



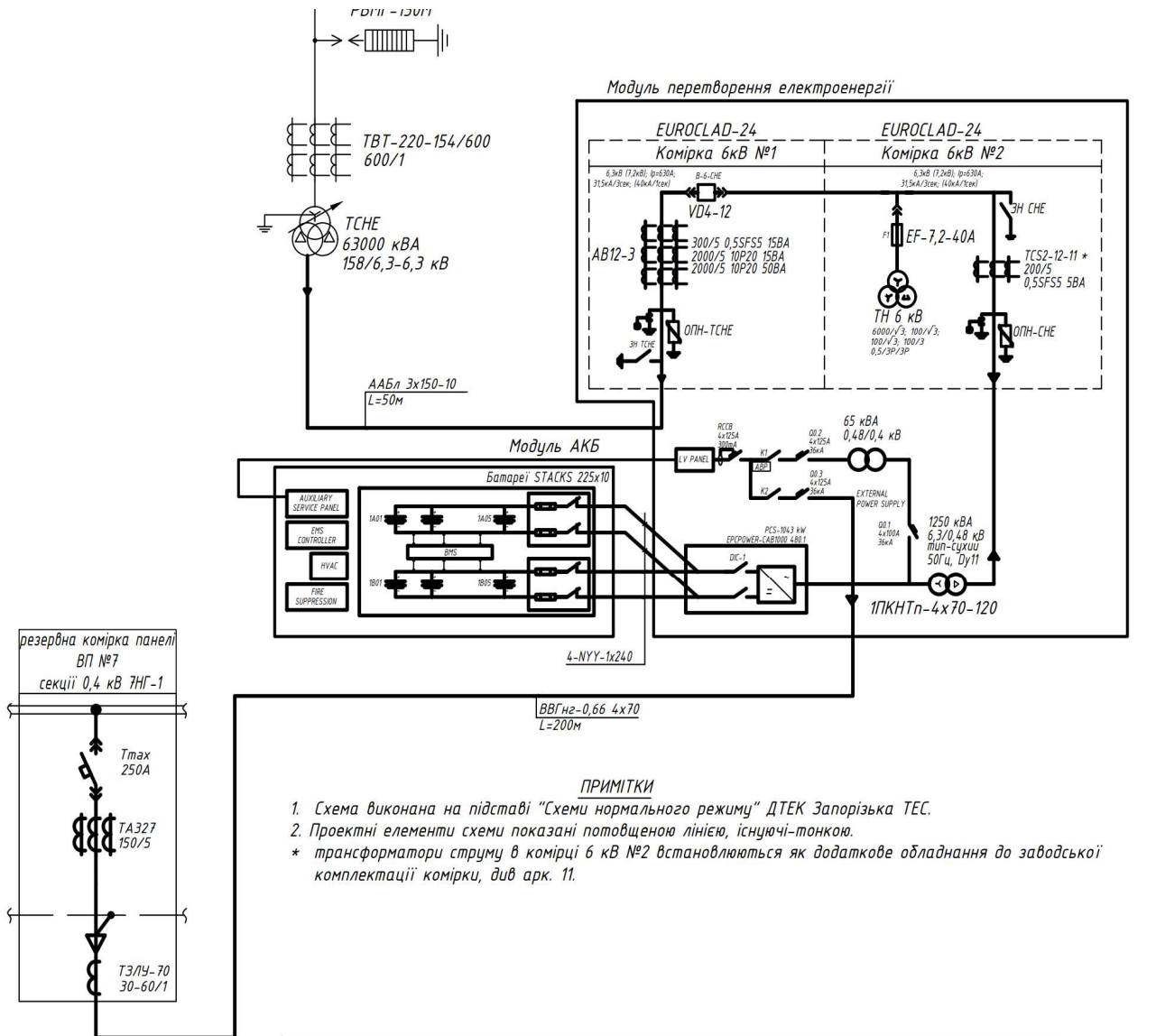
WORKSHOP ON THE ENERGY STORAGE TECHNOLOGIES: LESSONS LEARNED AND WAY AHEAD FOR GRID BALANCING

Energy Community 2023-10-14

Vadym Utkin, Energy Storage Lead, DTEK

D.TEK Energy
in action

DTEK ESS SLD and specs



ПРИМІТКИ

1. Схема виконана на підставі "Схеми нормального режиму" ДТЕК Запорізька ТЕС.
2. Проектні елементи схеми показані потовщеною лінією, існуючі – тонкою.

