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Utility-scale energy storage: system integration and market prospects

EPFL, Energy storage in power systems: technologies, applications and future needs
16.10.2025

Dr. Antonio Zecchino
BESS Technical Lead

Agenda

Part I

1. Context
2. Energy storage for grid applications
   i. Power system need for flexibility and grid services
   ii. Prequalification of energy storage units for the participation to the Swiss ancillary service markets
   iii. Aggregation of distributed EVs for ancillary service provision

Part II

3. Key components of a stand-alone battery energy storage system (BESS)
4. Key steps to develop a utility-scale BESS project
5. What is beyond Li-ion batteries? An overview of Medium/Long Duration Energy Storage technologies

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Alpiq – who we are

- Leading Swiss **power producer and energy service provider** – production, trading, sales
- **Flexible power** plant portfolio to be able to integrate renewable energy for a secure electrical power supply
- Over 100 years of producing **environmentally sustainable power from carbon-neutral Swiss hydropower**
- **Portfolio** of nuclear power plants, H_2 production, flexible thermal power plants, batteries, wind farms and photovoltaic systems

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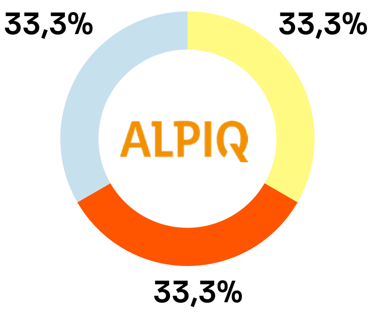
Alpiq at a glance

Key figures

- **Leading** in asset, portfolio, and risk management
- **30MW / 255MW** Managed/Owned pipeline BESS capacity (2025)
- **CHF 8.4bn** Net revenue
- **CHF 1,184m** EBITDA (before exceptional items)
- Alpiq **increased funding via a CHF 3.6bn RCF facility** whilst adding 10 new banks to its banking pool
- **1,350** Employees

Shareholder overview

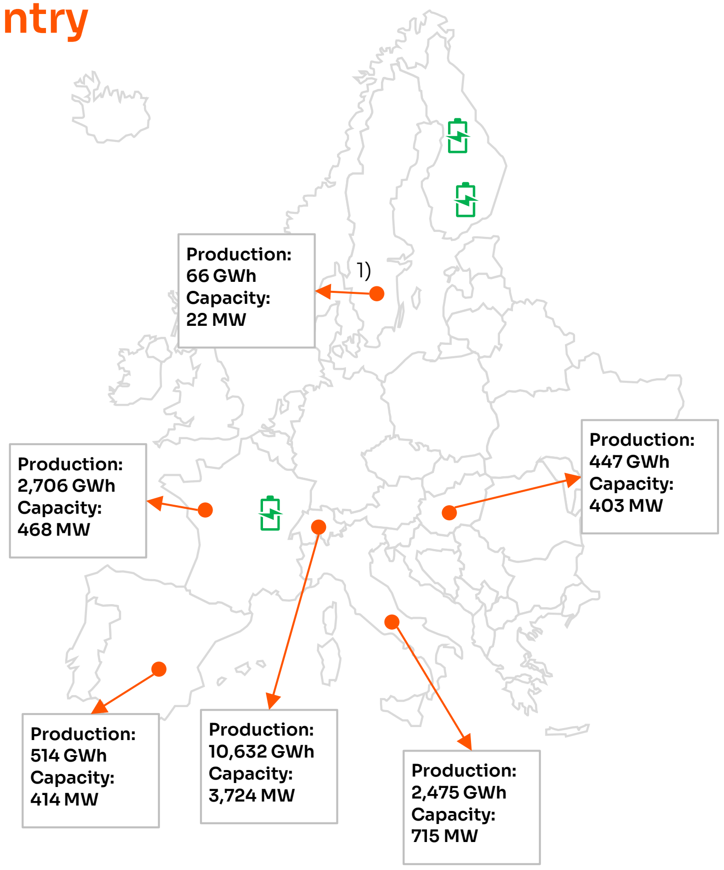


EOS HOLDING

KBG SA

Consortium of Swiss Minority Shareholders

Alpiq's power generation per country



1) Alpiq has 30% ownership of a windfarm in Sweden

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Alpiq is strategically positioned in a volatile environment to provide flexible energy solutions to meet increasing demand

5'723 MW installed capacity in 2023
80 % of which flexible

Switzerland, Europe	Europe	Switzerland, Europe	Switzerland, Europe
58%	**23%**	**15%**	**5%**
Hydropower	Thermal conventional (Gas)	Nuclear	Small Hydro, Wind, PV

16'840 GWh produced electricity in 2023 in Switzerland and the EU

6,644 GWh	3,121 GWh	6,595 GWh	481 GWh
39%	**19%**	**39%**	**3%**
Hydropower	Thermal conventional (Gas)	Nuclear	Small Hydro, Wind, PV

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Our powerplant portfolio

5,723MW installed capacity | 80% of which flexible

Hydropower plants	flexible	low CO_2 emissions	climate friendly	renewable		strengthen the security of supply	contribute to a better climate
Small hydropower plants, wind farms, photovoltaic systems		low CO_2 emissions	climate friendly	renewable		strengthen the security of supply	contribute to a better climate
Nuclear power plants		low CO_2 emissions	climate friendly		bridging technology	strengthen the security of supply	contribute to a better climate
Gas-fired combined cycle power plants	flexible				bridging technology	strengthen the security of supply	contribute to a better climate
Growth ambition: BESS	flexible	low CO_2	climate friendly			strengthen the security of supply	contribute to a better climate

Alpiq's strategy: Security of supply and decarbonisation through flexible assets and innovative solutions

Existing business

+ **Flexibility**
(including BESS)

+ **Trading**
(Proprietary trading activities)

+ **Origination / Customer business**

Our strategy

- Driving forward the **security of supply** in and the **decarbonisation** of the Swiss and the European energy systems
- Alpiq continues to **focus** on its **core markets*** through its existing business
- Strengthening through diversification, with **three strategic directions** for value-based growth: targeted investments in flexible assets, and expansion of Alpiq's Trading and Origination businesses respectively

*Switzerland, France, Italy, Spain, Germany, Finland, Sweden

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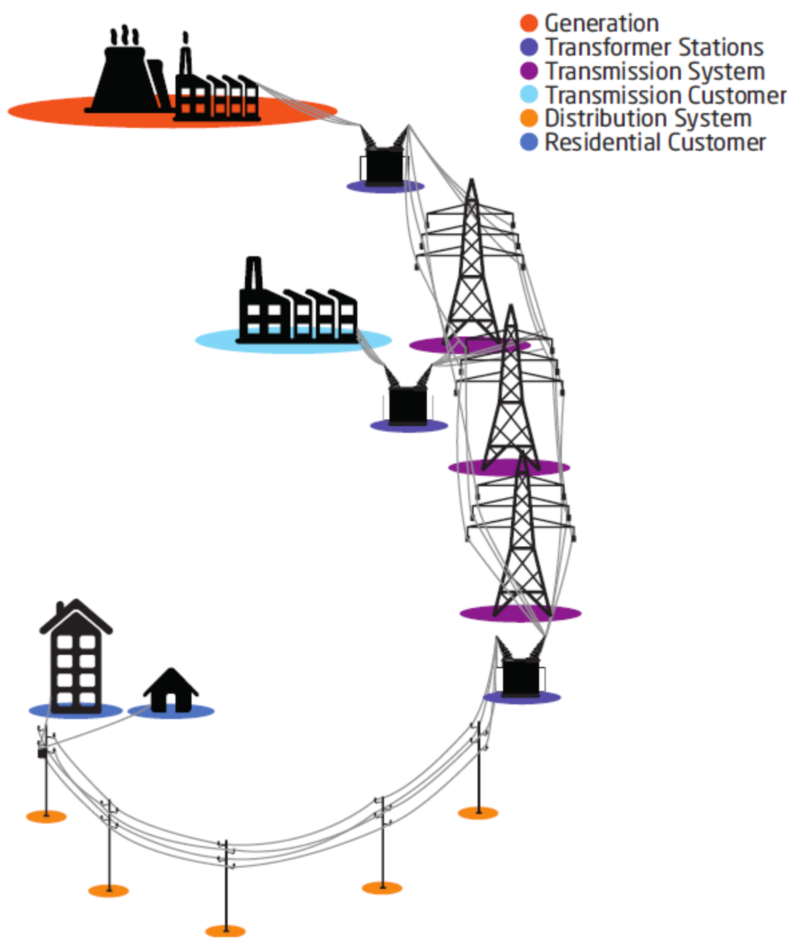
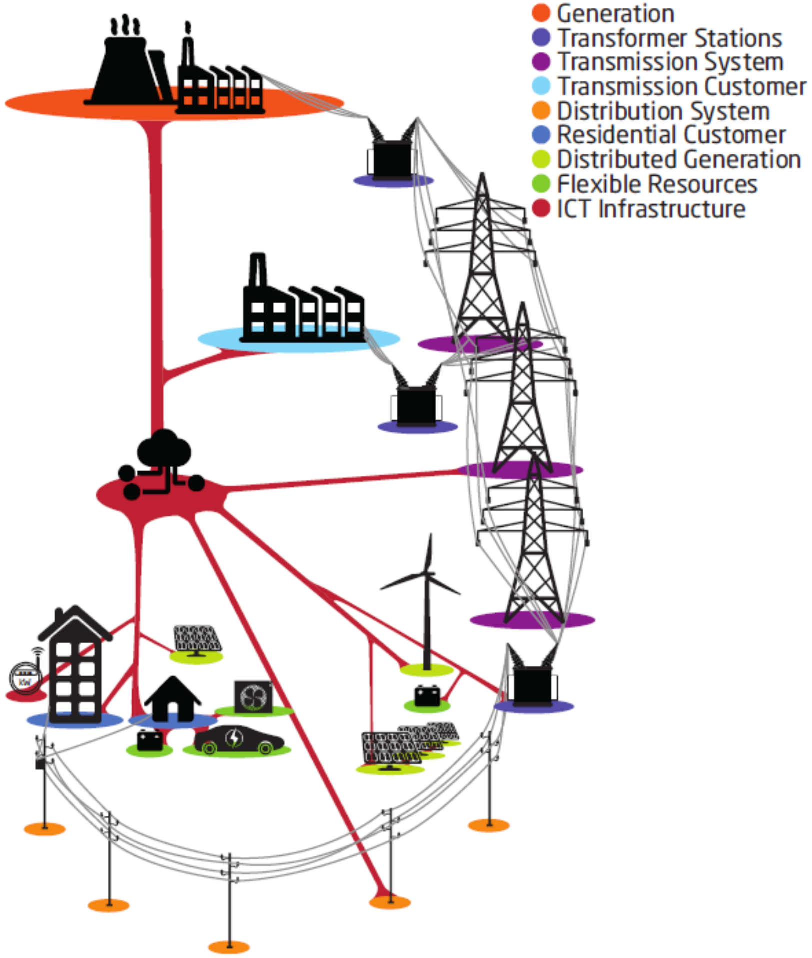
Context: evolving power system

Traditional power system paradigm: Centralized generation → uni-directional power flows



Modern power system paradigm: Decentralized generation → bi-directional power flows



Transmission

- RES success
- Fluctuations in the generation
- Fewer synchronous machines
- Lower system inertia
- **Grid-connected batteries**

Observability

- Wide-scale measurements
- ICT infrastructure

Distribution

- Distributed generation
- Smart pro-sumers
- New electrical loads
- **Grid-connected batteries**

Source: Zecchino A., Electric vehicles in the Nordic countries: Control strategies for coordinated grid services, PhD_Thesis_Antonio_Zecchino_DTU.pdf

