GESELLSCHAFT FÜR GROßBATTERIE-ANLAGEN MBH

Grid-scale Batteries as Key Element of Germany's Electricity System Transformation

IEEE PowerTech 2025

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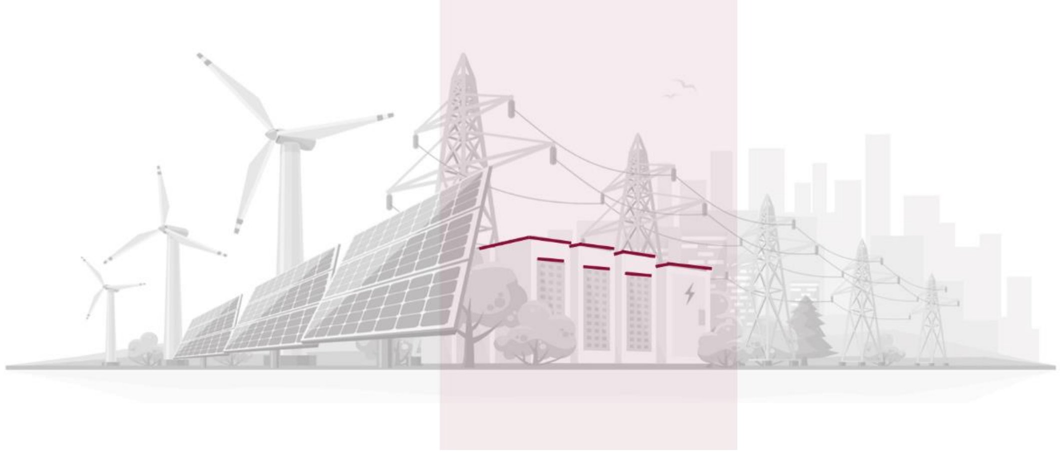


Summary

Transformation	▪ Storage Story – The Role of Excess Supply for Cost-efficient Electricity Systems ▪ What to Mine and to Store – From Just-in-time Generation to Just-in-time Distribution ▪ Falling Costs and Counting – Grid-scale Battery Margins Surpassing Gas Peaker Plants
Setting of Priorities	▪ Supply or Demand – Storage Investments versus Demand-side Management ▪ Batteries or Hydrogen – Learning Curve Competition Lost
Strategy and Implementation	▪ Economies of Scale and Scope – Bigger and Broader is Better ▪ Dealing with Demand Ambiguity – Topology Capacity Flexibility and Speed ▪ Upstream Preference – By the Sea, Upstream of Grid Bottlenecks ▪ Strict Standardization – Keep it Simple

Agenda

- **Transformation**
- Setting of Priorities
- Strategy and Implementation

In the past, four main value drivers determined the structure of the electricity supply chain

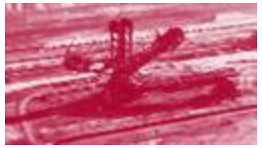
TRANSFORMATION – PAST VALUE DRIVERS OF ELECTRICITY SUPPLY

Value Driver	Effect
1 **Fuel access**	▪ Favors players with established or granted access to large-scale fossil fuel deposits
2 **Technology leverage**	▪ Favors players further down the experience curve and/or commanding economies of scale
3 **Logistics effort**	▪ Favors players in control of geographic proximity to location of generation asset (exploration) or grid connection point (generation)
4 **Just-in-time value**	▪ Favors players capable of fully adjusting supply to demand – not the other way around

Abundant fossil fuel supply, enabled by established mines, advanced technology, scale and efficient distribution, created the "just-in-time generation" electricity system of the past

