Energy storage in decarbonized power systems: role, technologies and trends

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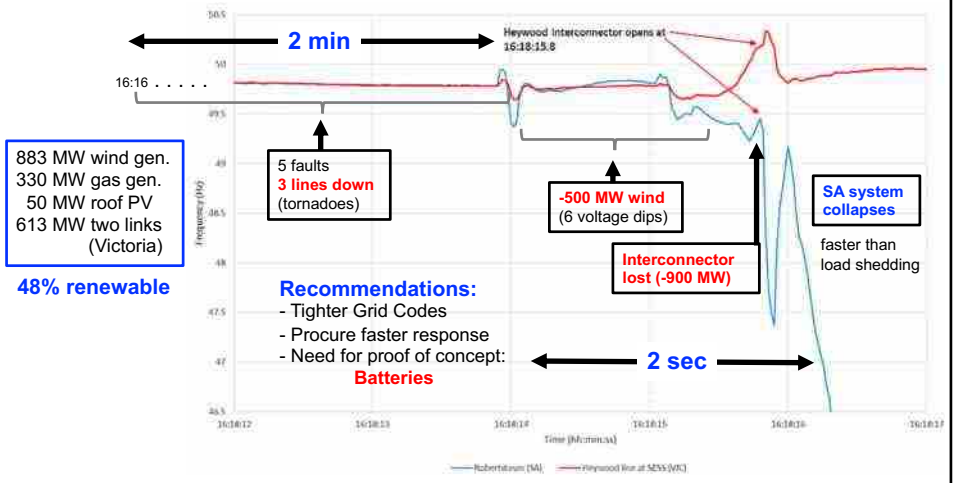
Need & role of energy storage

- **Grid stability:** inertia & fast frequency response

South Australia: Major blackout September 2016, after 6 disturbances

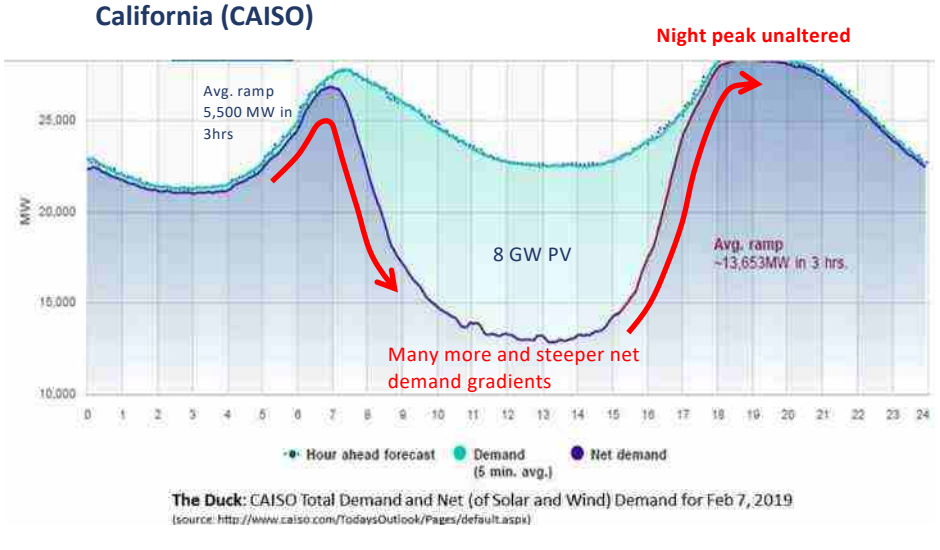


Source: Black system SA final report, AEMO (March 2017)

Need & role of energy storage

- **Firm and flexible capacity:**

California (CAISO)

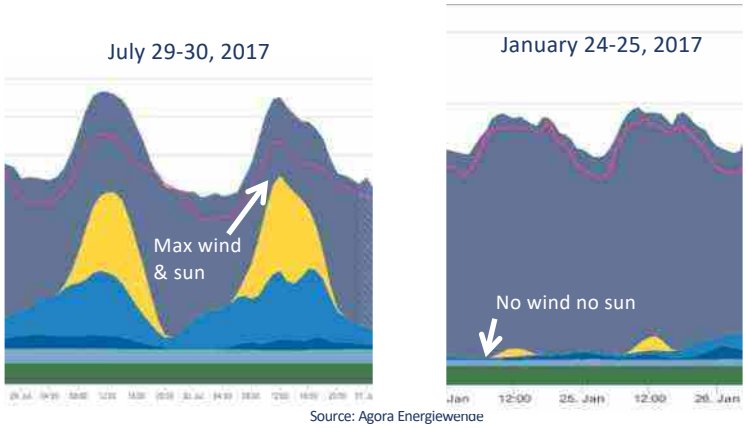


The Duck: CAISO Total Demand and Net (of Solar and Wind) Demand for Feb 7, 2019
(source: http://www.caiso.com/TodaysOutlook/Pages/default.aspx)

Need & role of energy storage

- **Energy arbitrage:** daily & seasonal

Germany: Installed power (end of 2019) { PV 49 GW (8.5% share); Wind 61 GW (21% share) }



Source: Agora Energiewende

Need & role of energy storage

In a future with >80-90% share of renewables:

Real-time

Time horizons

Long-term

- Grid stability (inertia, frequency reg.)
  - Milisec to sec
- Flexible capacity (power gradients)
  - Sec to minutes
- Firm capacity (peak power)
  - Hourly
- Energy arbitrage (time shift)
  - Daily to seasonal

