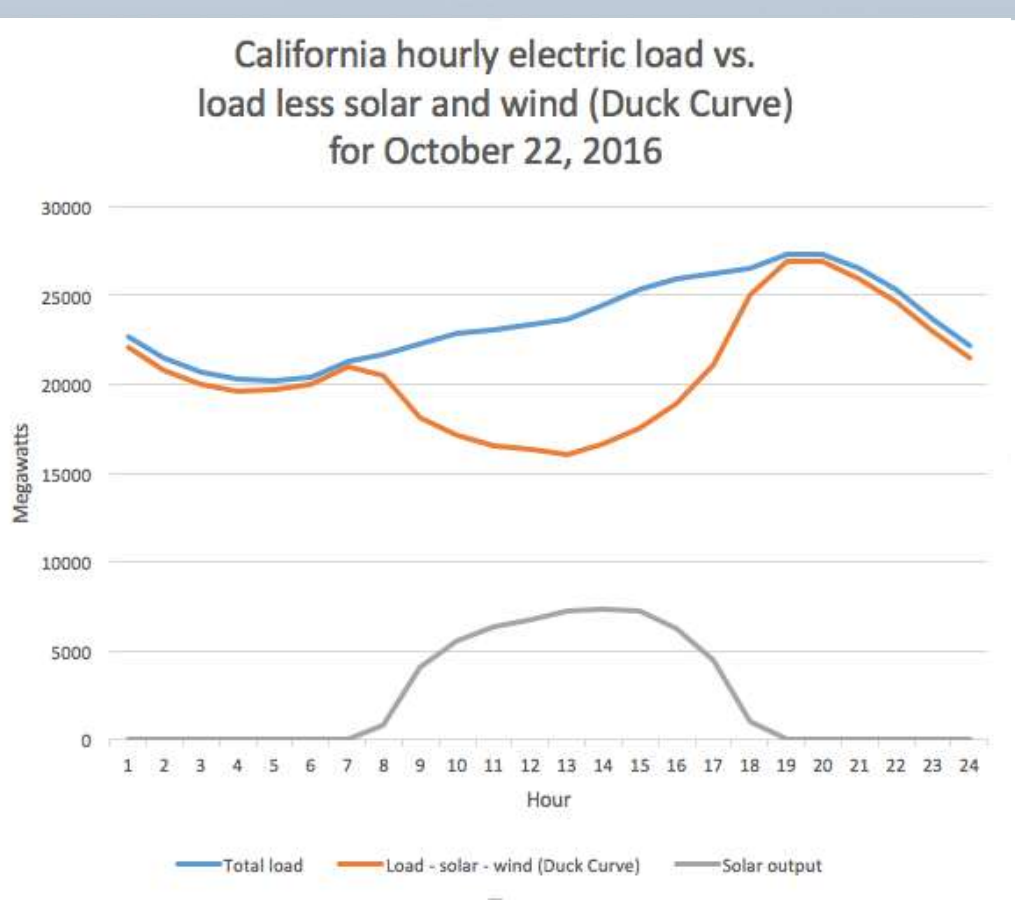
Daily demand across seasons (Source: New England ISO)



https://energymag.net/daily-energy-demand-curve/

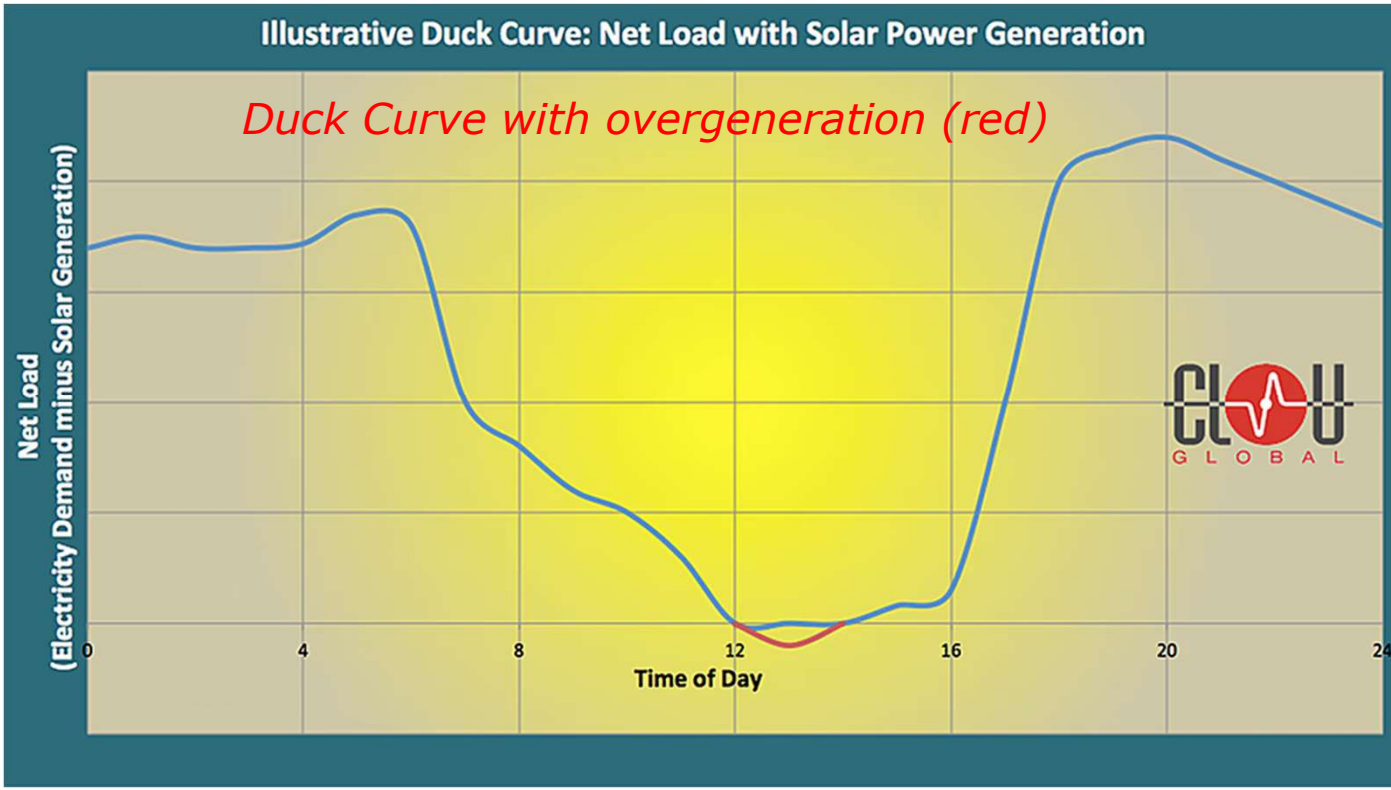
There is a mismatch between demand and production

- Blue curve: Demand for electrical power
- Orange curve: (the duck curve) supply of electrical power from dispatchable sources,
- Gray curve: supply of solar electrical power
- Data is for the State of California on October 22, 2016 (a Saturday),[1] a day when the wind power output was low and steady throughout the day.



Duck curve

- Solar production peaks at noon, but starts dropping in the late afternoon and evening as the sun sets.
- At the same time, people return home from work and school, boosting electricity use again.
- Other power plants must then ramp up quickly to meet the surging demand, forming the duck's neck and head

