Climate Change Calculated 8

Energy Storage

Prof. Dr.-Ing. Gerald Schuller

UN 2030 climate goals:

https://www.un.org/sustainabledevelopment/climate-change/#:~:text=be%20decreasing%20and-,need%20to%20be%20cut%2

- "To limit global warming to 1.5°C above pre- industrial levels, emissions must already be decreasing and need to be cut by almost half by 2030".

Goal: Have a Future Economy and Technology without Fossil Energy.

Outlook until 2030

- Question: What happens if it is dark and we have not enough wind?
- Conventional answer: we need **gas peaker plants** which generate electricity when needed
    - but that is again fossil fuel
- Better answer: We need **electricity storage**
    - but is that doable?

For renewable energy, storage is needed

"Installed capacity in Germany (2021): approx. 750 MWh, Total storage demand in Germany by **2030: 104 GWh**, by 2045: 180 GWh, of which **large-scale battery storage can cover a significant share**"
https://www.ise.fraunhofer.de/en/key-topics/stationary-battery-storage/large-scale-battery-storage.html#:~:text=Installed%20capacity%20and,a%20significant%20s

Levelized cost of storage (LCOS):

Paper: ”Projecting the Future Levelized Cost of Electricity Storage Technologies”, January 2019:

https://www.sciencedirect.com/science/article/pii/S254243511830583X#:~:Levelized%20cost%20of&text=The%20equation%20incorporates%20all%

"total lifetime cost of the investment in an electricity storage technology divided by its cumulative delivered electricity."
This includes the price for the stored electricity. Hence it can be seen the price a storage owner can sell the lectricity without making a profit.

Highlights:

https://www.sciencedirect.com/science/article/pii/S254243511830583X#:~:%E2%80%A2

• Lifetime cost for 9 storage technologies in 12 applications from 2015 to 2050

- Lowest lifetime costs fall by 36% (2030) and 53% (2050) across the 12 applications
- **Lithium-ion batteries are most competitive** in majority of applications from 2030
- Pumped hydro, compressed air, and hydrogen are best for long discharge applications

Cost in cent/kWh or $/MWh

```
In [ ]: !wget https://ars.els-cdn.com/content/image/1-s2.0-S254243511830583X-gr1_lrg.jpg
```

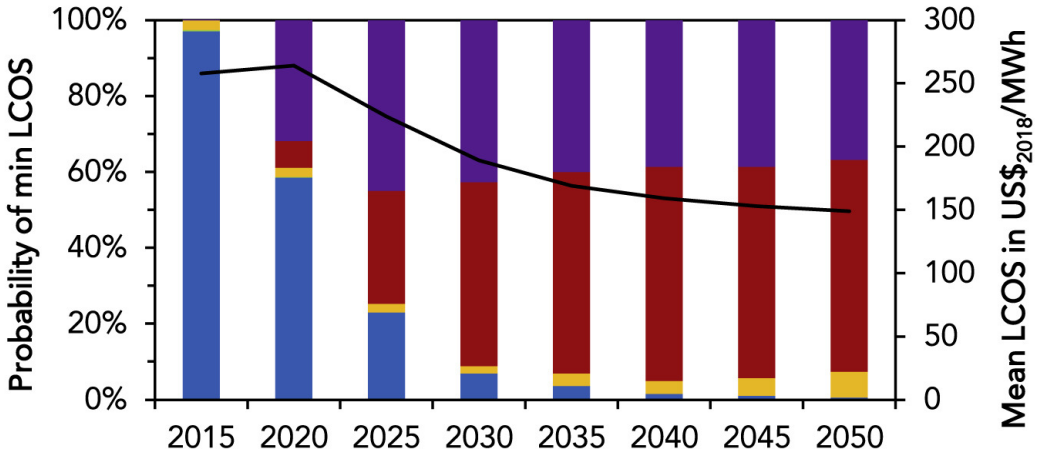
```
--2023-09-12 15:28:49--  https://ars.els-cdn.com/content/image/1-s2.0-S2
54243511830583X-gr1_lrg.jpg
Resolving ars.els-cdn.com (ars.els-cdn.com)... 104.18.32.42, 172.64.155.
214, 2606:4700:4400::6812:202a, ...
Connecting to ars.els-cdn.com (ars.els-cdn.com)|104.18.32.42|:443... con
nected.
HTTP request sent, awaiting response... 200 OK
Length: 420495 (411K) [image/jpeg]
Saving to: ‘1-s2.0-S254243511830583X-gr1_lrg.jpg.2’

1-s2.0-S25424351183 100%[===================>] 410.64K  --.-KB/s    in
0.02s

2023-09-12 15:28:49 (17.6 MB/s) - ‘1-s2.0-S254243511830583X-gr1_lrg.jpg.
2’ saved [420495/420495]
```