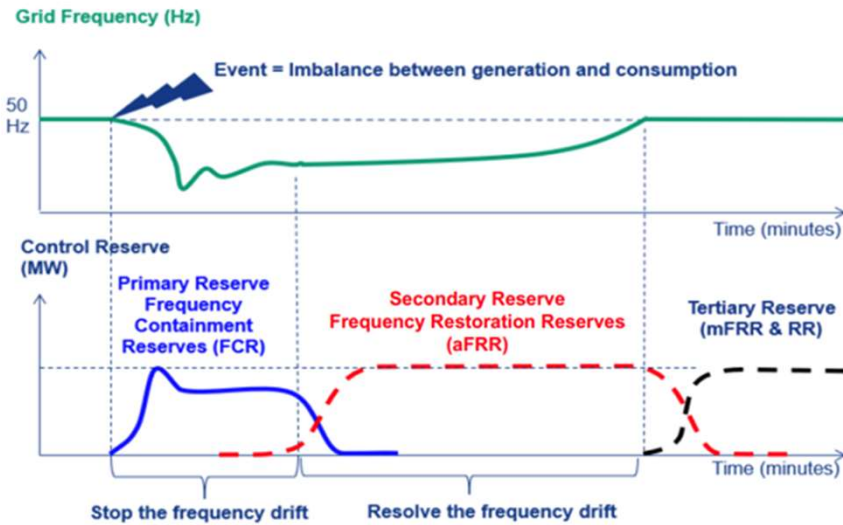
* трансформатори струму в комірці 6 кВ №2 встановлюються як додаткове обладнання до заводської комплектації комірки, див арк. 11.

ЕКЕУ.020-04.ЕТР				
1	-	Зам.	01-21	05.21

Нове будівництво системи накопичення електроенергії ДТЕК ЗАПОРІЗЬКА ТЕС на земельній ділянці 2312500000:11:032:0017 в Запорізькій області, Бунівська с/пгт, вул. Давидовська, 6

- Pmax = 1000 kW
- E = 2025 kWh
- C rate = 0.5
- LFP cells by CATL
- Stack and EMS designed by Powin Energy
- Power Plant Controller designed by Honeywell
- PCS – EPC Power CAB1000
- Air cooling
- Tender shortlist: Hengrui Technology Co Ltd (HRESYS), Narada Power Source, Storage Power Solutions Inc, BYD, Indrivetec AG, Honeywell, SAFT
- Contract signed July 2020
- Inverter energizing – 18:54 Mar 25th 2021
- Opening ceremony – May 20th 2021
- TSO market participation test – Sep 2nd 2021

Grid balancing: non-reactive (committed) balancing

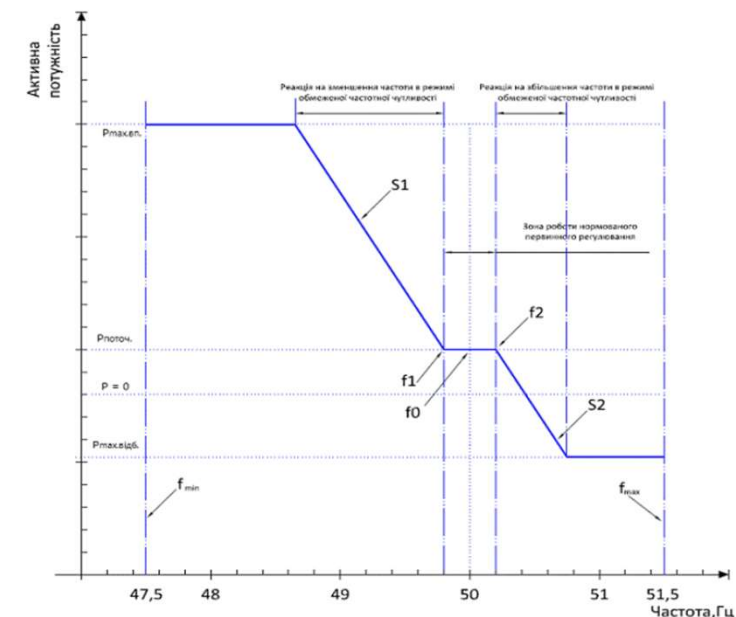


Ergebnisse

Lokaler Grenzpreis nach Produktzeitscheibe und Ländern

Land	Lokaler Grenzpreis (€/MW)					
	NEGPOS_00_04	NEGPOS_04_08	NEGPOS_08_12	NEGPOS_12_16	NEGPOS_16_20	NEGPOS_20_24
Belgien	415,2	415,2	415,2	415,2	415,2	415,2
Dänemark	78,8	102,6	74,9	137,72	75,6	54,4
Deutschland	78,8	102,6	74,9	137,72	75,6	54,4
Frankreich	6	4,48	24	24	21,45	12
Niederlande	78,8	102,6	74,9	137,72	77,777	54,4
Österreich	78,8	102,6	74,9	137,72	75,6	54,4
Schweiz	78,8	102,6	74,9	137,72	75,6	54,4
Slowenien	78,8	102,6	74,9	137,72	75,6	54,4
Tschechien	78,8	102,6	74,9	137,72	75,6	54,4

	Product	Demand, MW per hour	Price cap 2022/2023, UAH.	Gate closure time	Auction results	Cleared as
1	FCR±	135 (UA+MD)	1339,82	14:15 D-1	14:30	Pay as bid
2	aFRR±	50?	1339,82 + БР	14:15 D-1	14:30	Pay as bid
3	aFRR+	700	973.39 + БР	14:15 D-1	14:30	Pay as bid
4	aFRR-	421	366.43 + БР	14:15 D-1	14:30	Pay as bid
5	mFRR+	—	438.02 + БР	14:15 D-1	14:30	Pay as bid
6	mFRR-	—	164.89 + БР	14:15 D-1	14:30	Pay as bid
7	RR+	—	389,36	14:15 D-1	14:30	Pay as bid
8	RR-	—	146,57	14:15 D-1	14:30	Pay as bid
9	BM	—	—	-45 хв D-0	10 днів	Pay as cleared
10	DAM	—	2000/4000	12:0 D-1	12:30	Pay as cleared