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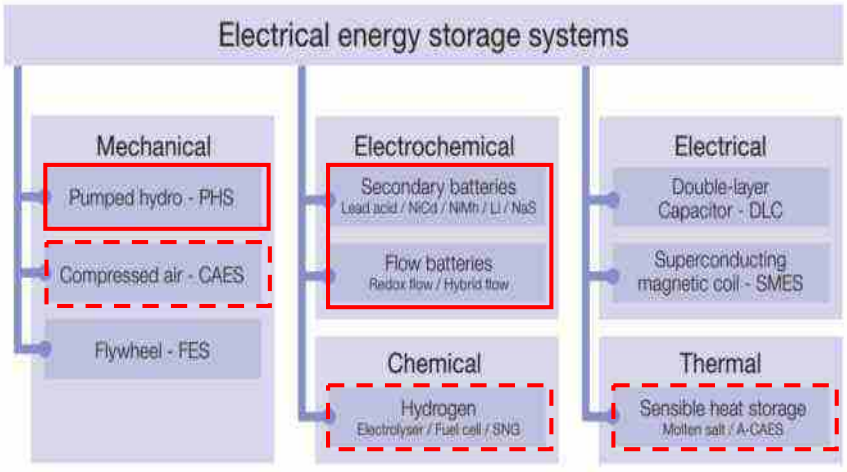
Energy storage Technologies

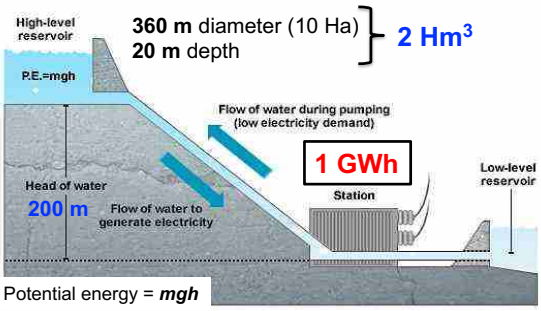
Taxonomy

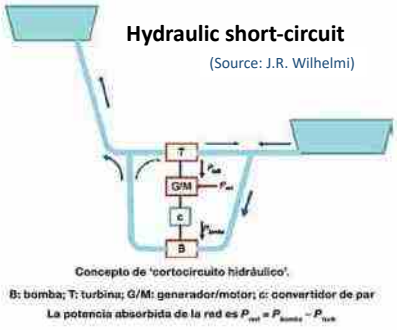


Source: Fraunhofer ISE

Hydro pumped storage

>95% of current energy storage





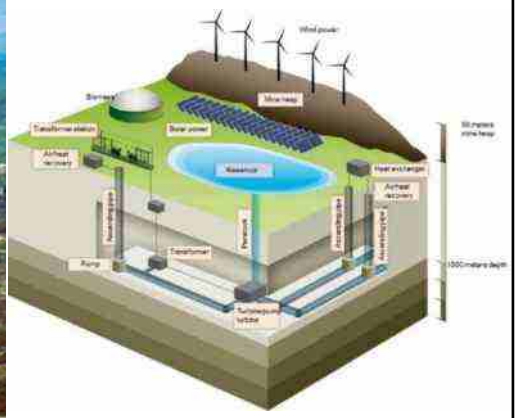
Technological improvements:

- **VARIABLE SPEED DRIVERS:** efficiency, speed of response, flexibility (Japan)
- Ocean as lower reservoir (Japan limited experience)
- Alternative placements: underground (mines, salt caverns), underwater

Hydro pumped storage

La Muela I & II, Júcar river
1,500 MW, 7 hours (10-12 GWh)

Upgraded in 2013, 7 years

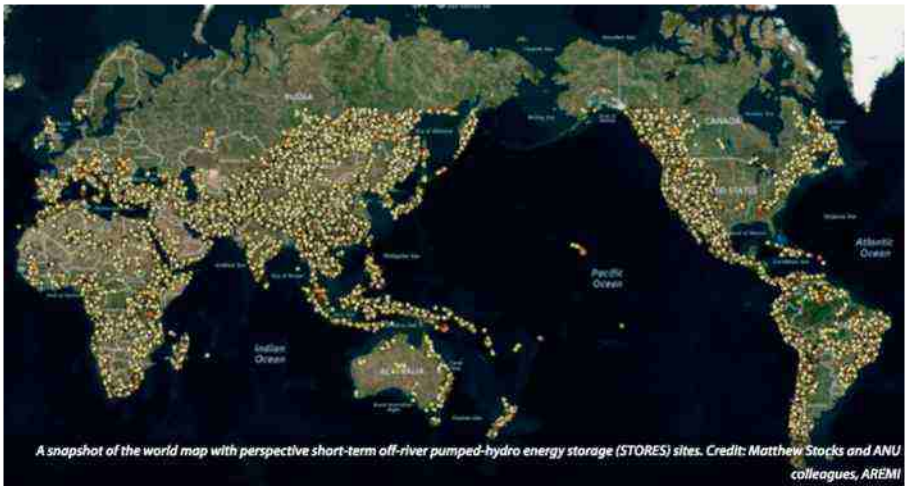


Old coal mine, Germany
200 MW

Source: https://www.renewableenergyworld.com/2017/03/17/german-coal-mine-to-be-reborn-as-giant-pumped-storage-hydro-facility/#gref

Worldwide potential for pumped storage

530,000 locations; 22,000 TWh (approx. worldwide consumption)



A snapshot of the world map with perspective short-term off-river pumped-hydro energy storage (STORES) sites. Credit: Matthew Stocks and ANU colleagues, AREMI

Source: https://smartwatermagazine.com/news/australian-national-university/study-finds-530000-potential-pumped-hydro-sites-worldwide