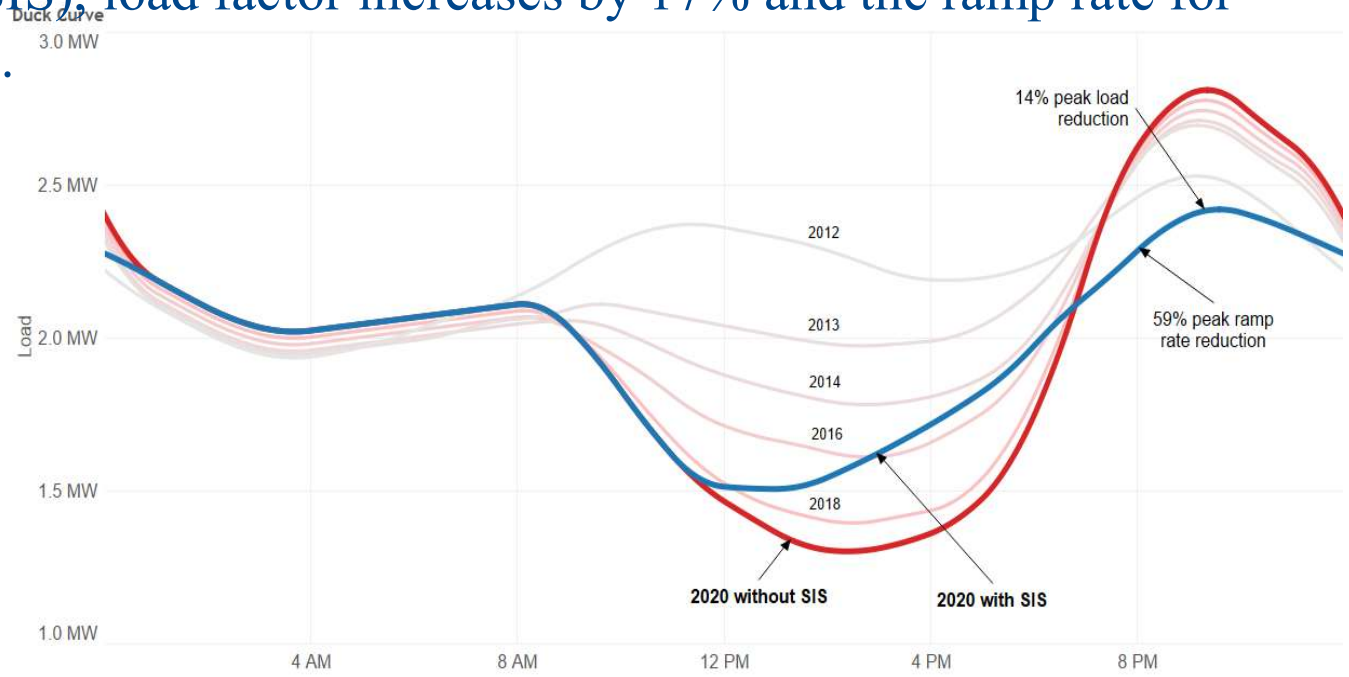


https://clouglobal.com/the-duck-curve-and-solar-power-integration/

How to solve the problem?

How to solve the problem?

- Curves for successive years assume continued solar uptake consistent with historical growth in solar deployments.
- Unabated, we can see a widening of the gap due to reduced daytime demand, uptake of solar PV and evening demand peaks.
- With Solar Integrated Storage (SIS), load factor increases by 17% and the ramp rate for evening peak is reduced by 59%.



https://www.sunverge.com/integrated-energy-storage-an-answer-to-addressing-the-duck-curve

What is energy storage?

- Energy storage is the capture of energy produced at one time for use at a later time.

- Energy storage involves converting energy from forms that are difficult to store to more conveniently or economically storable forms.

Outline

- Mismatches between electricity production and demand
- **Energy storages**
- Battery

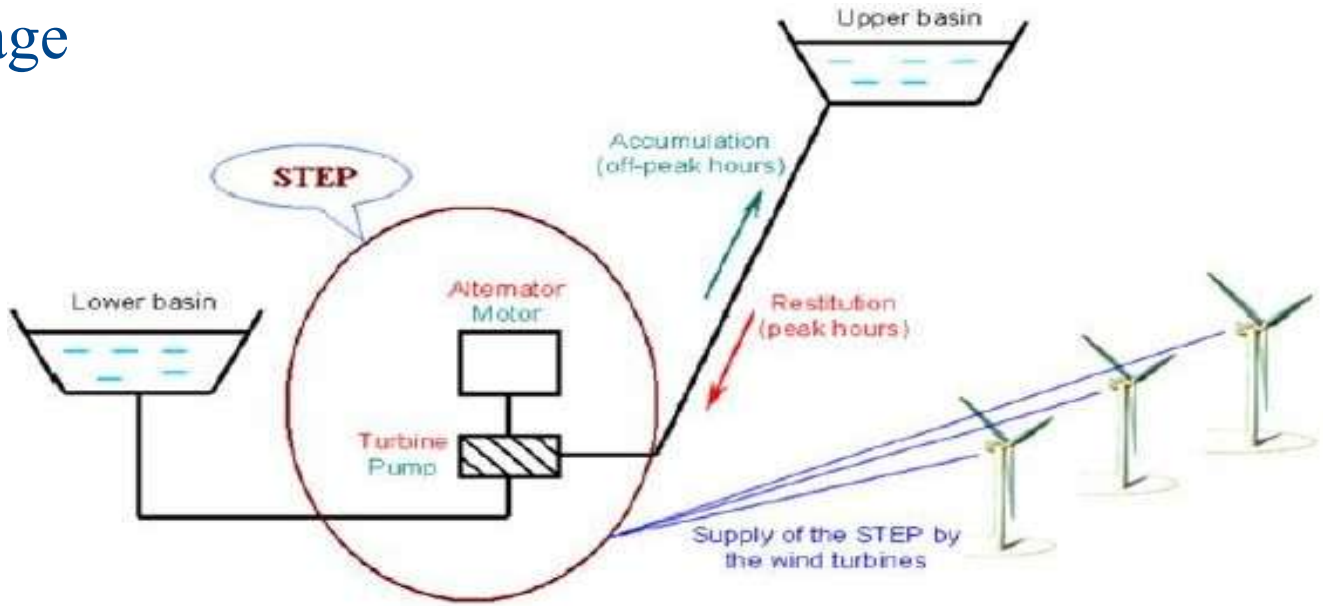
Different types of energy storage

- Mechanical energy storage
- Thermal energy storage
- Electrochemical energy storage

https://www.azom.com/article.aspx?ArticleID=22831

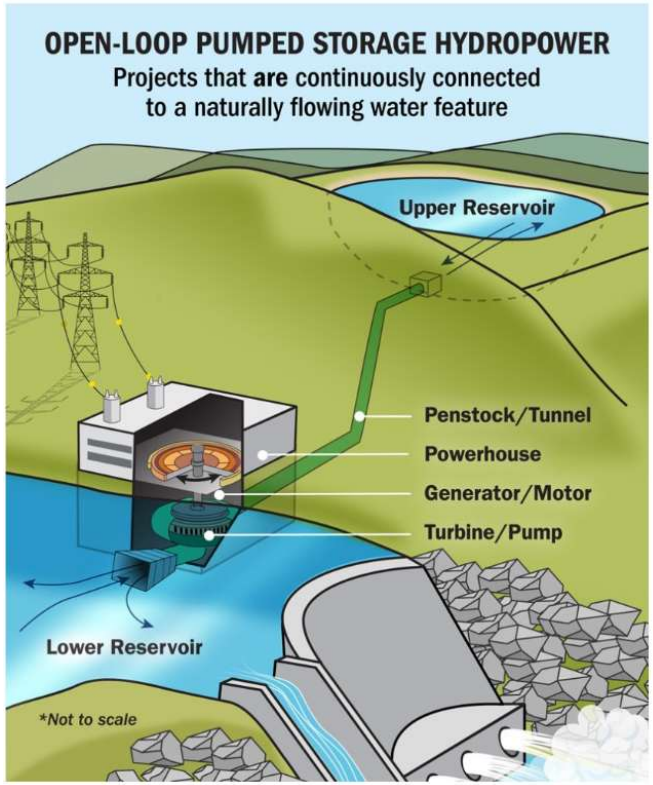
Pumped Storage Hydropower

- During low demand: pump water to upper reservoir
- During high demand: release water to lower reservoir
- 65-80% conversion efficiency
- Primary way of energy storage

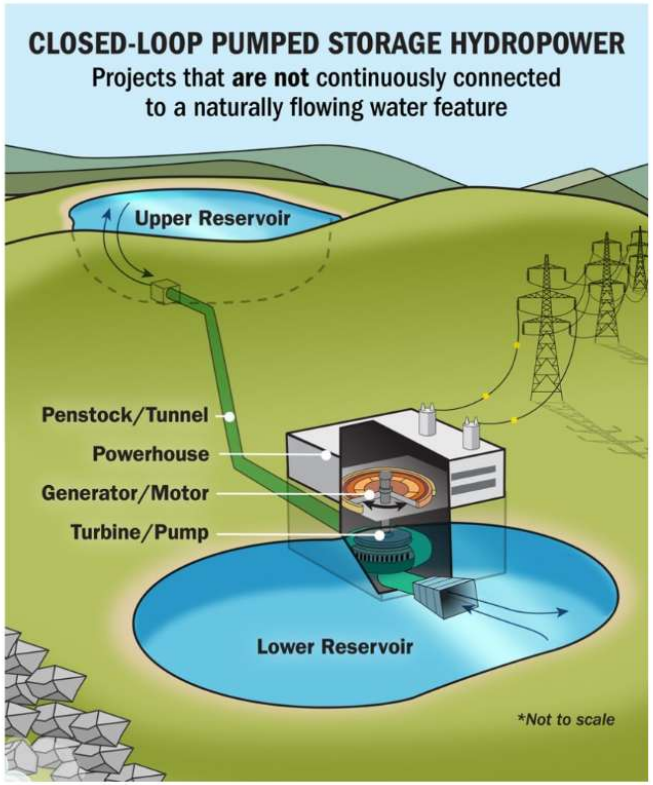


http://en.wikipedia.org/wiki/File:Pumpstor_racoon_mtn.jpg
H. Ibrahim et al. / Renewable and Sustainable Energy Reviews 12 (2008) 1221–1250

Pumped Storage Hydropower



Open-loop pumped storage hydropower systems connect a reservoir to a naturally flowing water feature via a tunnel, using a turbine/pump and generator/motor to move water and create electricity.