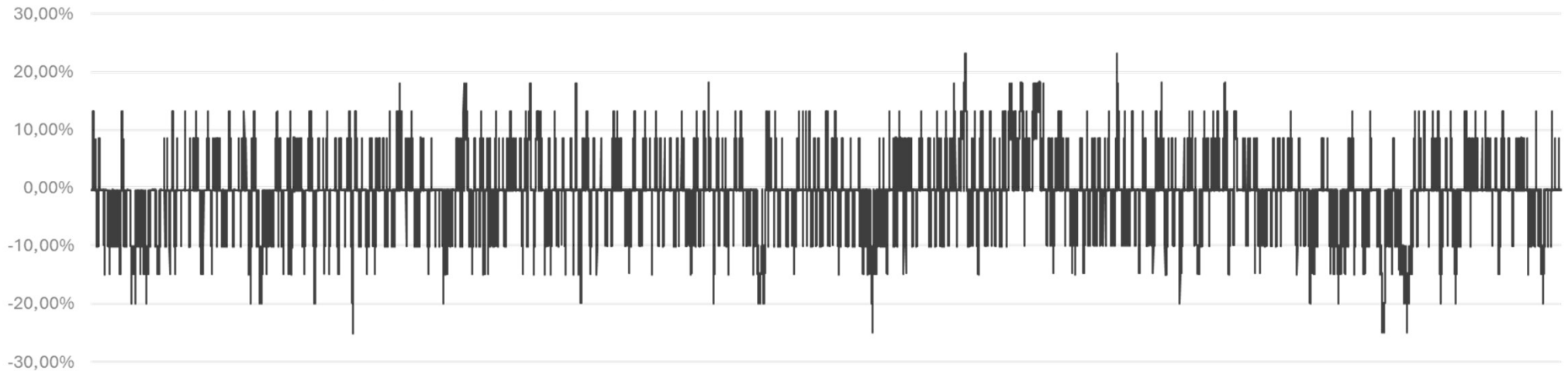


12 Dec 2022: one day of FCR delivered by ESS



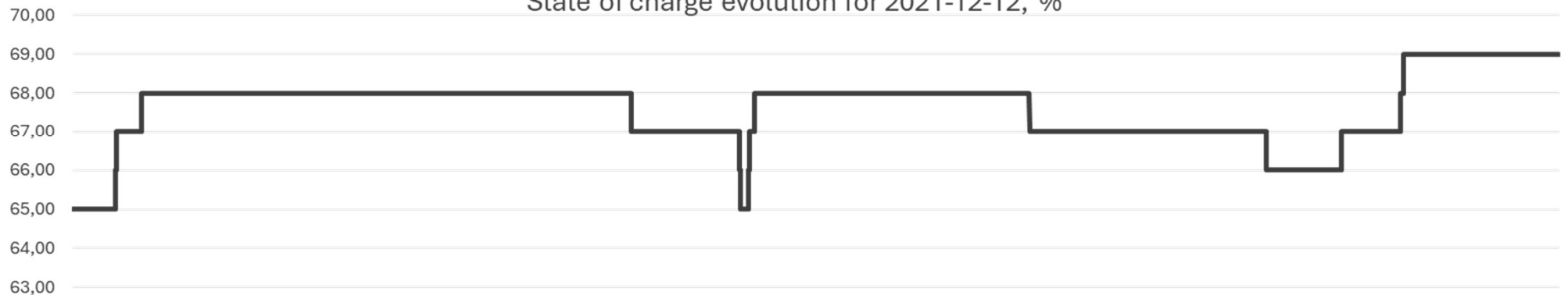
Power response stays within 30% limit of Pmax before synchronization with ENTSO-E. After 2022-03-16 volatility has increased (200 mHz, 100 mHz -> 15 min, 50 mHz ->20 min).

P, % of Pmax response to frequency deviations for 86 400 seconds of 2021-12-12. Pmax = 1000 kW



SOC management is a complex task, since the unique discharge profile of Li-ion and temperature sensitivity.