TRANSFORMATION – MAIN VALUE DRIVERS OF ELECTRICITY SUPPLY

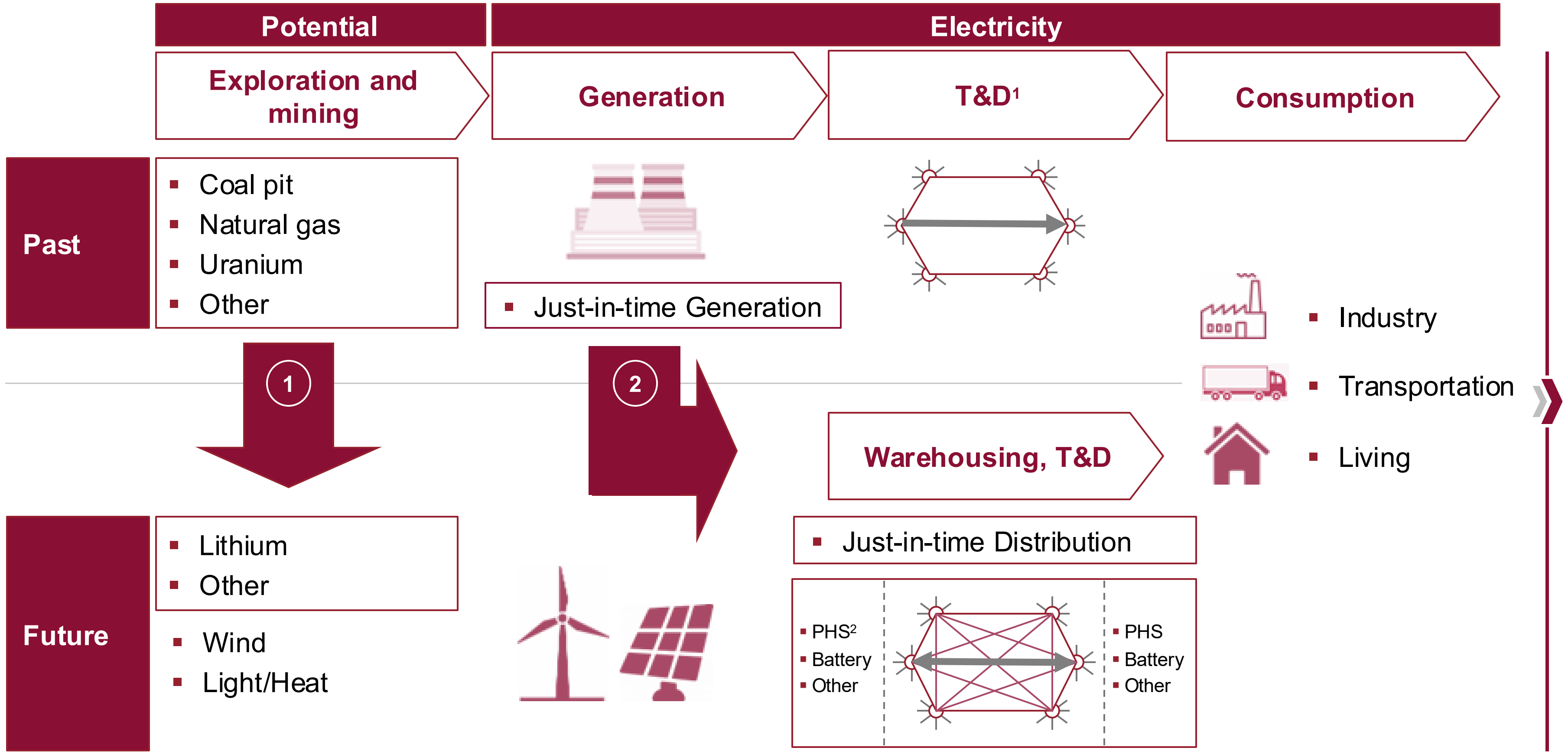
× Major impact

			Main Value Driver of Electricity Supply			
Supply Chain Stage	***Supply-side Asset***		**Fuel Access**	**Technology Leverage**	**Logistics Effort**	**Just-in-time Value**
Exploration and Mining		**Lignite mine**	×	×	×	×
		**Hard coal pit**	×	×		
		**Natural gas well**	×	×		
Generation		**Thermal power plant**	×	×	×	×

In future, the predominant challenge of the energy system is building and integrating electricity warehousing capabilities into the supply chain, downstream of generation