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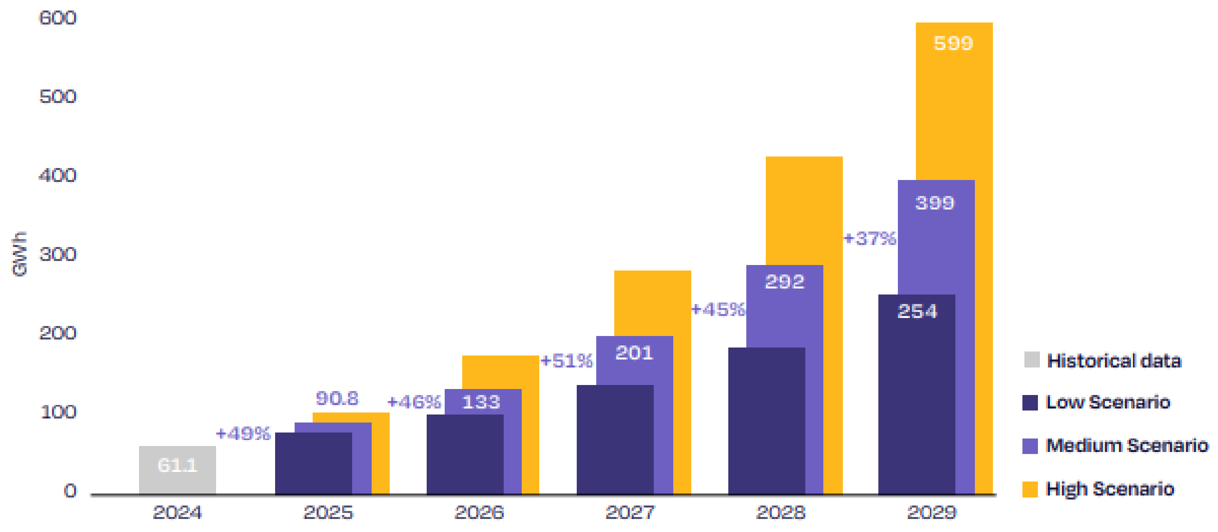
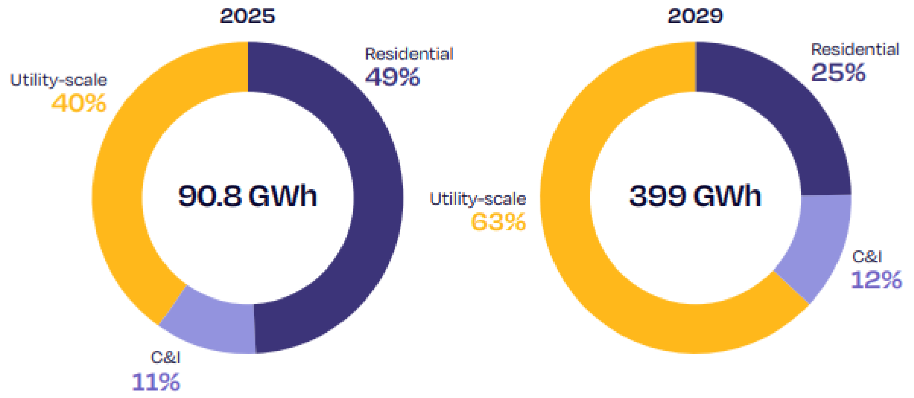
Europe battery market trends

The penetration of battery storage systems is expected to continue increasing in the coming years

Europe battery storage cumulative installed capacity scenarios 2025-2029



Europe cumulative battery storage segmentation scenarios 2025-2029



Source: SolarPower Europe (European Market Outlook for Battery Storage 2025-2029**)**

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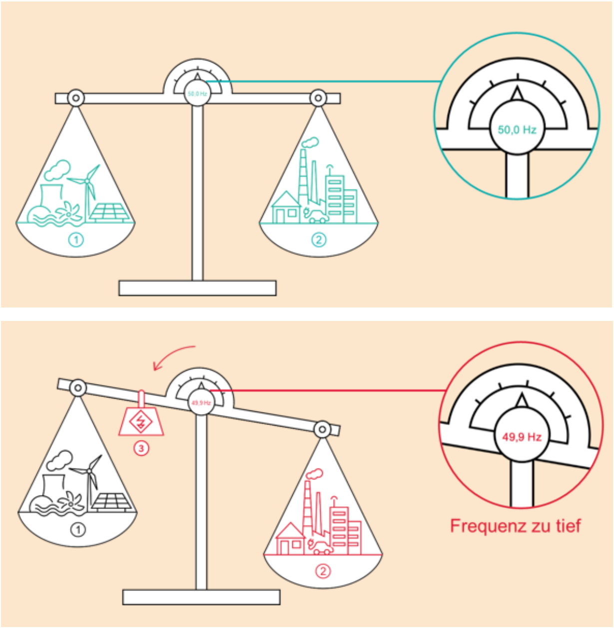
Massive integration of renewables (RES) and new electrical loads bring new challenges

Renewables (wind and solar) and new electrical loads (heat pumps, EVs) introduce new challenges for grid operators due to their stochastic nature, both at transmission and distribution grid level

High degree of fluctuations of generation and load bring new <u>challenges to the power system stability</u>.

Transmission system operators (TSOs) are in charge of maintaining the system stable, Swissgrid in CH.



① Generation plants

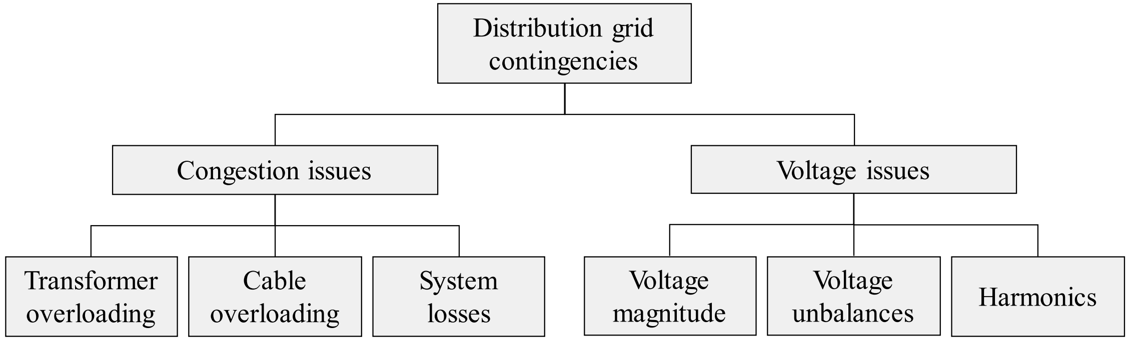
② Consumption

③ Balancing energy

Source: Swissgrid (<u>Grid stability (swissgrid.ch)</u>)

Increased challenges in predicting base and peak RES-based generation and consumption → more frequent and severe <u>congestion and voltage issues</u>.

Distribution system operators (DSOs) are responsible to safely deliver the electricity to the customers with high power quality standards (e.g., voltage magnitude, unbalance, harmonic distortion, ..).



Frequency regulation in Switzerland

Activation of primary, secondary, and tertiary control reserve as consequence of a power system contingency

Primary control / containment reserve
0.5 min. after outage

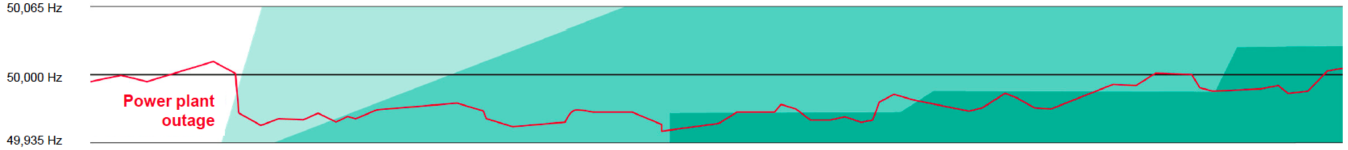
- Frequency measurement in the power plants
- Automatically activated in the generator of the power plant
- Across Europe

Secondary control / frequency restoration reserve
5 min. after outage

- Measurements at the Swiss cross-border lines
- Activated by the central load frequency controller at Swissgrid
- Across Switzerland

Tertiary control / frequency replacement reserve
15 min. after outage

- Easing of secondary control
- Activated by the operator
- Contracts with individual providers



Source: Swissgrid (Grid stability (swissgrid.ch))

Year	PRL± [MW]	SRL+ [MW]	SRL- [MW]	TRL+ [MW]	TRL- [MW]
2020	65	398	376	406	271
2021	67	391	388	542	512
2022	64	391	380	545	524
2023	62	406	401	481	507
2024	62	406	399	480	508

Source:
https://www.elcom.admin.ch/dam/elcom/de/dokumente/2025/bericht-regelleistung-regelenergie-2024.pdf.download.pdf/Bericht%20Regelleistung%20und%20Regelenergie%202024.pdf

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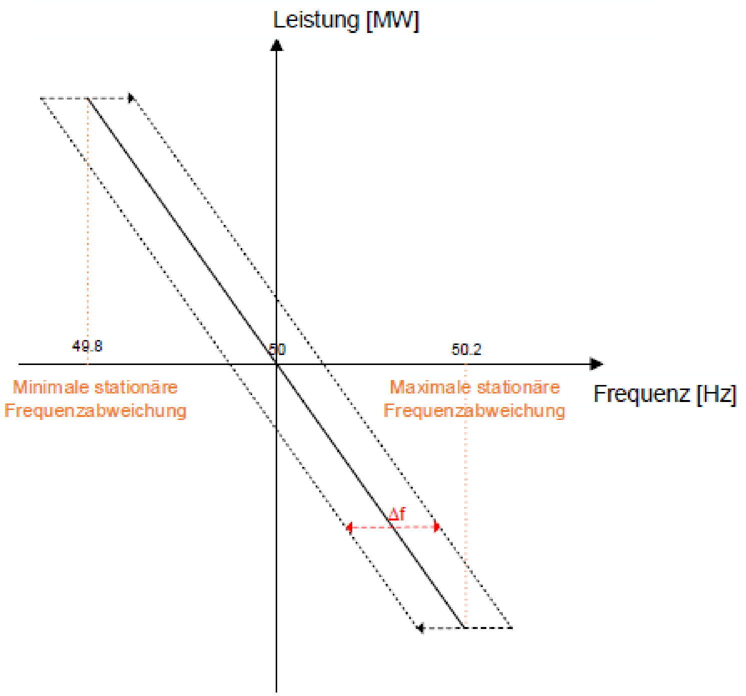
Prequalification for the participation to Frequency regulation (1/2)

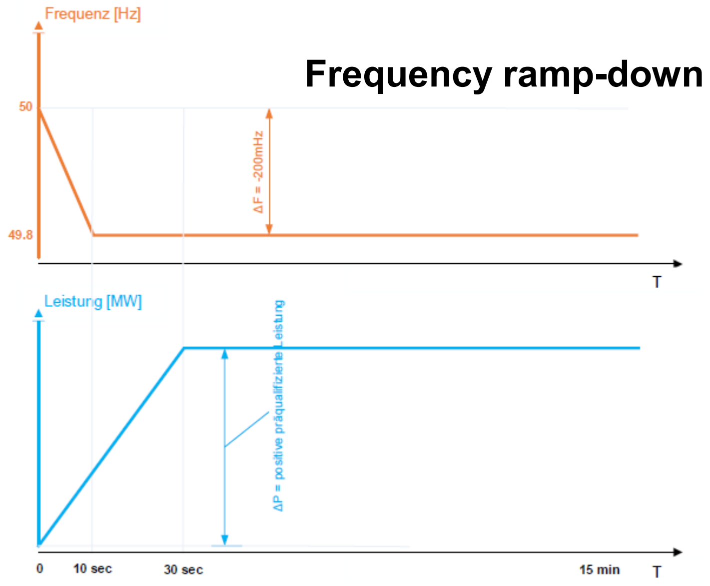
FCR – Frequency Containment Reserve – Technical requirements ant prequalification tests

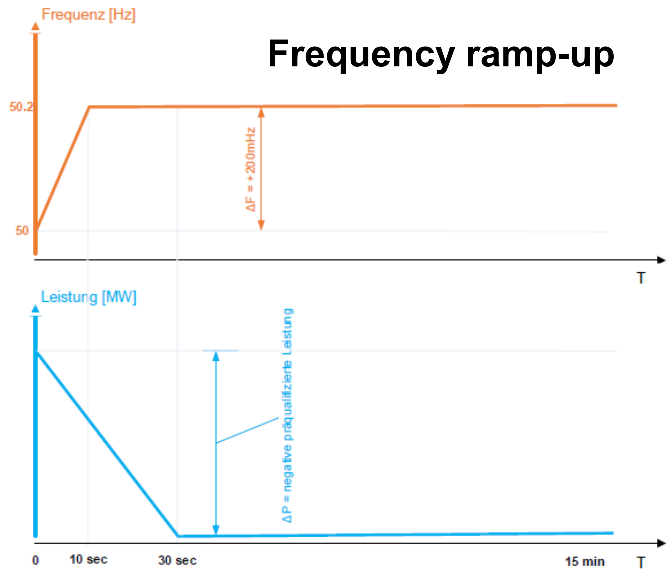
- Droop
- Active power measurement
- Frequency measurement
- Activation speed
- Activation duration
- Minimal eligible power per reserve providing pool of 1 MW

$$\frac{\Delta f}{f_n} = k_{droop} \cdot \frac{\Delta P}{P_{res}}$$



Source: Swissgrid (Präqualifikationsbedingungen (PRL, SRL, TRL, gültig ab 1. Juni 2022))

