



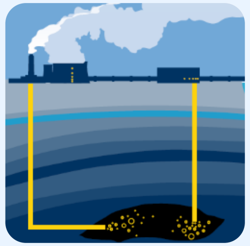



Techno-economic analysis of hydrogen storage in salt caverns

Hydrogen Storage in Caverns 2023

29th March 2023

hypster Hydrogen Storage

Co-funded by the European Union

Clean Hydrogen Partnership

"This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101006751. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research."

elementenergy
an ERM Group company

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Introduction to Element Energy and ERM

ERM's Hydrogen Expertise

- **Concept development of hydrogen projects** including technology selection, financial modelling, hydrogen demand and off-take scenarios.
- **Strategy Advisory** including development and analysis of strategic responses to climate change and the low carbon energy transition for **industry** and **Government**.
- Hydrogen **hazard assessment and risk assessment including** hydrogen production facilities, storage and pipelines.
- **Techno-economic feasibility** including detailed cost estimates, financial modelling, and technical options evaluation for new projects.
- **Stakeholder engagement** (technical and non-technical).
- **Safety & environmental consent** delivery for projects (Planning, EIA, Seveso III, Permitting, etc.).
- **Lifecycle assessment**

ERM is the world's largest pure play environmental, health and safety, risk and sustainability consultancy

In 2021 number of renewable consultancy services were acquired:

E4tech – an ERM Group company

elementenergy – an ERM Group company

rcg

We pride ourselves on supporting the projects that accelerate the transition to net-zero and are most involved in early stage projects

Level of involvement in projects:

Feasibility studies → Conceptual design → FEED → Detailed design → Construction / installation → EPC

Need for salt cavern storage: Ambitious hydrogen targets and meeting net-zero

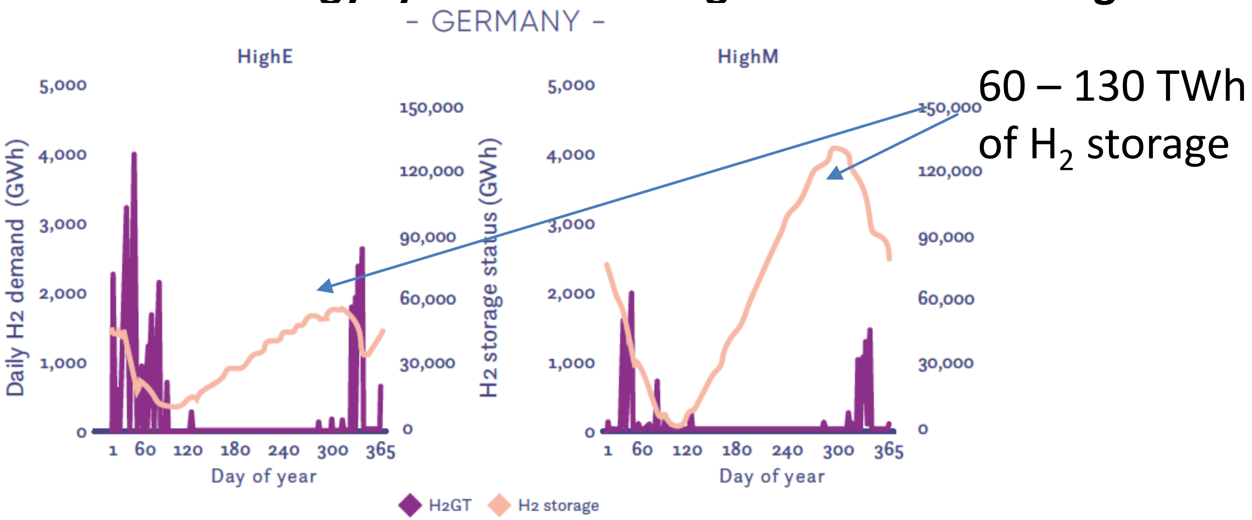
- There is a clear need for large scale, long duration storage in the future energy system: Managing variation in renewable supply and energy demands.
- By 2030, large scale H_2 production is targeted.
- Definition of 'Low carbon' and 'Renewable' hydrogen set by the EU will require some matching of renewable generation to hydrogen production:
  - UK: 30 minute matching
  - EU: Monthly to 2030, hourly from 2030