TRANSFORMATION – ELECTRICITY SYSTEM TRANSFORMATION

Challenge
Main Flow
Supply chain capability



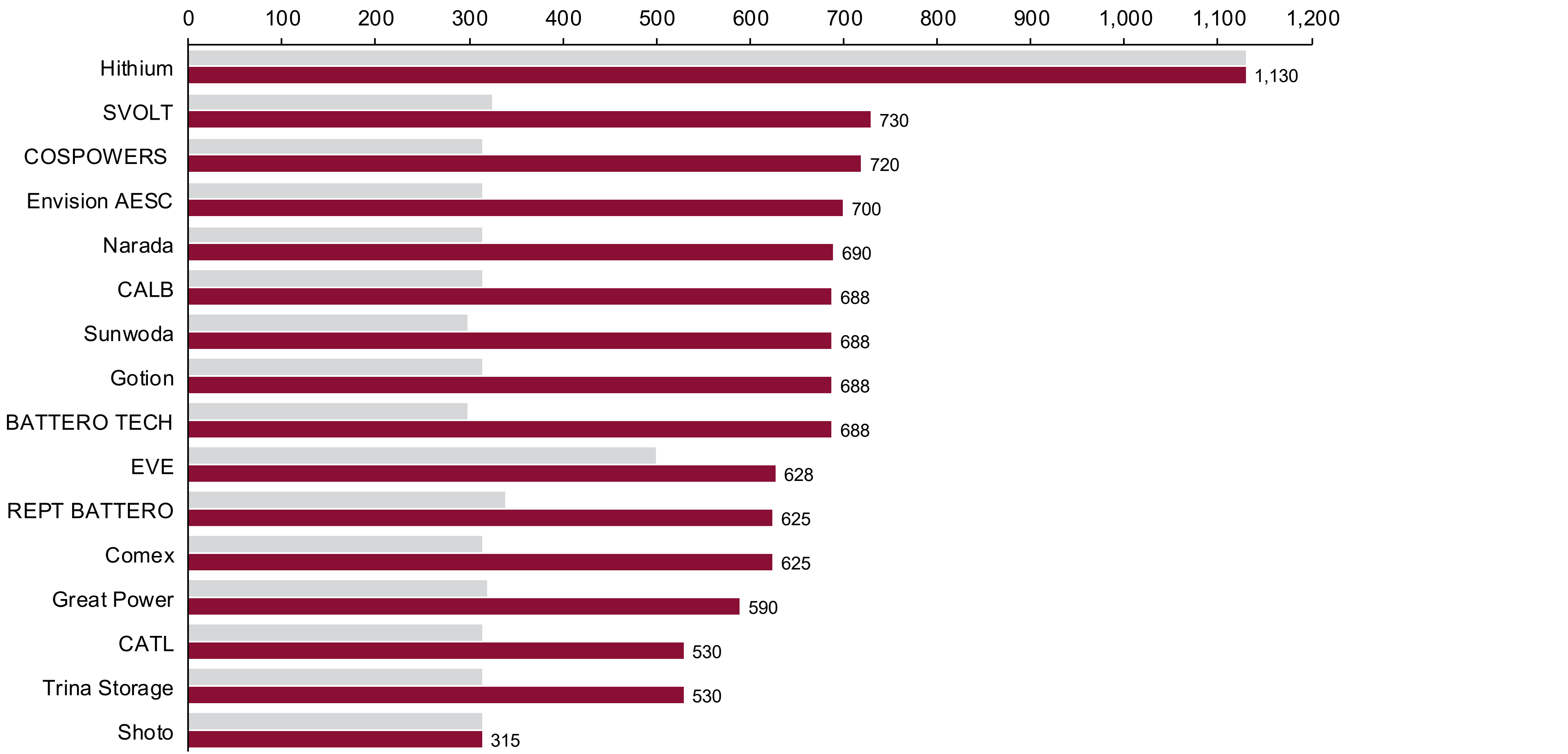
Transformation Tasks

1. **Exploring, mining, and production of electricity storage assets**
2. **Integrating effective electricity warehousing capabilities into the power grid**

1 Transmission and Distribution
2 Pumped Hydro Storage

The strong trend towards increasing battery cell sizes is enabling more energy-dense battery containers and driving economies of scale

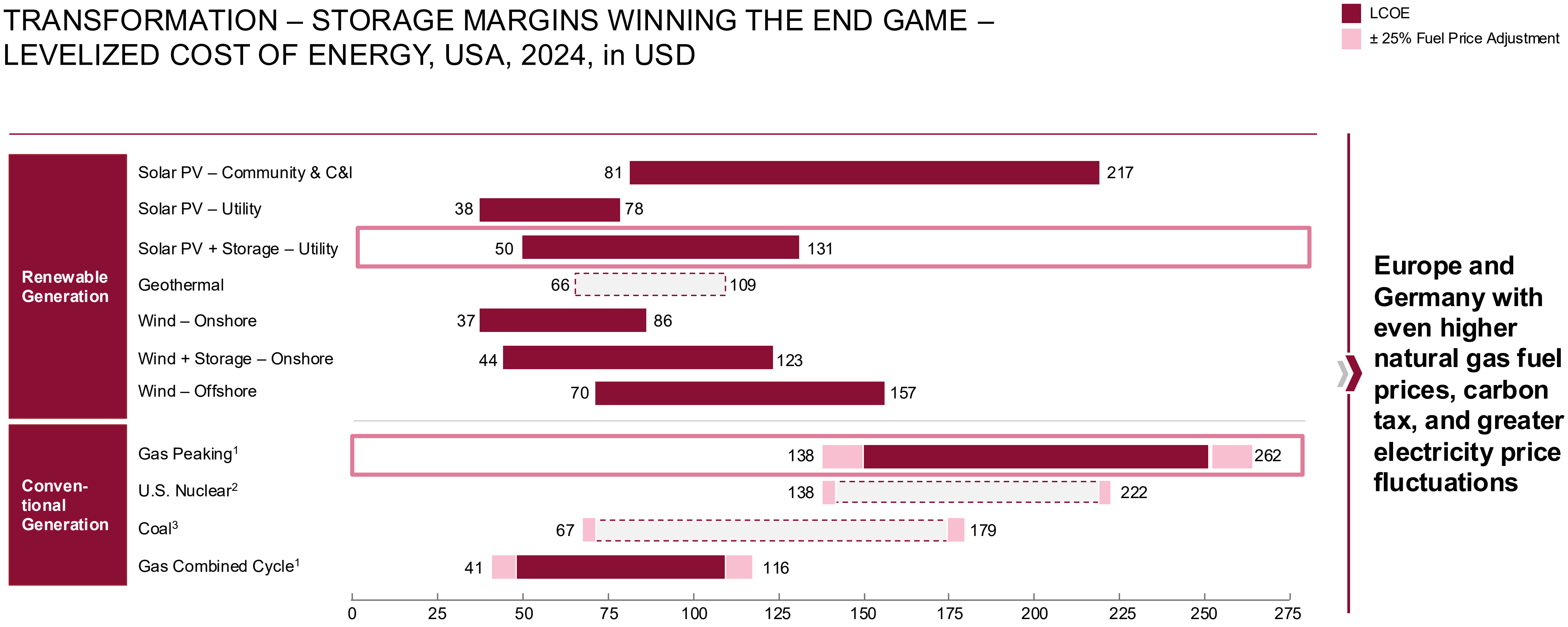
TRANSFORMATION – SELECTED COMPANIES' ANNOUNCEMENTS ON LITHIUM-ION BATTERY CELLS, 2023 versus 2024, in Amp. Hours



Source: BloombergNEF, company announcements.
Note: Data as of October 2024. 2023 and 2024 represent the year companies announced their biggest battery cells for stationary storage application, not the year the cells are mass-produced.