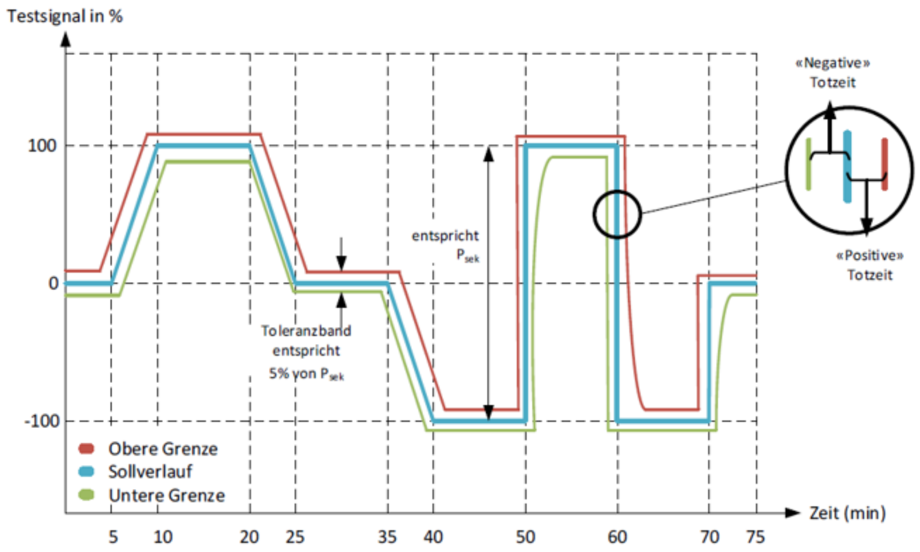




Prequalification for the participation to Frequency regulation (2/2)

aFRR – automatic Frequency Restoration Reserve – Technical requirements and prequalification tests

- Connection to Swissgrid's control room for real-time signal acquisition
- Information and implementation of the required reserve capacity
- Active power measurement
- Power gradient
- Minimal eligible power per reserve providing pool of 5 MW



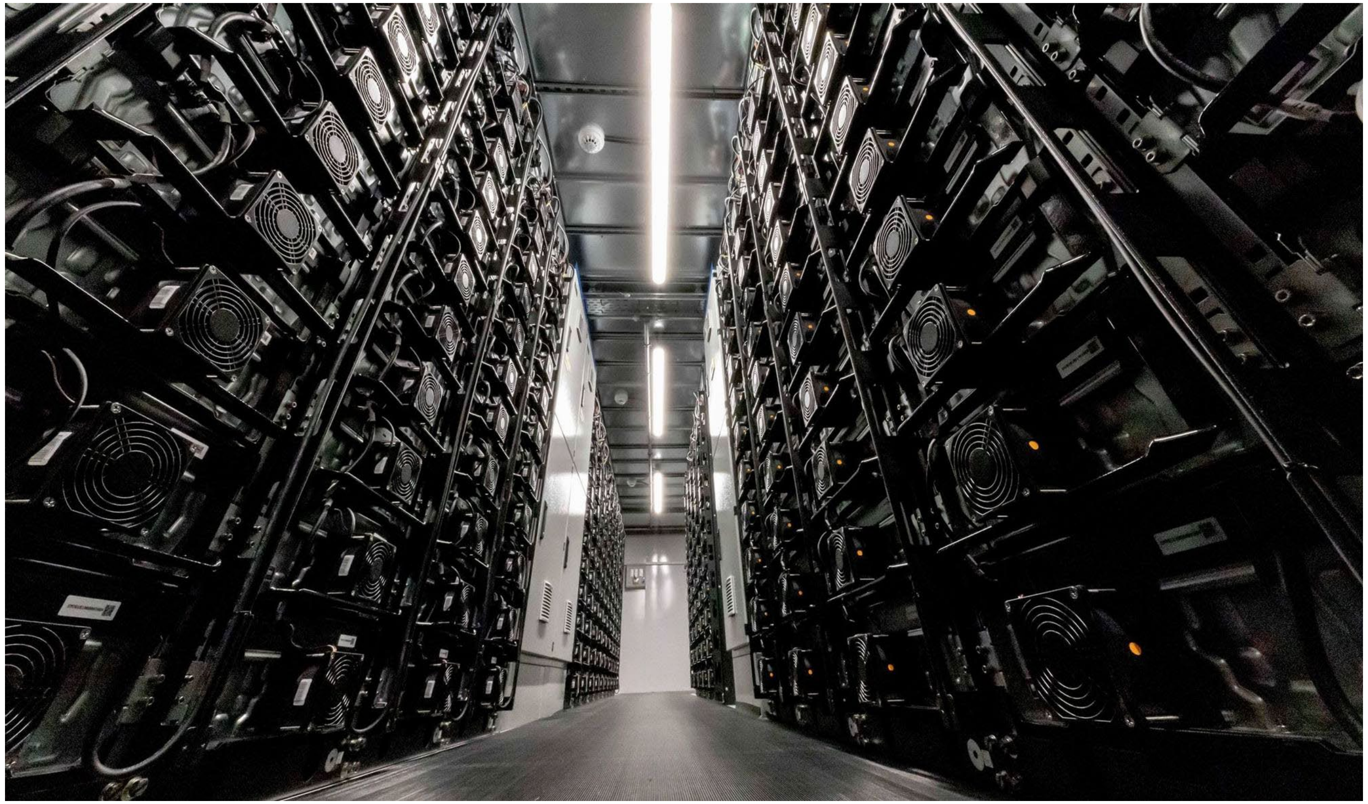
Source: Swissgrid (Präqualifikationsbedingungen (PRL, SRL, TRL, gültig ab 1. Juni 2022))

mFRR – manual Frequency Restoration Reserve – Technical requirements

- Acquisition and implementation of the required activation request
- Leadtime, activation time and minimal duration of an activation call
- Active power measurement
- Minimal eligible power per reserve providing pool of 5 MW

Definition of LER and additional requirements for the participation to FCR

LER have to prove their capability of providing reliable FCR via additional prequalification requirements: 15-minutes criterium, state of charge management, eligible FCR power, reserve operation mode



Source: Zecchino A., Gupta R.K., Paolone M., «Operation of battery storage systems for grid control, feeder dispatching (RE Demo)», SCCER-FURIES, 2021.

LER: technical entity with limited energy storage capacity

A technical entity (TE) with a time-limited energy storage capacity (**L**imited **E**nergy **R**eservoir) is a TE, which cannot provide the prequalified performance continuously for at least two hours in a positive or negative direction without additional measures (such as the use of storage management measures) (Art. 3 Abs. 5 (SAFA, Erwartet in 2021)).

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Additional requirements for LER to participate to FCR (1/4)

15-minutes criterion

LER-plants must be continuously available during normal state. From the moment of activation and during the endangered state, the LER system must be able to fully activate the **full FCR power continuously for at least 15 minutes** (Art. 156 Abs. 9 (SOGL, 2017)).

$$SoC_{max} = \frac{E - 0.25h \cdot P_{pq}}{E}$$

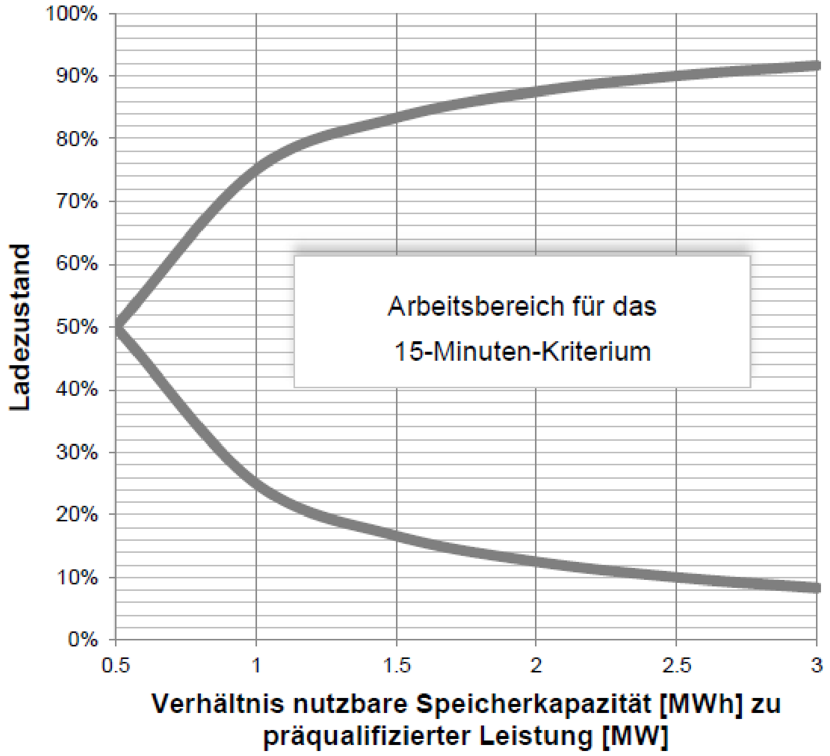
$$SoC_{min} = \frac{0.25h \cdot P_{pq}}{E}$$

E die nutzbare Speicherkapazität in MWh;

P_{pq} die präqualifizierte Leistung in MW.

Alert state:

- $\Delta f \geq \pm 50\ mHz$ for longer than 15 minutes; or
- $\Delta f \geq \pm 100\ mHz$ for longer than 5 minutes; or
- $\Delta f \geq \pm 200\ mHz$



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Additional requirements for LER to participate to FCR (2/4)

State of charge management

An active state of charge management strategy must be implemented, to ensure compliance with the 15-minutes criterion.

In the context of the prequalification process

2 preferred methods are allowed:

- State of charge management can either be done using scheduled transactions (power exchange or over-the-counter transactions) with lead time of 15 minutes; or
- by adjusting the production / consumption of other units that belong to the same balance group as the LER itself.

Proof of the State of charge management strategy

→ Via simulations based on historic frequency data (at least 1 year of data). The simulations must consider the necessary lead time before the charging/discharging as well as a «worst-case scenario» of a transition from normal to alert state. For example:
1. Δf of almost 100 mHz for 10 minutes, followed by a Δf of almost 200 mHz for 5 minutes; or
2. Δf of almost 50 mHz for 30 minutes before entering the alert state.

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Additional requirements for LER to participate to FCR (3-4/4)

Eligible FCR power

The ratio between BESS rated power and prequalified power must be at least 1.25:1 (80%).

z.B.: $P_{max} = 2\ MW$ → $P_{pq} = 1.6\ MW$

Reserve operation mode

All LER systems must ensure that near SoC_{max} and SoC_{min} the remaining capacity is sufficient to maintain an adequate response to short-term Δf. → Switching from normal operation mode (response to normal frequency deviation $\Delta f(t)$) to reserve operation mode (response to frequency deviation by following the «zero-mean» frequency).

$$\mathrm{DF}_{\mathrm{zero-mean}}(\mathrm{t}) = \mathrm{Df}(\mathrm{t}) - \frac{1}{\mathrm{t_{FAT}}} \sum_{\mathrm{i}=0}^{\mathrm{t_{FAT}}-1} \mathrm{D}f(\mathrm{t}-\mathrm{i})$$

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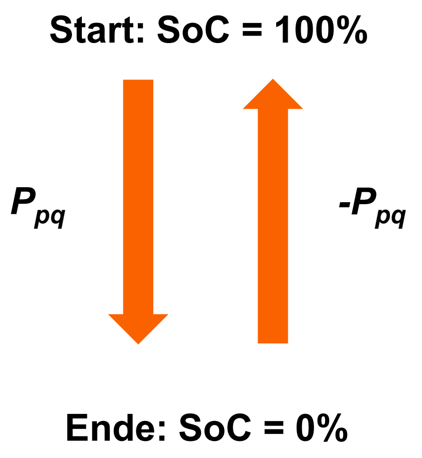
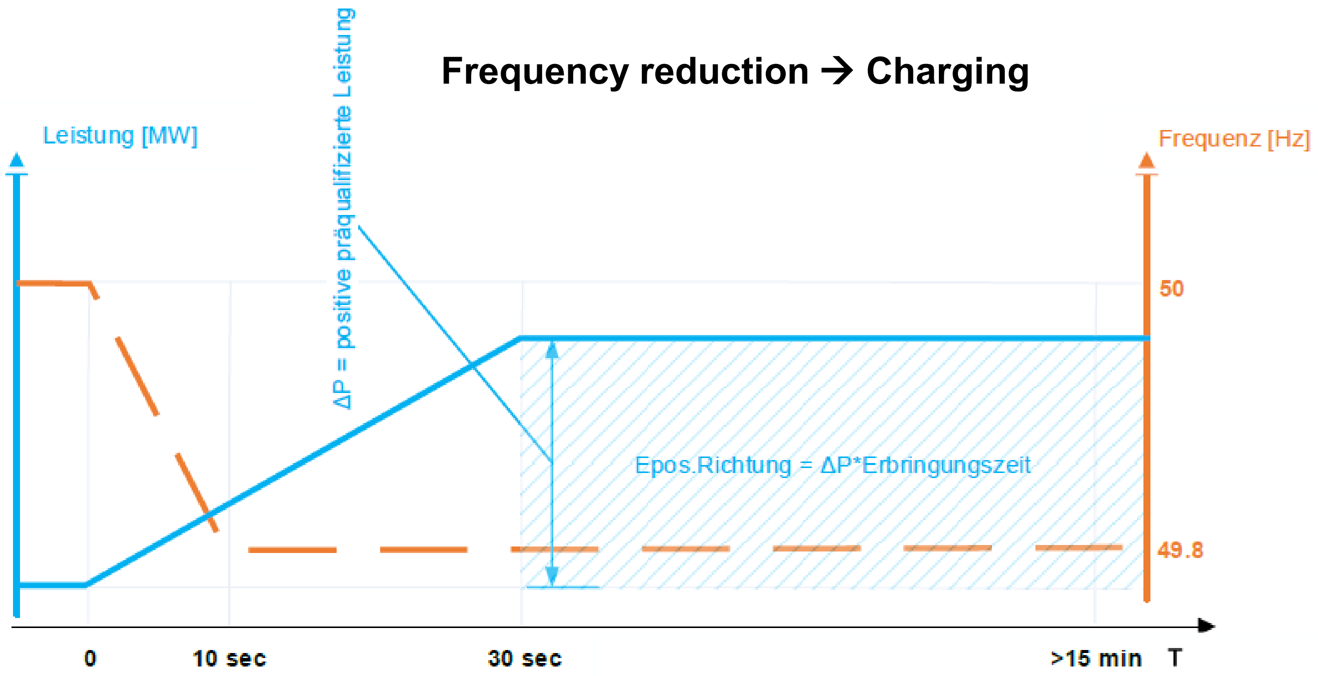
Determination of the usable energy storage capacity

