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H2 long-duration energy storage

How much capacity will there be across Europe by 2030, and will this be enough?

INVESTING IN ENERGY SERIES, 29.11.2023

LCP Delta Hydrogen

AGENDA

Introduction to LCP Delta

Electricity and hydrogen

European Hydrogen Storage Market Landscape to 2030

Market sizing: UK case study

Investment risks

Q&A

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LCP Delta supporting the energy transition

Deep expertise, knowledge and world-class capabilities across the energy value chain

LCP Delta

Supporting strategic and investment business decisions through our deep expertise, knowledge and world-class modelling capabilities to positively impact the global energy transition

Demand side
Deep understanding of customers, market dynamics, how new energy technology & services will be deployed, and how policy will shape & impact the demand side.

Energy networks
Assessment of the impact on energy networks of regulatory changes, demand & supply evolutions and deployment of flexibility.

Upstream assets
Revenue forecasting, hydrogen cluster modelling, and system optimisation of hydrogen energy system assets

How we help our clients

Strategic advice

Clear, independent advice supported by market leading knowledge & experience.

Research and data

Track and monitor a range of critical hydrogen data and market indicators

Forecasting & modelling

Revenue forecasting and optimisation assets in the hydrogen energy system.

Opportunity identification and market entry

Identifying key growth and high value areas for investors to target & explore further

Professional Development

Providing the detailed understanding of technologies, market trends, competitive landscape and outlook

Selection of our clients

sse

STATERA BALANCING THE GRID

centrica

bluefield Partners LLP

drax

NEXTENERGY CAPITAL

MACQUARIE Green Investment Group

nationalgridESO

Foresight group

Department for Energy Security & Net Zero

ANTIN INFRASTRUCTURE PARTNERS

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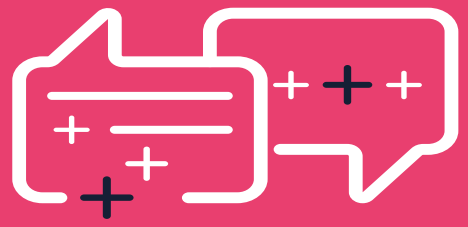
*Support for companies to **understand**, develop **strategy and tactics** for, and **invest** in emerging **hydrogen markets** in Europe and beyond*



LCP powering possibility

Knowledge and capability building	***Market insight & analysis***	***Strategy development***	***Market design, asset & system modelling***
Training	***Hydrogen Intelligence Service***	***Bespoke consulting and modelling support***	
	HYbase		
Hydrogen fundamentals	Subscription research	Strategic insights	
Energy market training for the hydrogen sector	Market data and visualisation	Power market analysis, hydrogen cluster modelling, and asset sizing & optimisation	
		Investment decision support	

Clients we support

Govt, Regulators & System Operators

Oil & Gas Sector

Utilities

Energy Networks

Investors

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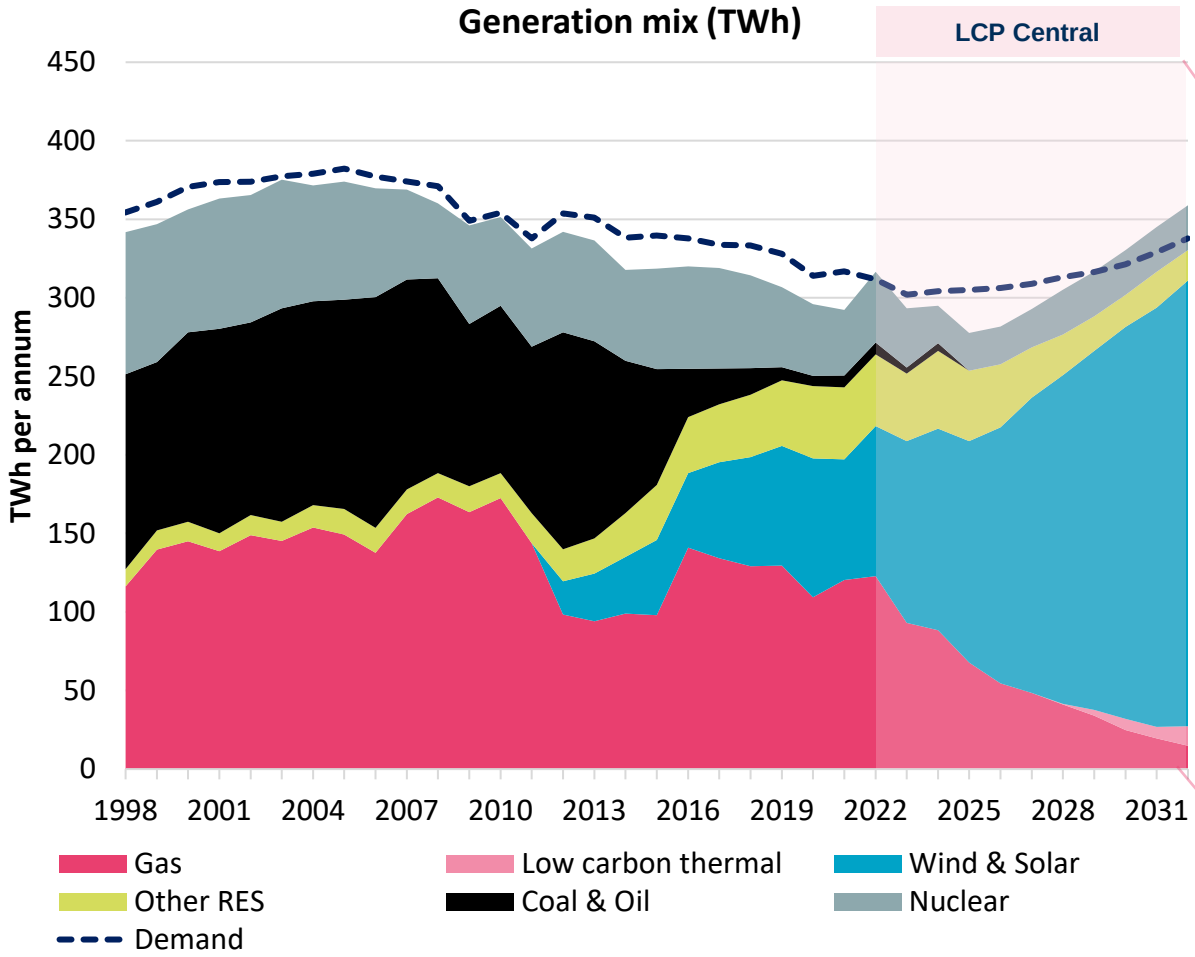
The need for LDES in GB

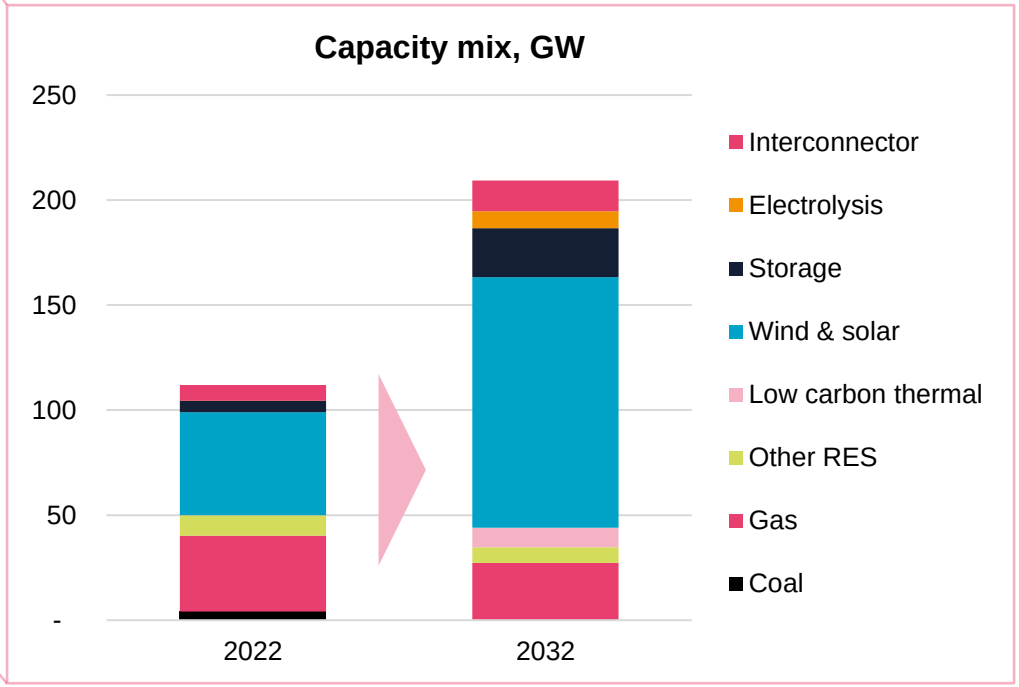
Evolution of GB Electricity Supply

Decarbonisation targets combined increasing energy demand – are expected to drive huge changes to the GB energy system over the next 10 years.