Energy costs of grid-scale batteries combined with electricity from renewables is already cheaper than gas peaker plants

TRANSFORMATION – STORAGE MARGINS WINNING THE END GAME – LEVELIZED COST OF ENERGY, USA, 2024, in USD



Europe and Germany with even higher natural gas fuel prices, carbon tax, and greater electricity price fluctuations

Source: Lazard estimates and publicly available information.

Note: Unless otherwise noted, the assumptions used in this sensitivity correspond to those used in the LCOE analysis as presented on the page titled "Levelized Cost of Energy Comparison – Version 18.0".

1. Assumes a fuel cost range for gas-fired generation resources of USD 2.59/MMBTU to USD 4.31/MMBTU (representing a sensitivity range of ± 25% of the USD 3.45/MMBTU used in the LCOE).
2. Assumes a fuel cost range for nuclear generation resources of USD 0.64/MMBTU to USD 1.06/MMBTU (representing a sensitivity range of ± 25% of the USD 0.85/MMBTU used in the LCOE).
3. Assumes a fuel cost range for coal-fired generation resources of USD 1.10/MMBTU to USD 1.84/MMBTU (representing a sensitivity range of ± 25% of the USD 1.47/MMBTU used in the LCOE).

Agenda

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- **Setting of Priorities**
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Supply-side flexibility will outpace value creation from demand-side management approaches at scale also in future – with grid-scale batteries as natural provider of flexibility

TRANSFORMATION – FLEXIBILITY COST DRIVERS OF ELECTRICITY SUPPLY AND DEMAND

X Fully applicable
(x) Partially applicable

		Capital Intensity	Processing Flow	Supply Chain Complexity	Just-in-time Value Potential	Specialty-type Output
Supply-side assets	**Grid-scale battery**	X		(x)		
	Fleet of distributed/ mobile batteries	X		X	(x)	
	Hydrogen electrolyser	X	X			(x)
	Thermal power plant	X	(x)	(x)		
Demand-side assets	**Industry**	X	X	X	(x)	(x)
	Transportation	X	X	X		(x)
	Housing				X	
		Asset utilization drives returns	**Physics requiring constant throughput**	**High cost of supply chain coordination**	**Opportunity cost of flexibility**	**Lack of large customer groups with varying demand**

Grid-scale batteries mean standard technology, standard management, and standard output

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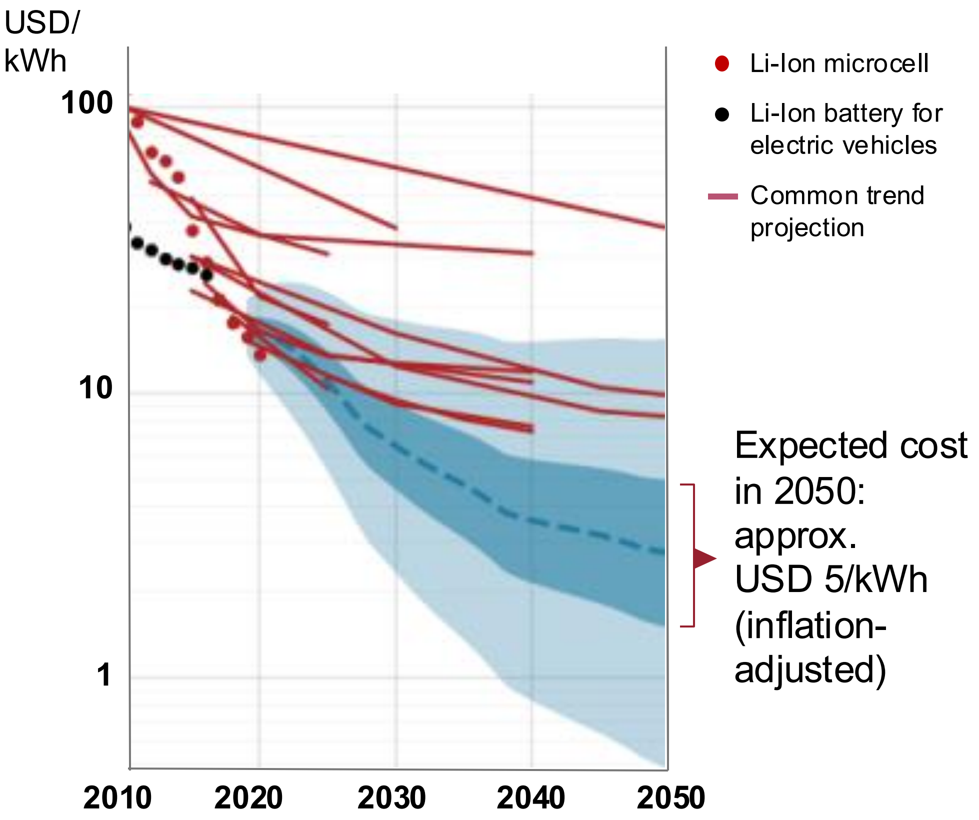
Continuously falling battery production cost, driven by increasing scale effects, is being significantly underestimated in trend projections – similarly as already with photovoltaics