Each LER unit must prove their actual usable energy storage capacity via a dedicated test





$$E_{pos.direction}\ [MWh] = P_{PQ.pos}[MW] * DeliveryTime[h]$$

$$E_{neg.direction}\ [MWh] = P_{PQ.neg}[MW] * DeliveryTime[h]$$

The usable energy storage capacity is calculated as:

$$E[MWh] = mean(E_{pos.direction}, E_{neg.direction})$$

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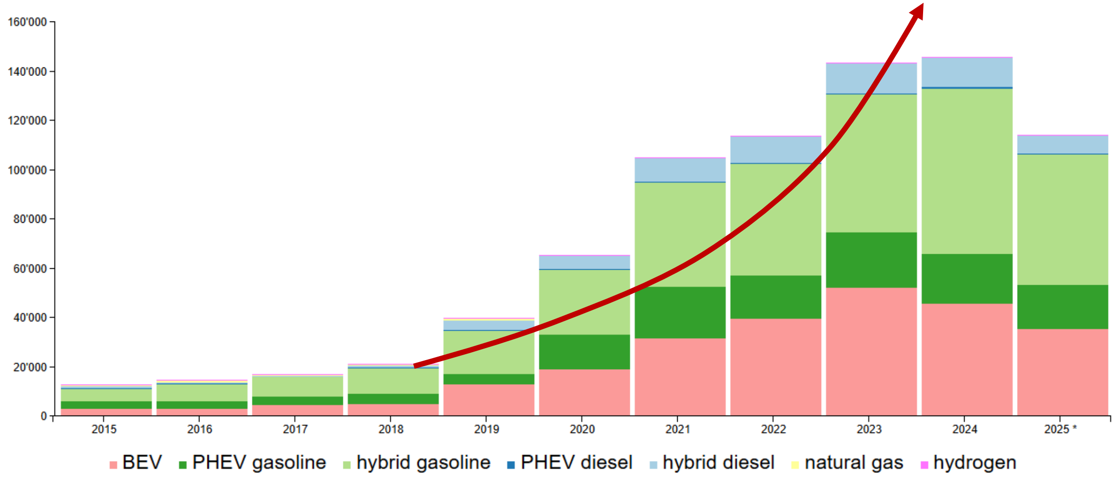
Electrification of the urban transport: increasing EV trends in CH

Grid services: from seconds to several hours

Shares of alternative drive systems and energy-efficient vehicles in new registrations in Switzerland
*Last update of the data: August 2025



Source: Bundesamt für Energie (Key figures new cars and charging infrastructure (admin.ch))

Growth forecasts towards 2050 show a high potential for a proactive grid integration

«In the transport sector, electricity consumption will be more than 5 times higher in 2050 than it is today, considering a total of around 3.6 million battery-powered passenger cars»

This corresponds to a total of:

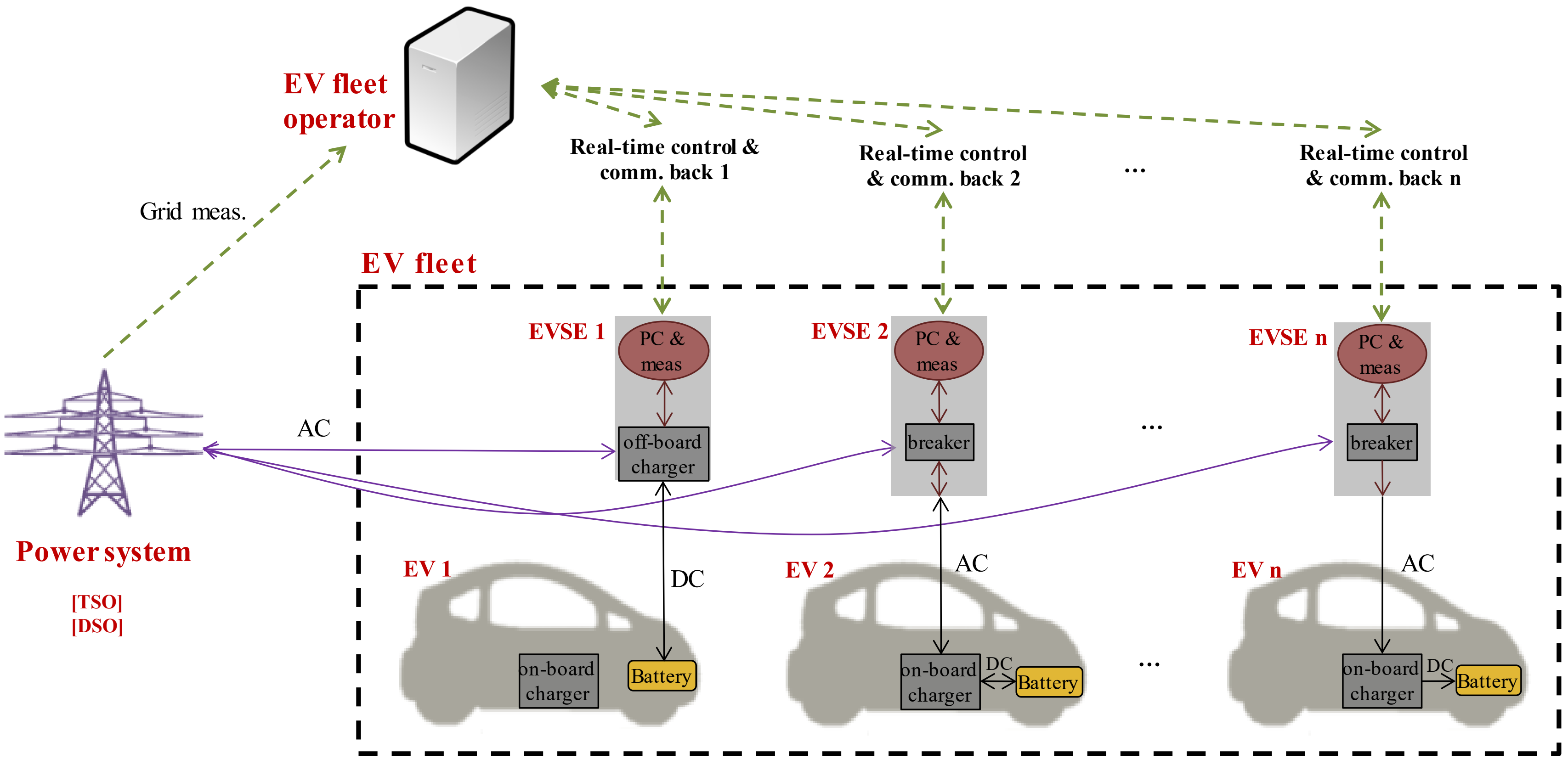
- ca. 7 GW of controllable power capacity (charging stations)
- ca. 144 GWh of cumulative energy storage capacity (batteries)

Source: Bundesamt für Energie (Energy Perspectives 2050+ (admin.ch))

Source: Energy Science Center - Swiss Federal Institute of Technology Zurich (Report_V2G_Study-3.pdf (swiss-emobility.ch))

Aggregation of EVs

Grid services: from seconds to several hours



To enable EV controllability and flexibility trading:

- Platforms for hardware and software deployment
- Actors involvement
- Market framework

Source: Zecchino A., Electric vehicles in the Nordic countries: Control strategies for coordinated grid services, PhD_Thesis_Antonio_Zecchino.pdf

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Aggregation of EVs for the provision of ancillary services in CH

Swissgrid has engaged to enable a fleet of aggregated EVs to participate to the ancillary service markets

Between 2022 and 2023 Swissgrid has been engaged on pilot projects with industrial partners with the goal of:

- Identification of technical challenges related to the provision of FCR, aFRR and mFRR from EVs; a pool vof EVs has dynamic properties (e.g., aggregated fleet power and energy capacity), which must be robustly considered by the technical and commercial aggregator;
- Definition of specific requirements for the prequalification to FCR, aFRR and mFRR and outline of guidelines for market operators;
- Operationalization and commercialization of aggregated EVs as ancillary service providers.

Publication of guidelines to for the prequalification of EVs on 2nd October '23
https://www.swissgrid.ch/content/dam/swissgrid/customers/topics/ancillary-services/prequalification/2/Richtlinien-Praequalifikation-e-Autos-de.pdf

First prequalification of an EV fleet for the provision of aFRR & mFRR in January 2024
Swissgrid zertifiziert die CKW Smart Charging Lösung

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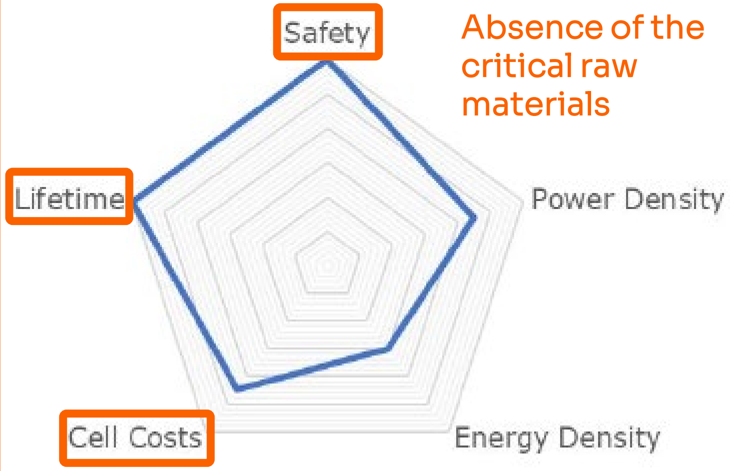
Li-ion battery cell technologies

Li-ion cell technologies are today the more suitable for BESSs than other technologies (e.g., lead-acid) because of their high energy density, long cycle life, safety, and ability to be charged/discharged repeatedly. As of today, the preferred battery cell technology for utility-scale BESS is Lithium Iron Phosphate (LFP).

Utility-scale Li-ion BESS

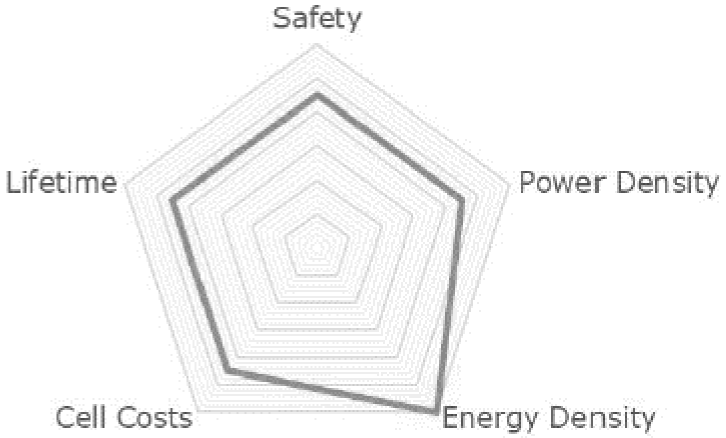
LFP
Lithium Iron Phosphate



Absence of the critical raw materials

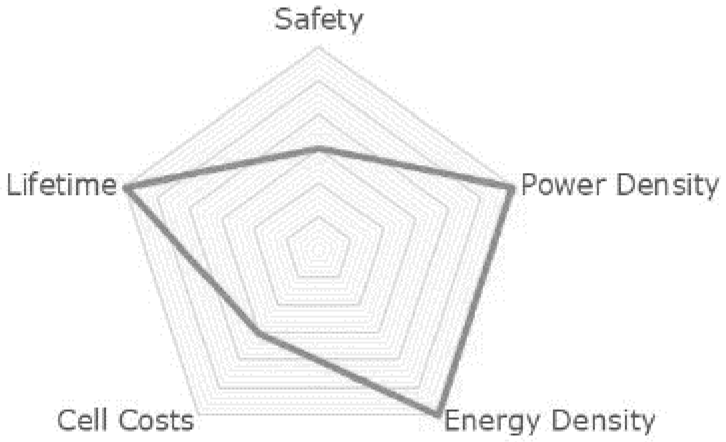
Best fit BESS and Electric **Vehicles**, excellent safety properties, long cycle life, chemical stability, high discharge rates, acceptable cost