Hydro pumped storage

PROS

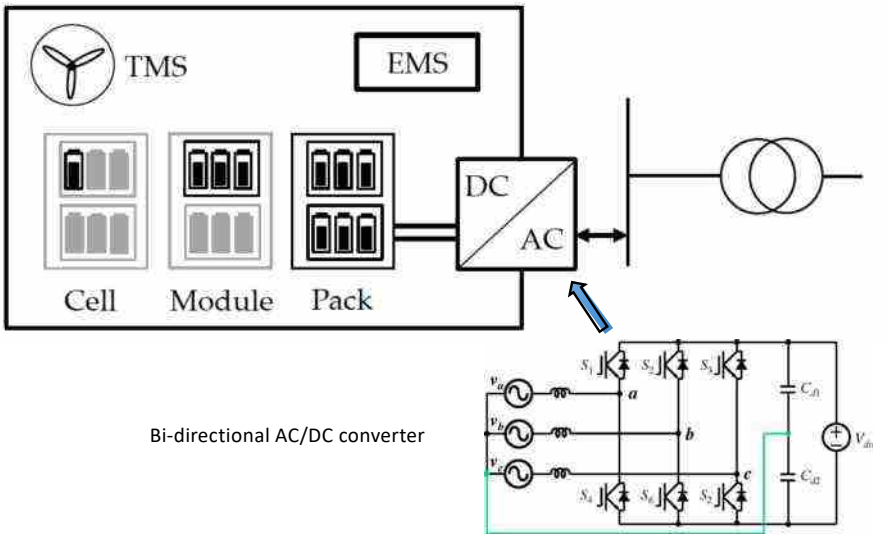
- Proven technology
- Long life
- Moderate flexibility (with hydraulic "short circuit")
- Fast response with variable speed configuration (sec.)
- High efficiency (70-85%)
- Very low self discharge

CONS

- Long commissioning time (years)
- Site requirements
- Environmental impact (very large footprint)
- Very high CAPEX
- Project complexity

Electrochemical storage

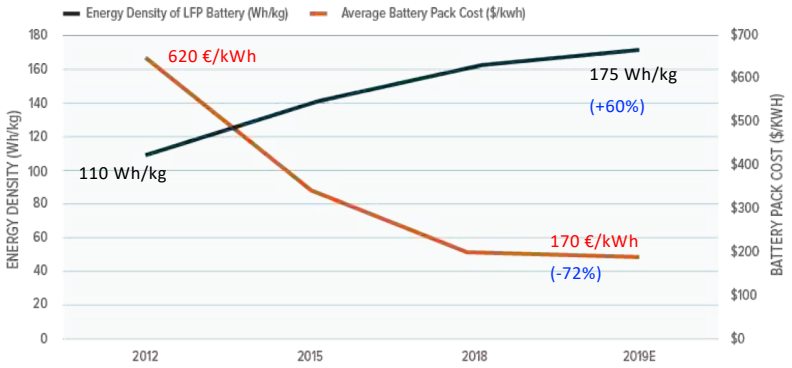
Rechargable batteries (Li-ion)



Bi-directional AC/DC converter

Battery improvements over time

Source: BYD, Bloomberg NEF, CairnERA



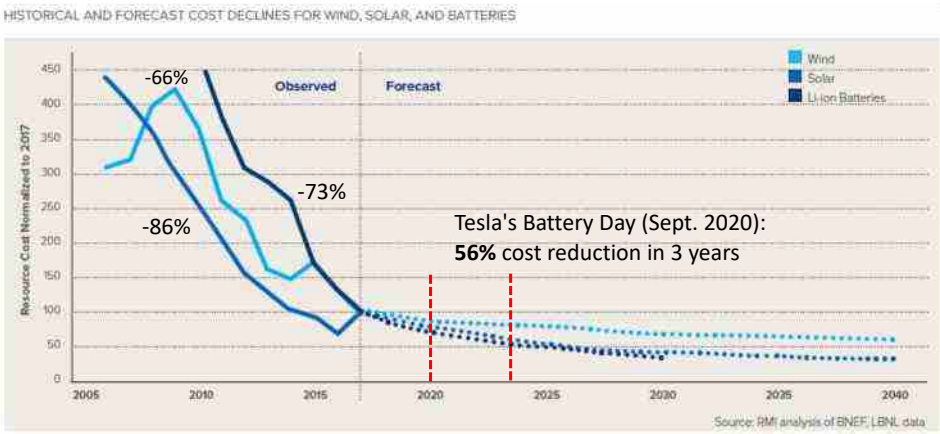
Recent announcements:

- 260 Wh/kg: https://chargedevs.com/newswire/xalt-energy-launches-high-energy-density-battery-pack/
- 350 Wh/kg: https://cleantechnica.com/2020/06/10/usas-battery500-initiative-has-achieved-li-metal-battery-energy-density-of-350-wh-kg/
- 500 Wh/kg: Nikola Co. https://www.greencarcongress.com/2019/11/20191120-nikola.html

Electrochemical storage

Rechargable batteries (Li-ion)

Drastic cost reduction



Electrochemical storage

Rechargable batteries (Li-ion)

Tesla batteries family:

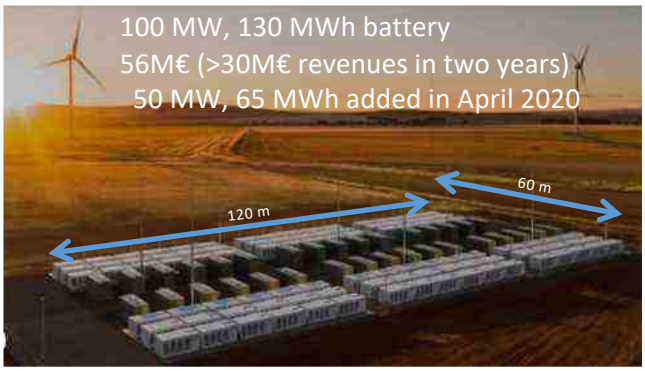
- Powerwall: 13.5 kWh
- Powerpack: 210 kWh
- **Megapack:** **3 MWh** (2020)

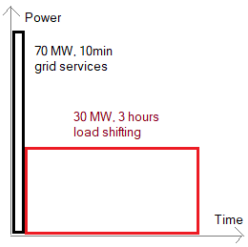
PG&E: 250MW & 1GWh in less than three months

Electrochemical storage

Rechargable batteries (Li-ion)

Hornsdale Power Reserve (SA): Tesla battery (Powerpack)





Elon Musk claimed in Tweeter that the battery would be ready in less than 100 days or it would be free for SA. Tesla finished the battery in about 60 days (from Sept 30 to Dec 1, 2017).

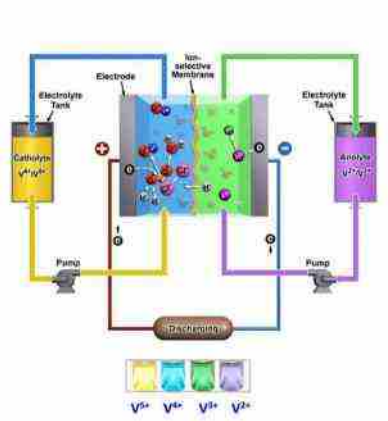
- Dec 15 2017: sudden loss of 560 MW at Loy Yang coal plant (1,000 km away). Tesla battery reacted in < 1 sec to provide frequency support, before thermal spinning reserve was able to react.

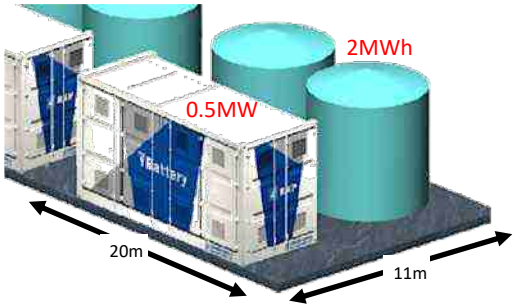
Electrochemical storage

Hornsdale Power Reserve (SA)

Electrochemical storage

Flow batteries (redox)





Tanks capacity determines the rated energy of the flow battery

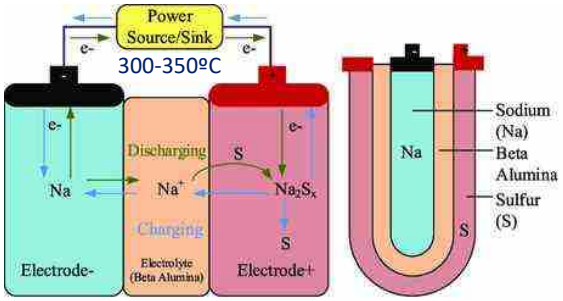
200MW/800MWh Vanadium flow battery (2020)

- Land occupation: 9 Ha
- Response time: 10-20 ms
- Efficiency: 65%-75%
- Expected lifetime: 15,000 cycles (zero degradation 20 years)
- Fuction: Peak load shifting & power supply for black start

http://www.rongkepower.com/Product/show/catid/175/id/103/lang/en.html

Electrochemical storage

Baterías NaS batteries (high temperature)



Terna project:
NaS battery
1.2 MW, 8.64 MWh

Pros
- Higher energy density than Li-Ion
- Almost null self-discharge: seasonal
- Inexpensive, recyble materials

Cons
- High operating cost
- Need to keep high temperature

Source: M.A. Hannan et al. "Review of energy storage systems for electric vehicle applications: Issues and challenges", RSER, vol 69(2017), pp 771-789.

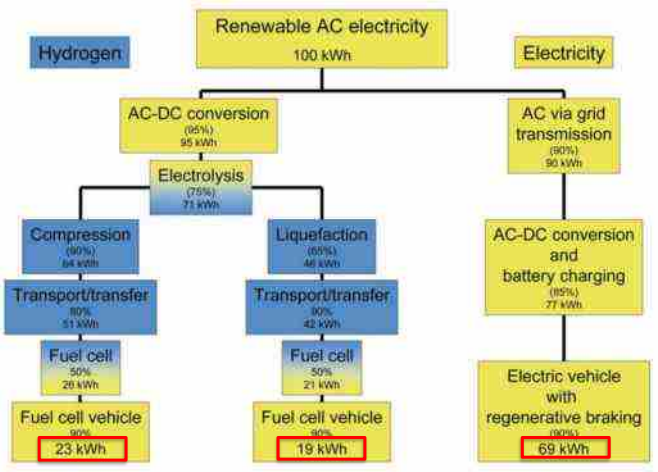
Electrochemical storage

PROS
- Modularity (distributed)
- Short commissioning time (months vs. years)
- Small footprint
- No specific site required
- Flexibility of operation
- Ultrafast response (ms)
- High efficiency (85-90%)
- Low self discharge (0.1-0.3%/day)
- Simplicity
- Low maintenance

CONS
- Relatively short life (10-15 years: Li-ion)
- High CAPEX (quickly reducing)
- Not completely mature technology