PRIORITIES SETTING – BATTERIES VERSUS HYDROGEN – FORECAST, 2010 TO 2050, in USD/kWh



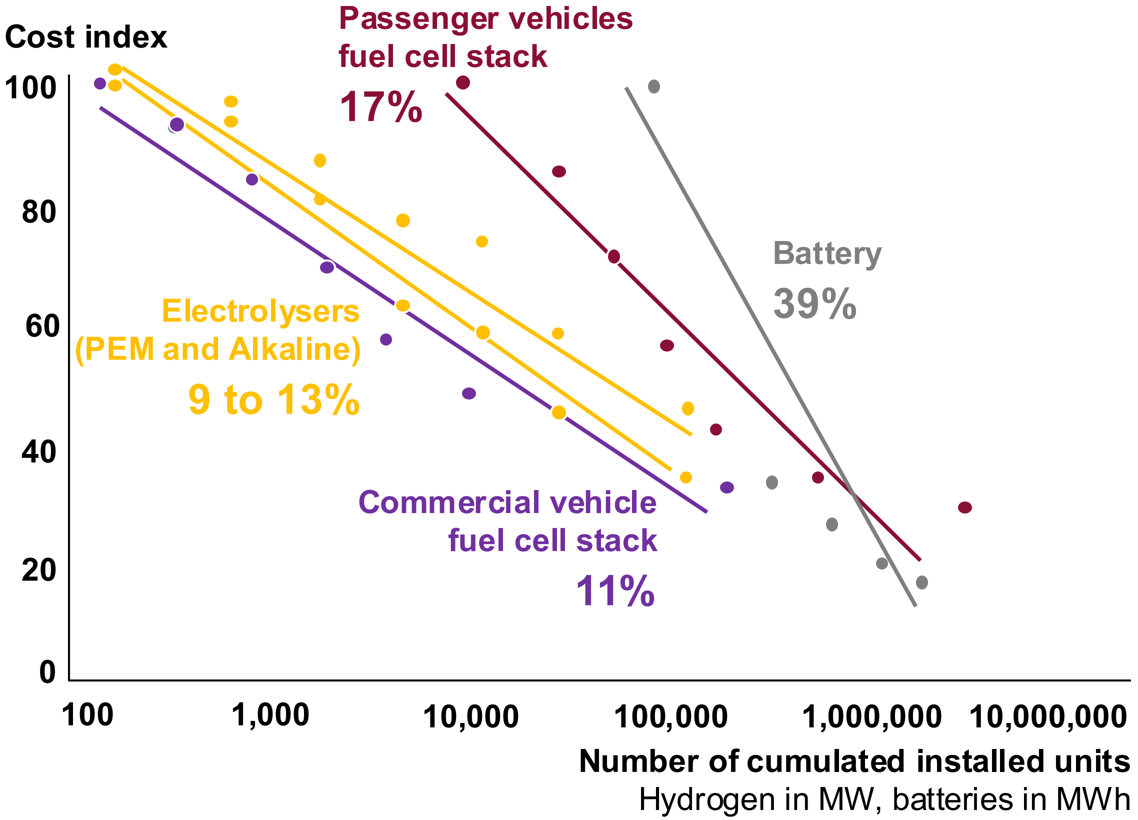
- Successful technologies tend to follow an S-curve[1] for deployment. Under Wright's law, during the exponential growth phase, costs drop exponentially in time due to experience and learning.
- Past projections of present renewable energy costs by influential energy-economy models have consistently been much too high, presumably caused by a flawed application of Wright's law.
- Current energy storage cost projections seem to be subject to a similar methodical error.
- Projections underestimating experience curve effects pose a threat of locking in investment at too high costs.
- Investment based on better cost projections will create an opportunity to price bids below locked-in competitors.

1 Gompertz function, i.e. a sigmoid function describing growth as being slowest at the start and end of a given time period

Source: Empirically grounded technology forecasts and the energy transition, Rupert Way et al., INET Oxford Working Paper No. 2021-01, Sept. 14th, 2021

The learning curve of Li-Ion batteries was significantly steeper in its first development decade than anticipated learning curve of hydrogen technology within comparable development period

PRIORITIES SETTING – LEARNING CURVES BATTERIES VERSUS HYDROGEN[1]



- It is highly unlikely that hydrogen technology will be reaching the steepness of the battery technology learning curve. Therefore, it is equally unlikely that it will be able to compete against batteries on cost:
  - **Learning curve** steepness in the first decade of a new technology development is a strong indicator for its long-term evolution.
  - **Hydrogen chemistry** is subject to inherent limitations. It has relatively low hard physical limits for application by generation as well as by conversion to electricity.
- "*The bad news is that the hoped-for reductions in the cost of clean hydrogen – with, for instance, the US aiming to produce green H_2 for USD 1/kg by 2031 – will not materialize. The average wholesale low-carbon hydrogen price will fall from EUR 7 (USD 7.73) per kg in 2025 to EUR 2.8/kg in 2050*", (Aurora Energy Research)

1 Considered time period Li-Ion batteries: 2010 to 2020; hydrogen: 2020 to 2030

Source: Hydrogen Council, Path to Hydrogen Competitiveness, 2020
Aurora Energy Research, UK, April 2023

