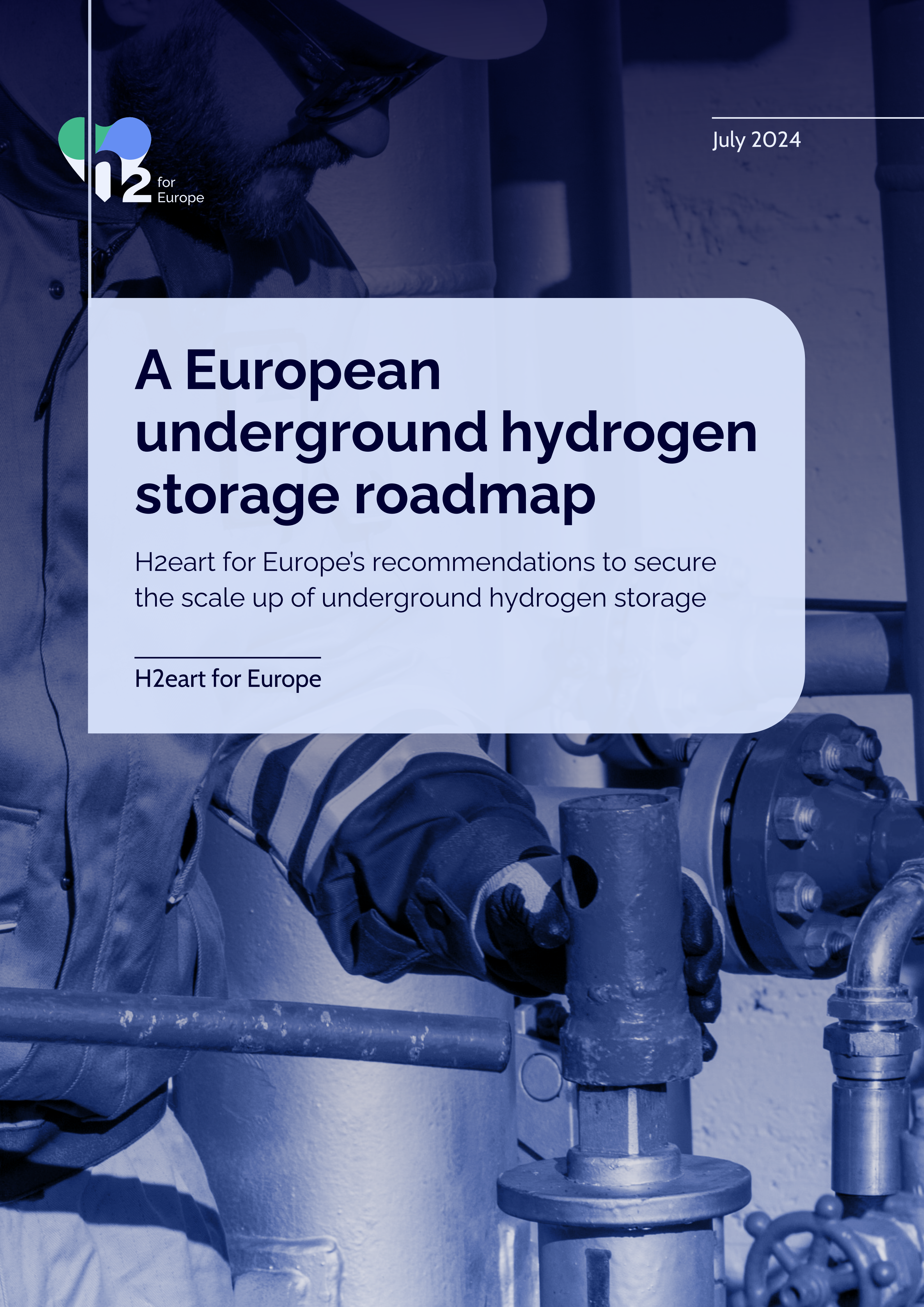


July 2024

A European underground hydrogen storage roadmap

H2eart for Europe's recommendations to secure the scale up of underground hydrogen storage

H2eart for Europe

A European underground hydrogen storage roadmap

Published in July 2024 by H2eart for Europe. Copies of this document are available upon request or can be downloaded from our website: www.h2eart.eu.