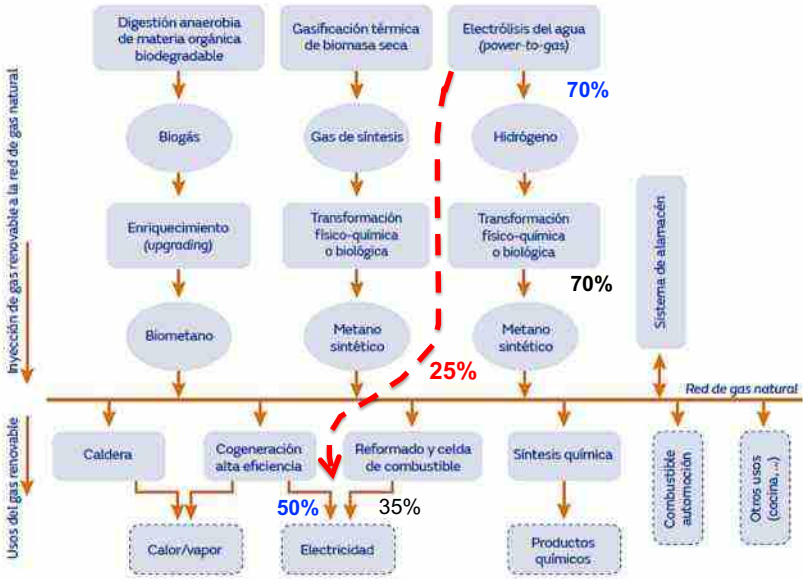
"Green" Hydrogen

Efficiency: Electric Vehicle vs Fuel-Cell Vehicle



Source: U. Bossel, *Proceedings of the IEEE*, 2006

Bio and synthetic gases



Source: A. Feliu, X. Flotats, "Los gases renovables: un vector energético emergente" (2019), Fund. Naturgy

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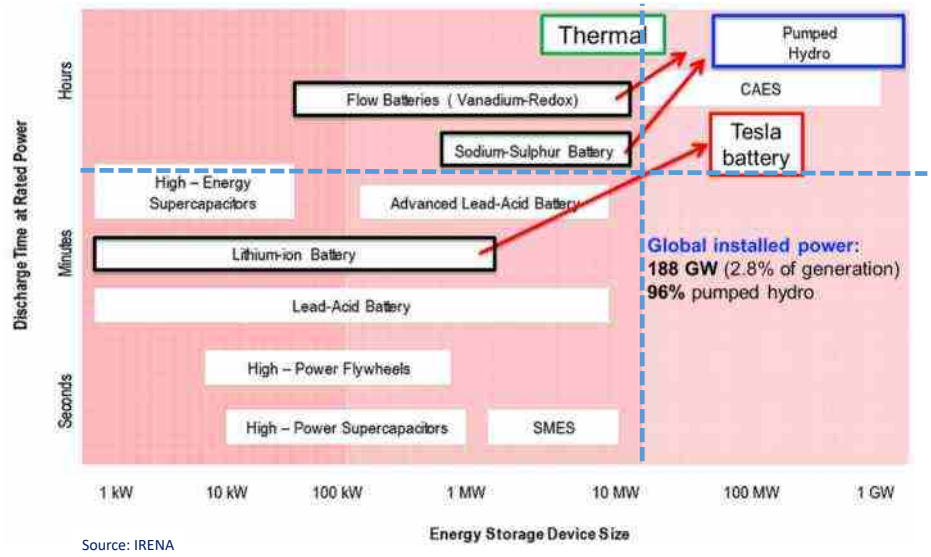
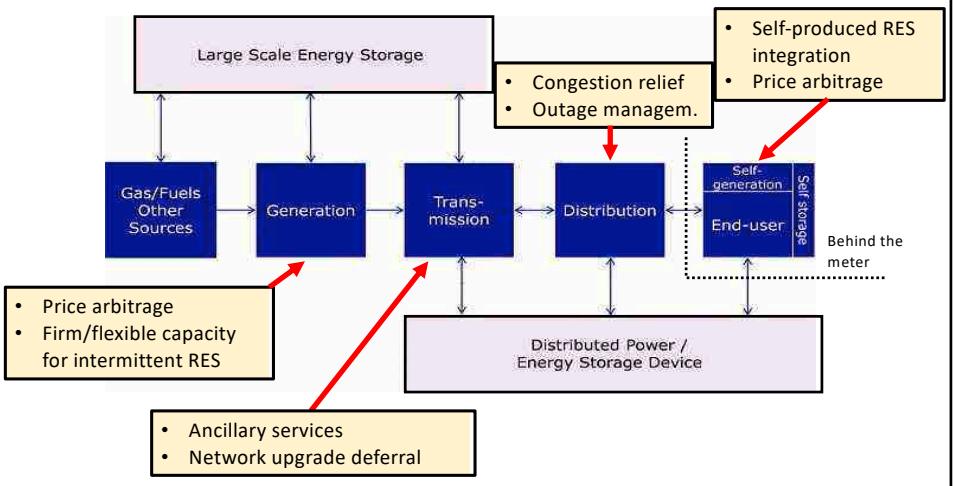
Niches of applications by sizes