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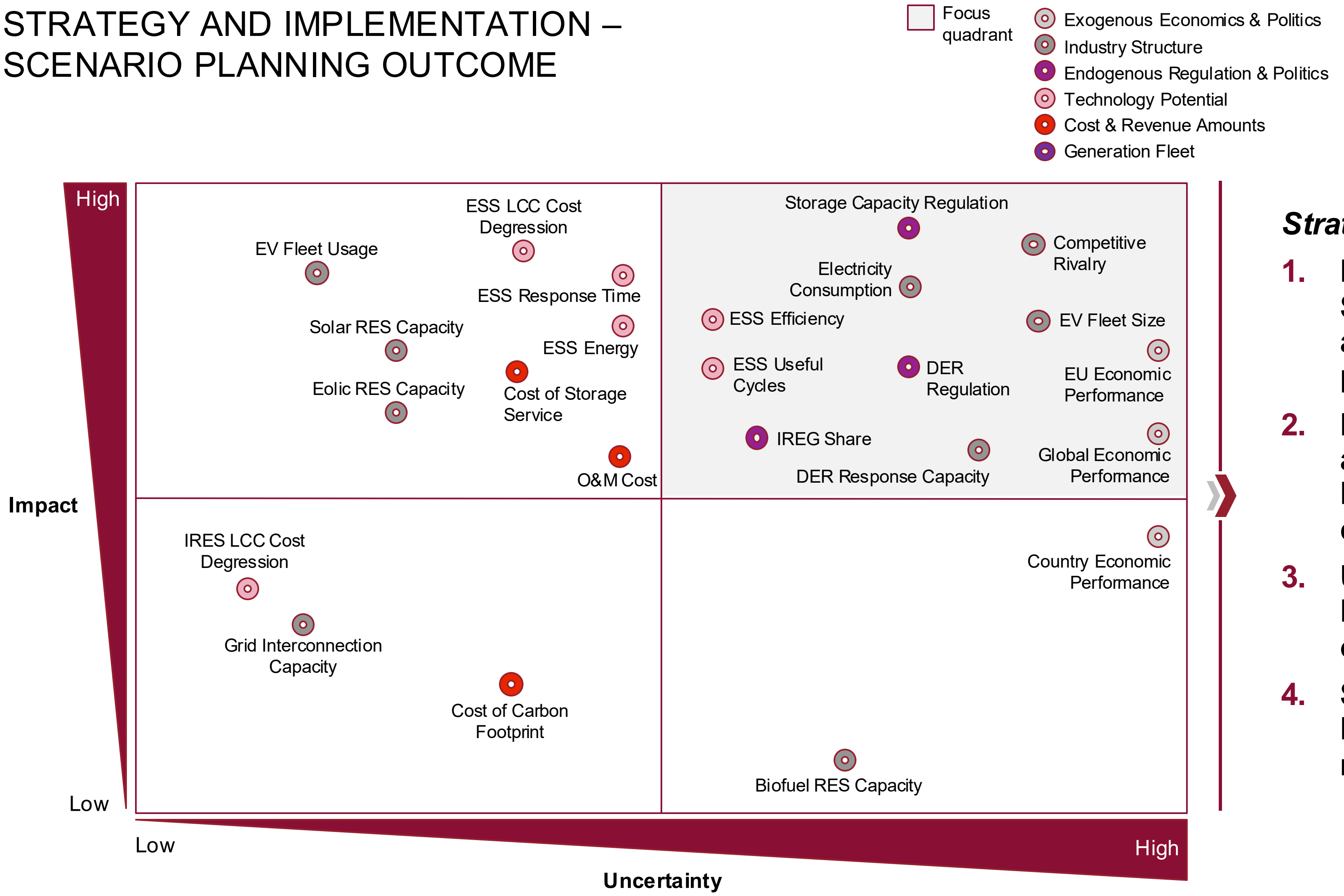
When devising GFGBA's strategy, a deep and thorough scenario planning was conducted to assess requirements and potential outcomes of Germany's energy system transformation

STRATEGY AND IMPLEMENTATION – SCENARIO PLANNING OUTCOME



DER = Distributed Energy Resource
ESS = Energy Storage System
EV = Electric Vehicle
IRES = Intermittent Renewable Energy Source
IREG = Intermittent Renewable Energy Generation
LCC = Life Cycle Cost
RES = Renewable Energy Sources

Strategic Guidelines

1. **Economies of scale and scope – Sustainable competitive advantages from asset size, asset portfolio, and application scope**
2. **Dealing with electricity demand ambiguity – Risk mitigation through configurational flexibility**
3. **Upstream preference – Near renewable clusters, upstream of grid bottlenecks**
4. **Strict Standardization – Efficiency and speed through re-use of knowledge and skills**