Closed-loop pumped storage hydropower systems connect two reservoirs without flowing water features via a tunnel, using a turbine/pump and generator/motor to move water and create electricity.

https://www.energy.gov/eere/water/pumped-storage-hydropower

Example

- Taum-sauk pumped storage in Missouri
- One of the first pumped storage in the U.S. started service in 1963

Example

- World largest pumped hydro storage
  - Fengning (丰宁), Hebei Province
  - Connected with wind farms
  - Install capacity of 3.6GW
  - Started service in August, 2024

https://www.hydroreview.com/hydro-industry-news/pumped-storage-hydro/china-completes-the-worlds-largest-pumped-storage-station/

Advantage

- **Advantages:**
  - ✓Rapid response
  - ✓Long service life
  - ✓Sustainable
  - ✓High efficiency
- **Disadvantages**
  - ✓Limited by geographical location : water, elevation differences
  - ✓Initial cost is high
  - ✓Evaporation water loss
  - ✓Environmental concerns.

https://pumpedhydro.com.au/education/pumped-storage-hydropower-advantages-and-disadvantages/

Mechanical energy storage using solid mass

- **Convert electricity to gravitational potential**
- **Using heavy blocks to store energy**

https://www.linkedin.com/pulse/gravity-energy-storage-systems-market-size-more-than-doubles-kumar

Use gravity to store energy

Use gravity to store energy

如东100MWh重力储能项目首套充放电单元测试成功

新浪财经　2024-05-04 15:24

来源：雷达财经

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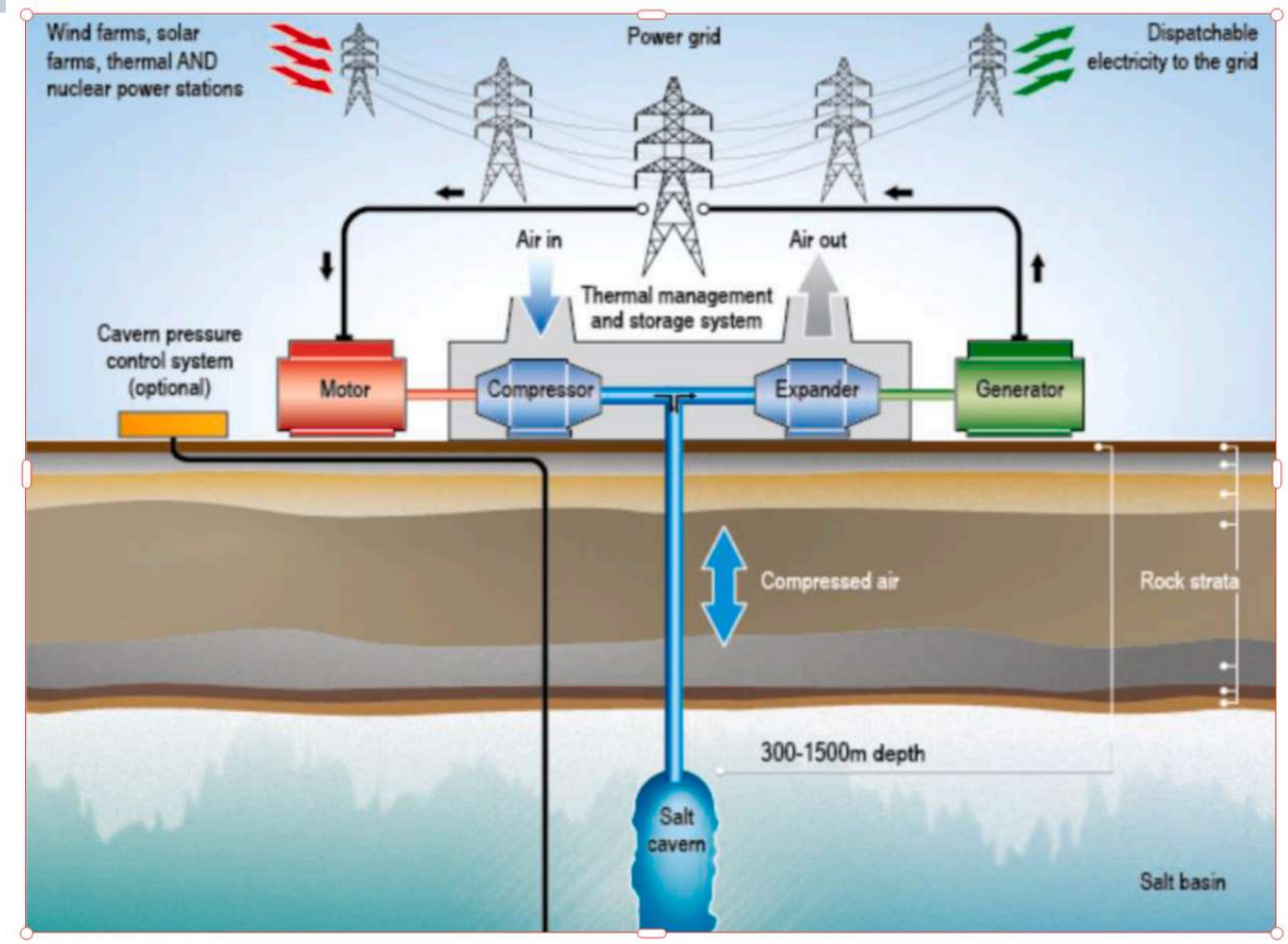
Mechanical energy storage using solid mass

- **Claimed advantages**
  - ✓Little energy losses
  - ✓Low cost
  - ✓Store energy for longer time (e.g., months)
  - ✓Conservation of water resources
- **Disadvantage**
  - ✓Lower energy density
  - ✓Slow response time

Compressed air energy storage (CAES)

- During low demand: compress air to high pressure
- During high demand: expand air to drive a turbine
- Efficiency is around 70%.

Compressed air energy storage (CAES)

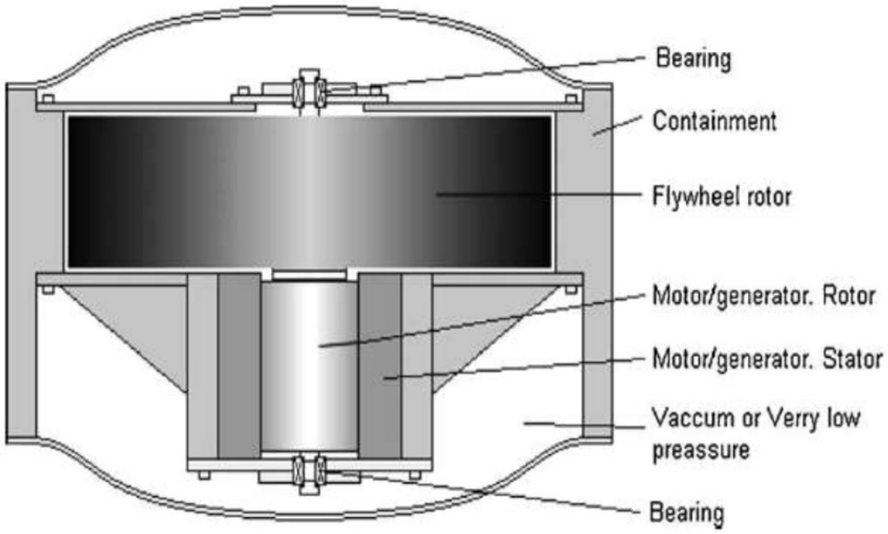


Compressed air energy storage (CAES)

- Advantages:
  - Could be easily integrated with renewable energy sources
  - Can be underground, saving land
- Disadvantages:
  - Limited by the available geological storages
  - Additional heating is needed to expand compressed air

Flywheel energy storage (FES)

- Flywheel energy storage works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy.
- Speeds from 20,000 to over 50,000 rpm
- Efficiency, can be as high as 90%
- Why they fly for a long time?
  - ✓**Conservation of energy**
  - ✓**Low friction/resistance**