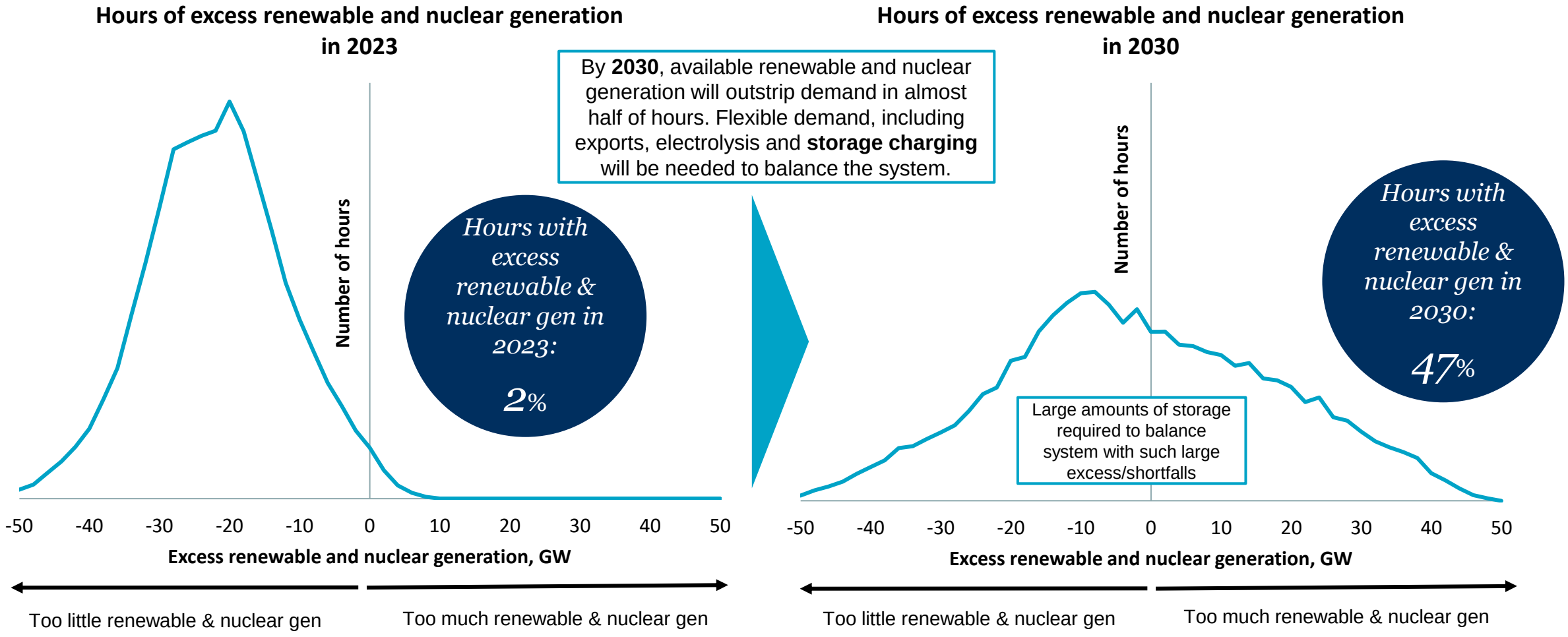
2032 vs. 2022 under the LCP Central scenario

- There is a sharp decrease in gas generation.
- Huge growth in renewable capacity as offshore wind, onshore wind and solar capacity increase to ***50GW***, ***27GW*** and ***42GW***.
- This will need to be supported by flexible assets such as LDES in order to balance the system



Increasing levels of excess and shortfall generation

Rapid transformation of GB system means generation-side and demand-side flexibility needs to be deployed at large scale to balance the system in 2030

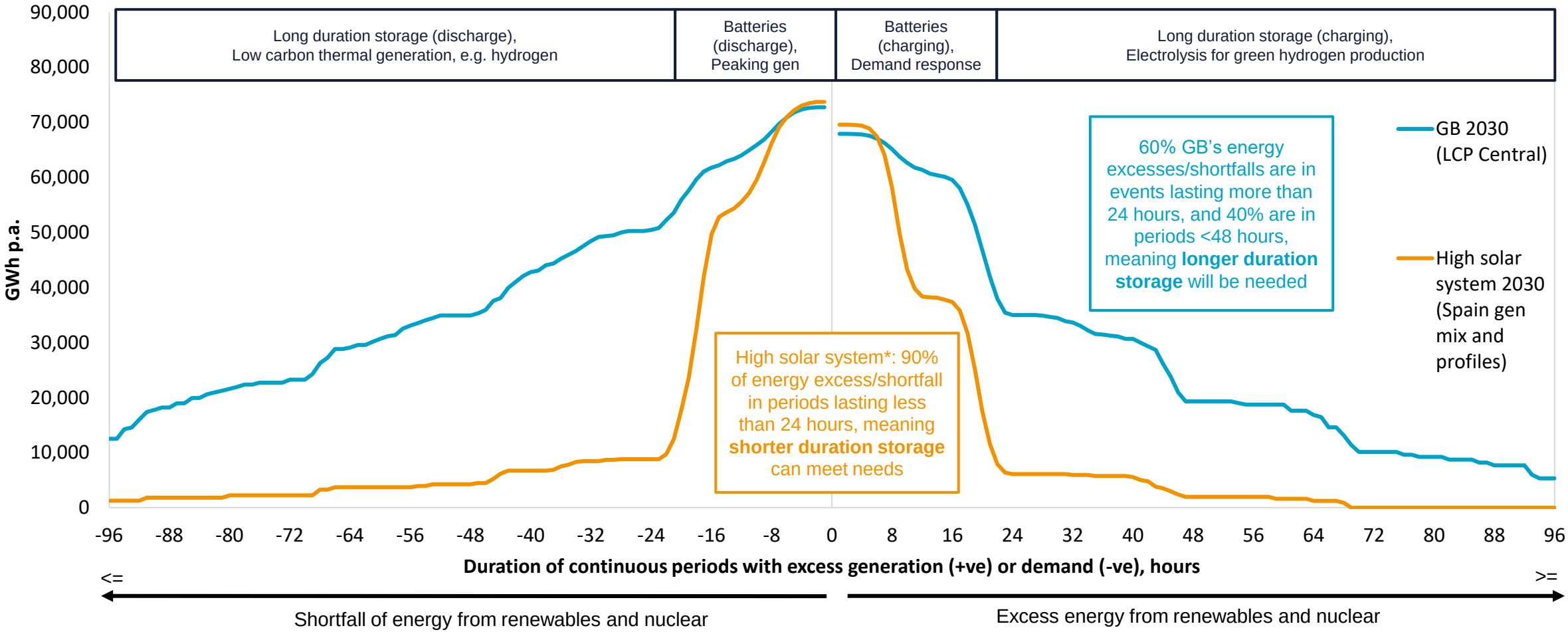


2030 projections based on LCP Central Scenario

Need for longer-duration storage is particularly acute in GB

In 2030, GB will require vast quantities of energy to be stored over long periods to balance the system

Energy in continuous periods of excess or shortfall of renewable generation:
GB system in 2030 vs High solar system



Curtailed electricity capture for green hydrogen production

£350m of payments in past two years – a figure forecast to increase to **£3.5bn annually by 2030**