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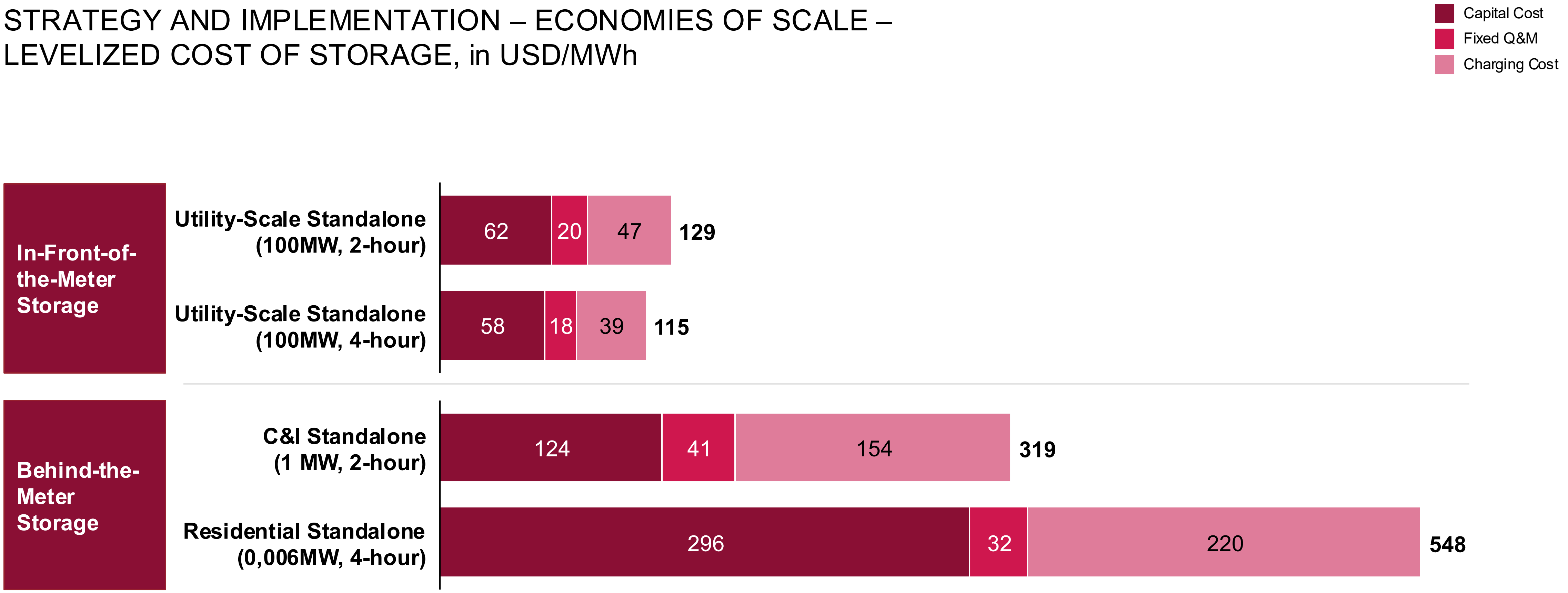
Bigger batteries generally have significant advantages over smaller batteries from economies of scale

STRATEGY AND IMPLEMENTATION – ECONOMIES OF SCALE – LEVELIZED COST OF STORAGE, in USD/MWh



Source: Lazard LCOE, June 2025

GFGBA has 24 partially overlapping revenue sources in scope when configuring and operating grid-scale battery systems

STRATEGY AND IMPLEMENTATION – ECONOMIES OF SCOPE – REVENUE SOURCES

Product/Service	Revenue Sources	Business Model Type
Power Wholesale	Spot Market Trading, Futures Trading, Electricity Forwards	Time Arbitrage Trading
Frequency Response	Momentary Reserve, Primary Reserve, Secondary Reserve, Tertiary Reserve	Insurance
Ancillary Services	Black Start, Voltage Support / Reactive Power, Energy Loss Compensation, TG Investment Deferral, DG Investment Deferral	Insurance
Power Adequacy	Reserve Capacity, Hedging Obligation	Insurance
Energy Cost Management	Energy Cost Management	Business Process Provision
Balancing Energy	Balancing Energy	Business Process Provision
Uninterrupted Power Supply	Uninterrupted Power Supply	Business Process Provision
RES Generation Management	Generator RES Curtailment Avoidance, RES Generation Power Quality, RES PPA Hedging, Full-fledged RES PPA Supply	Business Process Provision
Congestion Management	Redispatch Avoidance, TG Congestion Management, DG Congestion Management, Grid RES Curtailment Avoidance	Business Process Provision

Source: GFGBA Revenues Sources database

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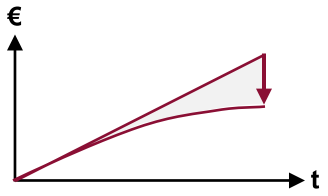
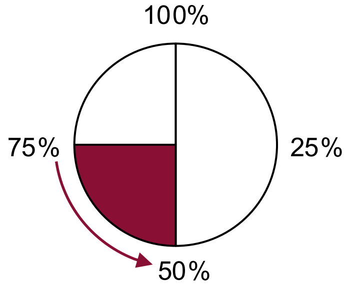
Future electricity demand is a major risk to any large-scale battery business case, which should be mitigated by configuration flexibility

Main Sources of Electricity Demand Ambiguity

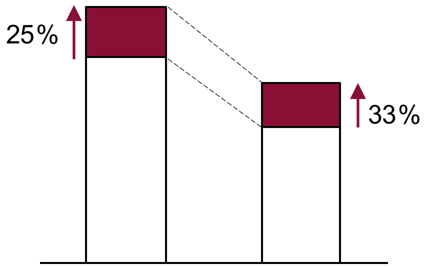
- **Slower overall growth of economy**
  due to geopolitical uncertainty and conflicts



- **Slower rate of electrification**
  due to high costs and uncertainty of industry sector transformation (e.g., EV penetration rate, power-to-heat trend in process industry)