FES: Advantage and disadvantages

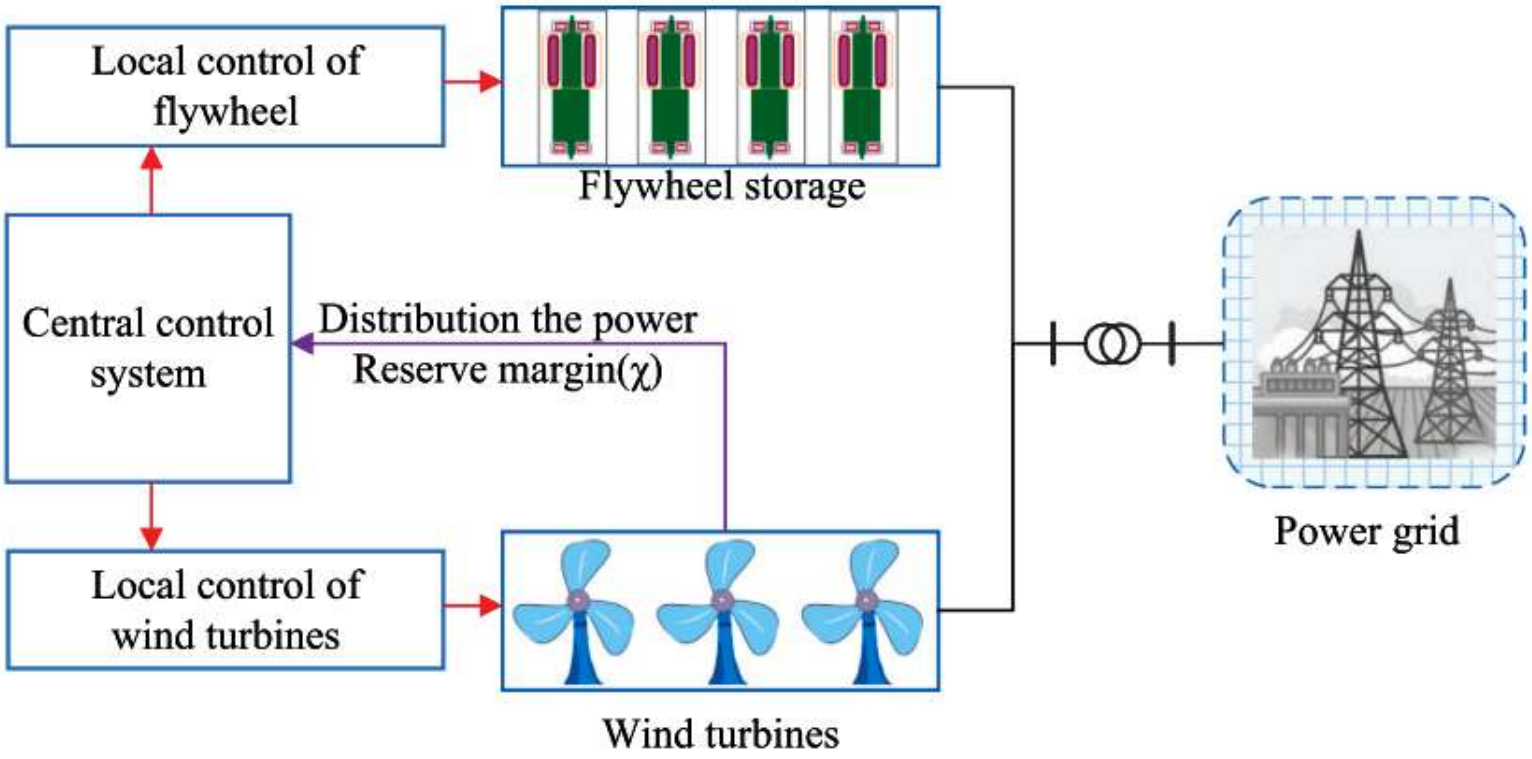
- Ji et al., 2024, Renewable energy

Fig. 6. Characteristics of flywheel energy storage system.

Flywheel energy storage (FES)

- Launch fighter jets from an aircraft carrier

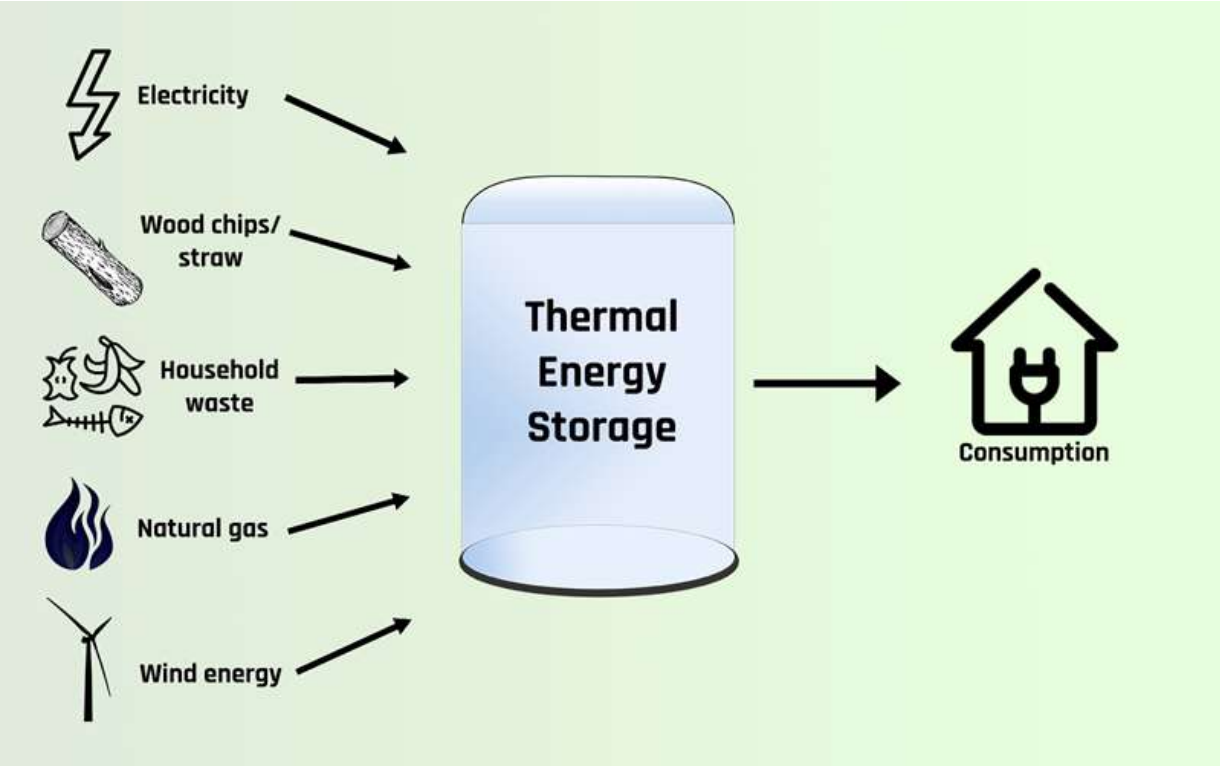
FES: Advantage and disadvantages



- Ji et al., 2024, Renewable energy

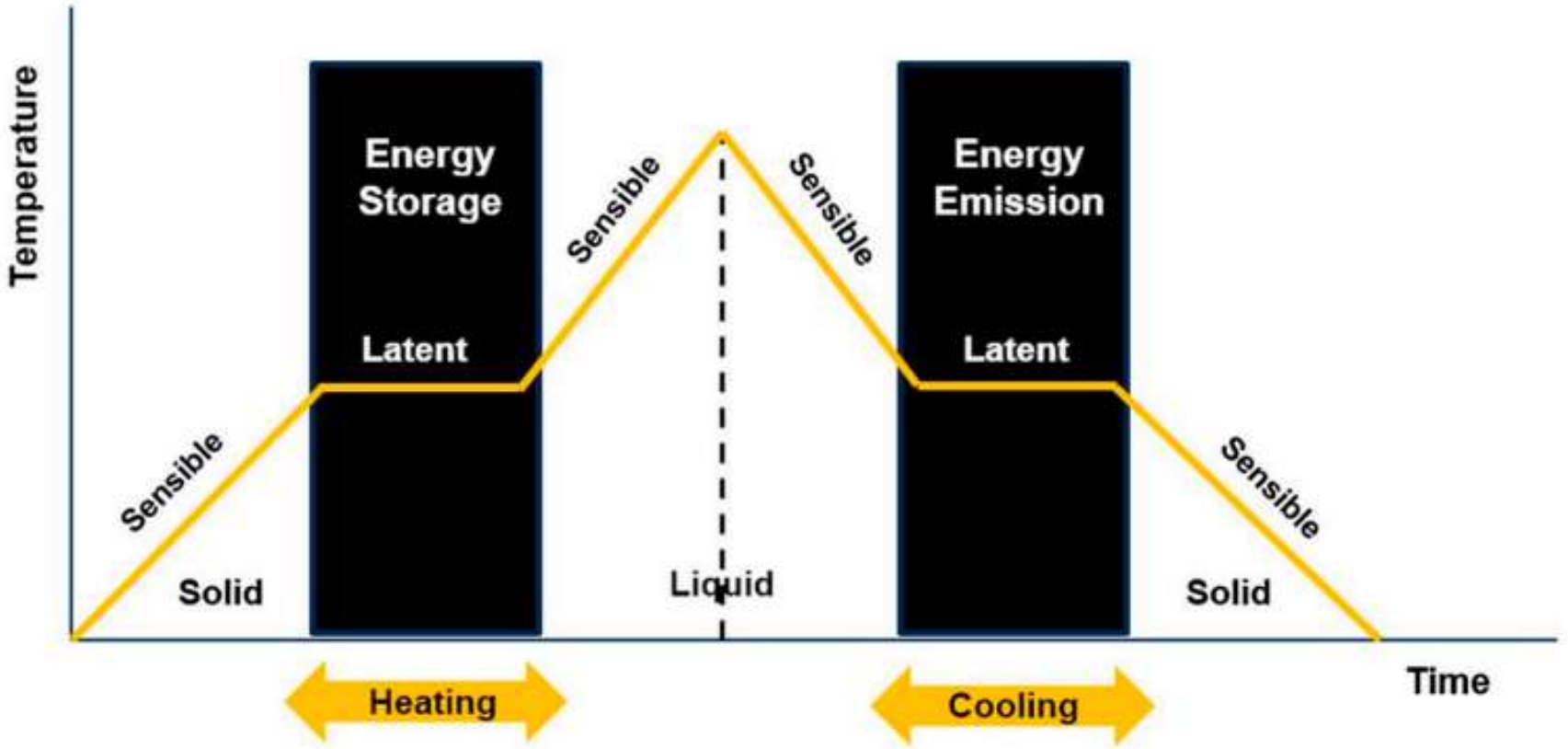
Thermal energy storage

- **Store energy up to seasonal scales**
- **Storage medium**
  - ✓Water, high specific heat, even for seasonal storage
  - ✓Water/steam transition, provide latent heat
  - ✓Molten salt/phase change material, provide latent heat