Offshore wind fleet to grow from 14GW today to the 50GW in 2030

Year	Production Potential (TWh)	Production Potential (tonnes)	Electrolyser Capacity (MW)
2022	5	118,731	3,560
2023	5	133,020	3,989
2024	9	222,970	6,686
2025	13	325,457	9,759
2026	17	424,467	12,728
2027	17	434,594	13,031
2028	16	412,589	12,371
2029	18	455,939	13,671
2030	15	371,244	11,132

Table 1: Hydrogen production potential to 2030 from curtailed power

Decarbonise the entirety of the UK's 7m tonne **annual steel production**

Displace two-thirds of the 700,000 tonnes of the UK's current, carbon-intensive **grey hydrogen consumption** annually

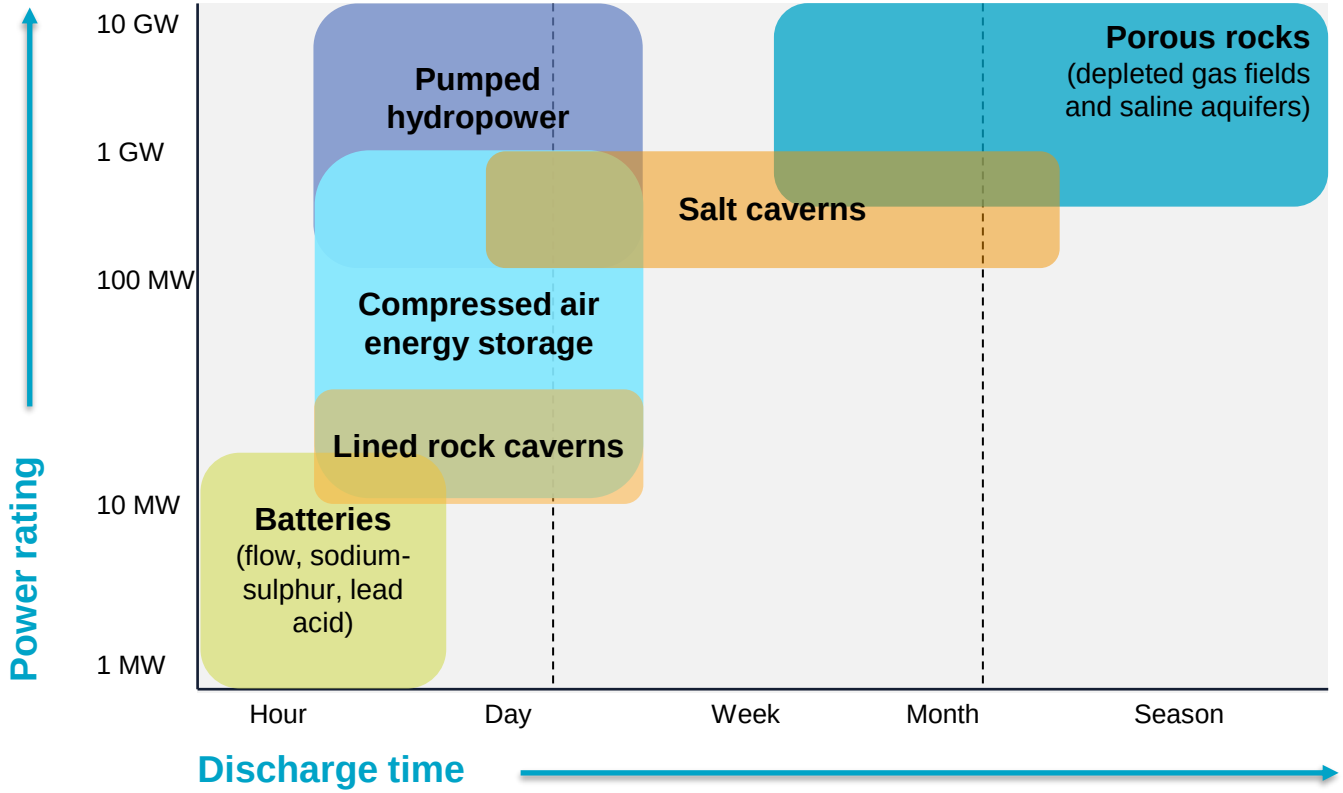
Meet over **90%** of our national Sustainable Aviation Fuel **(SAF) target for 2030**

Deliver **two-thirds** of our **electrolyser capacity** target for 2030.

Long-duration energy storage

Storage asset types & role in the future energy system

Graph with power vs discharge time of different storage technologies



Long-duration storage systems, typically sized at >100 MW, provide flexibility and security to the entire energy system.

Only geological hydrogen storage provides MW – TW scale renewables storage, with discharge durations of days to months.

Underground hydrogen storage solutions

Three main geological storage types are suitable for hydrogen

	Salt caverns	Depleted gas fields, Aquifers	Lined rock caverns
	+ Mature tech, fast cycling flexibility *- Geographically constrained and high construction cost*	*+ Large storage capacity, cost-effective* *- Limited experience, high cushion gas requirement*	*+ Can be constructed in many locations* *- Limited storage capacity*
			
Type of operation	Peaking	Seasonal	Peaking
Site availability (# of sites in EU27 & UK)	63 sites (concentrated in northwest Europe)	80 depleted reservoirs and 27 aquifers (covering most of Europe)	1 site – HYBRIT, Sweden (can be constructed anywhere with suitable rock)
Scale	100 – 250 GWh	100 – 20,000 GWh	10 – 30 GWh
Technological readiness	High – 8	Low / Medium – 3-6 (Higher for gas fields than aquifers)	Medium – 5-6
Cost for H2 storage* (CAPEX)	€0.44 – 0.69 EUR/kWh	€0.11 – 0.45 EUR/kWh	N/A

*Estimate values from IEA Task42, indicative due to lack of operational project data.

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European Hydrogen Storage Market Landscape out to 2030

How much underground hydrogen storage capacity will be available by 2030?

Where are the big projects being brought to market?

8 TWh underground hydrogen storage planned to 2030

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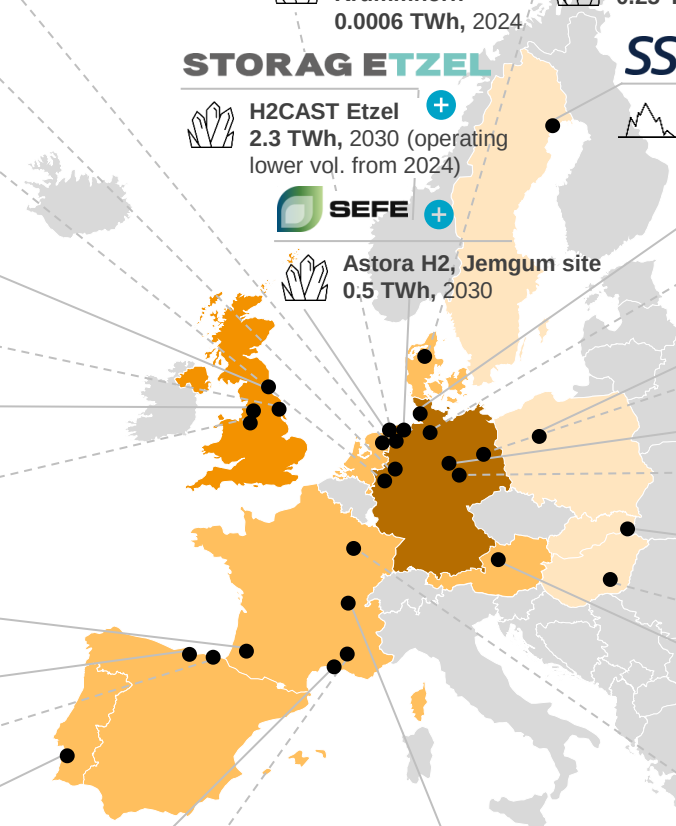
2030 Hydrogen storage
- >2 TWh
- 1 – 2 TWh
- 0.2 – 1 TWh
- < 0.2 TWh

Salt caverns | Depleted gas fields | Lined rock caverns

⊕ Commercial scale (≥0.2 TWh)



RWE ⊕
- **Get H2,** Gronau-Epe **0.13 TWh,** 2029

RWE ⊕
- **H2 Storage Xanten 0.14 TWh,** 2030-31

gasunie ⊕
- **Hystock,** Zuidwending **0.24 TWh,** 2028

uniper
- **Salt cavern Krummhörn 0.0006 TWh,** 2024

GAS STORAGE DENMARK ⊕
- **Green Hydrogen Hub Denmark,** Lille Torup **0.25 TWh,** 2025