Ambitious goals for large scale H_2 production in 2030

10 GW Low carbon hydrogen production. 5 GW renewable

10 Mt Renewable H_2 production (c. 80 GW) with equal imports

Net-zero energy systems need large volumes of storage:



European Climate Foundation – Towards Fossil-Free Energy in 2050, March 2019 - link

The lack of hydrogen storage is a challenge for large scale production projects

- We will present some learnings based upon:
  - Support for EU and UK's leading >100 MW scale H_2 production projects
  - Work in Progress on H_2 storage business case for HyPSTER

- 100 MW scale renewable hydrogen projects without salt cavern storage are compensating renewable variation by:
  - Ramping up and down 'grey' H_2 supply to compensate.
  - Importing power from the grid.
  - Using flexibility in offtakers
  - Procuring more renewable capacity than the electrolyser needs

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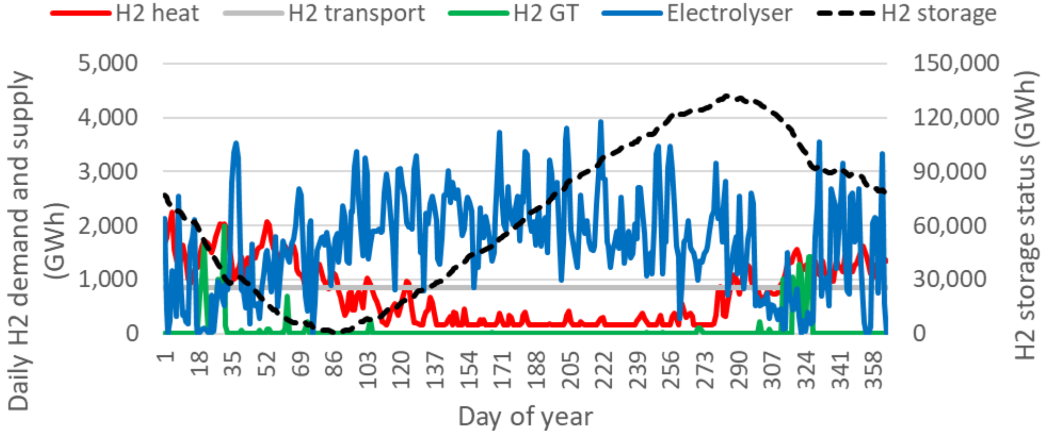
Demo scale: 43 tH_2 (Hypster[1])

Full scale: 6,000 tH_2

Salt cavern information	Demo	Full scale
Electrolyser supported (MW)*	30	350
Time for full withdrawal	4 days	43 days

Example H_2 production modelling



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There are several key questions that need to be addressed to better understand the business case for hydrogen storage in caverns

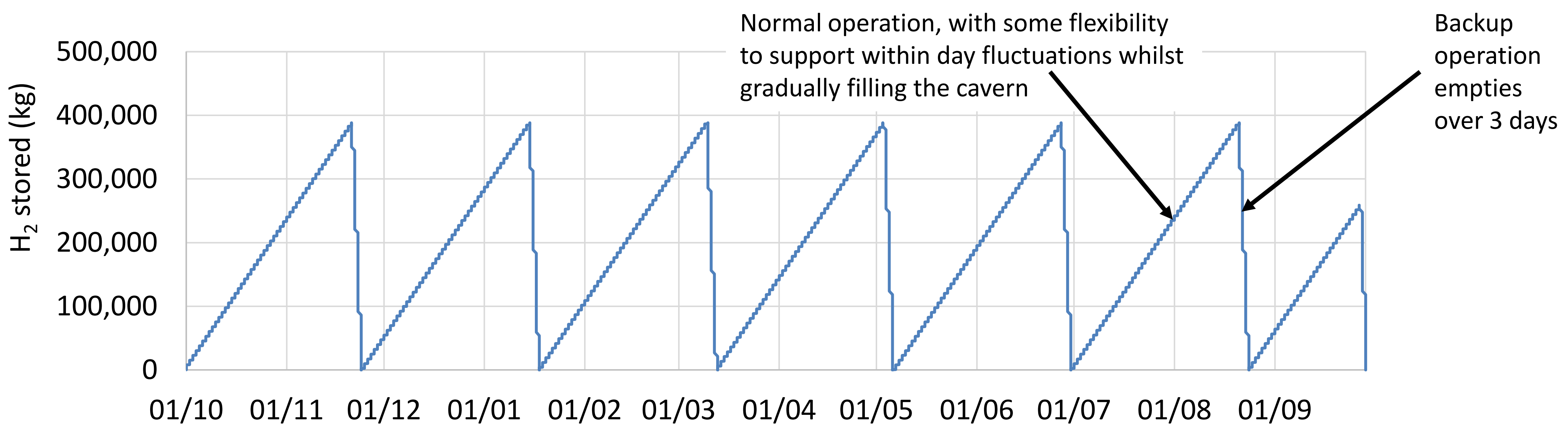
1. What services can hydrogen caverns provide during the energy transition?