Credit to Prof. Yunlong Zi
https://www.senmatic.com/sensors/knowledge/thermal-energy-storage

Heating and cooling



Hua et al., 2023, Journal of Energy Storage

Thermal energy storage containers

- Tanks
- Rock caverns
- Thermal energy storage towers/buildings

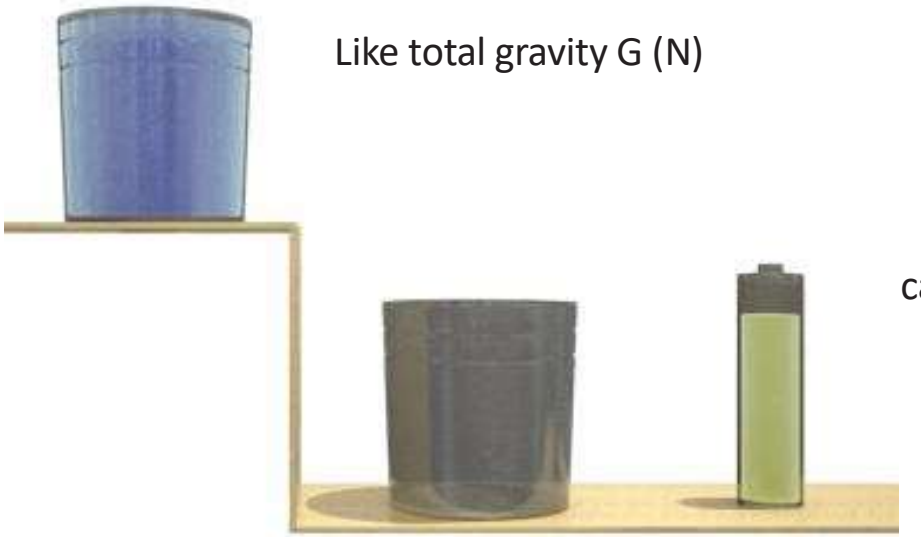
2GWh Heating accumulation tower in Austria

Thermal energy storage tower in Italy

Outline

- Mismatches between electricity production and demand
- Energy storages
- **Battery**

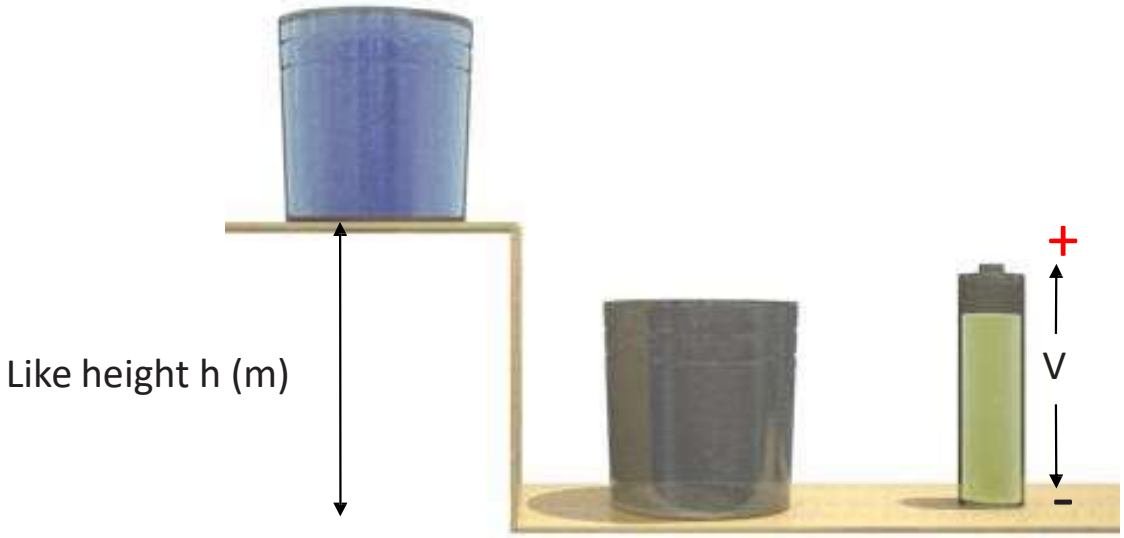
Electrochemical energy storage: Battery



- Capacity
  - Units: ampere·hour (Ah)
  - Typical AA alkaline: 3 Ah
  - Typical car starter battery: 80 Ah

Credit to Prof. Yunlong Zi

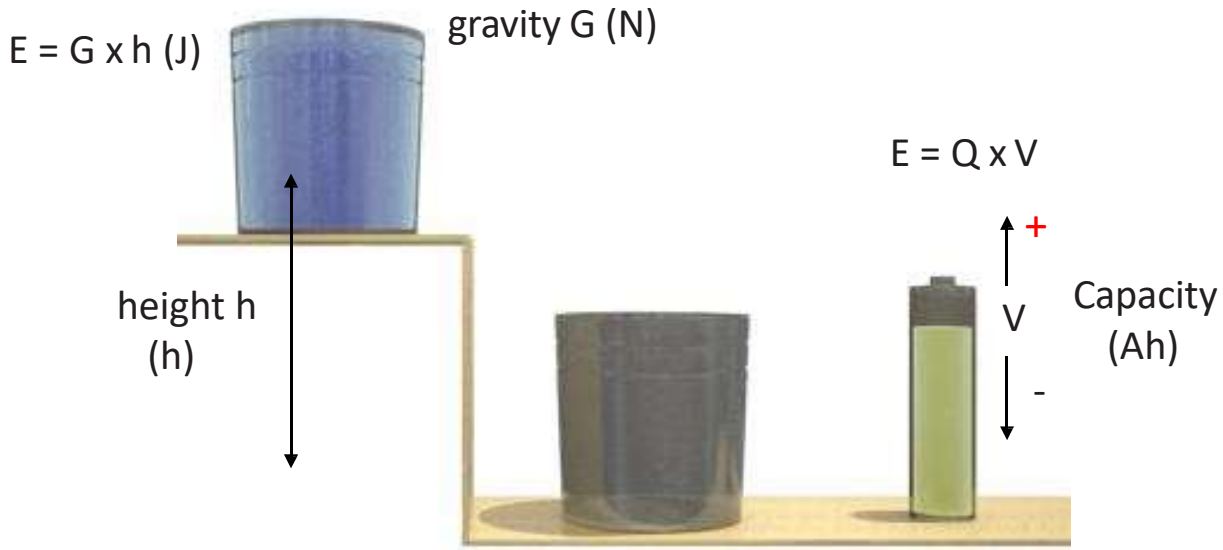
Voltage – electric potential difference



- Voltage
  - Units: Volts (V)
  - Typical AA alkaline: 1.67 V (fully charged)
  - Typical lithium-ion cell: 3.6 -4.2 V (fully charged)