This report was authored by H2eart for Europe in collaboration with Guidehouse as knowledge partner. The authors of the report confirm that:

1. There are no recommendations and/or any measures and/or trajectories within the report that could be interpreted as standards or as any other form of (suggested) coordination between the participants of the study referred to within the report that would infringe EU competition law; and
2. It is not their intention that any such form of coordination will be adopted.

Whilst the contents of the report and its abstract implications for the industry generally can be discussed once they have been prepared, individual strategies remain proprietary, confidential and the responsibility of each participant. Participants are reminded that, as part of the invariable practice of H2eart for Europe and the EU competition law obligations to which membership activities are subject, such strategic and confidential information must not be shared or coordinated – including as part of this report.

Imprint

Design
Annemiek Schellenbach | annem.nl

Authors
Helena Lönnberg, Jeroen Wegh, Jaap Peterse

Picture credits
Cover: ©Snam

Date
July 2024

Contact
Guidehouse France
6 Rue Auber
Office 404
Paris, 75009 France

Steps to ensure the development of underground hydrogen storage

Underground hydrogen storage (UHS) is pivotal for a decarbonised, cost-efficient and reliable future of Europe's energy system, but important steps need to be taken to ensure its development.

UHS brings a broad range of cross-sectorial benefits to the EU energy system:

+ **Balances** intermittently produced renewable energy sources (RES) and can **limit RES curtailment**;
+ Makes **green hydrogen more affordable** as it facilitates production at peak RES hours;
+ Unlocks **cost-efficient network planning & prevents oversizing** of other system parts (e.g. interim fossil fuel solutions, RES);
+ **Ensures reliable supply of hydrogen** & improves of European energy security;
+ **Meets evolving flexibility needs** (ranging from short-term to seasonal storage needs which cannot be met by batteries).

Unlocking these benefits and ensuring the timely & smooth development of UHS **requires pragmatic measures to de-risk UHS projects and kick-off private investment.**

To ensure that UHS projects can be operational by the time they are needed, the **implementation of multifaceted solutions is urgently needed.**

For 2030, there is a 36 TWh H_2 storage gap in the EU. Today, UHS development times are long (5-10 years) and urgent action is needed. H2eart for Europe proposes the following actions to be taken for successful UHS development until 2030 and beyond:

Actions

Policy

» Develop long-term clarity on preferred tariff methodology (e.g. transition between nTPA to rTPA by 2032).

» Incorporate UHS across network plans for H_2, gas, and electricity.

» Streamline permitting processes (short-term) & grant UHS projects priority status (long-term).

» Discuss and decide EU-wide H_2 purity standards to provide investment security for purification-related infrastructure.

Economics

» Develop a toolbox on EU-level from which Member States can construct UHS financial support mechanisms.

» Design & implement financial support on Member State-level to bridge the gap between developing & developed market (e.g. CfD, MRF).

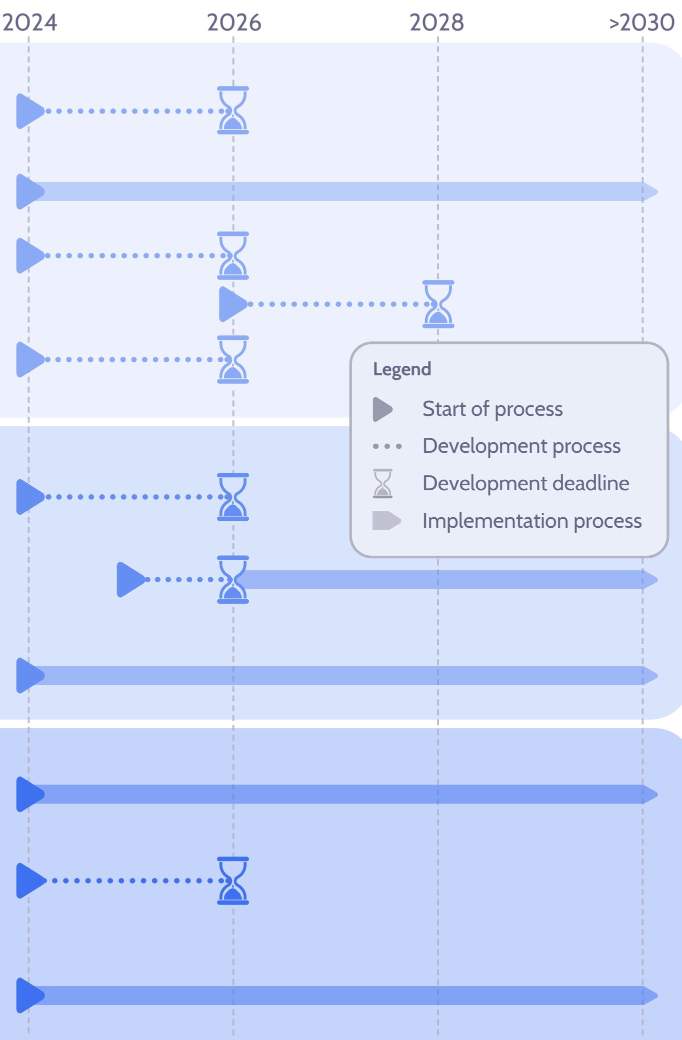
» Grant financial support for UHS from EU funds.