2. How do the costs of developing and operating caverns compare to customers’ potential willingness to pay?

3. What is the potential of hydrogen storage in caverns to contribute to the wider energy system?

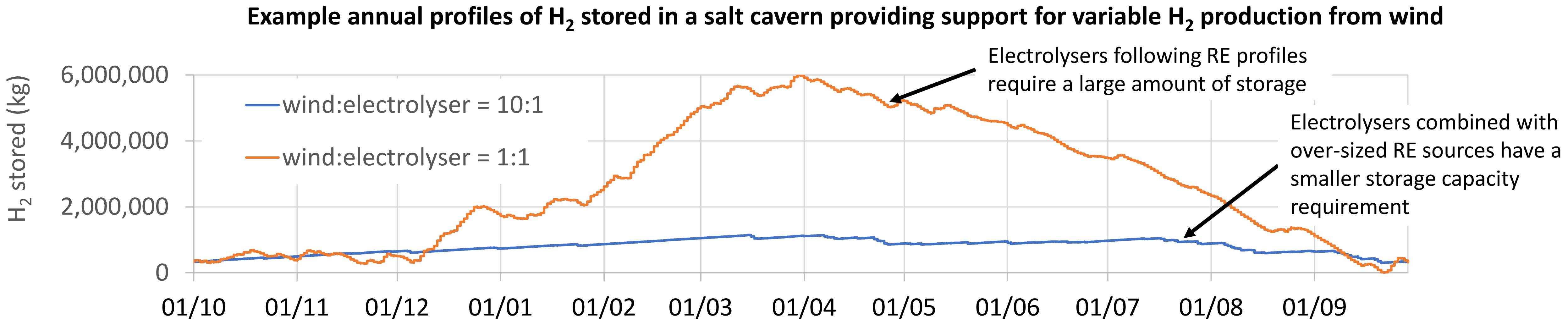
One potential use case is to ensure guaranteed supply to end users by providing back up services during periods of hydrogen production downtime

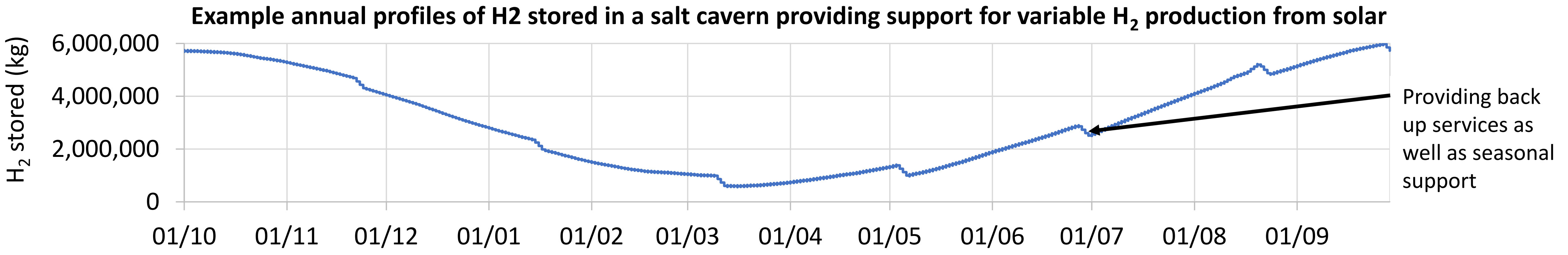
Example annual profile of H_2 stored in a salt cavern providing backup services