Li-NMC
Nickel Manganese Cobalt



Best fit for **Electric Vehicles**, high energy density and low weight. Combination of nickel and manganese eliminates disadvantage of each material

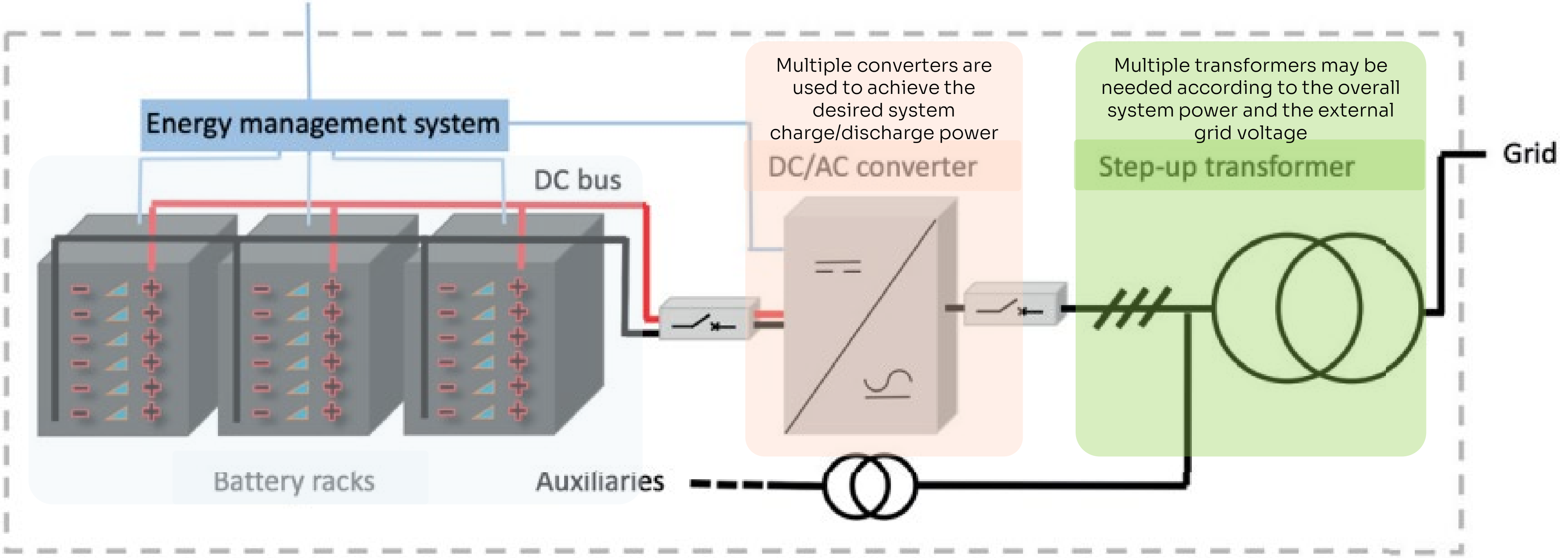
Li-NCA
Nickel Cobalt Aluminium



Best fit for **mobile devices**, with fast charging times and high energy density and low weight

Key components of a utility-scale Li-ion BESS

Overview of key elements of a BESS



Adapted from: Namor E., Advanced models and algorithms to provide multiple grid services with battery storage systems, PhD_Thesis_Emil_Namor_EPFL.pdf

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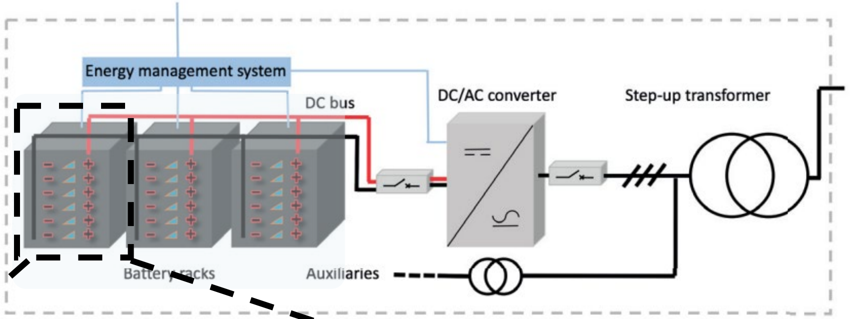
Key components of a utility-scale Li-ion BESS

Overview of key elements of a BESS

BMS = Battery Management System

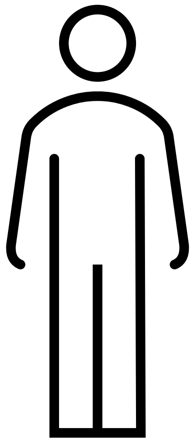


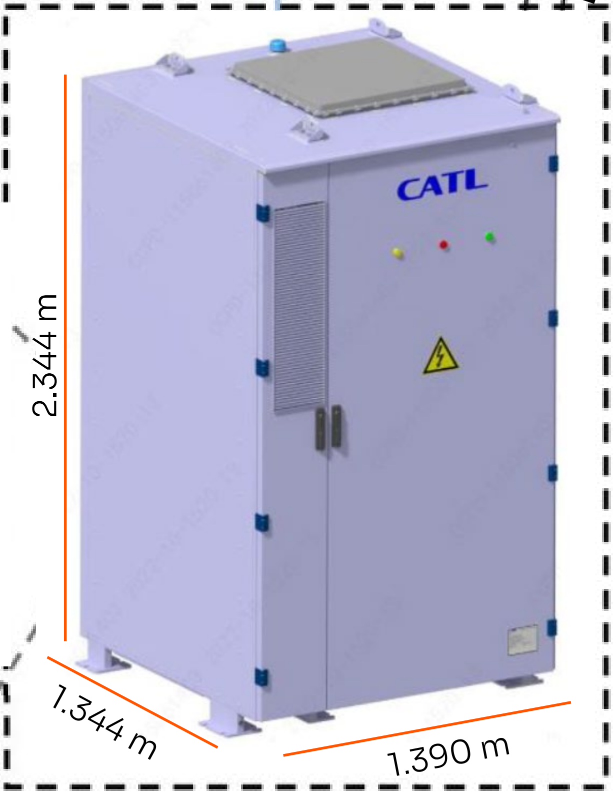
Example:
1p52s (52 cells)
47.424 kWh
166.4 V
...
Module BMS

Example:
LFP Li-ion
285 Ah
3.2 V
...

Li-ion cell

Battery module





Example:
CATL EnerOne+
8 modules (416 cells)
0.3794 MWh
1331.2 V
...

Inside each cabinet:
- 8x modules
- Liquid cooling sys.
- Fire suppr. sys.
- Rack BMS

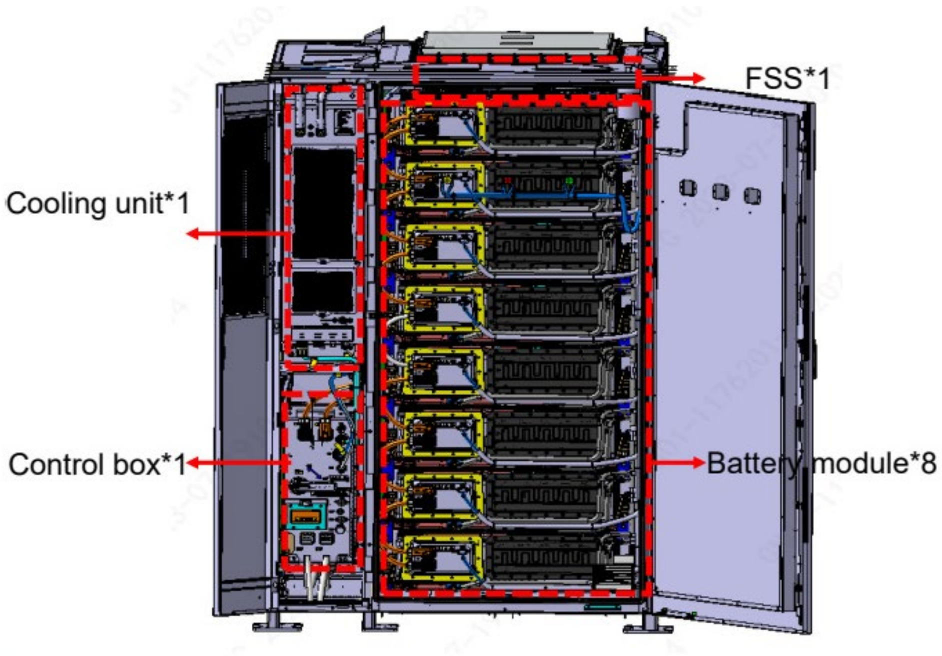
x96 = 36 MWh
Beskar Valkeakoski (FIN) BESS

Battery rack

Deep dive into one BESS rack cabinet

One single rack can be enclosed within a unitary system (cabinet), suitable for outdoor installations

Example:
CATL EnerOne+
8 modules
0.3794 MWh
1331.2 V
...
Rack BMS



Each cabinet includes:
- 8 battery modules
- Liquid cooling system
- Fire suppression system (FSS)
- Control box (Rack BMS)

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Deep dive into one BESS container (DC block)

A number of racks can be enclosed in a single 20 ft. container

x10

Example:
CATL
EnerC
10 racks
10x8 modules
3.794 MWh
1331.2 Vdc
...
10 Rack BMS

Each container includes:
- 10 battery racks
- Liquid cooling system
- Fire suppression system (FSS)
- Control boxes (incl. 10 Rack BMS)

Note: Newest containerized products claim energy storage up to **6 MWh**, thanks to layout optimization and more performing cells (e.g., CATL EnerS)

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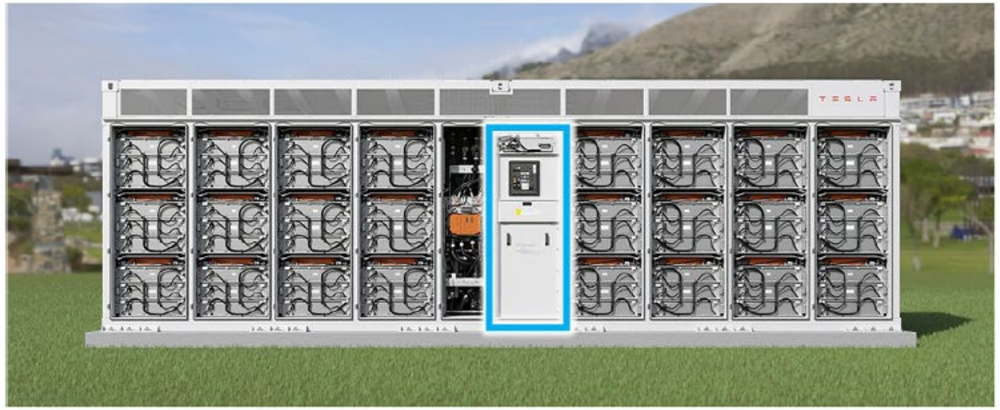
Deep dive into one BESS container (AC block)

Inside the container, in addition to battery modules, the power conversion units are installed too

Example:
TESLA
Megapack 2 XL
3*8 racks
3*3*8 modules
3.916 MWh
480 Vac
2400 kVA (2h)
1320 kVA (4h)
...
10 Rack BMS



Each container includes:
- 3*8 battery racks
- 3*8 power conversion units
- Liquid cooling system
- Fire suppression system (FSS)
- Control boxes (incl. 3*8 Rack BMS)

Agenda

Part I

1. Context
2. Energy storage for grid applications
   i. Power system need for flexibility and grid services
   ii. Prequalification of energy storage units for the participation to the Swiss ancillary service markets
   iii. Aggregation of distributed EVs for ancillary service provision

Part II

3. Key components of a stand-alone battery energy storage system (BESS)
4. Key steps to develop a utility-scale BESS project
5. What is beyond Li-ion batteries? An overview of Medium/Long Duration Energy Storage technologies

Key steps to develop a utility-scale BESS project

RtB
Ready-to-Build

COD
Commercial Operation Date

Development → Pre-construction Planning → Construction & Commissioning

Development

- Identification of business model based on market conditions, regulatory frameworks, CAPEX/OPEX, revenues, COD,..
- Identification of suitable land: flat, given size, not subject to high geotechnical or hydrological risks, not too far from grid access point, …
- Land securing
- Urbanism applications, building permit, appeals clearing
- Grid connection request

Pre-construction Planning

- Detailed structuring of project management organization
- Appointment of health and safety coordinator
- Detailed electrical and mechanical engineering design
- Preparation and launch of tender process for the procurement of the overall system with all detailed technical specifications
- Selection of contractors and contract negotiations, based on technical and commercial conditions, quality standards, tracked records, …