STORAG ETZEL
- **H2CAST Etzel 2.3 TWh,** 2030 (operating lower vol. from 2024)

SEFE ⊕
- **Astora H2, Jemgum site 0.5 TWh,** 2030

SSAB
- **HYBRIT,** Luleå **0.0004 TWh,** 2022

RAFFINERIE HEIDE
- **Westküste 100 0.003 TWh,** 2023

GAZ system
- **UGS Damasławek TBD,** 2030

sse Thermal | equinor ⊕
- **Aldbrough Hydrogen**
  - **Pathfinder, 0.02 TWh,** 2025
  - **Storage, 0.32 TWh,** 2028

sabic
- **Teesside 0.027 TWh,** 1972

storengy ⊕
- **SaltHy,** Harsefeld **0.205 TWh,** 2030

EWE
- **HyCAVmobil,** Rüdersdorf **0.0002 TWh,** 2023

RWE ⊕
- **H2 Storage Staßfurt 0.21 TWh,** 2030-31

Inovyn ⊕
- **HyNet NW Keuper Gas Storage,** Cheshire, **1.38 TWh,** 2025 (est.)

Inovyn storengy
- **HySecure,** Crewe **0.04 TWh,** TBD

VNG Gasspeicher
- **Bad Lauchstädt Energy Park TBD,** 2026

TERĒGA ⊕
- **HyGeo,** Carresse-Cassaber **0.002 TWh,** 2024
- **HySoW, 0.5 TWh,** 2030

nafta
- **UGS Velke Kapusany 0.01 TWh** (est.) (increasing blend in NG ~0.18 TWh), 2025

enagas ⊕
- **H2 Storage North-1,** Santander **0.335 TWh,** 2029

MFGT
- **Aquamarine 0.01 TWh,** 2023

enagas ⊕
- **H2 Storage North-2,** Bilbao **0.24 TWh,** 2029

REN ⊕
- **Carriço 0.2 TWh** (est.), 2025 (increasing blend in NG)

Geostock
- **GEOGAZ H2,** Lavera **0.04 TWh,** 2028

storengy ⊕
- **GeoH2,** Manosque **0.24 TWh,** 2028

storengy
- **HyPSTER,** Bourg-en-Bresse **0.002 TWh,** 2023

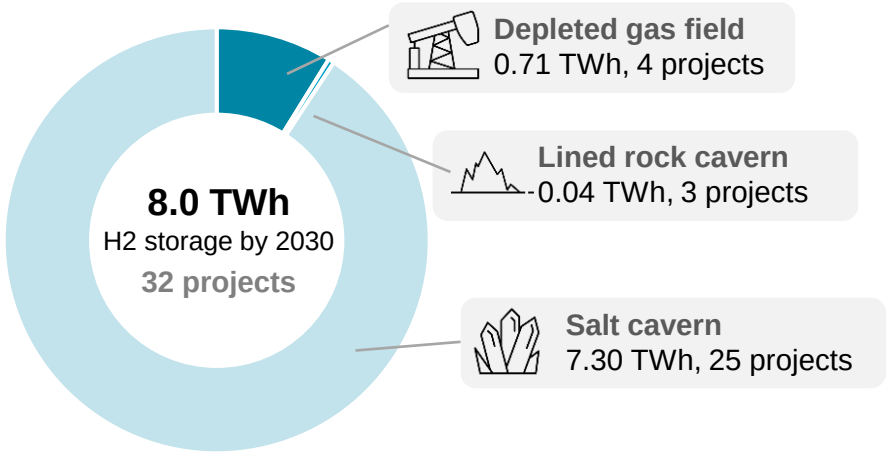
storengy
- **Cerville,** Nancy **TBD,** 2028 (est.)

RAG AUSTRIA AG ⊕
- **Underground Sun Storage,** Gampern
  - **0.004 TWh,** 2023
  - **0.52 TWh,** 2030

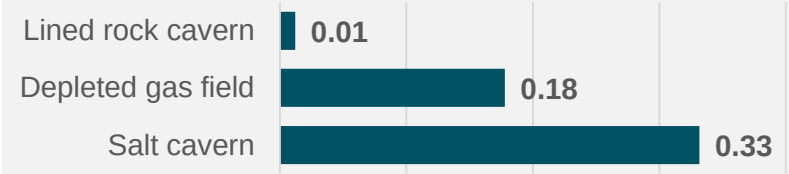
Hydrogen storage pipeline of 8 TWh by 2030 across Europe

Over 90% of storage capacity coming from salt caverns

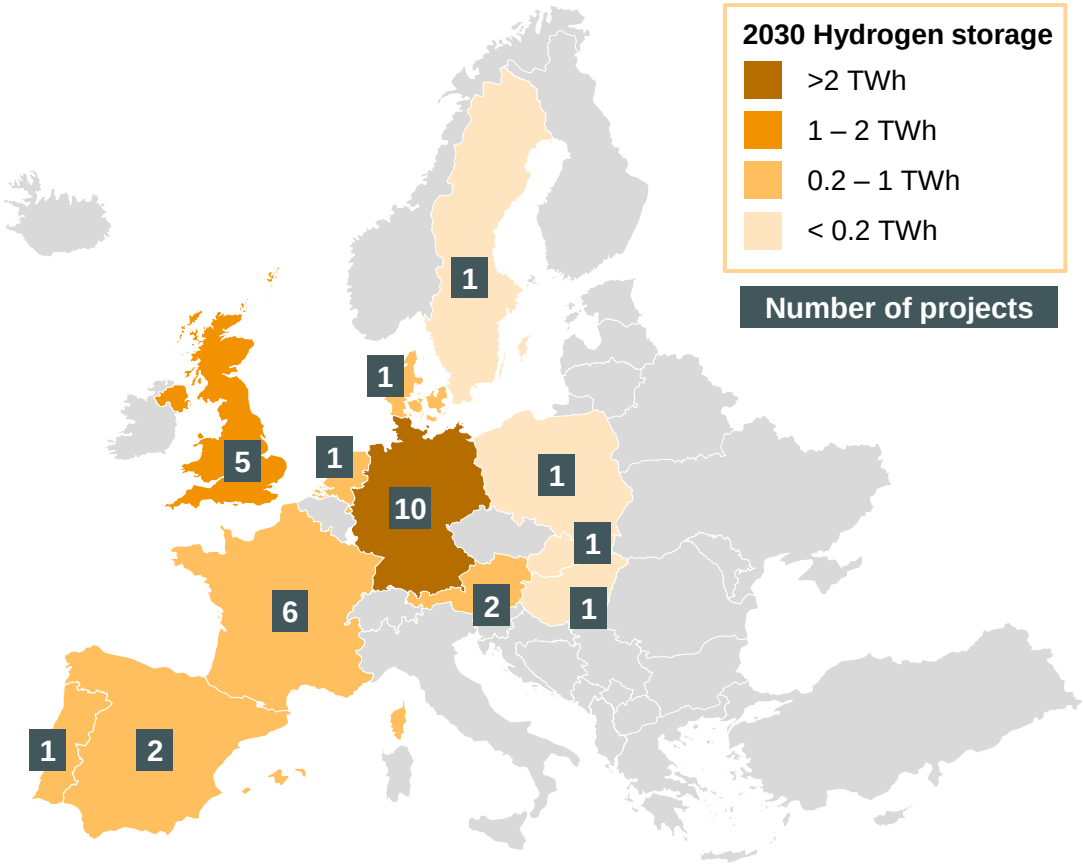
Hydrogen storage projects in Europe by 2030



Average project hydrogen storage capacity in Europe by 2030 (TWh)