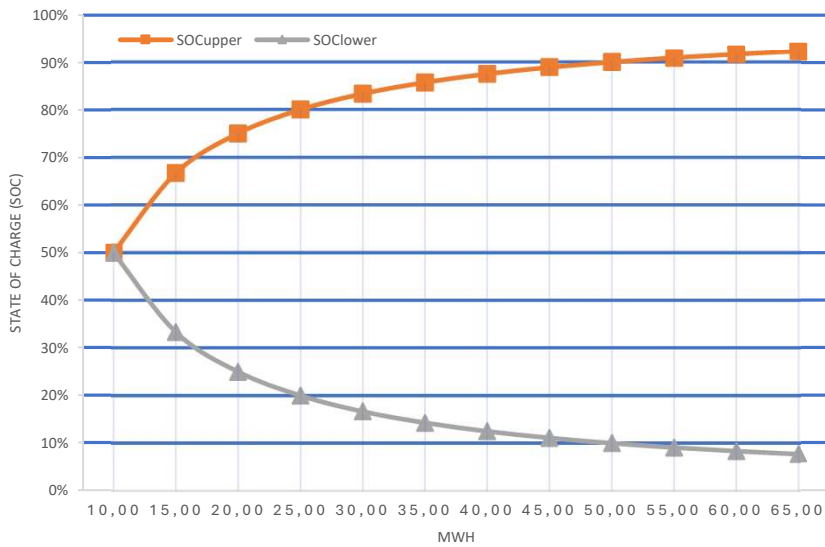
State of charge evolution for 2021-12-12, %



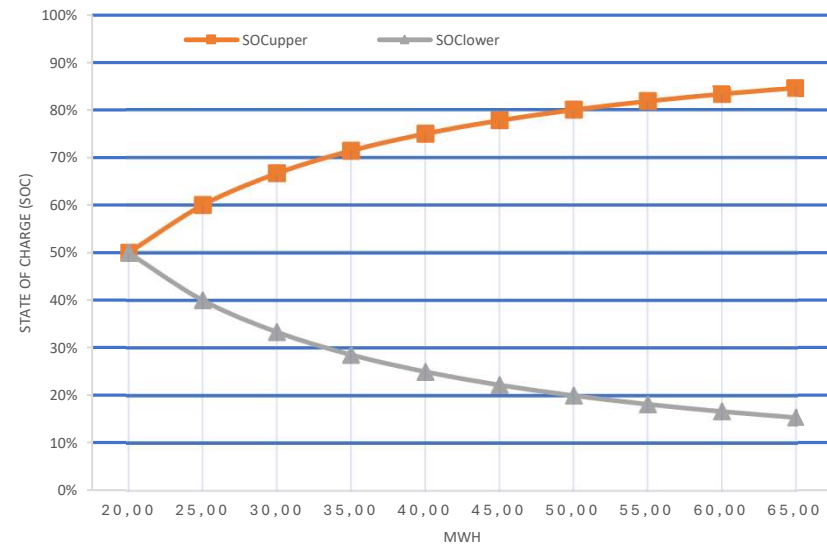
Safe permissible energy capacity for the frequency response



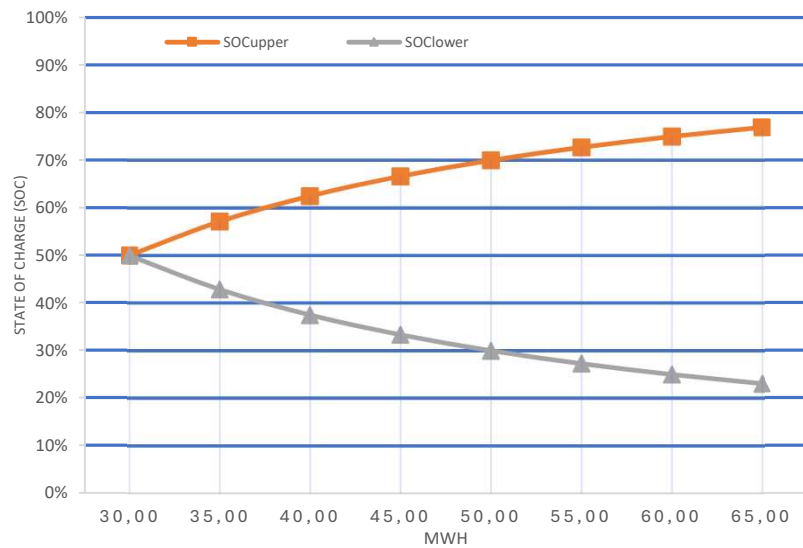
‘Safe’ energy capacity largely depends on market rules and FCR product design. Simulation for 20 MW FCR. This will also impact the business case through the CAPEX.