Source: IRENA

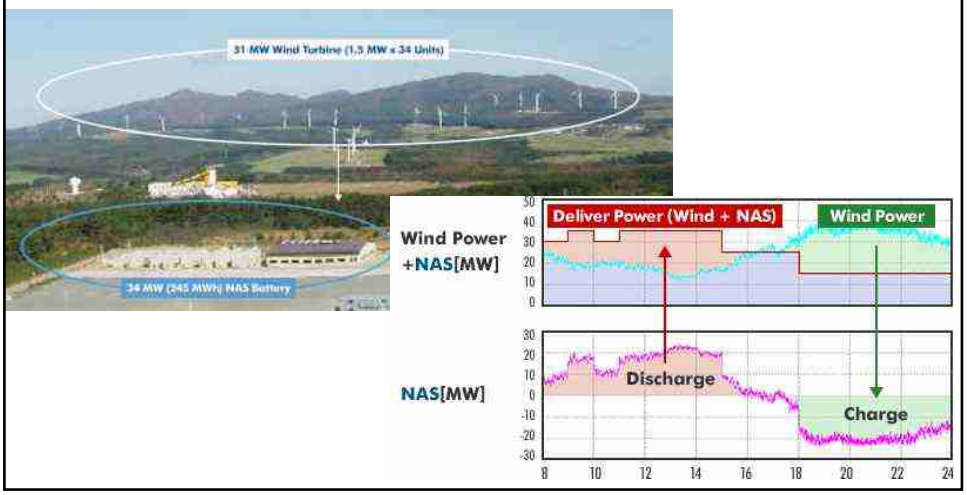
Niches of applications by agents



Applications in renewable generation

Rokkasho Futamata Wind Farm in Japan (2008)

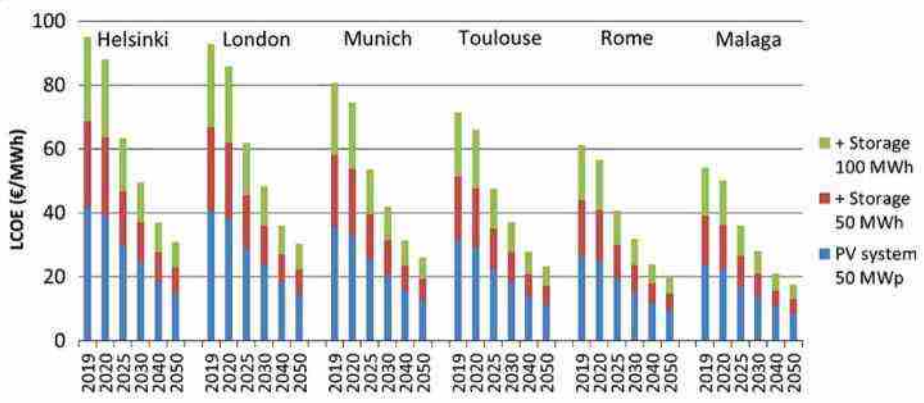
Wind Park 51 MW, NaS battery 34 MW (224 MWh)



Applications in renewable generation

Renewables + storage

LCOE evolution (utility-scale) in 6 European cities

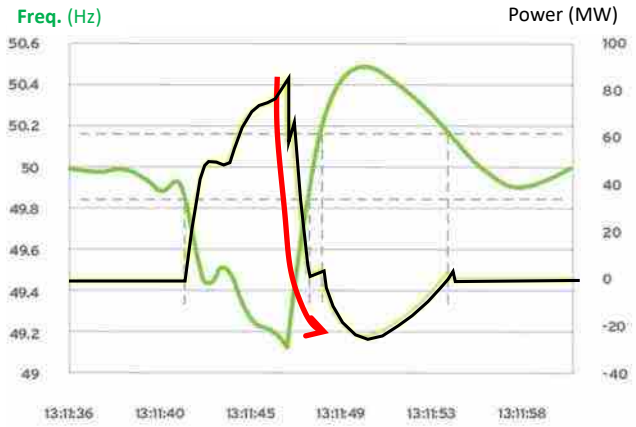


Source: EU PVSEC report: 'Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelized cost of electricity.'

Applications in transmission systems

Example: synthetic inertia

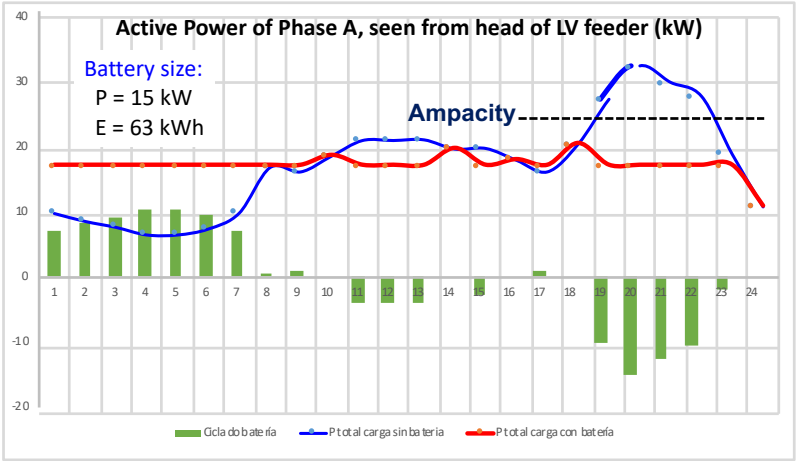
TESLA BATTERY: August 25 (2018): interconnector between Queensland and New South Wales lost. HPR required to discharge up to 100MW in under 150ms



Its "speed and laser precision in response to system events has been encouraging,"
Australian Energy Market Operator (AEMO)