Hydrogen storage planned project pipeline out to 2030

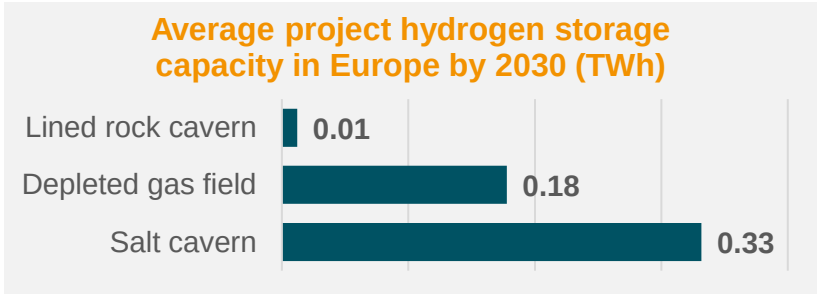


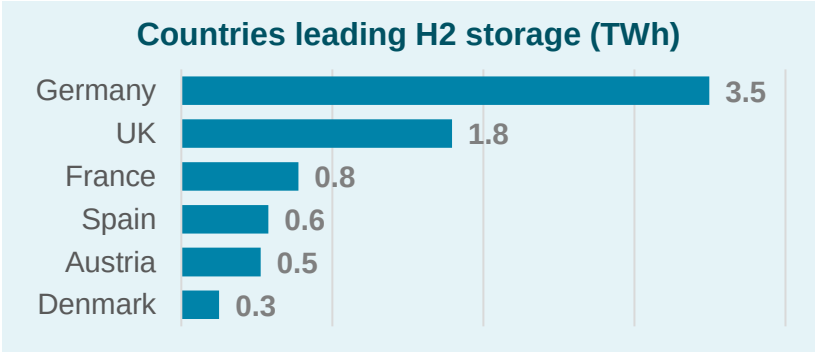
Leading markets, storage types, and capacities

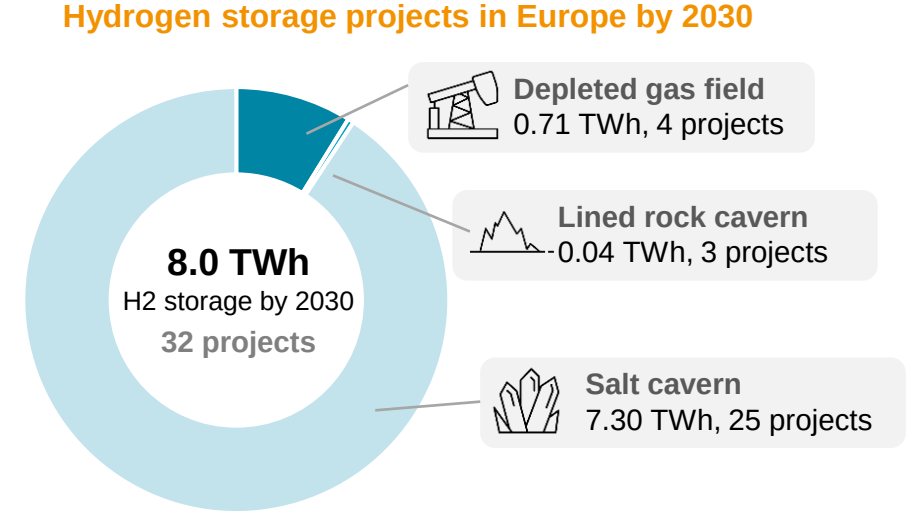
25 out of 32 underground hydrogen storage facilities by 2030 will be salt caverns

Two thirds of the planned hydrogen storage capacity by 2030 will be located between Germany and the UK, with the former accounting for the largest pipeline of 10 projects.

- **Salt caverns** make up over 90% of the storage capacity by 2030. The technology is mature, and the sites can be scaled up to accommodate smaller initial H2 volumes. Most of the sites use existing caverns.
- **Depleted gas field** projects will be fewer in number, but the few boast high storage capacity: just 3 projects will bring 0.71 TWh online. Some larger gas fields have been proposed for hydrogen storage, but these won't be developed by 2030.
- **Hardrock line caverns** can offer smaller scale storage solutions and are not restricted in location by geology. Initial projects are underway.
- There are some projects storing **hydrogen blended in methane** sites during the transition phase, a handful of these in Eastern European gas fields.







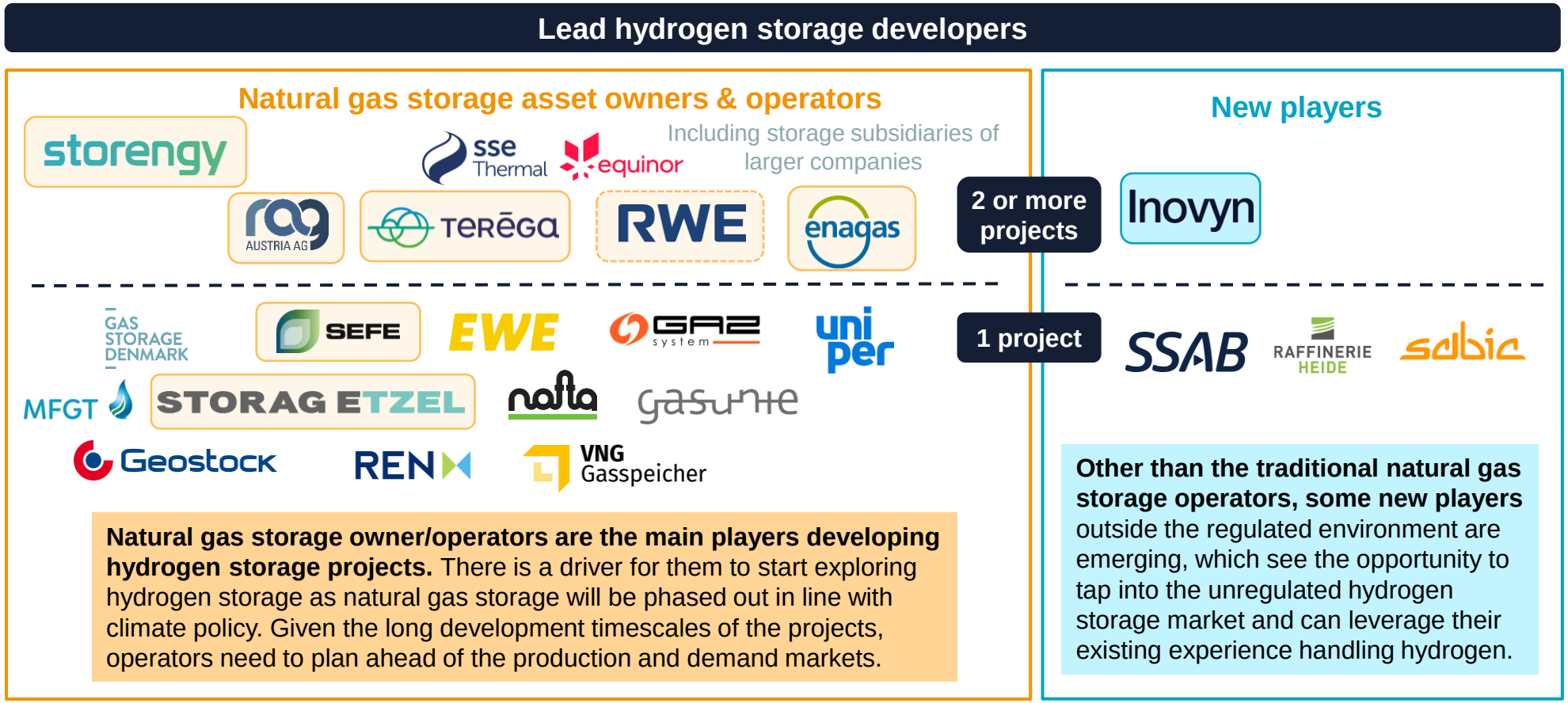
Natural gas storage asset owners & operators key developers

Storengy stands out with five hydrogen storage projects in the pipeline to 2030

~80% of planned H2 storage capacity projects are led by current natural gas storage operators. The top 8 developers by capacity and project count make up 84% of the pipeline capacity.

By capacity, 6 developers are aiming for ≥500 GWh hydrogen storage capacity by 2030. These are: Storag Etzel, Inovyn, Enagás, RAG Austria, Astora (SEFE) and Teréga.

By number of projects, **Storengy** is the leader, with five different sites planned out to 2030, followed by **RWE Gas Storage West GmbH**, which has three.



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Market sizing – GB case study

How much long-duration hydrogen storage will be available by 2030, and will this meet demand-supply requirements?