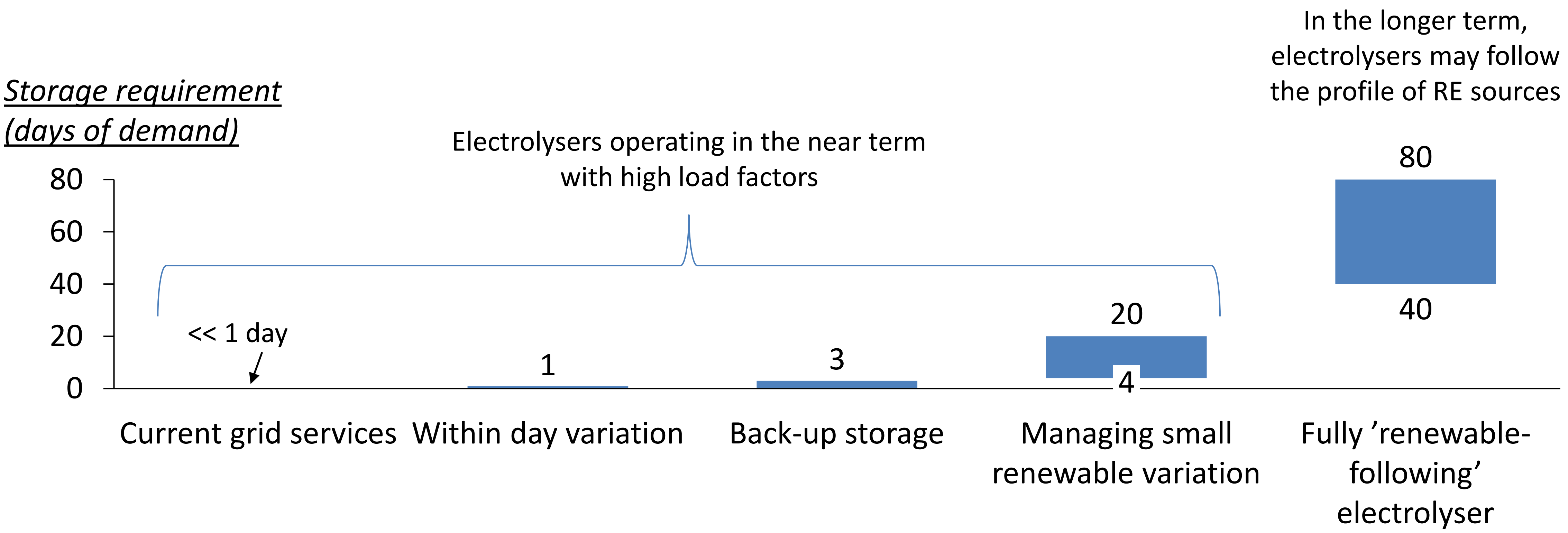
Example profile based on a 6,000 tH_2 cavern with a maximum withdrawal rate of 5390 kg H_2/hr

Salt caverns can provide storage on a seasonal timescale to support variable hydrogen production from renewables





The scale of storage required is highly variable depending on the services provided by the cavern



Hydrogen caverns could adapt their operating profiles to provide a range of other services

- Supporting large scale **variable demand from hydrogen for heating**.
- Providing buffer storage for large scale **energy import/ export projects**.
- Providing large scale energy storage for the **power sector**.
- Supporting network operators in managing **extreme events in the energy system**, such as extreme weather events.

Larger storage capacity requirement use cases

- Enabling H_2 production facilities to adapt operations in response to **electricity price signals** and/or to **maximise compliance with renewability criteria**.
- Providing **grid balancing services**.

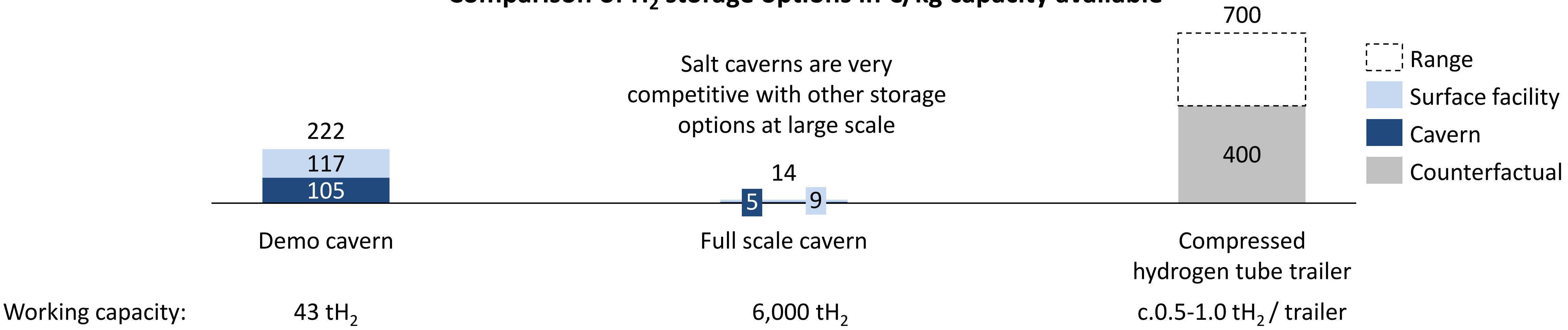
Potential additional benefits to the H_2 value chain (likely to be withdrawal rate limited)