Credit to Prof. Yunlong Zi

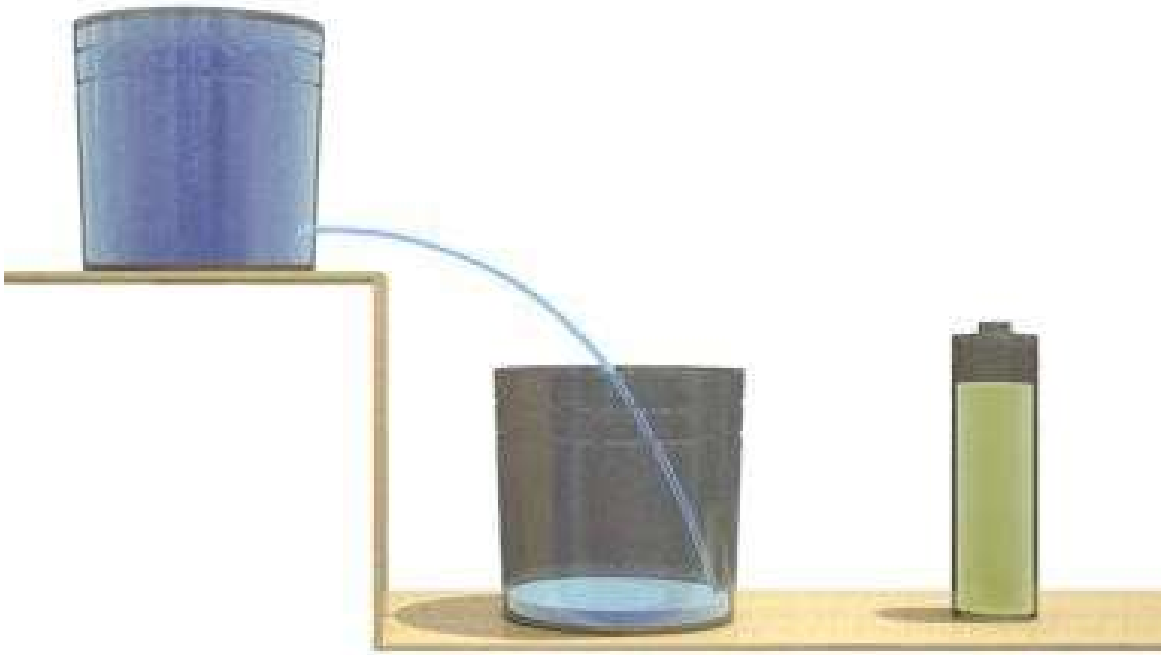
Energy – capacity × voltage



- Energy:
  - Units: Watt-hours (Wh)
  - Other common units include Joules, calories and BTUs
  - Typical AA alkaline: 3.6 Wh

Credit to Prof. Yunlong Zi

Power – rate of Energy release



- Power (the speed at which energy can be used):
  - E/t (average) or dE/dt
  - Units: Watts (W)

Credit to Prof. Yunlong Zi

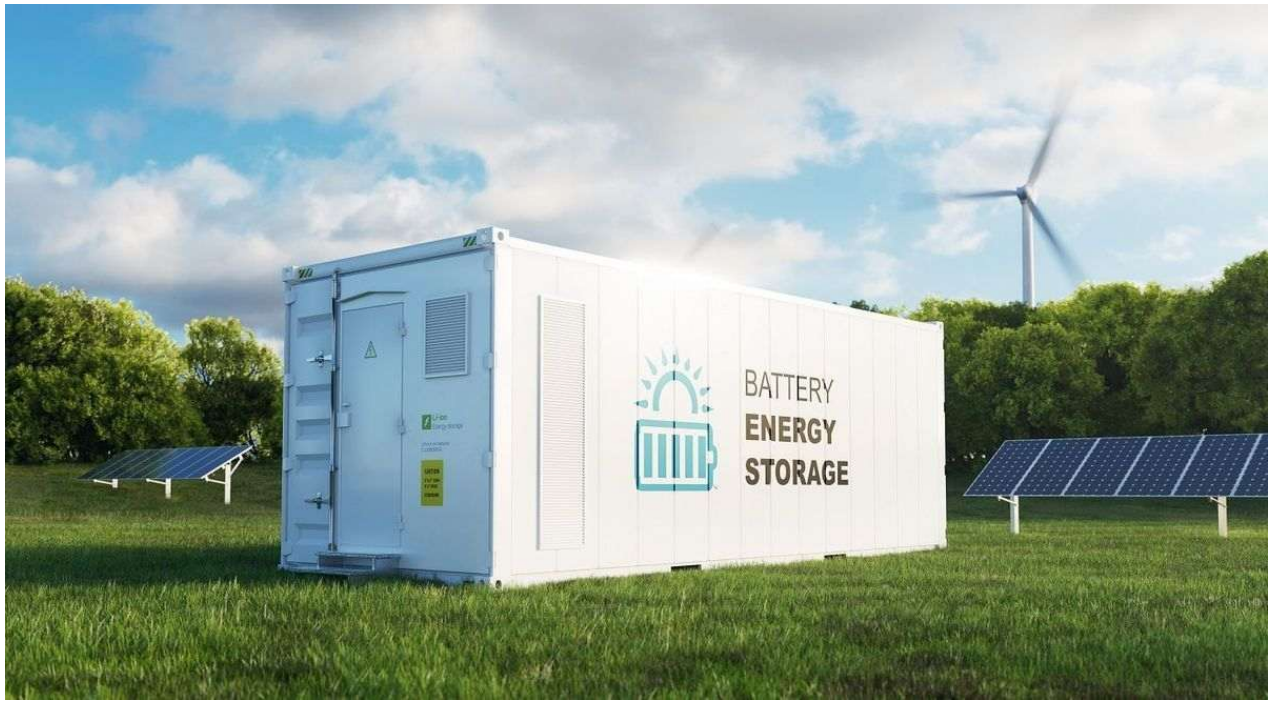
Rechargeable Battery

- Can be charged and discharged for many times
  - ✓Lead-acid battery, for vehicles
  - ✓Nickel-metal hydride (NiMH) battery
  - ✓Lithium-ion (Li-ion) battery (best charge density, slow loss of charge, controllable risk)

Credit to Prof. Yunlong Zi

Battery energy storage system

- Devices that enable energy from renewables, like solar and wind, to be stored and then released
- Grew five-fold between 2015 and 2020.
- Will replace dispatchable thermal plants
- Expect (680GW) to supersede pumped hydropower storage in 2030



https://www.next-kraftwerke.com/energy-blog/flexibility-battery-storage

Battery energy storage system

Advantages

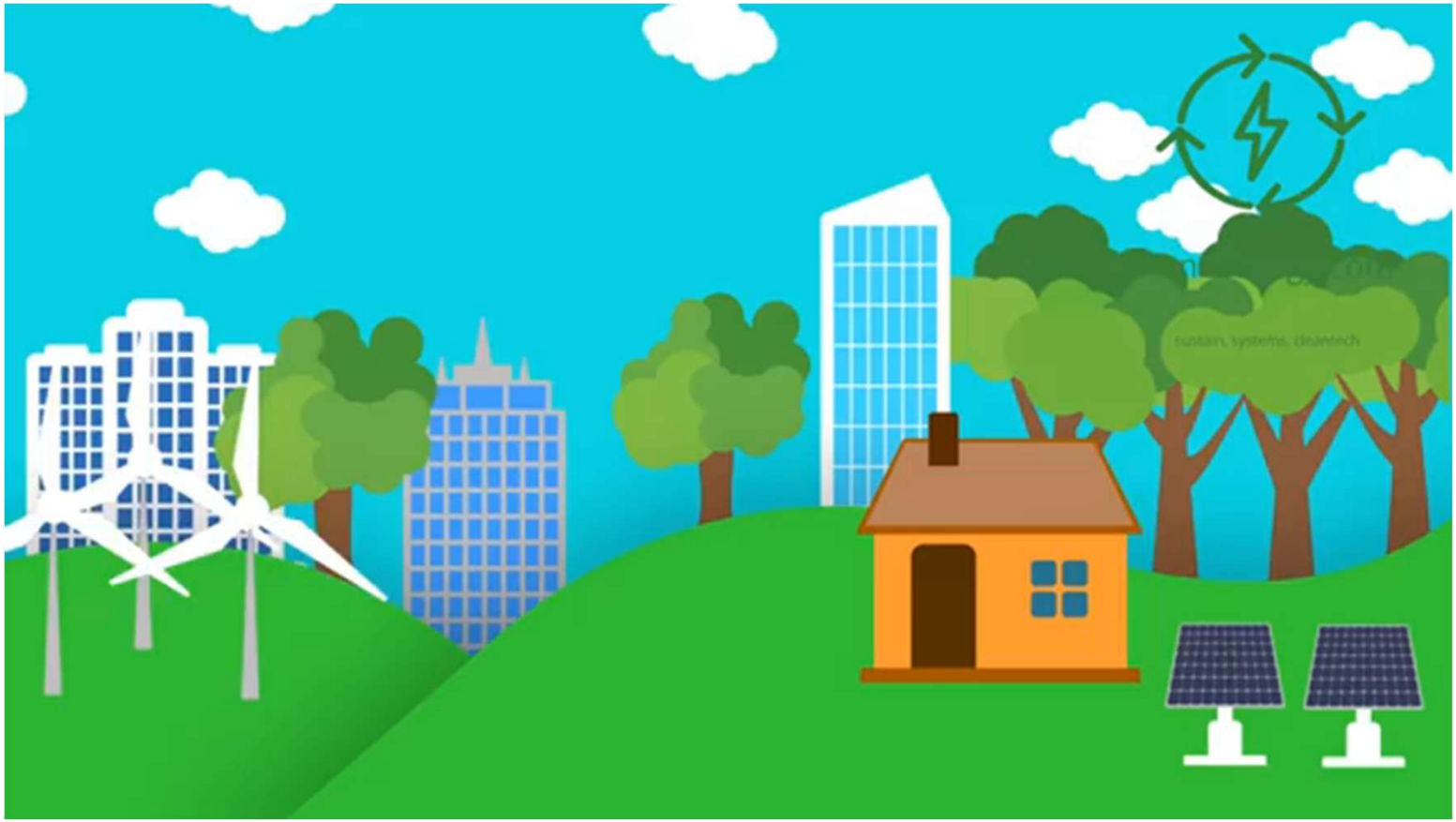
- Ideal for short-term storage (one to two cycles/day)
- Quick response to demand
- Environmental friendly