- **Higher costs of electricity**
  due to higher costs of upstream assets (e.g., natural gas, green/blue hydrogen, conventional and renewable generator technology, power grid components, carbon tax)



Configurational Flexibility

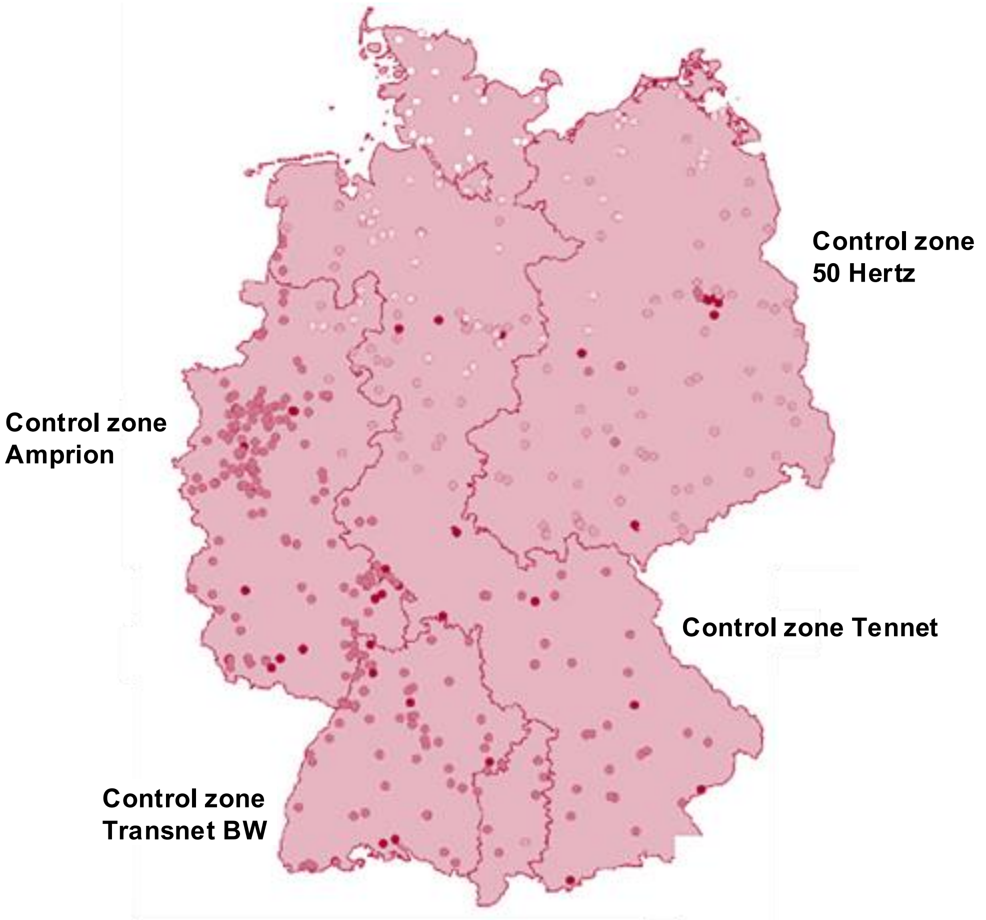
- Strictly modular and standardized design of main BESS and balance-of-plant components, enabling "plug & play" **upgrading** (higher energy density, power)
- Excess area available on individual sites for **upscaling** of energy/duration (additional containers)
- Geographical spreading of sites, avoiding cluster risk, i.e., **diversification**

Map of construction cost grants to be paid by battery developers to TSOs demonstrates the regulator's view on grid-scale batteries' system benefits, fully in line with GFGBA's strategy

STRATEGY AND IMPLEMENTATION – UPSTREAM PREFERENCE – PLANNED GRID CONSTRUCTION COST GRANTS

Rate of grid construction cost grant payable by transmission grid customers planning to connect BESS at 380kV or 220kV grid connection points

- 100%
- 80%
- 60%
- 40%
- 20%



Main Assumptions

- Burden of transmission grid extension costs partially to be shared by grid-scale battery sector as one of the main beneficiaries of grid extensions
- Total excess supply of renewable energy presumed to decline from north toward south
- Grid-scale battery benefits to transmission system highest at northern grid connection points
- Potential negative effect of grid-scale batteries on redispatch demand larger in the South than in the North

Source: Grid construction cost grants, Bundesnetzagentur, November 2024
Based on preliminary calculation of transmission system operators

A GFGBA grid-scale battery is planned in accordance with a standard configuration fitting the typical characteristics of preferred locations

GFGBA GRID-SCALE BATTERY SYSTEMS – STANDARDIZATION

Characteristics of preferred GFGBA locations

- Proximity to substation with 380 kV connection
- Proximity to offshore DC-AC converters
- North of the bottlenecks in the electricity transmission grid
- Proximity to large electricity consumers
- Excess area available on site

Standard configuration of a GFGBA grid-scale battery system

- Power output of 250 MW with expansion potential
- Storage capacity of 500 MWh, modularly expandable to 1.5 GWh
- Redundant HV island architecture
- Grid-supporting use through multifunctional converter electronics

Efficiency and speed through maximum re-use of knowledge and skills during development and construction

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