Construction & Commissioning

- Civil works
- FAT of major equipment
- Major equipment shipment and installation
- Site energization
- SAT and commissioning tests
- IT/OT integration, flexibility pool integration and market integration
- Commercial operation

Advanced analytics and modelling needed to extract the full real value potential of the asset

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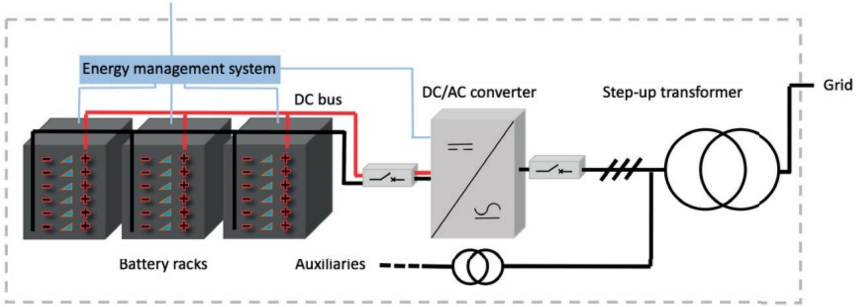
Key players needed for BESS equipment procurement



Providers of BESS equipment can provide one of the following components, or a cluster of them:

a) Procurement of BESS equipment up to medium voltage AC:
   i. DC solution (Battery racks)
   ii. DC/AC conversion
   iii. System integration
   iv. Medium voltage equipment (trafo + switchgears and protection)

b) High voltage equipment (trafo + switchgears and protections)

c) Balance of System (auxiliaries, lighting, fire suppression systems, …)

d) Monitoring and Communication Systems (Sensors, meters and comm. infrastructure)

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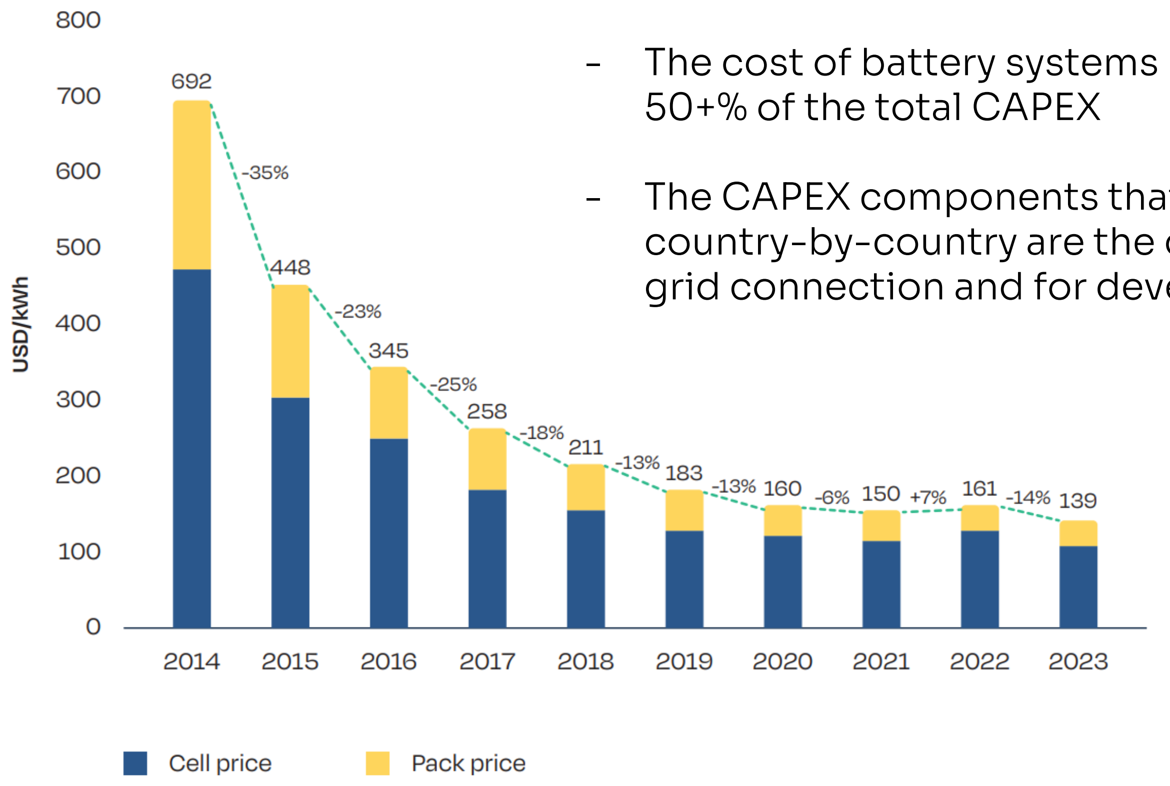
BESS CAPEX trends

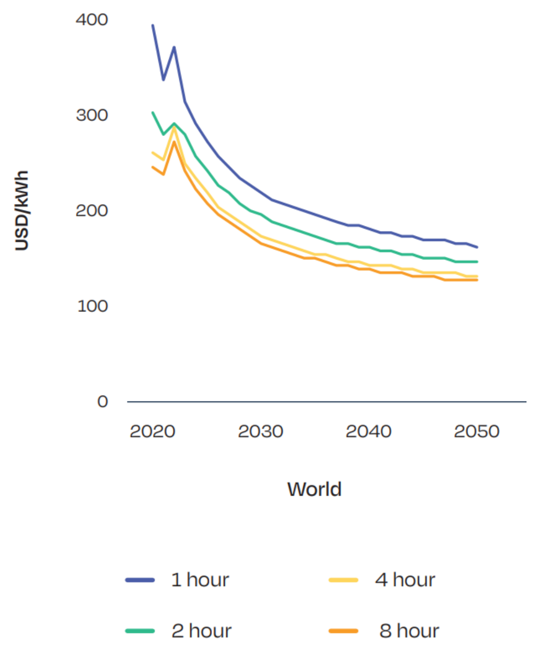
The cost of battery cells is expected to continue dropping in the coming years



- The cost of battery systems represent 50+% of the total CAPEX

- The CAPEX components that vary country-by-country are the costs for grid connection and for development.

Expected trend of total CAPEX for a BESS



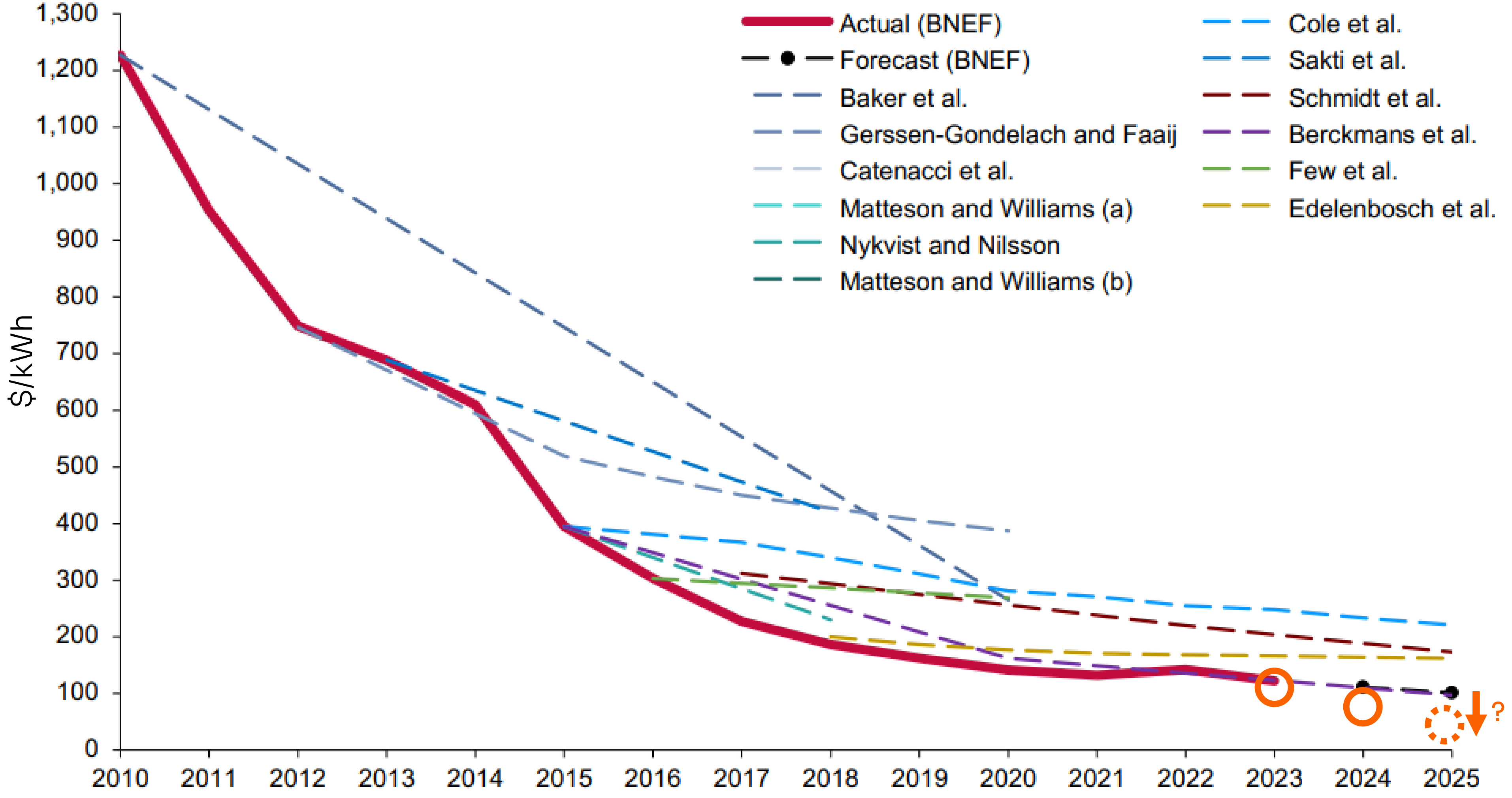
Source: SolarPower Europe (European Market Outlook for Battery Storage 2024-2028)

Expected drop of total CAPEX in 10 years: **ca. 20%**

Could this cost drop happen faster?

Overestimation of forecasted Li-ion battery cells costs?

Realized actual cell costs ($/kWh) have always been lower than what was forecasted in the previous years



X-Change: Batteries — **The Battery Domino Effect**, RMI, based on data from Mauler et al. and BNEF

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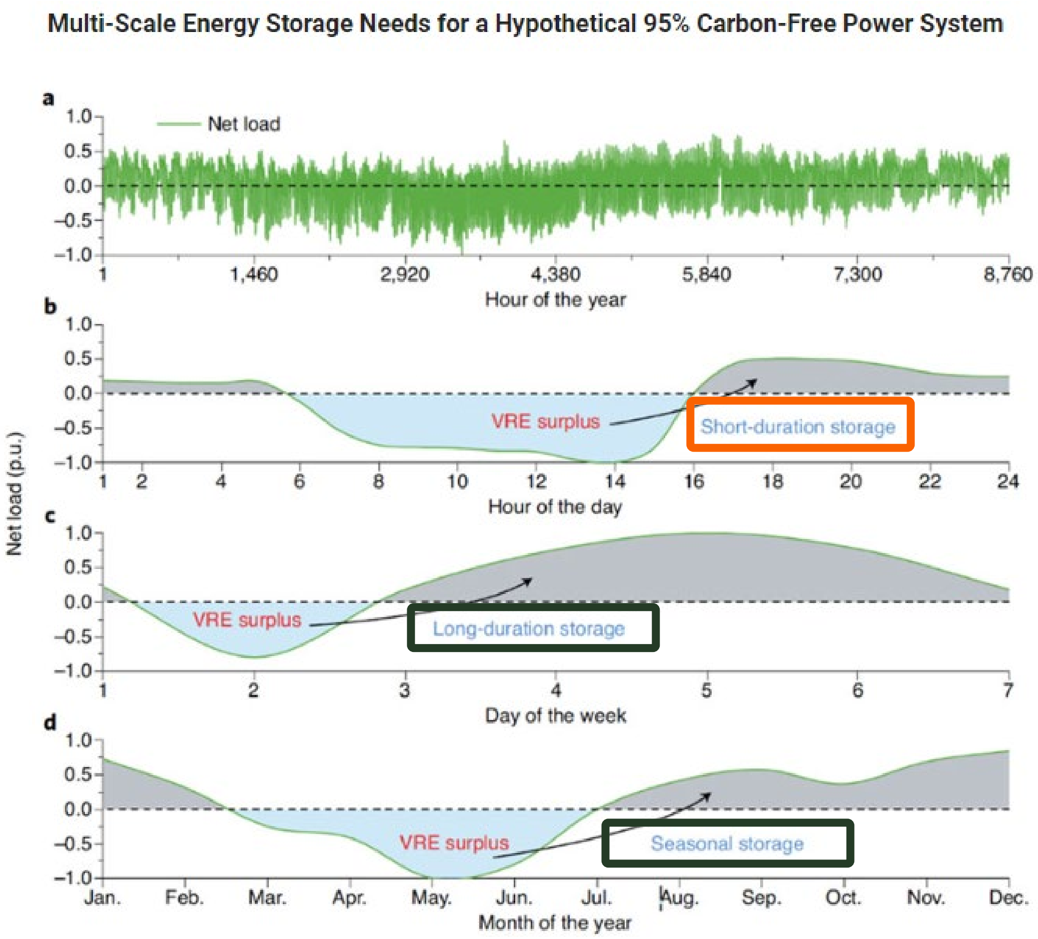
The system needs also Medium/Long Duration Flexibility

Different duration storage is needed for the energy transition: from several hours to several months



Utility-scale Li-ion BESS
- balancing ancillary serv.
- wholesale arbitrage

What is beyond Li-ion batteries?