Implementation

» Conduct site-specific screening process to determine suitability for UHS.

» Leverage lessons learned from pilot projects to simplify and standardise permitting procedures in a bottom-up approach.

» Provide coordination for nation-wide market consultation processes & Open Seasons.



Executive Summary

The integration and scale-up of underground hydrogen storage (UHS) is crucial for the optimisation of the European energy system as UHS presents a valuable solution for balancing the volatility inherent in renewable energy production and guaranteeing overall energy system resilience by ensuring a reliable supply of hydrogen.[1]

By limiting the curtailment of renewable energy sources (RES) and unlocking cost-efficient hydrogen production, the integration of UHS can lead to overall system cost savings from the first year of operations, and facilitate the efficient build out of Europe's future decarbonised energy system (e.g. optimising all other system parts).[2]

However, significant investment uncertainty – primarily linked to the nascent status of the European hydrogen market – inhibits the development of European UHS projects. Urgent action is required to mitigate risks (e.g. long lead times), establish a viable business model, and trigger investments starting as soon as 2025 so that operation around 2030 is realistic.

Regulatory Framework: Opportunities, Risks & Solutions

» The Gas Decarbonisation Package sets a foundational regulatory framework for the integrated gas and hydrogen market, explicitly including UHS. It introduces a phased approach to tariff setting, granting Member States the optional flexibility to start with negotiated tariffs until 2032, followed by a transition to regulated tariffs. More detailed guidance is needed on the exact changeover between possible tariff methodologies as soon as possible so as to increase investment security for storage operators and minimise price risk for customers.

» Coordinated network planning across energy carriers is emphasised, yet the package lacks sufficient clarity on integrating UHS, necessitating further guidance for effective stakeholder engagement and infrastructure development at both national and EU levels.

» Additional measures, such as the introduction of EU and Member State UHS ambitions as well as KPIs tracking the development of the UHS market, are essential.

1 H2eart for Europe (2024). The role of underground hydrogen storage in Europe (Link)

2 Gas Infrastructure Europe (2024). Why European underground hydrogen storage needs should be fulfilled, executed by Artelys and Frontier Economics (Link)

Derisking the UHS Business Model

- Financial support mechanisms are crucial in the early stages to decrease financial risk and increase rewards, incentivising investment in UHS projects.
- Risk mitigation can be achieved through the implementation of mechanisms aimed at enablingan intertemporal cost allocation of CAPEX-intensive UHS projects. H2eart for Europe proposes a toolbox which discusses tools such as Contracts-for-Difference (CfD) and Minimum Revenue Floors, as well as mechanisms like amortisation accounts and clawback.
- Risk mitigation initiatives in combination with publicly coordinated and binding capacity allocation tenders can unlock private financial backing for UHS projects.

Remaining Implementation Challenges

- The existing commitment and technical expertise of UHS operators to develop UHS technologies and projects has greatly mitigated technical and project risks, making implementation risks significantly lower than the regulatory and financial challenges.
- Remaining implementation roadblocks are mainly linked to lacking standardised UHS guidelines that complicate permitting processes. Developing clear standards as well as leveraging learnings from pilot projects is essential to streamline these processes.
- Moreover, understanding market requirements through consultations and Open Seasons is critical for planning UHS capacities and ensuring system flexibility. Today, market consultations are mostly conducted by UHS operators. A centralised approach for market consultations or coordinated capacity tenders / auctions combined with financial support mechanisms is crucial to unlock private financial backing for UHS projects.