Disadvantages

- Expensive
- Safety concerns
- Battery life span is shorter than hydropower

https://montelgroup.com/blog/advantages-applications-and-challenges-of-battery-energy-systems-bess

Tesla’s megapack system



Electric Vehicle Battery (EVB)

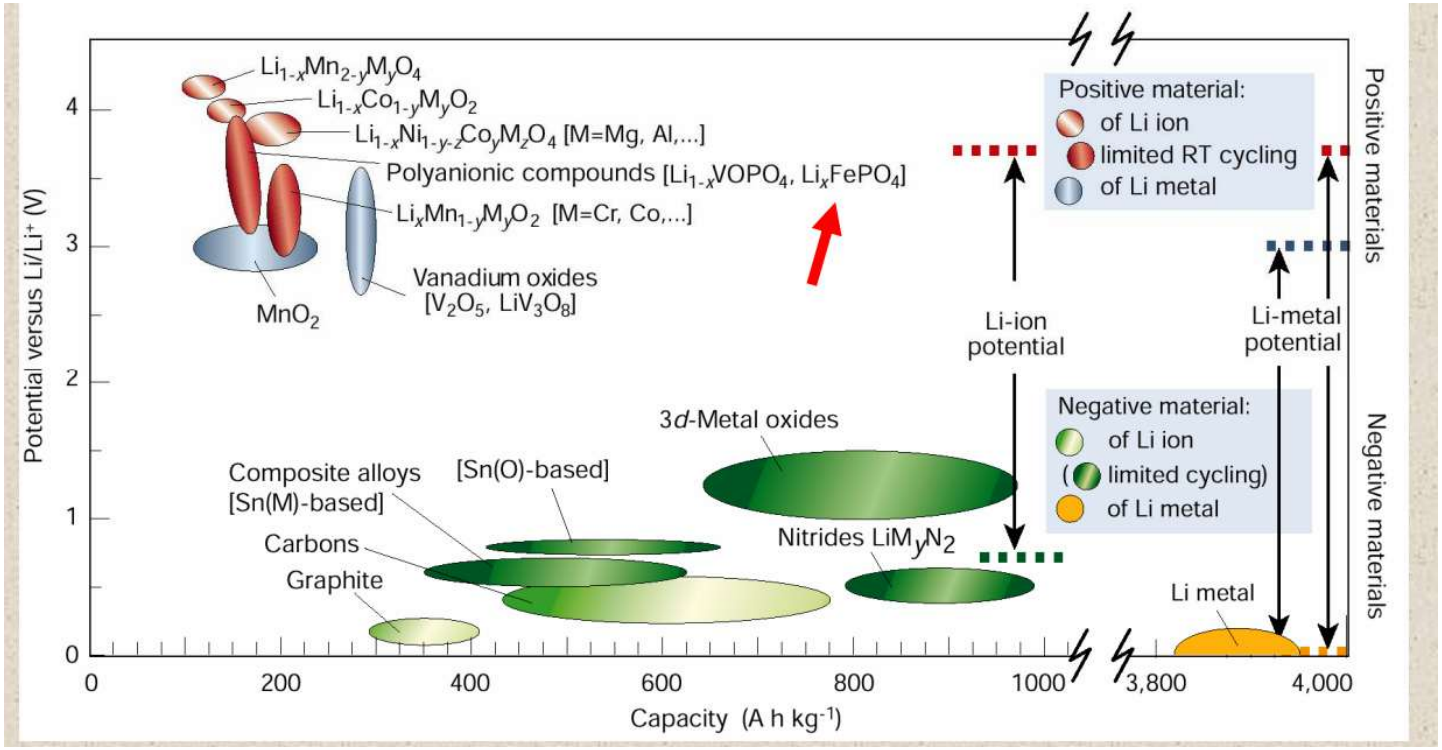
Compared with the battery used for energy storage, EVB has:

- Higer energy density
- Frequent recharge-discharge cycles
- Shorter life span (5-8 vs. 10yr)
- Higher safety requirements

https://montelgroup.com/blog/advantages-applications-and-challenges-of-battery-energy-systems-bess

Lithium-Ion Battery

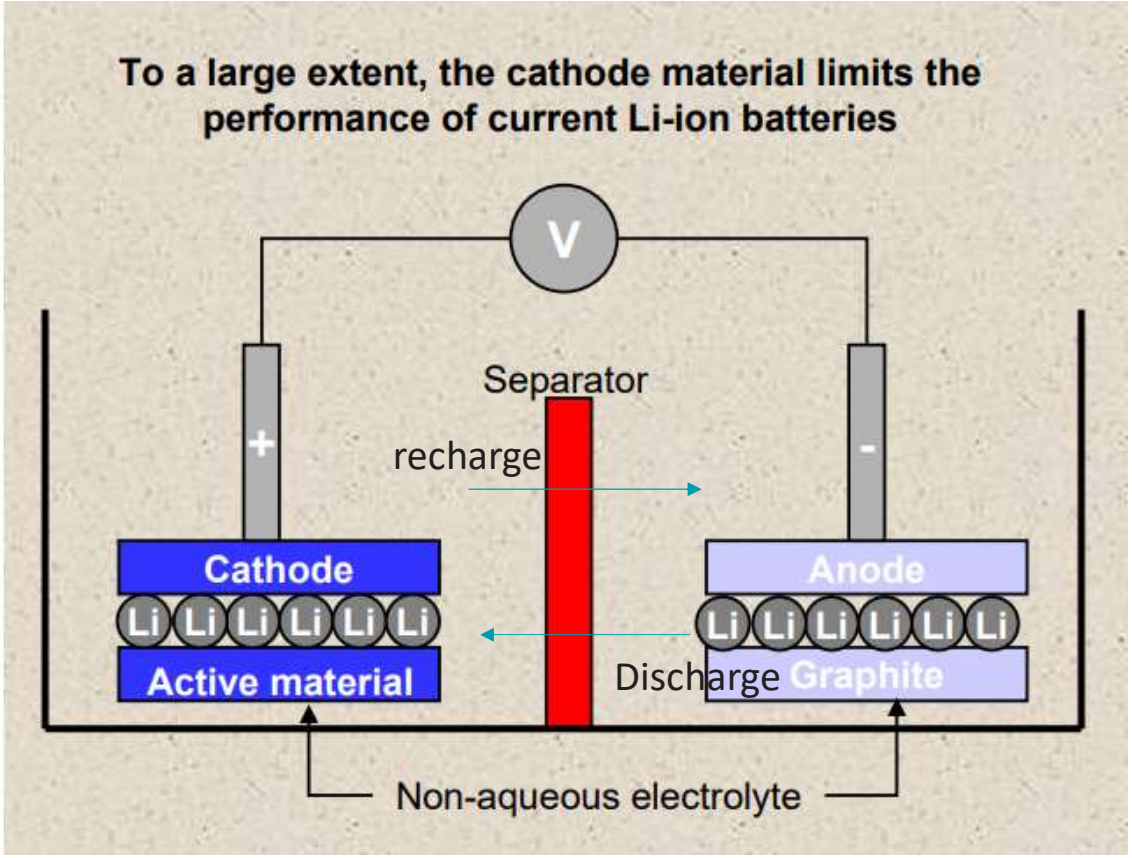
- In the 1970s, the no-rechargeable Lithium battery became commercially available
- 1991, Lithium-ion battery was invented by SONY
- Different Li-compounds have been tested (e.g., LiFePO4)



Lithium-Ion Battery

Compared with traditional batteries, Li-Ion Battery has:

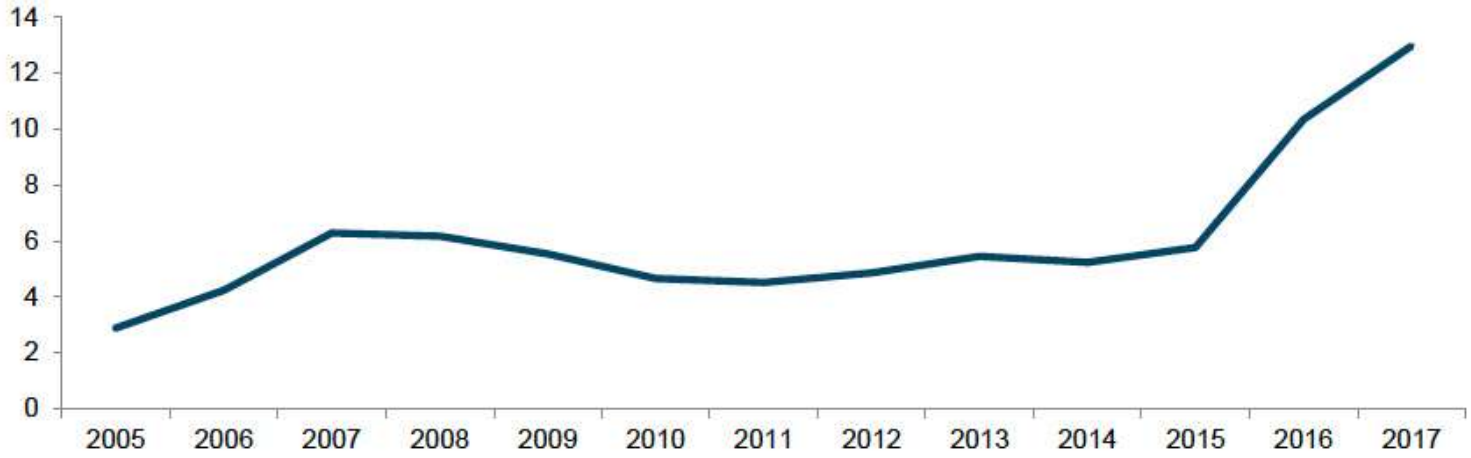
- Higher battery density
- Higher voltage
- Longer life span
- Lower self-discharge (1-2 % per month)