Flexibility timescale	Very short term (sub-seconds to minutes)	Short term (minutes to hours)	Medium term (hours to days)	Long term (days to months)	Very long terms (months to years)
Challenges	Ensuring system stability by keeping voltage and frequency in required range	Meeting frequent, rapid, and nonpredictable changes in electricity supply and/or demand	Determining operation schedule of generation capacity to balance electricity supply and/or demand	Addressing longer periods of surplus or deficit in electricity generation	Balancing seasonal and interannual availability of generation resources with electricity demand
System relevance	Dynamic system stability and frequency control	Real-time balancing	Hour-ahead and day-ahead planning	Generation adequacy guarantee	Power system planning

Source: NREL (Researchers Take a Practical Look Beyond Short-Term Energy Storage | News | NREL)
*VRE: variable renewable energy

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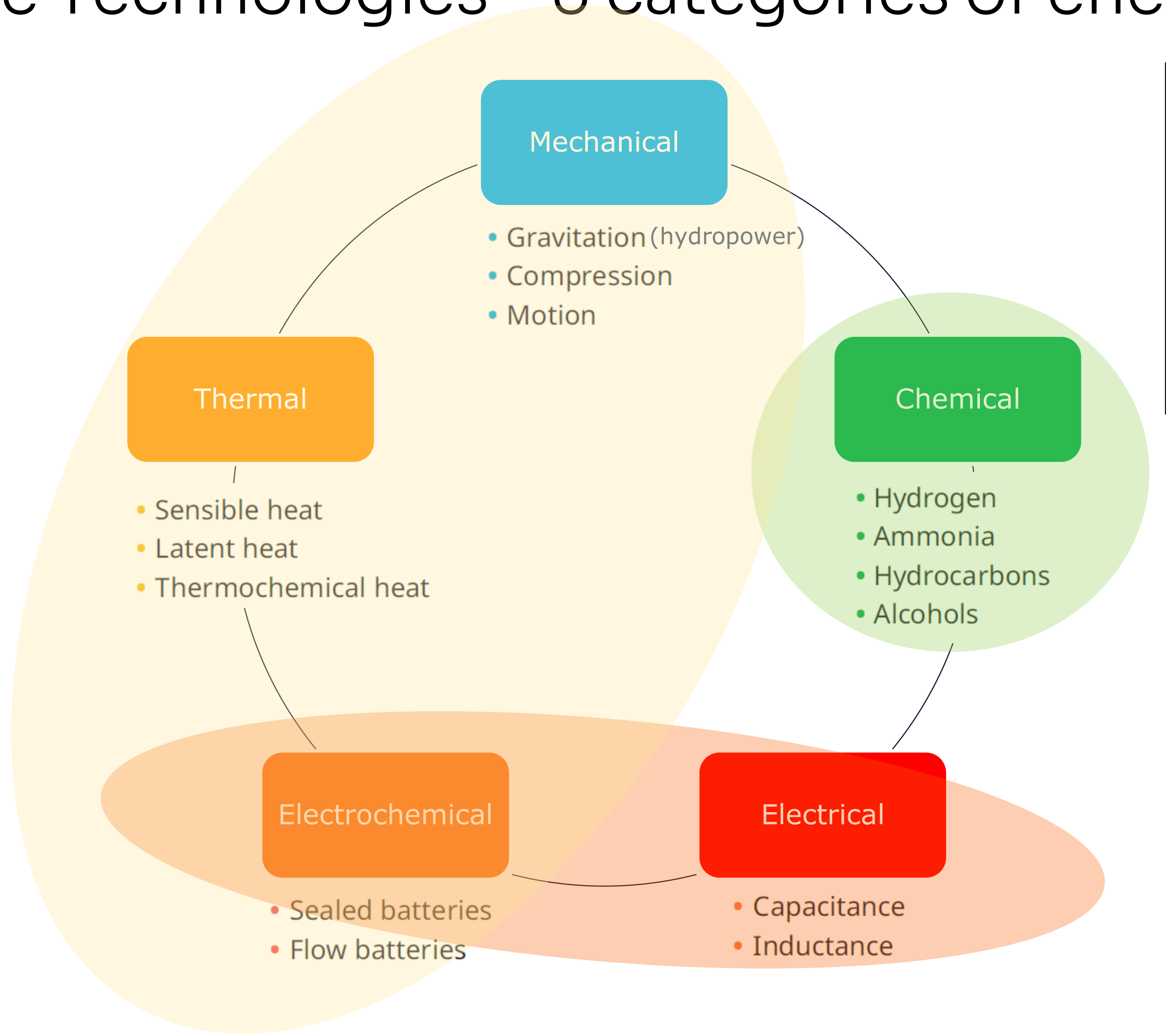
Storage Technologies - 5 categories of energy storage



Short duration: < 4(8) h
(SDES)

Medium duration: 4(8) h < x < 1 week
(MDES)

Long duration: > 1 week
(LDES)

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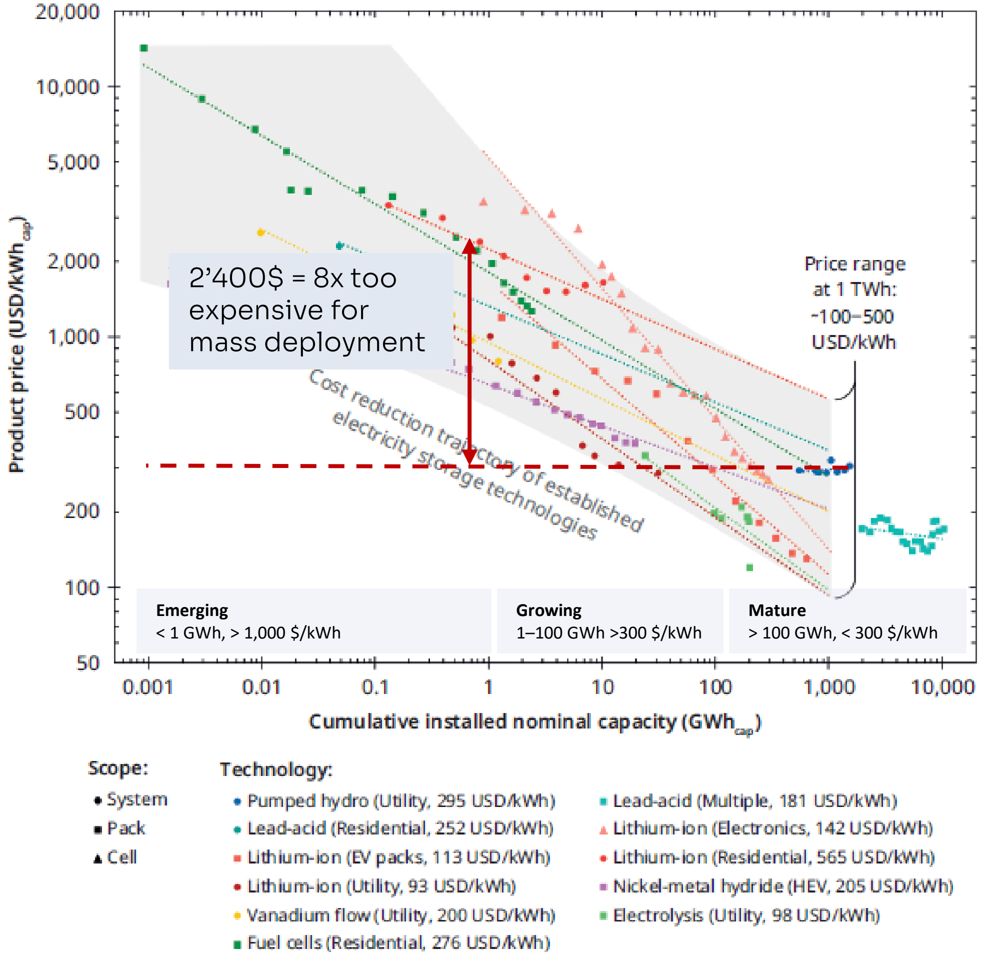
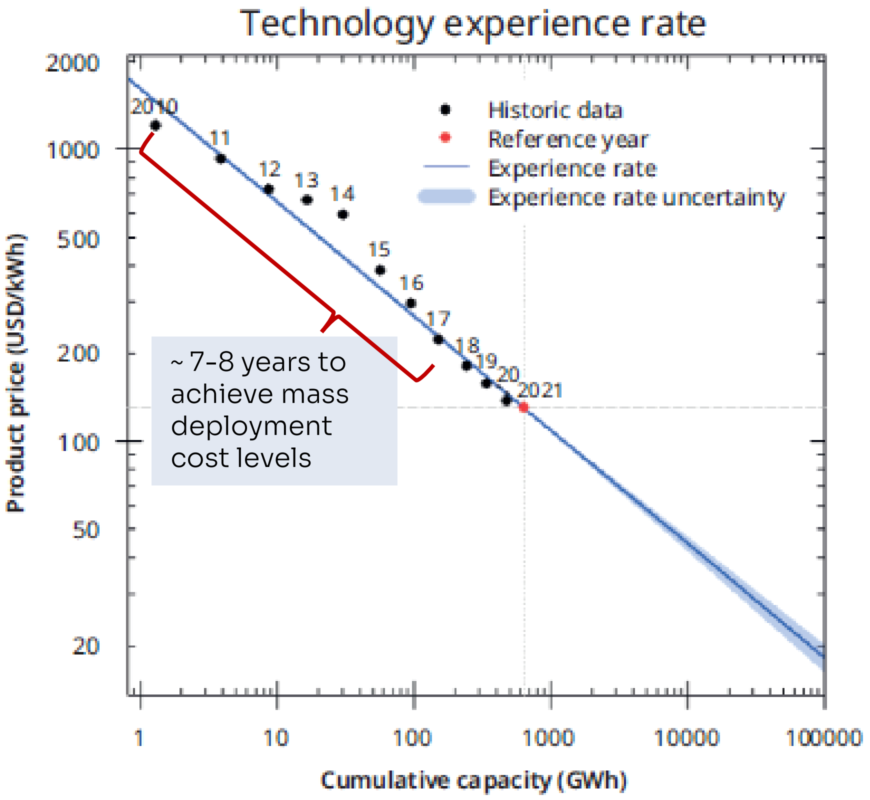
Expected trend of the costs of new storage technologies

Energy storage cost reduction as a direct consequence of the maturity level (i.e., on cumulative installed capacity)



The cost descending trend for a given storage technology is confirmed over time

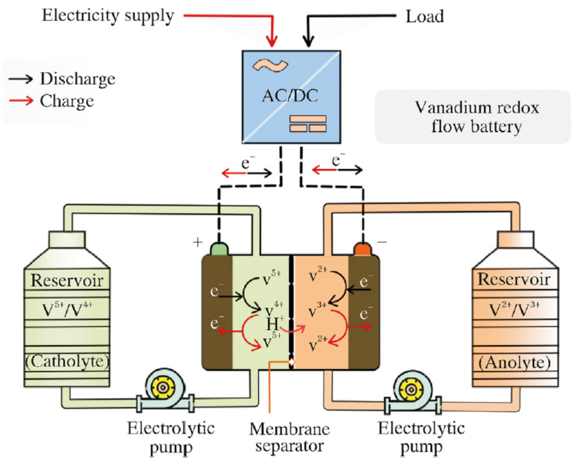


This is real data based on historical prices and capacity deployment.