Table of Contents

Executive Summary III

Glossary VII

About VIII

01. Introduction 10

1.1 H2eart for Europe's strategic vision: increasing investment security 10

1.2 Situating UHS in Europe's decarbonised future 11

1.3 Starting point & aim of this roadmap 13

1.4 Report structure 13

02. Policy & regulation 14

2.1 UHS and the Gas Decarbonisation Package: ambiguity remains 15

2.2 Pathways for market certainty: EU UHS ambitions and KPIs 19

2.3 Removing permitting roadblocks 21

2.4 Developing UHS whilst guaranteeing security of supply 23

2.5 European hydrogen purity standards to ensure maximum compatibility with use cases 23

2.6 Discounts may encourage use of UHS capacities 24

03. Economics 25

3.1 Status quo: high market uncertainty undermines UHS business model 26

3.2 H2eart for Europe's Toolbox of financial support mechanisms: mitigating risk and creating a valid business model 29

04. Implementation 36

4.1 Lacking high-level vision for UHS translates into overall market uncertainty 37

4.2 Project-level implementation risks 37

4.3 Understanding market needs – market consultations and open seasons 38

05. Conclusion & recommendations 40

Appendix 42

Glossary

API	American Petroleum Institute standard(s)
CAPEX	Capital expenditure
CBA	Cost-benefit analysis
CEF-E	Connecting Europe Facility Energy
CfD	Contracts for Difference
DEVEX	Development expenditure
ENNOH	European Network of Network Operators for Hydrogen
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	The European Network of Transmission System Operators for Gas
ESMA	European Securities and Markets Authority standard(s)
EU	European Union
GIE	Gas Infrastructure Europe
KPI	Key performance indicator
LCOH	Levelised cost of hydrogen
MRF	Minimum Revenue Floor
MS	Member state(s)
NRA	National Regulatory Authority
nTPA	Negotiated third-party-access storage regime
O&M	Operation and maintenance
OPEX	Operational expenditure
PCI	Project of common interest
RES	Renewable energy source(s)
RFNBO	Renewable fuels of non-biological origin
ROI	Return on investment
rTPA	Regulated third-party-access storage regime
SSO	Storage system operator
TEN-E	Trans-European Networks for Energy
TYNDP	Ten-year network development plan
UGS	Underground (natural) gas storage
UHS	Underground hydrogen storage

About

Underground hydrogen storage

Most European countries are increasing their production and consumption of renewable energy sources in an effort to gradually decarbonise their energy consumption due to the unprecedented challenge of climate change.

This increase in reliance on intermittently produced energy reveals the urgent need for the development of sustainable energy storage solutions, capable of balancing out the inherent volatility in electricity production from renewable sources.

Underground hydrogen storage (UHS) is a low-cost, market-ready and scalable storage solution that is safe and can build on existing infrastructure resources, as well as complement a nascent hydrogen ecosystem in Europe.

Currently, salt caverns, depleted gas fields, aquifers, and lined rock caverns are the predominately discussed hydrogen storage technologies. Amongst these storage types, distinctions in size, withdrawal and injection rates, cycle capacity, and repurposing maturity are evident. A series of innovative UHS projects are currently being carried out within the EU to investigate and analyse repurposing potential, as well as necessary changes in plant design and layout to meet exacting standards.

H2eart for Europe

H2eart for Europe is an EU-wide, CEO-led alliance committed to accelerating the decarbonisation of the European energy system at the lowest cost to society by scaling up the deployment of underground hydrogen storage. Launched in January 2024, the alliance aims to provide fact-based reports and analysis that can serve policymakers as guidance, and that utilise and build on the experience of our members, leading companies paving the future of hydrogen storage across Europe.

The organisations listed below are the members of H2eart for Europe. The report was prepared by the alliance in collaboration with Guidehouse as knowledge partner.

Guidehouse

Guidehouse is a leading global provider of consulting services to the public sector and commercial markets, with broad capabilities in management, technology and risk consulting. Over 1,700 of Guidehouse's 16,500 consultants are specialised in accompanying industry, utility, investor and government clients through the energy transition.

The founding partners

01 Introduction

1.1 H2eart for Europe's strategic vision: increasing investment security

Rising to the challenge of climate change requires unprecedented innovation, investment, and commitment to develop actionable solutions across sectors. Limiting the rise of global temperatures to 1.5°C will require $3.8 trillion in investments by 2050 and must focus on clean power technologies as well as energy efficiency measures.

Investment in the development of renewable energy sources (RES), as well as other necessary elements of a green and resilient energy system – including underground hydrogen storage (UHS) – can be hindered by their assessment as commercially "high risk". This assessment derives from the fact that many innovative green solutions are in the early stages of deployment, and consequentially both capital-intensive and disruptive.