Lithium-Ion Battery

Disadvantages:

- Fire hazard
- Sensitive to temperature (Ideal T: 5°C -20°C)
- Raw materials are expensive (Price of Lithium Carbonate Equivalent in kUSD/ton)



Source: SQM Corporate Filings

Next Generation EV Battery

Energy storage/EV research in the SEE thrust

Chao FANG 方超

Wei HAN 韩伟

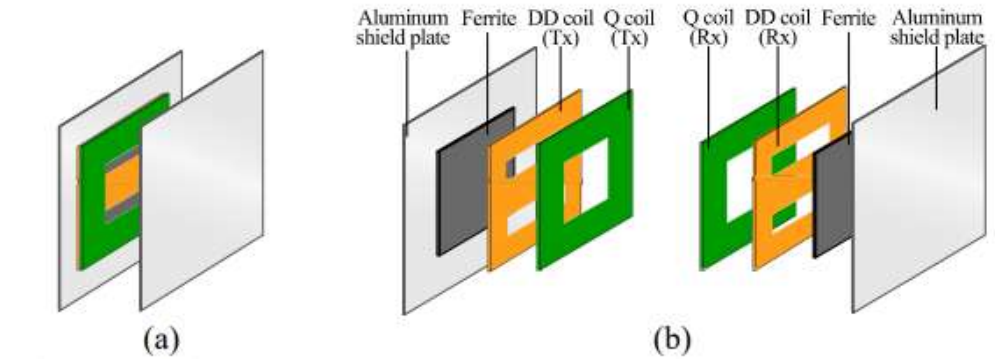
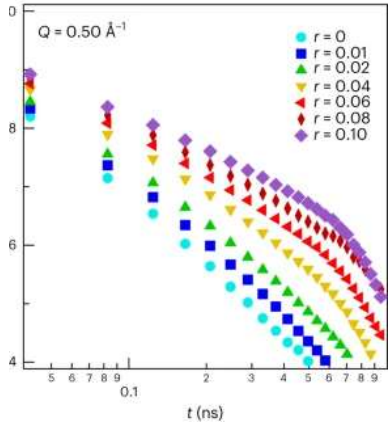


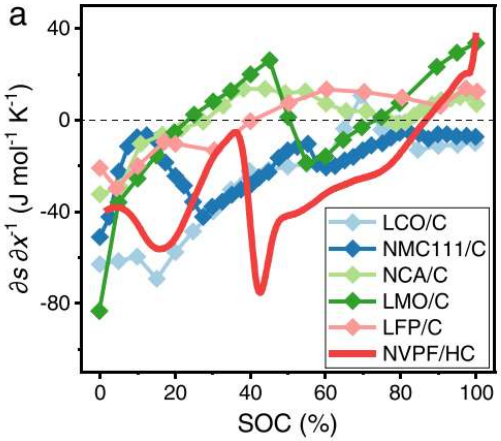
Fig. 1. Coupling units. (a) Placement; (b) Composition.

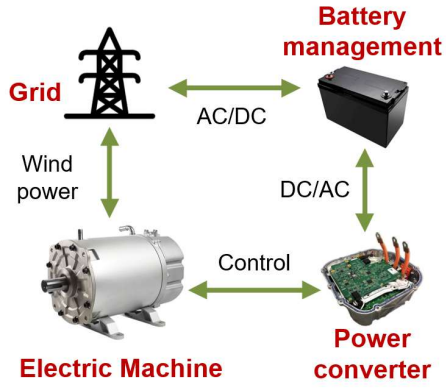


Jiaqiang HUANG
黄加强

Yuheng LI
李昱亨

Dianxun XIAO 肖殿勋

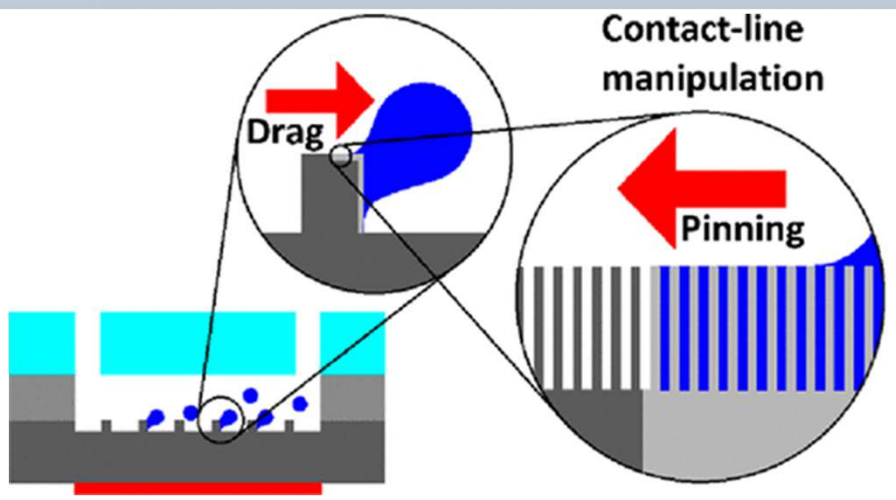


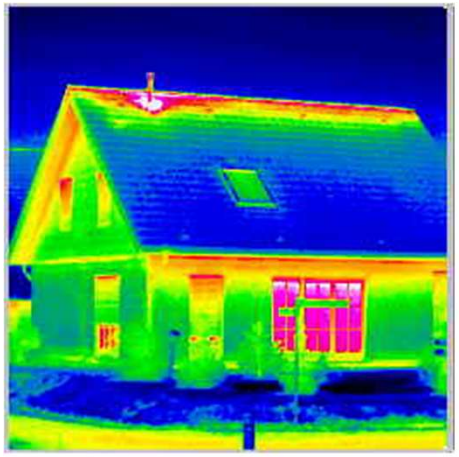


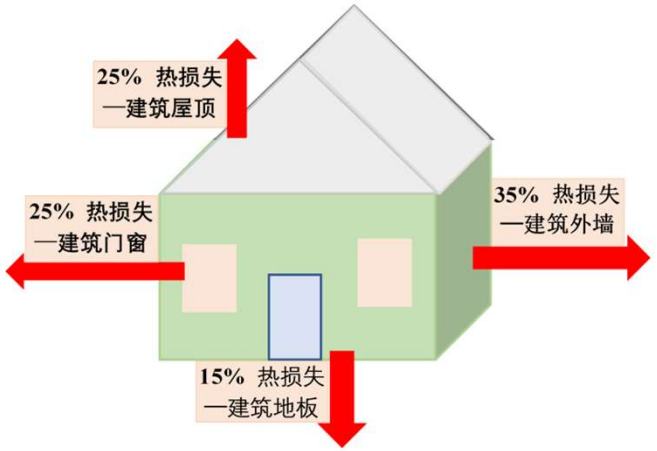
Energy related research in the SEE thrust

Huihe Qiu 邱惠和

Yuekuan Zhou 周跃宽







Lab tour next week

Brilliant Energy of Science and Technology lab (BEST)

Details will be announced through Canvas

Essay Rubric

	4-5 Points	2-3 Points	0-1 Point
Focus	Focuses on all points in the given topic	Basically focuses on the given topic, with some deviation	Not relevant to the given topic
Development	Specific, concrete, relevant information to support arguments	Uses support, but it maybe insufficient	Lacks sufficient details
Style	Excellent language use; precise wording	Adequate use of language	Vague and abstract
Length	>=750 words	400-750 words	<400 words
Statement on AI use, when AI is used	Comprehensive, detailed information	Including some examples	Lacks sufficient details

Essay 1 Out of 25	Essay 2 Out of 25	Essay 3 Out of 25	Assignments	**Total**
0	0	–	0%	0%
5	8		26%	26%
–	7	–	28%	28%
18	0	–	36%	36%
10	8	–	36%	36%
18	5		46%	46%
7	17	–	48%	48%
17	8	–	50%	50%
20	6		52%	52%
8	19	–	54%	54%
20	8	–	56%	56%
10	19	–	58%	58%
10	20	–	60%	60%

Essay 3

Deadline is Nov 17th

Your feedback is highly appreciated!