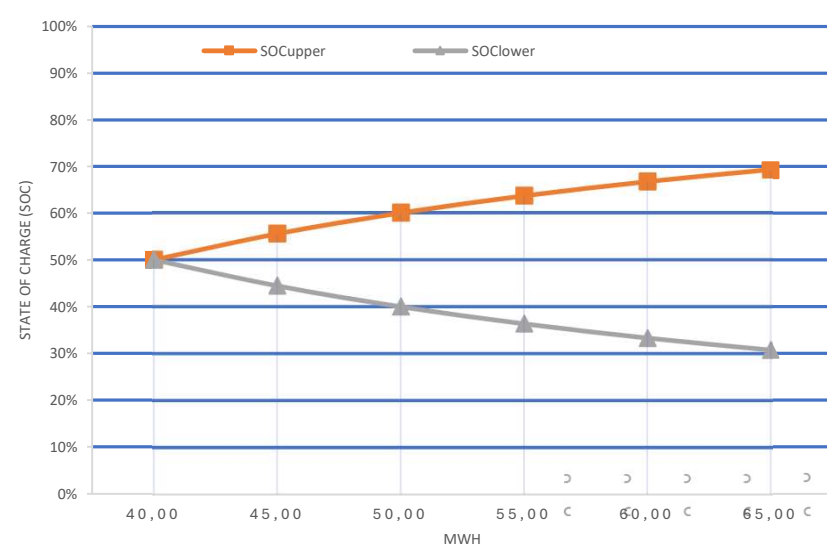
15



30



45



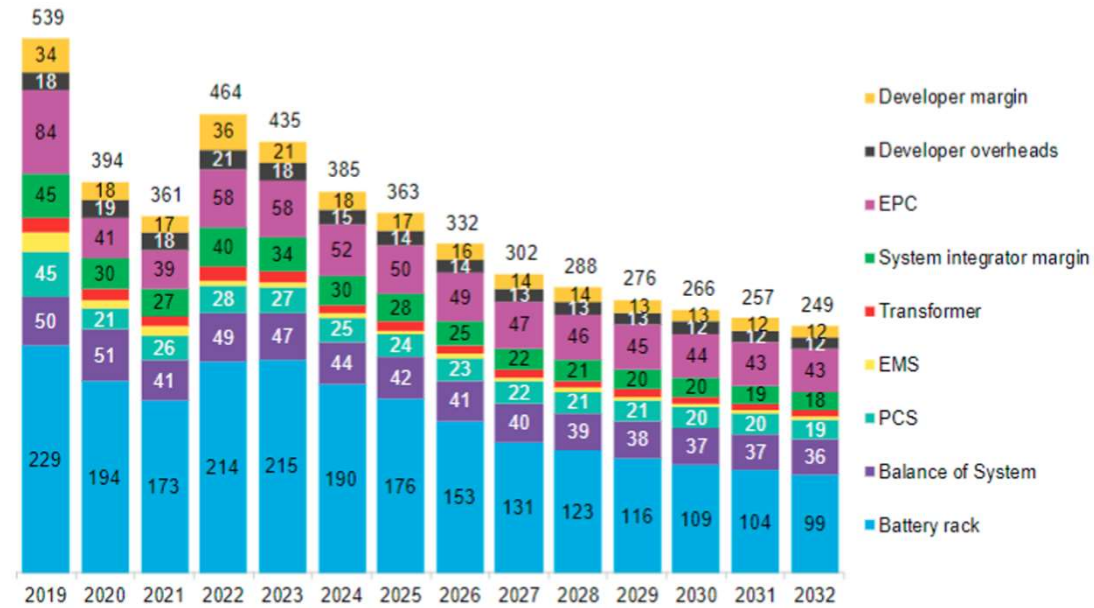
60

ESS costs: 2022 was outliers, prices are going down



Cost structure	Category	Inclusion	
Energy storage project cost	DC-side battery system	Battery rack	Consists of multiple cells/modules, the BMS, wiring and rack housing. The rack housing is generally a skeletal frame that holds the modules in place. Based on usable capacity, rather than nameplate capacity.
		Balance of system (BOS)	Includes electrical infrastructure, containers, thermal management system, fire suppression devices, battery operation monitoring system and sensors
	Turnkey energy storage system price	Power conversion system (PCS)	Converts DC to AC when discharging, and AC to DC when charging
		Energy management system (EMS)	Optimizes the behavior of a storage asset to maximize revenue or avoided costs for the owner
		Transformer	Steps-up or down the voltage depending on where a project is connected to the grid
		Expenses	Expenses relating to system shipping, tariffs, on-site installation and testing. Sometimes they are undertaken by component suppliers or EPC providers.
		System integrator margin	Net profit to the system integrator
	Fully-installed energy storage system cost	Engineering, procurement and construction (EPC)	EPC includes project design, site preparation, project debugging and electricity infrastructure deployment. EPC costs include the labor cost, materials cost, engineering and construction costs, administration cost during this process.
		Grid connection	Charge from a utility or network operator for connecting to the grid
		Developer overhead	Project permitting, environmental impact assessment, legal and administration costs
Energy storage project cost	Developer margin	Net profit in developing the project or after selling the project	

Real 2022 \$/kWh



2h ESS CAPEX (AC, fully installed, BOL).