Source: Monetizing Energy Storage - A Toolkit to Assess Future Cost and Value, Oliver Schmidt and Iain Staffell, Oxford University Press, September 2023, DOI: 10.1093/oso/9780192888174.001.0001

3 examples of prominent Medium Duration En. Storage (MDES)

Flow battery (even beyond vanadium, e.g., organic-based [CMBlu])



During the charging cycle, vanadium ions accept electrons at the anode (V3+ to V2+) and deposit electrons at the cathode (V4+ to V5+). These reactions are reversed during the discharging cycle.
RTE = ~68%; cost = 800-1'300 $/kWh
duration = 8-50 h

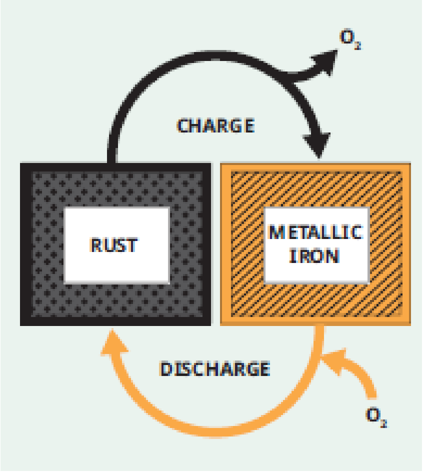
RTE = Round Trip Efficiency

Source: J. Mitali, S. Dhinakaran, A.A. Mohamad, **Energy storage systems: a review**, Energy Storage and Saving, Volume 1, Issue 3, 2022, Pages 166-216, ISSN 2772-6835, https://doi.org/10.1016/j.enss.2022.07.002.

Latent heat battery (e.g., graphite-based [E2S Power])

Electricity is used to heat a transfer fluid or an electrical heater. This transfers the heat to a storage material, for example a mixture of concrete and steel, or graphite. When electricity is needed, the transfer fluid takes up the heat stored in the material and drives a turbine. Possible integration with industrial processes.
RTE = ~44%; cost = 1'000-1'300 $/kWh
duration = 25-100 h

Metal-air battery ([Form Energy])



Metal-air batteries are based on the electrochemical process of corrosion, also called 'rusting' for iron. In iron-air batteries, the battery uses oxygen from the air to convert iron metal to rust, which releases electricity (discharging). The application of an electrical current converts the rust back to iron and the battery releases oxygen (charging).
RTE = ~55%; cost = 1'700-2'400 $/kWh
duration = 50-168 h

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Recent news on MDES

NEWS

Developer in Ireland submits application for Europe's first multi-day iron-air battery project

By Kit Million Ross

October 1, 2024

Europe | Grid Scale | Technology, Business

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Render of the proposed project site. Image: FuturEnergy Ireland

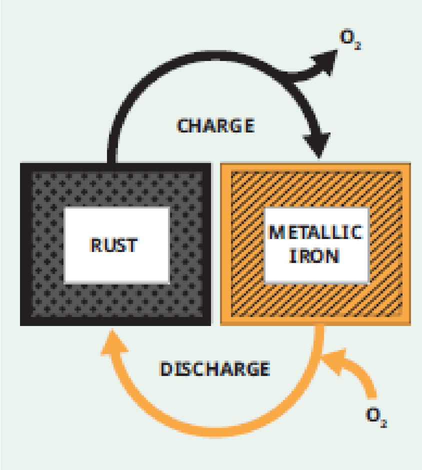
Developer FuturEnergy Ireland has announced its intentions to build Europe's first iron-air battery energy storage system (BESS).

The company, a joint venture between two state-owned groups, forestry business Coillte and electricity generation, transmission and distribution business ESB, has submitted a planning application for the proposed Ballynahone Energy Storage project to Donegal County Council. If approved, the project will be located next to Trillick Substation, near the town of Buncrana in County Donegal

...intention of developing the first large-scale project in Europe based on iron-air technology from Form Energy (10MW/1GWh → **100 hours!**)

Developer in Ireland submits application for Europe's first multi-day iron-air battery project - Energy-Storage.News

Metal-air battery ([Form Energy])



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RTE = ~55%; cost = 1'700-2'400 $/kWh
duration = 50-168 h

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Recent news on UK LDES eligibility assessment (Ofgem)

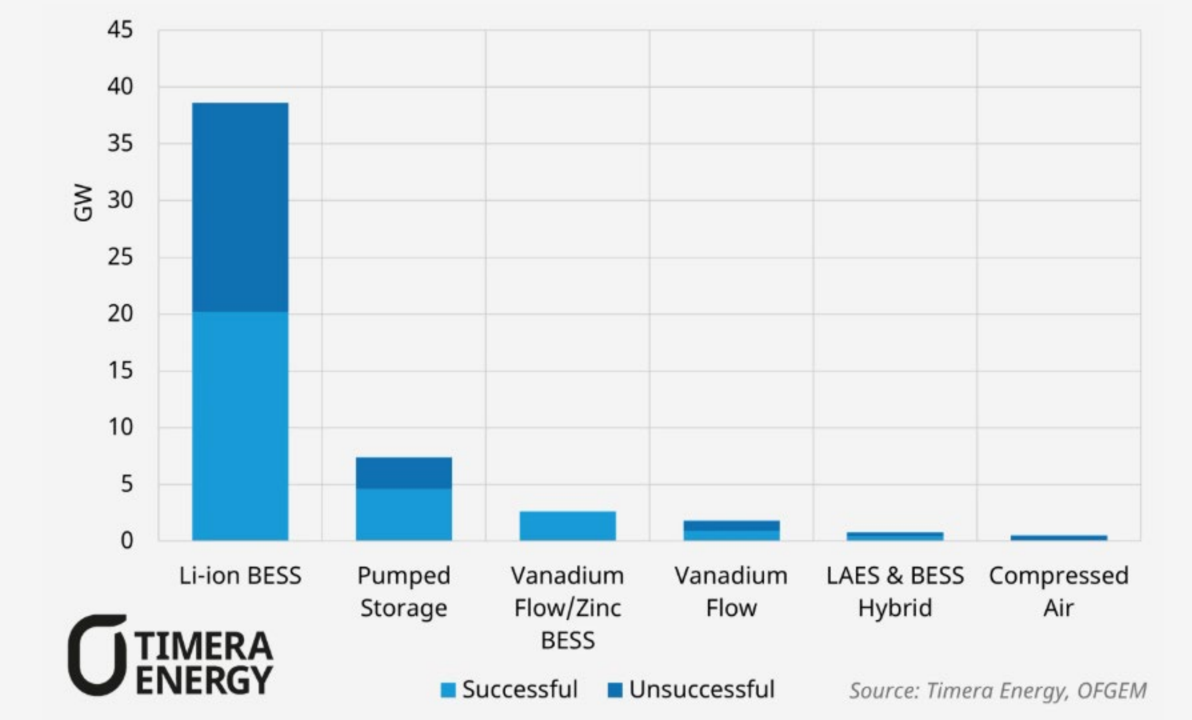
As per Ofgem, LDES must have duration > 8h

Storage assets eligible to the UK Ofgem's subsidy regime must be able to retain capacity (MW) and the duration (MWh) for the entire Cap&Floor subsidy period of 25 years → the Li-ion assets need to be oversized at the beginning of life or repowered at least once.

171 Projects applied; 77 met the eligibility criteria for a combined discharge capacity of 28.7 GW.

- Track 1: 71 proj for, tot. of 24.5 GW, by 2030
- Track 2: 6 proj for, tot. of 4.2 GW, by 2033

LDES Eligibility Assessment Outcome



Li-ion dominates in GB LDES eligibility outcome - Timera Energy

[Vanadium/Zinc Flow: 21 projects (tot: 3.5 GW, ca. 10%)]

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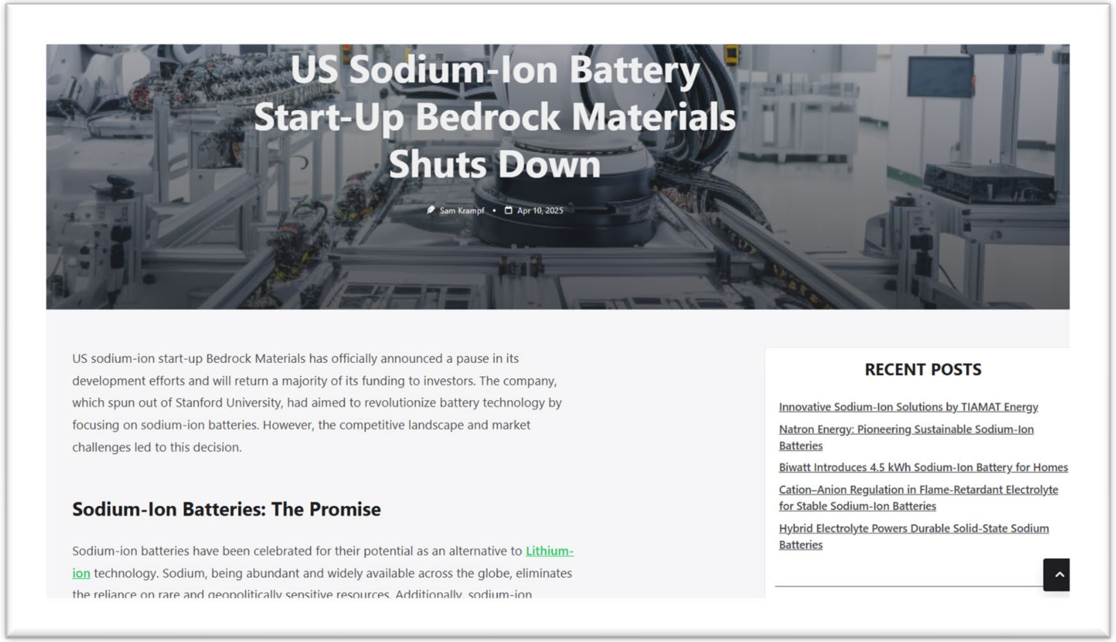
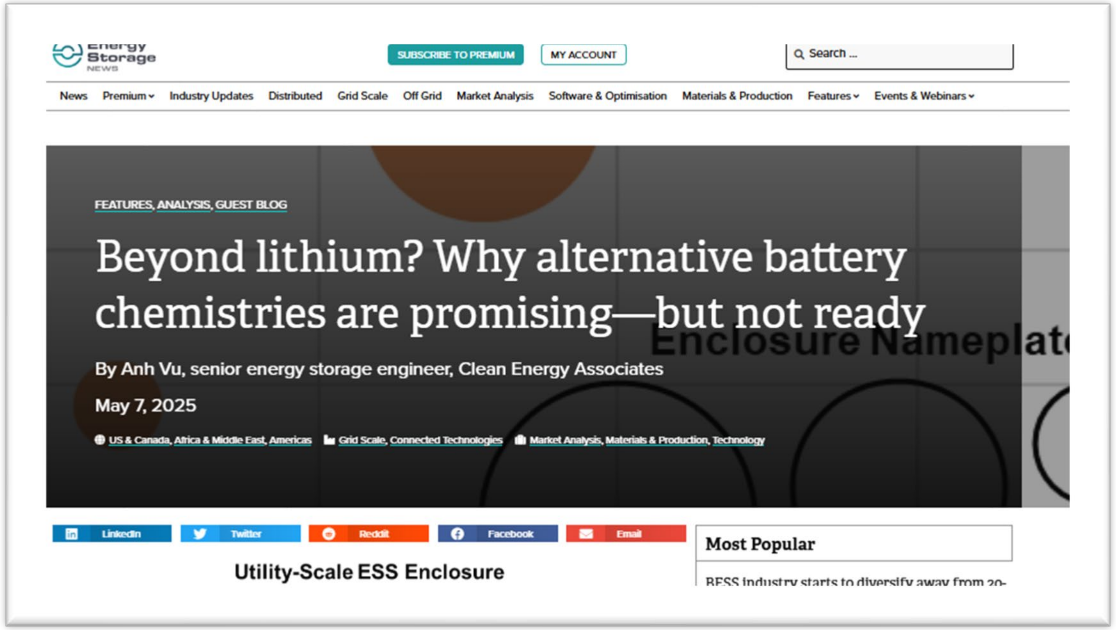
Recent news on Sodium-ion as alternative to Li-ion: alternative battery chemistries are promising—but not ready





[US Sodium-Ion Battery Start-Up Bedrock Materials Shuts Down - SodiumBatteryHub](#)

The continuous fall of Lithium prices makes the competition from alternative electrochemical technologies for short-term flexibility impossible

"Even companies that are actively investing in alternative chemistries often continue to deploy lithium-ion in the field"

[Beyond lithium: Alternative chemistries are promising, but not ready - Energy-Storage.News](#)

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Key Take-aways

- Modern power systems have increasing need for flexibility at different time-scales
- Today energy storage technologies play already an active role in enabling massive roll-out of renewables, among others, supporting the power systems by participating in the ancillary service markets
- Li-ion BESS is today the most attractive technology solution for the current market conditions. Further technological product development and cost reduction further lower market entry barriers
- What is beyond Lithium-ion cell-based BESS?
  - The continuous fall of Lithium prices makes the competition from Sodium-ion technologies for short-term flexibility impossible
  - Different flexible storage technologies are suitable for different services
  - Big uncertainty on the main key future technology that will succeed in the MDES/LDES space: key contending technologies appear to be redox flow batteries, latent heat storage, and novel metal-air batteries
  - Current overall maturity and cost levels are not yet attractive enough for commercial deployment of MDES/LDES technologies, unless suitable regulatory frameworks set the conditions in a market-based environment
  - Need for continuous collaboration of technology providers and utilities with research institutes, with grid and market operators, as well as with regulators and policy makers

Thank you!

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