The urgent implementation of decarbonisation measures can therefore only be unlocked by developing risk mitigation measures to facilitate and encourage private investment. The EU is uniquely positioned to reduce risks for green solutions across Member States.

The EU is uniquely positioned to reduce risks for green solutions across Member States. Early risk mitigation has shown to significantly reduce costs in the long-term, and to therefore guarantee the energy transition and quick implementation of decarbonisation solutions at the lowest cost to society.

The risks analysed in this report and associated with the development of clean energy technologies can be broadly categorised as follows:

- Regulatory (e.g. stable & clear political and regulatory environment, permitting)
- Financial (e.g. market development, revenue, competitiveness, funding and support schemes)
- Implementation (e.g. technical feasibility, maintenance, performance, infrastructure availability).

These risk categories also apply to the development of UHS in Europe and impede its successful deployment. **The aim of this report is to propose concrete risk mitigation approaches to scale-up UHS in the coming years.**

3 European Commission JRC (2023) Global Energy and Climate Outlook 2023 (Link)

Figure 1

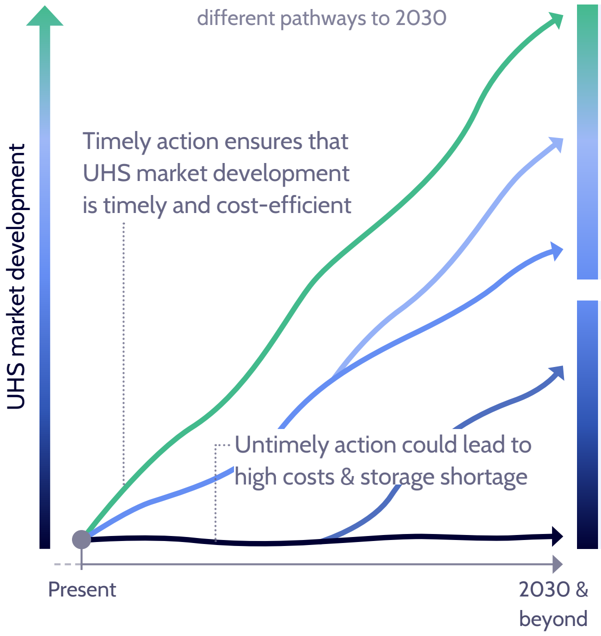
Illustration of pathways for UHS market development to 2030 and beyond. Late or inadequate support could lead to UHS market failure.

Conditions that enable

- Financial support mechanisms on EU- and MS-level (H2eart for Europe's toolbox)
- Clear regulatory framework
- Bottom-up implementation support

Conditions that constrain

- Demand risk
- Price risk
- Unclear regulations
- Complicated permitting procedures
- Technological risks



Favorable outcomes

- Mature UHS market that meets storage needs of the energy system
- Effective regulatory framework
- Reduced system costs

Unfavorable outcomes

- Untimely UHS development
- Shortage of storage
- UHS market failure
- Increased system costs

1.2 Situating UHS in Europe's decarbonised future

Hydrogen and hydrogen-based synthetic fuels are expected to play an important role in decarbonising hard-to-abate sectors such as heavy industry, shipping, and aviation. The uptick in hydrogen demand in recent years is illustrative of its growing role in accelerating European and global decarbonisation efforts. With increasing hydrogen production and demand, the need for hydrogen storage will grow in parallel.

Hydrogen storage offers various benefits for the future energy system, and specifically UHS stands out as an integral, future-oriented infrastructure solution due to a number of factors, recently outlined and analysed by a study conducted on behalf of Gas Infrastructure Europe (GIE) by Artelys and Frontier Economics.[4] The study highlights that the integration of UHS into the European energy system would result in a series of system-wide benefits, detailed more below.

Narrowing the gap

Aforementioned GIE-commissioned study equally indicates that to achieve REPowerEU targets, UHS capacities of around 45 TWh will be required in Europe by 2030 and roughly 270 TWh by 2050. Whilst it is still unclear what projects will go live by 2030, a significant gap between planned projects and predicted need is certain, and further indicates the urgent need for market intervention.