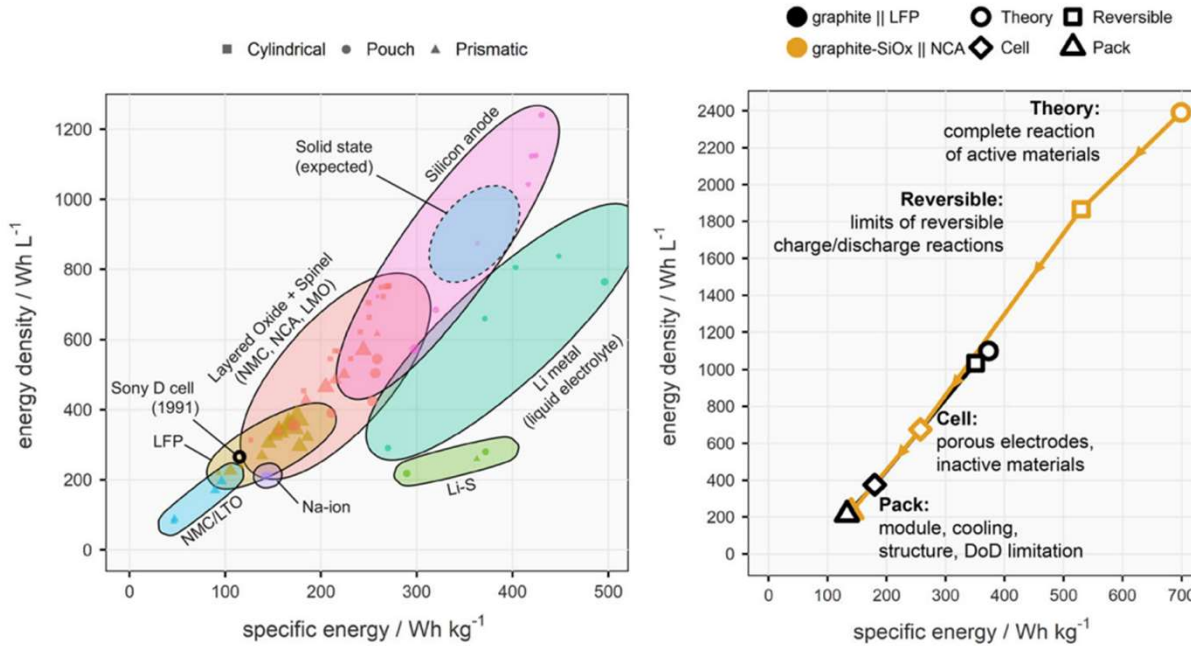
Reference: Battery Storage cost values from C. Augustine and N. Blair, "Energy Storage Futures Study Storage Technology Modeling Input Data Report," NREL/TP-5700-78694, Golden, CO National Renewable Energy Laboratory. <https://www.nrel.gov/docs/fy21osti/78694.pdf>