Case Study: 2030 UK hydrogen market – Inputs & Outputs

Annual hydrogen production to reach 27.8 TWh, 77% coming from blue H2

Model inputs

Production

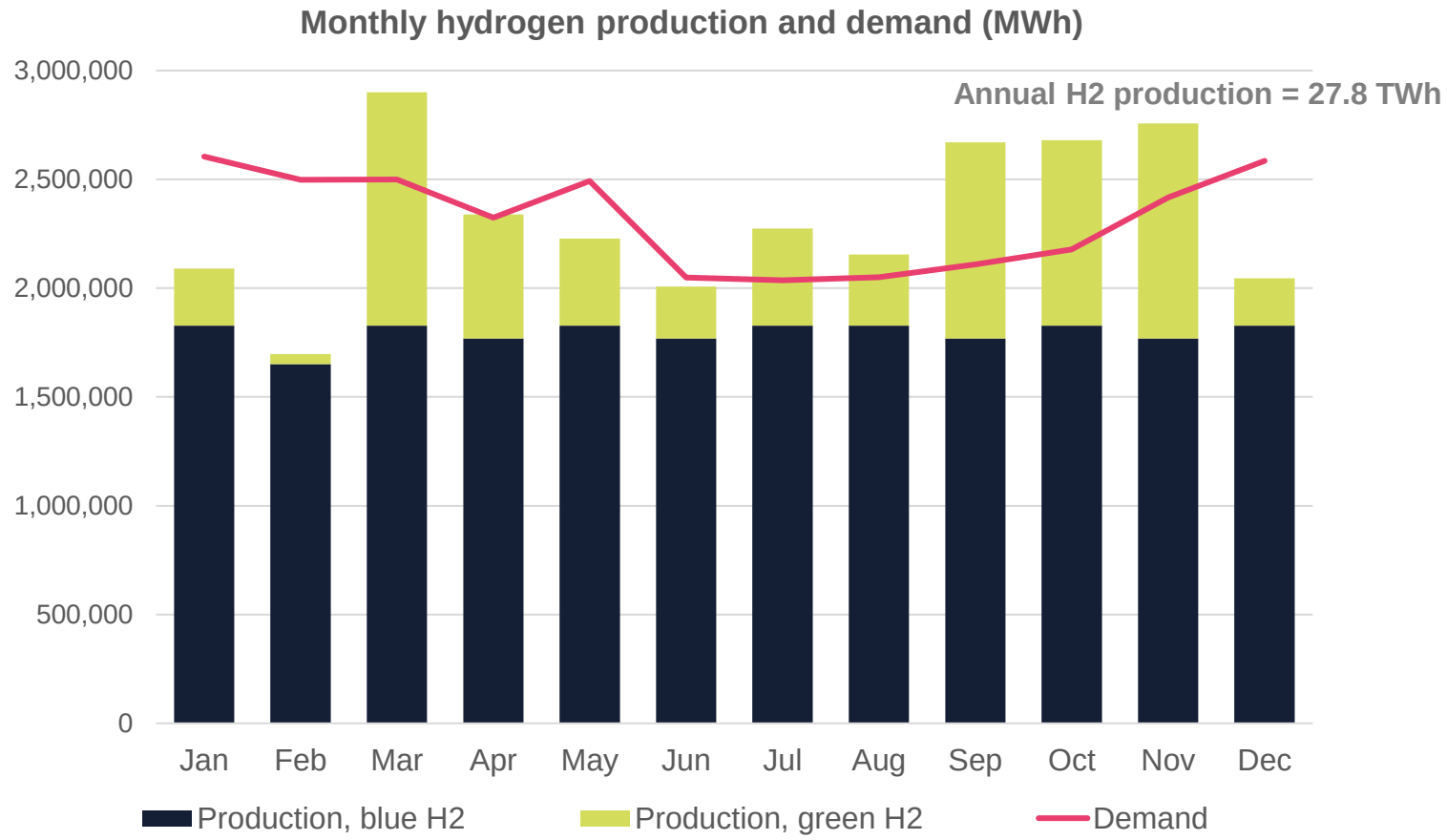
- **Green hydrogen:** 6.9 GW based on the pipeline in our project database, HYbase. LCP Delta's electricity dispatch model was used for this simulation.
- **Blue hydrogen:** 21.5 TWh annually to meet total annual demand after green hydrogen production.

Demand

Demand levels are based on the UK's hydrogen strategy and National Grid's 2023 Future Energy Scenarios as a benchmark.

- **Industry:** 21.3 TWh
- **Transport:** 1.9 TWh
- **Power generation:** 4.6 TWh
- **Heating:** 0 TWh

Model output

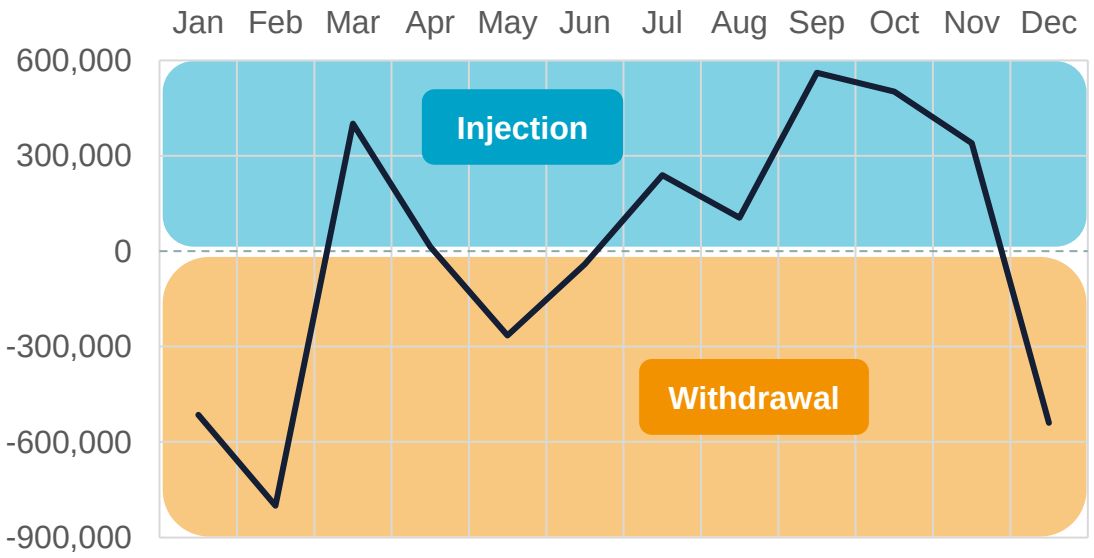


Case Study: 2030 UK hydrogen market – Storage requirements

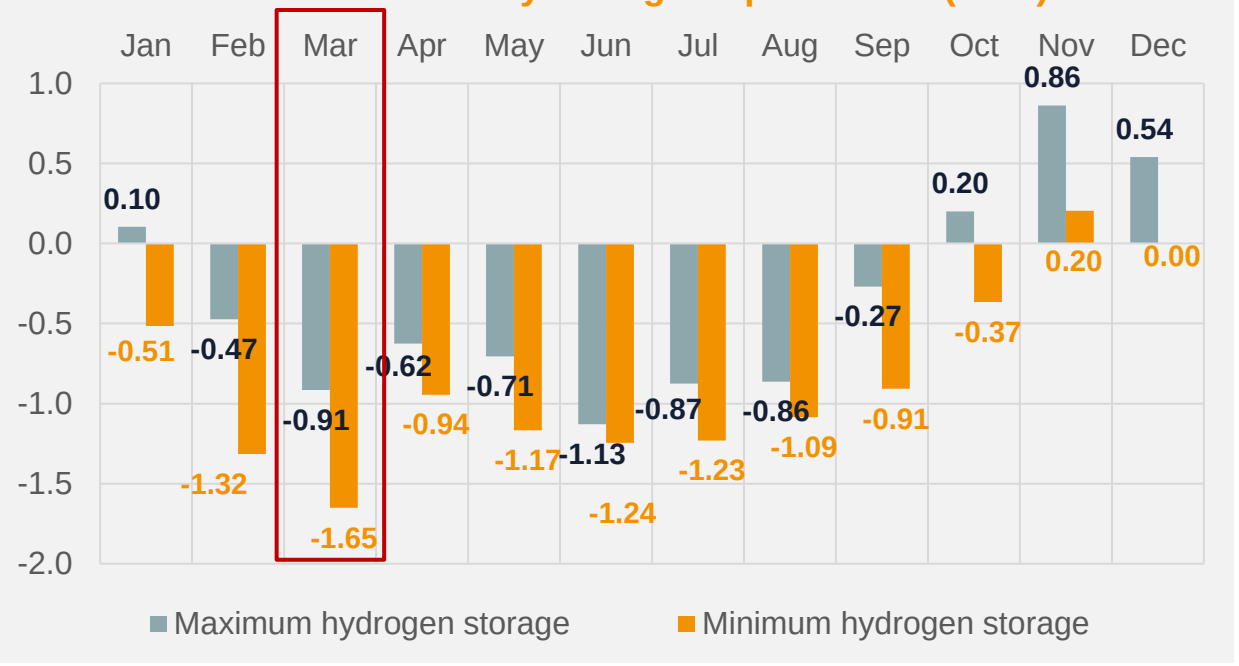
Hydrogen storage capacity volume requirements