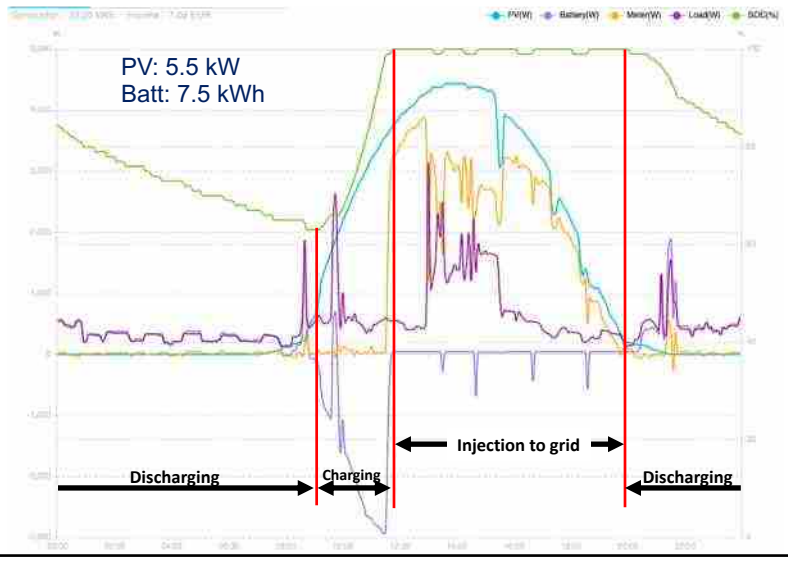
Applications in distribution systems

Feeder-level load management: daily cycle



Behind-the-meter applications

Residential prosumer: typical daily cycle



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FERC order #841 (feb 2018)

Goal: "to remove barriers to the participation of electric storage resources in the capacity, energy, and ancillary service markets operated by RTOs and ISO".

- Grid operators have **1 year** to create market rules and another year to implement them.
- Minimum bid size ≤ 100kW
- FERC opening new process to study the participation of aggregated distributed resources (rooftop PV and batteries)

Source: https://ferc.gov/whats-new/comm-meet/2018/021518/E-1.pdf

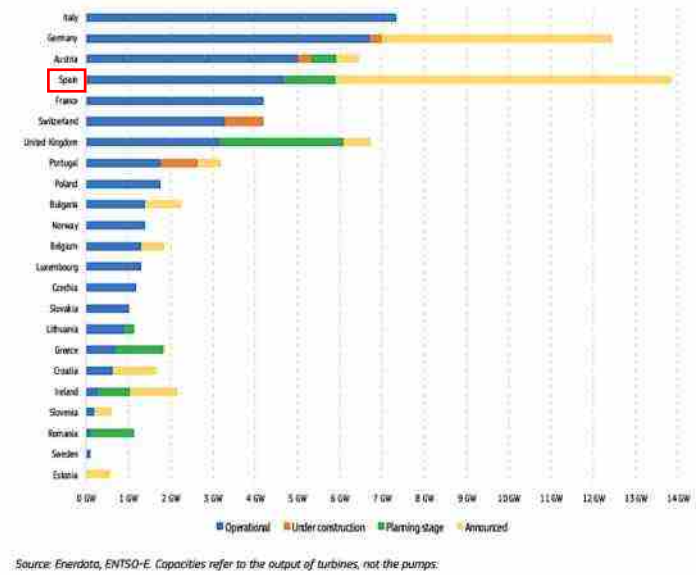
UE Directive 2019/944 (june 6, 2019)

[Reglamento 2019/943]

- Clompletes the “Clean Energy Packet” (2016)
- Active loads, demand response and **storage**: key components of the new regulatory framework
- Allow and encourage **participation** of (aggregated) demand response along with traditional stakeholders in **all electricity markets**
- Minimum bid size (daily & intradaily markets) ≤ 500kW

Source: https://www.boe.es/doue/2019/158/L00125-00199.pdf

Pumped storage capacity in Europe

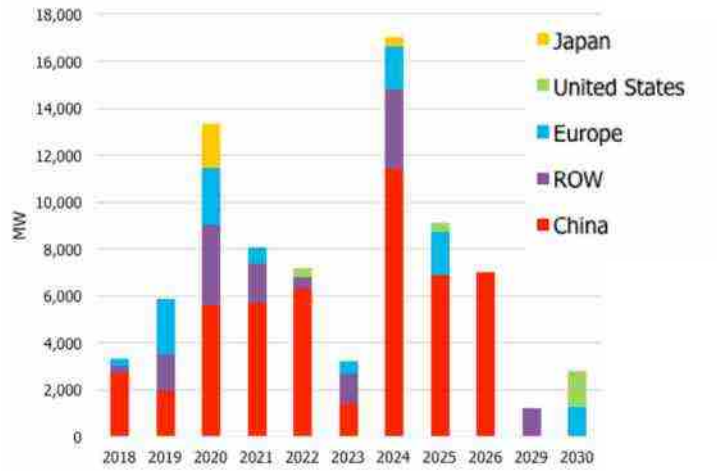


Source: Enerdata, ENTSO-E. Capacities refer to the output of turbines, not the pumps.