Hydrogen storage in caverns can be cost competitive with counterfactuals on a per capacity basis

Example counterfactuals include:

- Alternative geological hydrogen stores (aquifers, depleted oil & gas reservoirs)
- Other hydrogen storage facilities (compressed hydrogen storage, linepack, H_2 carriers e.g. LOHC)
- Other energy storage options (batteries, compressed air energy storage, thermal)

Comparison of H_2 storage options in €/kg capacity available[1]



However the relatively cheap cost per kg is only a fair comparison if the majority of this much larger storage capacity is actually utilised.

1 - EE high-level analysis. Note that costs vary depending on factors such as whether cavern is new built or repurposed, and end use (and therefore output pressure and purity).

There is a need to assess the counterfactual to hydrogen storage in caverns to understand customers' willingness to pay

- Customers' willingness to pay will be influenced by the other options for providing similar services.

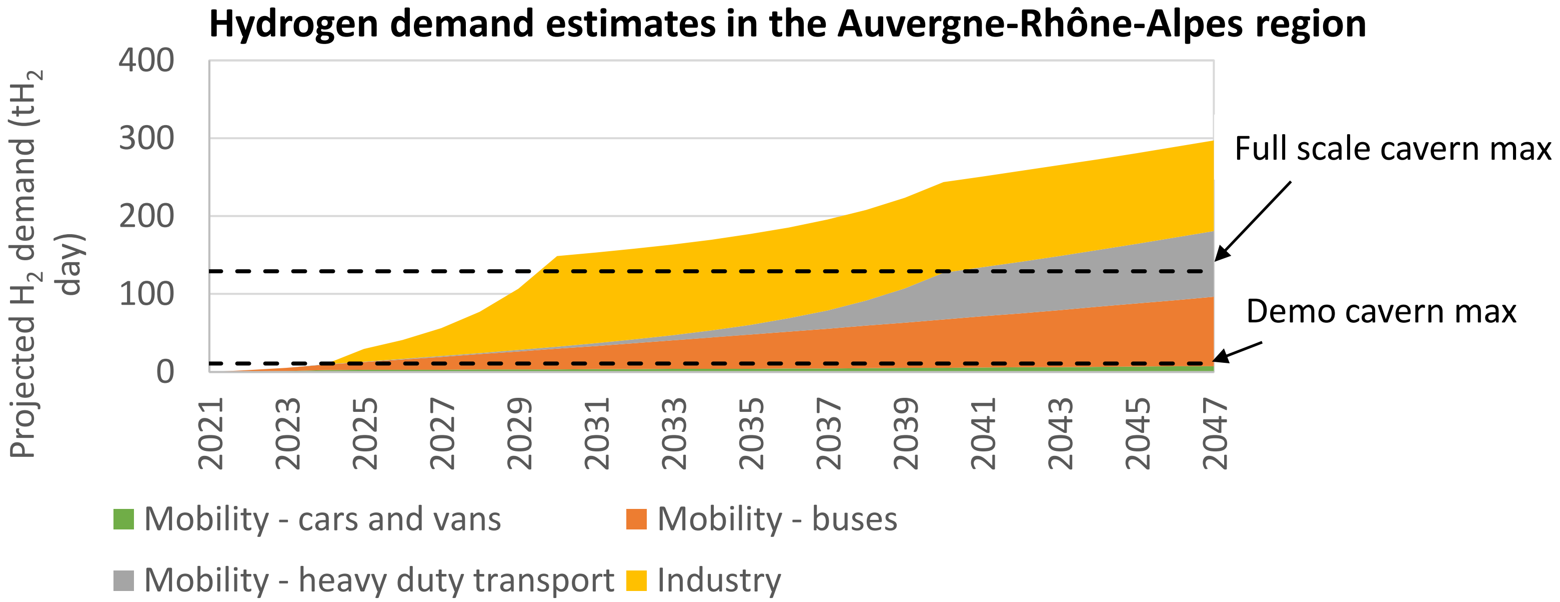
- Different use cases are likely to have different counterfactuals.