Peak hydrogen storage capacity of 1.65 TWh met by current 2030 project pipeline of 1.85 TWh. Required storage corresponds to ~6% of the annual hydrogen demand.

Net monthly injection/withdrawal (MWh)



Cumulative monthly storage requirements (TWh)

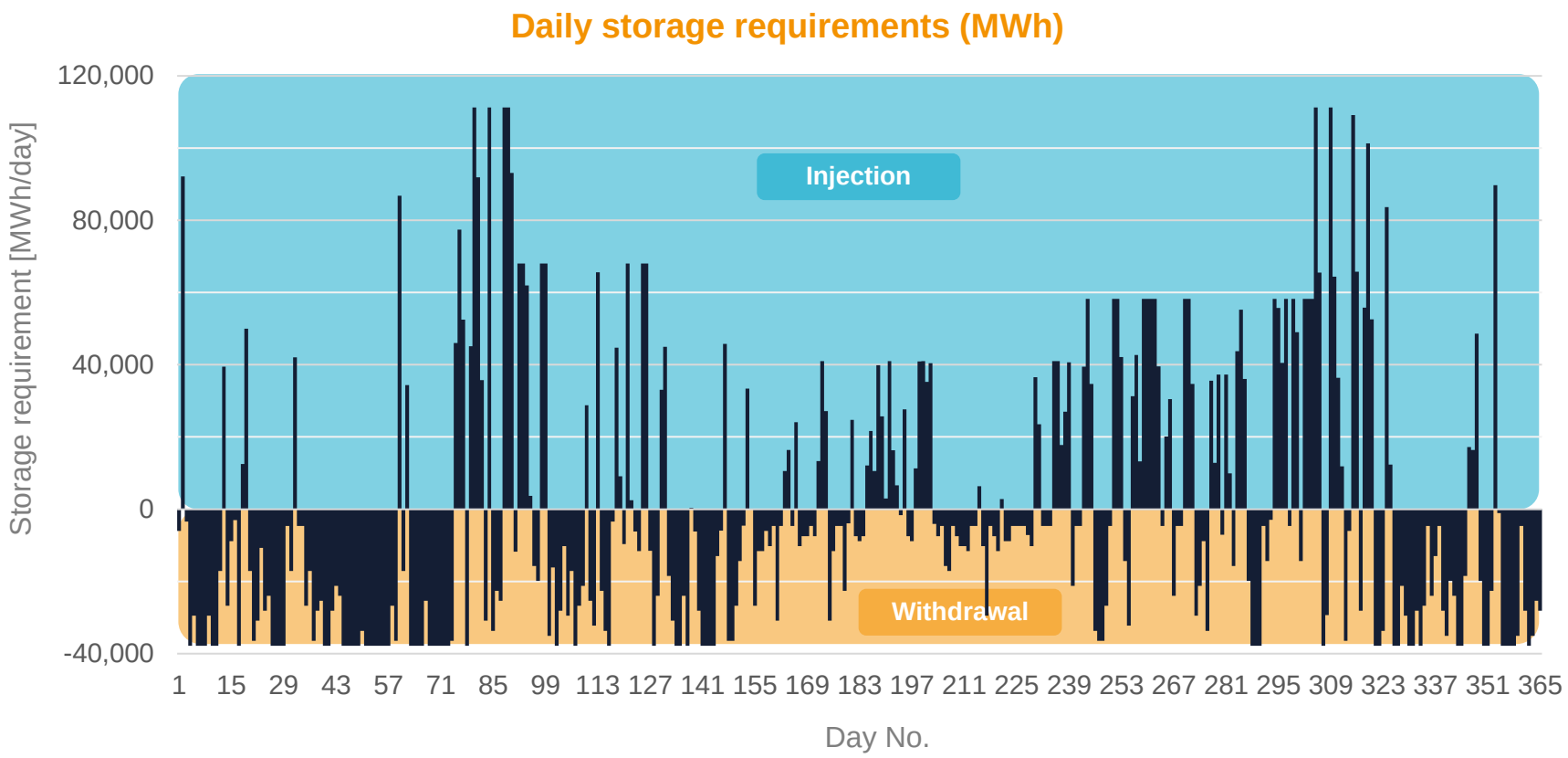


Case Study: 2030 UK hydrogen market – Storage requirements

Flexibility requirements

Max. Injection rates required
111 GWh/day

Max. Withdrawal rates required
38 GWh/day



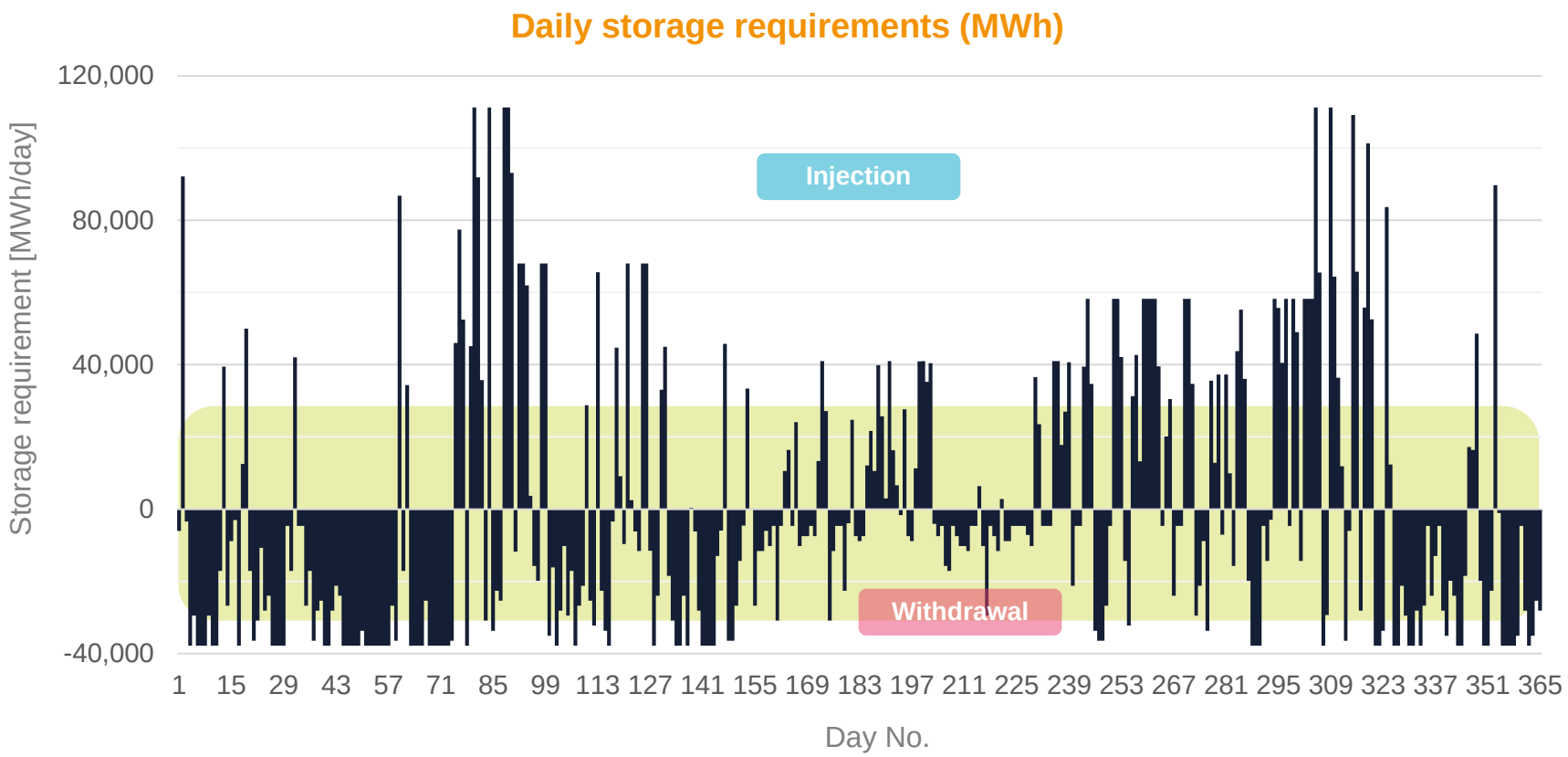
Case Study: 2030 UK hydrogen market – Storage requirements