Technology	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Battery Energy Capital Cost (\$/kWh)														
Advanced	\$389	\$309	\$285	\$270	\$255	\$240	\$225	\$210	\$195	\$180	\$165	\$150	\$135	\$120
Moderate	\$369	\$309	\$282	\$255	\$230	\$216	\$202	\$191	\$179	\$167	\$156	\$144	\$132	\$120
Conservative	\$369	\$309	\$301	\$292	\$284	\$275	\$269	\$263	\$258	\$252	\$246	\$240	\$234	\$228
Battery Power Capital Cost (\$/kW)														
Advanced	\$249	\$238	\$239	\$230	\$181	\$162	\$152	\$141	\$131	\$120	\$110	\$100	\$107	\$108
Moderate	\$249	\$238	\$243	\$236	\$249	\$240	\$246	\$252	\$252	\$262	\$264	\$261	\$258	\$252
Conservative	\$249	\$238	\$232	\$225	\$218	\$212	\$207	\$203	\$198	\$194	\$190	\$190	\$190	\$190
Total System Cost (\$/kWh) = Battery Energy Cost (\$/kWh) * Storage Duration (hr) + Battery Power Cost (\$/kW)														
Future Projections														
All values are given in 2020 U.S. dollars, using the Consumer Price Index (BLS, 2021) for dollar year conversions. For 30-year life (values in 2025\$):														
CAPEX (\$/kW)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Utility-Scale Battery Storage - 2Hr Advanced	\$988	\$857	\$789	\$720	\$652	\$584	\$546	\$508	\$470	\$433	\$395	\$358	\$338	\$338
Utility-Scale Battery Storage - 2Hr Moderate	\$988	\$857	\$807	\$748	\$708	\$672	\$632	\$604	\$565	\$527	\$489	\$451	\$414	\$414
Utility-Scale Battery Storage - 2Hr Conservative	\$988	\$857	\$833	\$809	\$786	\$762	\$746	\$730	\$714	\$698	\$682	\$666	\$650	\$634
Utility-Scale Battery Storage - 4Hr Advanced	\$1,727	\$1,475	\$1,358	\$1,240	\$1,123	\$1,005	\$940	\$875	\$810	\$745	\$680	\$615	\$550	\$550
Utility-Scale Battery Storage - 4Hr Moderate	\$1,727	\$1,475	\$1,371	\$1,256	\$1,147	\$1,034	\$1,007	\$1,015	\$968	\$931	\$895	\$864	\$827	\$827
Utility-Scale Battery Storage - 4Hr Conservative	\$1,727	\$1,475	\$1,430	\$1,394	\$1,353	\$1,312	\$1,295	\$1,297	\$1,229	\$1,201	\$1,174	\$1,147	\$1,121	\$1,121
Utility-Scale Battery Storage - 6Hr Advanced	\$2,496	\$2,094	\$1,927	\$1,760	\$1,594	\$1,427	\$1,334	\$1,242	\$1,150	\$1,057	\$965	\$873	\$781	\$781
Utility-Scale Battery Storage - 6Hr Moderate	\$2,496	\$2,094	\$1,935	\$1,765	\$1,626	\$1,526	\$1,462	\$1,396	\$1,326	\$1,266	\$1,210	\$1,156	\$1,105	\$1,105
Utility-Scale Battery Storage - 6Hr Conservative	\$2,496	\$2,094	\$2,038	\$1,978	\$1,920	\$1,862	\$1,823	\$1,784	\$1,745	\$1,705	\$1,666	\$1,626	\$1,587	\$1,587
Utility-Scale Battery Storage - 8Hr Advanced	\$3,205	\$2,713	\$2,497	\$2,280	\$2,064	\$1,848	\$1,729	\$1,609	\$1,489	\$1,370	\$1,250	\$1,130	\$1,010	\$1,010
Utility-Scale Battery Storage - 8Hr Moderate	\$3,205	\$2,713	\$2,499	\$2,275	\$2,065	\$1,908	\$1,806	\$1,770	\$1,684	\$1,601	\$1,525	\$1,457	\$1,397	\$1,397
Utility-Scale Battery Storage - 8Hr Conservative	\$3,205	\$2,713	\$2,638	\$2,563	\$2,488	\$2,413	\$2,360	\$2,290	\$2,230	\$2,168	\$2,106	\$2,044	\$1,982	\$1,982
Utility-Scale Battery Storage - 10Hr Advanced	\$3,944	\$3,331	\$3,066	\$2,800	\$2,535	\$2,270	\$2,123	\$1,976	\$1,829	\$1,682	\$1,535	\$1,388	\$1,241	\$1,241
Utility-Scale Battery Storage - 10Hr Moderate	\$3,944	\$3,331	\$3,063	\$2,785	\$2,544	\$2,400	\$2,271	\$2,119	\$2,042	\$1,935	\$1,840	\$1,745	\$1,649	\$1,649
Utility-Scale Battery Storage - 10Hr Conservative	\$3,944	\$3,331	\$3,239	\$3,147	\$3,055	\$2,963	\$2,900	\$2,838	\$2,775	\$2,713	\$2,650	\$2,588	\$2,525	\$2,525
Annual Technology Baseline (ATB) NREL	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Utility-Scale Battery Storage - 2Hr Advanced	\$25	\$21	\$20	\$18	\$16	\$15	\$14	\$13	\$12	\$11	\$10	\$10	\$10	\$10
Utility-Scale Battery Storage - 2Hr Moderate	\$25	\$21	\$21	\$20	\$19	\$18	\$17	\$16	\$15	\$14	\$14	\$14	\$14	\$14
Utility-Scale Battery Storage - 2Hr Conservative	\$25	\$21	\$21	\$20	\$20	\$19	\$19	\$19	\$18	\$17	\$17	\$17	\$17	\$17
Utility-Scale Battery Storage - 4Hr Advanced	\$43	\$37	\$34	\$31	\$28	\$25	\$24	\$22	\$20	\$19	\$17	\$17	\$17	\$17
Utility-Scale Battery Storage - 4Hr Moderate	\$43	\$37	\$34	\$31	\$28	\$26	\$26	\$26	\$25	\$24	\$23	\$22	\$22	\$22

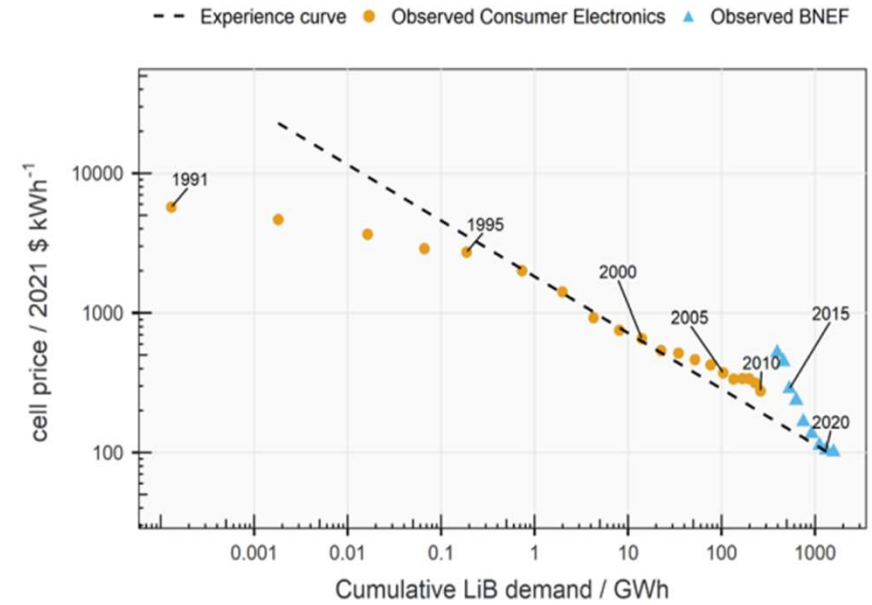
The 2024 total cost ranges from \$355 to \$390/kWh while the 2025 projects are expected to be in \$315 - \$370/kWh range (for turnkey including BOP from Tier 1 suppliers)