4 Gas Infrastructure Europe (2024). Why European underground hydrogen storage needs should be fulfilled, executed by Artelys and Frontier Economics (Link)

5 Gas Infrastructure Europe (2024). Why European underground hydrogen storage needs should be fulfilled, executed by Artelys and Frontier Economics (Link)

1.2.1 | UHS enables cost-efficient network planning

By providing network flexibility – both as a power-to-hydrogen-to-power solution and by producing hydrogen at lowest cost during RES peak production and therefore minimising curtailment – UHS enables the construction of optimised electricity and hydrogen networks, lowering overall energy system development costs.

Investing in underground hydrogen storage generates system-level savings starting from the first year of operations.[6] The combined impact of UHS integration on initial costs, annual fixed operational costs, and annual operational savings (including environmental benefits) totals around 2.5 billion euros.[7]

After the first year of operation, investing in UHS continues to lower the costs of running the EU energy system each year, mainly by preventing RES curtailment costs and cutting CO_2 emissions. According to the assumptions in the aforementioned GIE report, over a 20-year period with a 4% discount rate, the total cost savings, including operational and environmental cost reductions, amount to 32 billion euros.

1.2.2 | UHS as an essential element for kick-starting the hydrogen ecosystem

Introducing UHS to the future energy system enables the integration of larger volumes of RES, reduces curtailment of additional renewables and mitigates (electricity) grid congestion. It can therefore play a pivotal role in promoting the complete decarbonisation of electricity generation in energy systems with a high RES-share. By facilitating the production of renewable hydrogen during peak RES production when marginal electricity prices are low, UHS not only successfully minimises curtailment costs and thus maximises the value generated through RES production, but it will also ensure the production of affordable renewable hydrogen. UHS will help to ensure the reliable supply of cheap hydrogen to end users – also by facilitating the import of affordable hydrogen from third countries – encouraging hydrogen uptake and contributing to the decarbonisation of hard-to-abate use cases. This will result in a robust hydrogen ecosystem integrating greater volumes of hydrogen, and contribute to solving the demand-supply paradox, where demand materialises only when a reliable supply is available, and supply ramps up once demand is established.

1.2.3 | UHS will improve the resiliency of the European energy system

In addition to minimising curtailment costs, UHS will improve the resiliency of the European energy system. It ensures a reliable supply of hydrogen and helps to provide net-zero firm capacity by reducing the need for fossil-based power generation when RES production is low, reducing emissions in the power sector.

In addition to renewable hydrogen produced in Europe, UHS will ensure that sufficient quantities of imports may be stored locally or regionally. As a consequence, and in combination with the flexibility that UHS provides via Power-to-Gas-to-Power, UHS will enhance energy supply security and contribute to decarbonised European energy security.

6 S. Qudaih, Z. Bektas, D. Guven, G. Kayakutlu and M. Ö. Kayalica, "Technology Assessment of Hydrogen Storage: Cases Enabling the Clean Energy Transition," in IEEE Transactions on Engineering Management, vol. 71, pp. 5744-5756 (2024). Doi: 10.1109/TEM.2024.3366973.

7 Gas Infrastructure Europe (2024). Why European underground hydrogen storage needs should be fulfilled, executed by Artelys and Frontier Economics (Link)

1.3 Starting point & aim of this roadmap

This report will build on the assumption that in the future a mature European hydrogen market will develop which will require UHS to offer cost savings, energy flexibility, and energy security. Although the exact size of a mature hydrogen market and the development towards it are currently uncertain, it is likely that such a market will develop based on European hydrogen targets and investments.

Today, storing hydrogen in underground geological structures is the only viable option to fulfil the energy system need for large-scale storage of hydrogen. Underground hydrogen storage is currently technically feasible; however, its development is hindered by significant challenges for a business case in Europe. Investment insecurity is high, project development times are often long, the future hydrogen market size is uncertain, and policies are not yet developed.

This report will also build on the first H2eart for Europe report, called "*The Role of Underground Hydrogen Storage in Europe*", which addressed the importance of UHS to meet the European climate goals.[8] It is also connected to a recently published study by Artelys and Frontier Economics on UHS that elaborates on the values of UHS in an optimised energy system.

This report aims to outline a roadmap which addresses UHS-specific investment risks, and focuses on UHS policy, business cases, and implementation of UHS. Whilst other reports have highlighted a need for action, this report aims to provide concrete guidance on barriers and challenges, as well as run through possible solutions.

1.4 Report structure

The roadmap outlines H2eart for Europe's vision for investment security on UHS as well as discusses its role in Europe's decarbonised future.