Flexibility requirements

Maximum injection and withdrawal rates would not be met under the proposed project pipeline. Higher injection rates are required compared to withdrawal peak rates.

Max. Injection rates required
111 GWh/day

Max. Withdrawal rates required
38 GWh/day



Only 40% of the hourly flexibility requirements would be met

Outlook across Europe

8 TWh of hydrogen storage is equivalent to storing 1% of the targeted H2 volumes

In the modelled UK 2030 scenario, storage equivalent of 6% of total hydrogen demand is required.

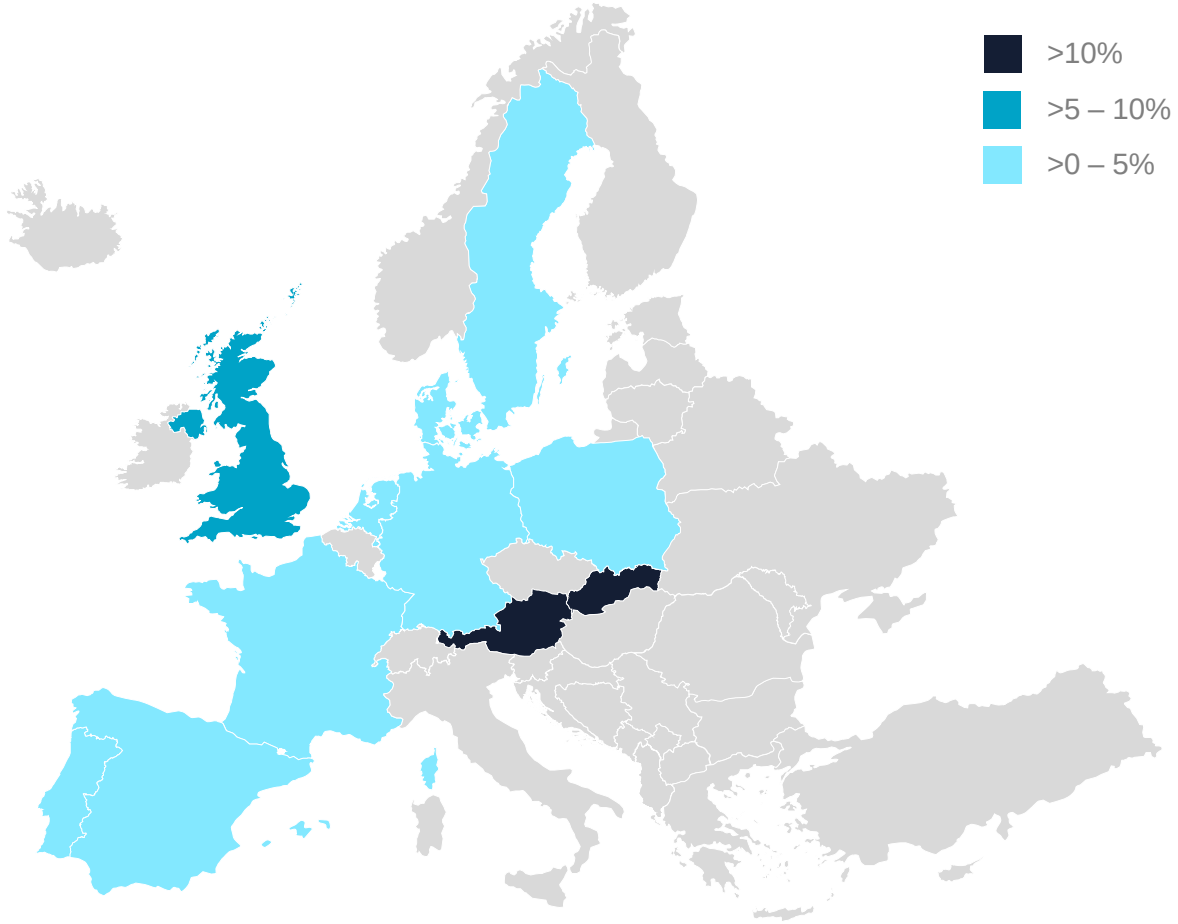
Looking into Europe…

- Hydrogen storage pipeline accounts for less than 5% of expected hydrogen availability, for most countries. These **storage volumes will fall short** of operational needs.
- **Austria and Slovakia** are exemption, as both have a gas field planned by 2030, and low hydrogen targets.
- **Higher production variability** from focus on green hydrogen will increase need for storage.
- **Fast cycling** of hydrogen storage must be designed into the storage facilities to accommodate the expected demand profiles and enable production scale-up.

Under the RePowerEU strategy, the EU's goal for hydrogen availability is to produce 10 million tonnes of clean hydrogen and import an additional 10 million tonnes. Including UK this would **total ~810 TWh.**

8.0 TWh of hydrogen storage would only represent **1% of the total hydrogen available across Europe**, which again is likely to fall short.

Storage capacity as a share of the available clean hydrogen



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Investment Risks

What types of value does long-duration hydrogen storage provide?

Which risks limit the realisation of this value, and how can these be overcome?

What risks are storage operators facing?

Large investments without regulatory or commercial visibility create a large risk burden on developers.

First project costs ●○○

Uncertainty about construction costs (CAPEX)

Costs for different types of hydrogen storage are not well understood due to a lack of commercial operation. A risk of construction overrunning could increase capital costs.

Energy security ●○○

Uncertainty about availability of sites for hydrogen

The conflict in Ukraine and the energy crisis brought to the forefront the need for natural gas storage for resilience. This limits the sites that can be used for hydrogen.

Supply chains ●○○

Uncertainty about reliability of the new supply chain

Being a new market, there are limited players to provide components and the technology (and compliance) is somewhat immature. Construction gets delayed as a result.

Technical ●○○

Uncertainty about the behaviour of hydrogen in sites

Initial tests and research are ongoing to better understand the behaviour of hydrogen in storage (e.g., chemical interactions) and how this can be safely managed.

Demand profiles ●●○

Uncertainty about the type of demand to cater to

The type of demand dictates the type of storage operation profile (cycling speed) needed. There is a lack of visibility on which hydrogen end-users will use storage, and when.

Demand volumes ●●●

Uncertainty about volume of services demanded

It is difficult to see when the hydrogen market will mature to the extent to need large-scale storage, and thus if storage will make enough revenue to cover operation costs.

Regulation ●●●

Uncertainty about how/when regulation will form

There is little visibility on how hydrogen storage will be regulated and how much this framework will depart from the natural gas model. This limits investment in projects.

Pricing ●●●

Uncertainty about the prices users will pay for storage

Remuneration of hydrogen storage is a central element, but unclear. Storage operators have no visibility on willingness to pay as they deal with sellers, not end-customers.

Impact of risk on investment

High ●●●
Medium ●●○
Low ●○○

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Questions

Contact us

Investing in energy storage assets in an ever-changing regulatory and competitive backdrop has never been more complex.

If you would like to hear how we help our clients with their battery assets, from investor due diligence to real time trading, get in touch with us..

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