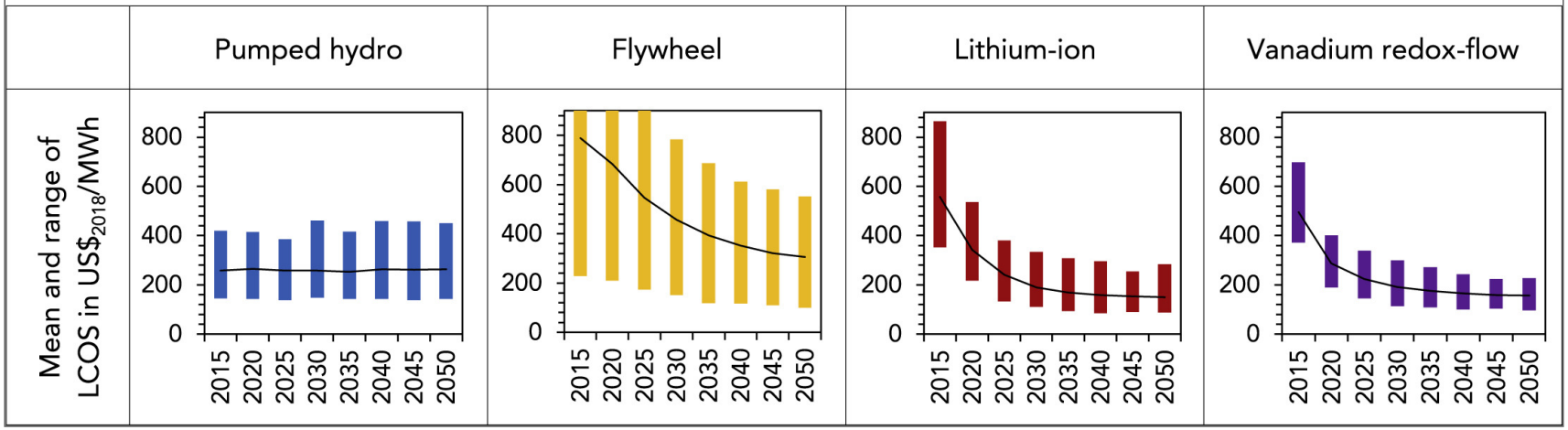
In [ ]:
```
#!pip install Pillow
from PIL import Image
im = Image.open("1-s2.0-S254243511830583X-gr1_lrg.jpg")
display(im)
```

```
Requirement already satisfied: Pillow in /usr/local/lib/python3.10/dist-
packages (9.4.0)
```

③ Secondary Response

Power capacity	100 MW
Discharge duration	1 hour
Annual cycles	1,000
Response time	>10 seconds
Electricity price	50 $/MWh$_{el}$





<PIL.JpegImagePlugin.JpegImageFile image mode=RGB size=2208x1229 at 0x7C0403D53B80>

1$/MWh=100 cents/1000kWh = 0.1 cents/MWh

- assumed **electricity cost**: 50$/MWh, **5 cents/kWh** (producer price)

After 2025:

- Li-Ion storage below 200$/MWh =20 cents/kWh
- Li-Ion **Cost of storage**, without the assumed electricity cost of 5c/kWh or 50$/MWh (see table above), is **15 cents/kWh**
- Pumped hydro: 259 $/MWh = 25.9 cents/kWh
- Flywheel: 440 $/MWh = 44 cents/kWh

Similar in **https://www.storage-lab.com/levelized-cost-of-storage** Figure 1.

Result

- We see: **Lithium-Ion Batteries** will be among the cheapest storage option.
- Cost of storage approaches **15c/ kWh**

Example: Tesla Megapack:

https://electrek.co/2023/04/19/tesla-reports-massive-increase-energy-storage-deployment-thanks-megafactory/

- "to reach 40 GWh of annual production capacity."
- "many more Megafactories would be coming", e.g. in Shanghai.
- Hence a Megafactory with 40 GWh of annual production could cover the total storage demand in Germany by 2030 of 104 GWh in just about 2.6 years!

Megapack Order: **https://www.tesla.com/megapack/design**

- 19.3 MWh,
- $9,972,420, including installation,
- this is **517 $/kWh**.
- Est. Annual Maintenance $29,610 (neglible compared to purchase price)

How long does the battery last?

Number of equivalent full charging cycles for Lithium-Ion batteries

Dissertation “Aging of Lithium-Ion Batteries in Electric Vehicles”, Dipl.-Ing. Univ. Peter Keil (from 2016), for 18650 Batteries (Tesla), **https://mediatum.ub.tum.de/doc/1355829/file.pdf**

- Page 127: Section 6.5.4, Long-Term Cycling at 25°C, Figure 88 left:

After 2000 equivalent full cycles mostly more than 80% capacity left.

- Hence after an assumed lifetime of 3*2000= **6000 cycles**, 0.8^3=0.51 = **51%** capacity is left.

Cost of Storage for the Tesla Megapack with 6000 cycles

- Round-trip efficiency of Lithium Ion batteries: ca. 85-95%, which means around 10% of electricity cost (0.5c/kWh) has to be added for the cost of storage. (**https://www.sciencedirect.com/science/article/pii/S136403212200136**)
- With an average capacity of 75% (between 100% and 50%) or 0.75*19.3=14.475 MWh, this results in a cost of storage (without maintanence cost) of $9972420/(6000*14475 kWh) + 0.5c/kWh= **11.5c/kWh**
- This is already at or below the price range predicted for 2030!

Levelized Cost of Storage

- We add the above assumed price of electricity to the cost of storage:
- 11.5 +5 c/kWh = **16.5 c/kWh**

Comparison to Gas Peaker Plants

- **https://en.wikipedia.org/wiki/Cost_of_electricity_by_source** :
- 2020: ca. **15-20 c/kWh**
- This 2020 price range is similar to that of storage (16.5 c/kWh), but likely rising, unlike storage costs, which are falling.
- The batteries could replace gas peaker plants, in which they could be installed (**https://www.nsenergybusiness.com/projects/moss-landing/#**).

Conclusions:

- Electric grid storage with batteries has a cost comparable or lower than gas peaker plants.
- Grid storage with batteries is doable, relatively cheap, and the technology is there or will be there soon.
- Grid storage thus enables complete decarbonization of electricity generation.
- It just needs to be done.