Annual Technology Baseline (ATB) NREL
<https://atb.nrel.gov/electricity/2022/data>

Technology challenges



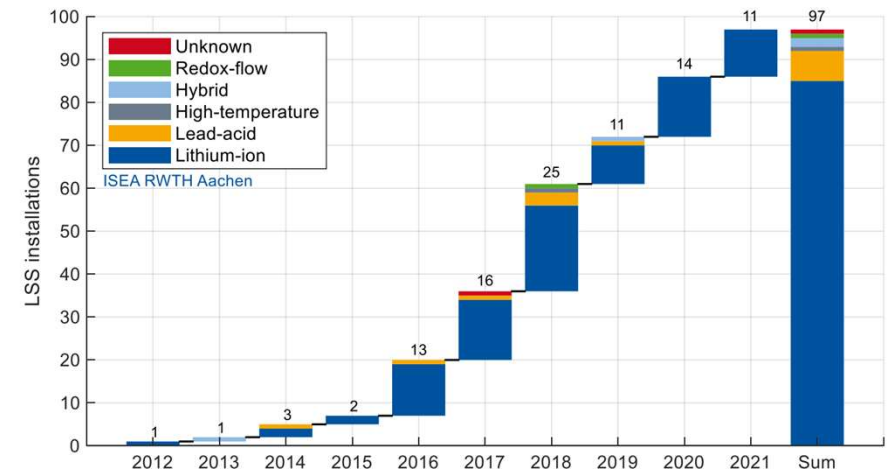
A non-academic perspective on the future of lithium-based batteries, James T. Frith, Matthew J. Lacey Jan 26th 2023



Every double of Li-ion use results in 25% price reduction.

Why Li-ion is dominating?

1. Large installed and knowledge base. Engineers are not afraid to work with Li-ion.
2. They are bankable.
3. Li-ion is largely driven by automotive.



The death of ESS: when and why?



Degradation causes

Growth of SEI

Solid Electrolyte Interface begins from the very first cycle at the factory. SEI is protecting anode (graphite) but at the same time reduces Li deposit. SEI growth decrease the Li⁺ volatility and correlates to volage and temperature. SEI is growing even without cycling!

Lithium plating

Function of high C-rates and low temperature. Very dangerous.

Electrodes cracks

Physical damages during the intercalation phase and cycling.

Year	SOH	Nameplate Capacity, MWh	SOH	Nameplate Capacity, MWh
0	100.00%	44.032	100.00%	44.032
1	94.95%	41.808	92.15%	40.574
2	92.15%	40.574	87.79%	38.655
3	89.83%	39.555	84.19%	37.07
4	87.79%	38.655	81.01%	35.67
5	85.92%	37.833	78.11%	34.392
6	84.19%	37.07	75.41%	33.205
7	82.56%	36.352	72.87%	32.088
8	81.01%	35.67	70.47%	31.028
9	79.53%	35.018	68.17%	30.015
10	78.11%	34.392	65.96%	29.042

Real life experience: 10 years and 5000 – 7000 cycles after (1,2 – 2 cycles per day) 1 hour ESS at 75..85% SOH.

NMC and NCA are layered oxides (A_xMO₂). High mobility of Mn³⁺ damage the layers and transform to spinel.

LFP has a conductive polyaniline with high sensitivity to C-rates.

5.5.2 Cycle lifetime

Cycle lifetime gives the number of full charge-discharge cycles the EES system is capable to provide within its calendar lifetime. Some technologies (predominantly batteries and electrochemical capacitors) see a degrading of their properties (mainly capacity and internal resistance) with the growing number of charge-discharge cycles. In that case the end of life is commonly defined as the number of cycles after which the actual capacity has reached a given reduced value. Expected lifetime of a system in a defined application can be prolonged by deploying a hybrid EES system that combines the high cycle life of a high-power EES technology (such as supercapacitor or flywheel) with the high energy of a low cycle life EES technology (e.g. battery).

For many battery types, their applicable performance standards state the EoL capacity. For example, IEC 60896 (stationary lead-acid batteries) and IEC 62660-1 (Li-ion batteries for electric vehicles) state 80% as the EoL capacity, while IEC 62620 (Large format secondary lithium cells and batteries for use in industrial applications) and IEC 61960 (Secondary lithium cells for portable applications) use 60% remaining capacity as the EoL criterion. For many battery technologies, small cycles are less damaging than deep cycles. This means the processed energy (integral of discharge power over the lifetime) can be increased significantly if the allowable depth of discharge is reduced. In such cases, cycle life as a function of DOD should be given for a number of DOD values relevant for the EES application

A low-angle photograph of a roller coaster's tracks, showing several loops and curves. The tracks are dark and silhouetted against a bright, colorful sky at sunset or sunrise, with orange and yellow hues near the horizon and blue above. The tracks are supported by dark metal pillars.

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