Following a general introduction, this report is structured in 3 main sections, each addressing a specific risk and opportunity type (regulatory, financial and implementation) and providing an analysis of investment barriers in combination with a discussion of solutions. The policy and regulation section discusses pathways for market certainty, ambiguity in the European Gas Decarbonisation Packages, security of gas supply, and permitting roadblocks. The economics section analyses the financial challenges and proposes financial risk mitigation mechanisms for UHS. The implementation section introduces a bottom-up analysis of practical investment barriers at European, Member State, and project levels. The roadmap concludes with recommendations for advancing the integration of UHS across energy systems.

8 H2eart for Europe (2024). The role of underground hydrogen storage in Europe (Link)

02
Policy & regulation

Key messages

- **Clear third-party access and tariff methodology:** The Gas Decarbonisation Package establishes a regulatory framework for the integrated gas and hydrogen market in Europe, explicitly mentioning UHS for the first time. It sets out a two-phased approach to tariff setting for UHS, with the possibility of negotiated tariffs allowed until 2032, followed by regulated tariffs from 2033, but would benefit from a detailed guidance for this transition.
- **Integrated network and storage capacity planning:** The package highlights the need for coordinated network planning across different energy carriers while preserving Security of Supply, but provides insufficient clarity on integrating UHS into these plans, necessitating further guidance for effective stakeholder engagement (e.g. through ENNOH) and infrastructure development on both a national and EU-level.
- **Market development ambitions and KPIs:** However, the Gas Package alone is insufficient in kicking-off a functioning and viable UHS market in a timely manner. Further measures are needed, such as the introduction of an EU strategy determining EU-level UHS ambitions which can then be translated dependent on Member State potentials. Both overall EU and national UHS market development must be evaluated using KPIs determined through market consultations and coordinated capacity planning (such as the PCI process).
- **Streamlining permitting processes:** Prioritising UHS in national network plans are essential to facilitate timely deployment and maximise network cost reduction benefits. Best-practices for natural gas storage infrastructure should – where applicable – be extended to hydrogen storage projects. This must include streamlined authorisation procedures and the extension of existing permitting rights as indicated by the Gas Decarbonisation Package. Also, revising PCI criteria to recognise the value of UHS, setting European hydrogen purity standards, and implementing discounts on capacity-based transmission tariffs for hydrogen storage sites will encourage their use and enhance energy security.
- **Security of supply:** To ensure European energy security during the energy transition, UHS projects must be developed in a coordinated manner to maintain sufficient natural gas storage.

The European policy landscape on green and clean energy solutions has developed rapidly over recent years, and come to include a multitude on legislative files, all gearing the European Union towards achieving emission reduction goals as outlined by the Paris Agreement.

The development of underground hydrogen storage is influenced indirectly by a series of European policy documents which intend to shape the future European hydrogen economy, e.g. the European Hydrogen Strategy, REPowerEU, as well as the Delegated Act on a Methodology for Renewable Fuels of Non-Biological Origin.[9] Most directly treated, however, is UHS within the Hydrogen and Gas Market Decarbonisation Package ("Gas Decarbonisation Package") passed in May 2024.[10] The related files provide important clarification on the future envisaged for hydrogen, and consequently UHS, and mark a first step towards increased legal certainty for the development of UHS projects.

Within the context of the energy transition, legal certainty is essential for the acceleration of clean energy projects as minimised ambiguity on e.g. regulatory frameworks or technical requirements sets clear expectations for projects owners, investors and off-takers.

However, since the development of decarbonisation measures is constantly evolving due to everchanging technical capabilities and situational challenges (e.g. geopolitical developments), regulatory certainty has to adapt at an unprecedented rate.

As a result, this report analyses both the existing European regulatory environment relevant for the development of UHS, as well as proposes measures that exceed the current status quo. More concretely, this report conducts a detailed analysis of the Gas Decarbonisation Package and its effect on the deployment of UHS in Europe, and investigates further European regulatory measures required for the successful implementation of UHS projects (e.g. European UHS ambitions, EU hydrogen purity standards, etc.).

Only by continuously developing a more ambitious and technology-focussed legislative environment will the European Union be able to achieve its decarbonisation goals and successfully de-risk and scale up clean energy sources.