- The framing of costs for cavern operators can significantly affect the comparison to counterfactuals. For example, the cost of the cavern could be considered:
  - based on the **storage capacity provided**;
  - based on the **maximum withdrawal rate capacity**;
  - per unit of **hydrogen throughput** through the salt cavern;
  - by **distributing costs across end users' total hydrogen consumption**.

The commercial viability of hydrogen storage in caverns is highly dependent on the development of key enabling factors: demand and infrastructure

- Development of **large scale hydrogen demand** is needed to fully utilise the salt caverns.
- **Pipeline infrastructure** is needed between users, storage and production.

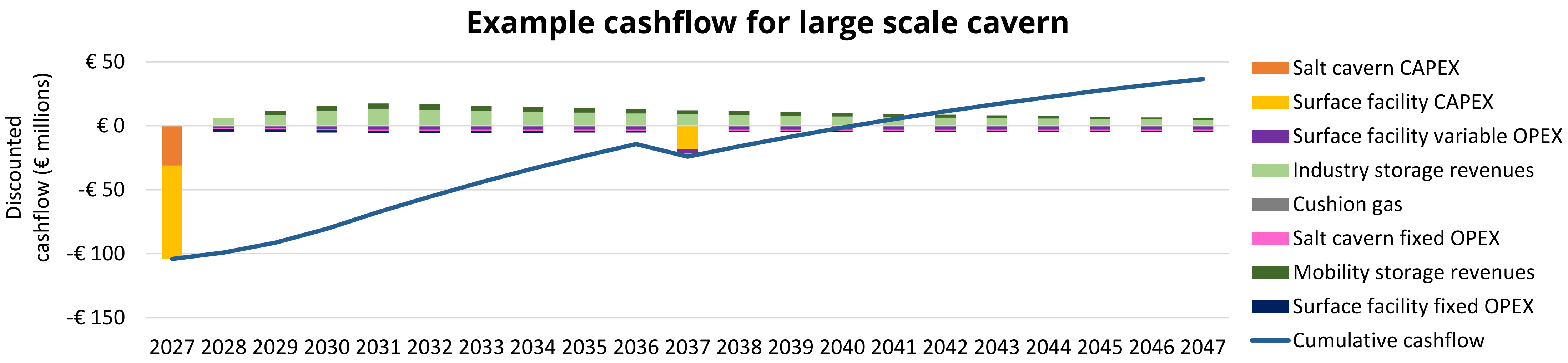
Key salt cavern information	Demo	Full scale
Electrolyser size supported (MW)*	30	350
Time for full withdrawal	4 days	43 days
Amount of storage (t H_2)	43	6,000



*Assuming able to meet demand when electrolyser running at 70% load factor has downtime.

Large scale cavern costs are not high within the context of hydrogen supply chain

- A hydrogen salt cavern could result in an **increase of c. €0.50 for the levelised cost of hydrogen** (LCOH), when fully utilised[1], which is not high in the context of current H2 production costs 3.70-5.50 €/kg[2].
- Cavern costs are **CAPEX dominated**, and benefit from economies of scale.
- The **withdrawal rate** is often the limiting factor for caverns providing multiple services.



1 – based on analysis for the 6,000 tH_2 large scale capacity cavern
2 – See for example Hydrogen Europe analysis in NWE, before subsidy, see for example link, reflects projects in development

Further work is required to understand the techno-economics of hydrogen storage in caverns during and after the energy transition

- By 2030, it is clear that salt cavern storage will be valuable to the hydrogen sector based on projections for hydrogen demand and supply.

- However, the business case for early projects needs to be considered on a case by case basis depending on early market conditions, including demand-side, supply-side, infrastructure, national energy system decarbonisation etc.

- If storage operators and governments act now, this work will support the next generation of projects (in turn enabling future projects to benefit from technical and commercial learnings), develop understanding regarding optimal subsidy scheme structuring, and ultimately mean that hydrogen storage in caverns can make a valuable contribution to the energy system in a fully decarbonised world.