Pumped storage in the pipeline

Projects under construction or approved (2030)

78,000 MW (50,000 MW in China)

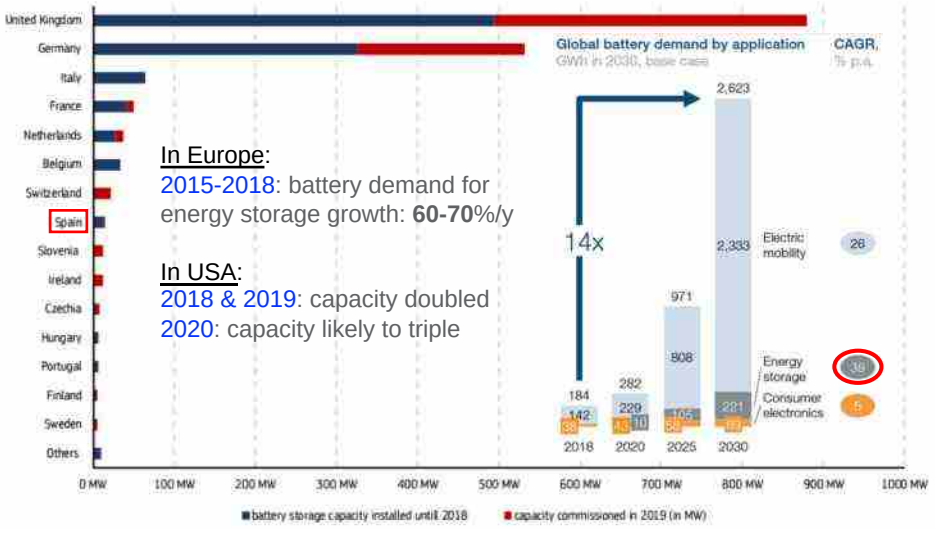


Source: International Hydropower Association

Electrochemical storage capacity

Installed capacity in Europe (2018-19)

Global growth (2030)



In Europe:
2015-2018: battery demand for energy storage growth: **60-70**%/y

In USA:
2018 & 2019: capacity doubled
2020: capacity likely to triple

http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf

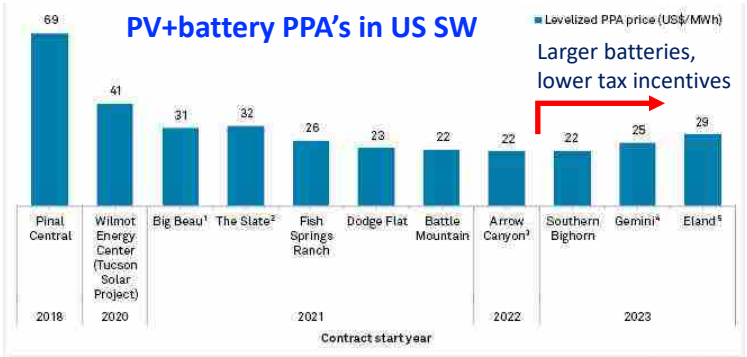
Electrochemical storage

Examples of undergoing projects

Project	Location	Technol.	Power / Energy MW - MWh	Comments
Hornsdale Power Reserve (**Tesla**)	South Australia	Li-ion	**100** MW / **139** MWh +(**50** MW / **64.5** MWh)	56 M€, installed in 60 days 50% upgrading in 2020
Solar River Project	South Australia	Li-ion	100 MW / 300 MWh	associated to 200 MW PV (2020)
Xcel Energy	Colorado	Li-ion	275 MW / 1000 MWh	5 plants near 700 MW PV
PG&E: Dynegy-Vistra	California	Li-ion	300 MW / 1200 MWh	renew. share increase (2020)
PG&E: Tesla	California	Li-ion	182 MW / 1100 MWh	based on Megapack modules
Ronkepower	China	Vanadium	200 MW / 800 MWh	Goal: 1 GW (2020)
Abu Dahbi	Arab Emirates	NaS	108 MW / 648 MWh	10 coordinated facilities
Andes Solar II-B & Campo Lindo	Chile	Li-ion	112 MW / 560 MWh	associated to 253 MW solar
Eskon	South Africa	¿?	**360** MW / **1440** MWh	tender released (2021)

1h (2017) → 4-6h (2020)

Electrochemical storage



Plant	Plant ultimate parent	State	Solar (MW)	Energy storage (MW)
Pinal Central Solar Energy Center	NextEra Energy Inc.	AZ	20	10
Wilmot Energy Center (Tucson Solar Project)	NextEra Energy Inc.	AZ	100	30
Big Beau Solar+Storage Project[1]	EDF Group	CA	128	40
The Slate Solar Project[2]	Canadian Solar Inc.	CA	150	45
Fish Springs Ranch Solar Farm	NextEra Energy Inc.	NV	100	25
Dodge Flat Solar Energy Center	NextEra Energy Inc.	NV	200	50
Battle Mountain Solar Project	Cypress Creek Holdings LLC	NV	101	25
Arrow Canyon Solar Project[3]	EDF Group	NV	200	75
Southern Bighorn Solar & Storage Center	8minute Solar Energy LLC	NV	300	135
Gemini Solar + Battery Storage Project[4]	Low Carbon Power Fund	NV	690	380
Eland Solar and Storage Center[5]	Capital Dynamics Holding AG	CA	400	300

[bifacial modules]

Batteries vs. Pumped Storage

"…There is room for both batteries and pumped storage hydro, and they may even complement each other. **Batteries** are more cost-effective at delivering **small** amounts of stored **energy** over a short time at **high power** levels. **Pumped** storage is more cost-effective at storing and releasing **larger** amounts of stored **energy**.

Achieving the optimum storage solution will depend on careful planning and finding the best fit for the particular circumstances.

What is certain is that **both technologies** will play important roles in the development and expansion of a network powered by renewable energy."

- D. Vaughan, N. West

entura

http://www.entura.com.au/batteries-vs-pumped-storage-hydropower-a-place-for-both/

http://www.raing.es/sites/default/files/ALMACENAMIENTO_ENERGIA%20FINAL%20B.pdf

"Batteries are among the key technologies enabling a climate-neutral Europe by 2050"

H2020 project (March 2019)

Vision: inventing sustainable batteries of the future

- Technology: materials & interfaces
- Safety & self-healing
- Recyclability, manufacturing

https://battery2030.eu/

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