2.1 UHS and the Gas Decarbonisation Package: ambiguity remains

The Gas Decarbonisation Package provides a regulatory framework aimed at encouraging the energy transition by providing a fundamental vision for the future of the integrated gas market in Europe, as well as laying down foundational elements for Europe's future hydrogen market. Within this context of a hydrogen economy, UHS is explicitly regulated as a storage solution for the first time.

Previous EU polices on energy storage (e.g. the Electricity Market Package[11]) have failed to fully account the extent to which UHS may create added value within an energy system by providing scalable network flexibility in the short-, medium-, and long-term.

9 European Commission (2022). REPowerEU: Joint European Action for more affordable, secure and sustainable energy (Link), European Commission (2020). A hydrogen strategy for a climate-neutral Europe (Link), European Commission (2023). Delegated Act on a methodology for renewable fuels of non-biological origin(Link), European Commission (2023). Delegated regulation on methodology for assessing GHG emission savings from RFNBOs and RCFs (Link)

10 European Council (2023) Gas package: Council and Parliament reach deal on future hydrogen and gas market (Link)

Figure 2
Key policy levers to unlock UHS in Europe

Market development: European policy makers must actively shape the European hydrogen market & UHS. This must involve defining parameters necessary for a market creation such as KPIs and targets.

Integrated Network Planning: EU-level integrated network planning must consider the cross-sectorial benefits of UHS. ENNOH must incorporate & consider the benefits generated by UHS integration.

EU Hydrogen Purity Standards: An EU hydrogen purity standard should be set to ensure the lowest cost from a system perspective.

Clarification on TPA Regime: EU policy makers must provide clarification on how nTPA will transition to rTPA. Meanwhile, Member States should be encouraged to use the regulatory leeway left in the Decarbonisation Package to kick-off UHS projects.

Permitting & Priority Status: Streamlined UHS permitting procedures as well as a clarified criteria for UHS as PCI (including CBA-analysis).

Provide UHS with Discounts: Similar to provisions for natural gas storage, a 100% discount on capacity-based transmission tariffs at storage entry and exit points would strongly encourage the filling up of UHS capacity.

The Gas Decarbonisation Package, on the other hand, considers UHS as an essential infrastructure component of Europe's decarbonised future. This is illustrated by the expectations defined for the future development of UHS. For instance, the Gas Decarbonisation Package assumes that UHS will have developed to such an extent that regulated third-party access – similar to what is currently applicable to gas storage – will be needed by the end of 2032.[12]

Simultaneously, the Gas Decarbonisation Package fails to provide a clear pathway for the development of UHS in Europe. Beyond assuming that UHS will be needed, it does not address any sort of supporting measures or mechanisms and therefore only partially contributes to reducing regulatory risks associated with the development of UHS projects. Meanwhile, a sound and incentivising regulatory framework creates more opportunities than risks. As a result, the later part of this report will investigate how ambiguity around potential support mechanisms can be minimised, and what shape clear market signals for UHS may take.

Meanwhile, the following subchapters will examine what provisions from the Gas Decarbonisation Package require further clarification in order to fully address challenges faced by UHS project developers and clients.

2.1.1 | Third-party access and tariffs

EU policies on UHS third-party access and tariff setting are essential in creating investment certainty for project development by indicating or guaranteeing a certain return on investments. Ideally, a tariff setting regime would – in parallel – both encourage private investment as well as ensure affordable tariffs to storage users. Although the Gas Decarbonisation Package provides a regulated regime to be applied on an EU-level, Member States shall require more detailed provisions to secure a successful deployment of UHS.

11 European Commission (2019). Internal market for electricity (recast) Directive (Link) and Regulation (Link)
12 European Commission (2024). Gas Decarbonisation Package Directive Article 37

The final version of the Gas Decarbonisation Package foresees a two-phased approach: until December 2032 at the latest, UHS operators may negotiate tariffs directly with potential hydrogen storage users. The text foresees that these negotiations must be conducted in "good faith", and that tariffs must be based on "objective, transparent and non-discriminatory criteria".[13]

Starting 2033, however, UHS operators are expected to transition to "regulated third party access" i.e. a regulated tariff model. This appears to be based on the assumption that by 2033, the UHS market will have reached a degree of maturity that justifies regulated third-party access. Furthermore, negotiated third-party access contracts prior to 2033 may remain valid until their expiry, even if this expiry date is set after 2032, provided that Member States choose to apply the grandfathering clause.

Although the Gas Decarbonisation Package provides a general framework of the development of UHS tariffs in the near future, hydrogen storage operators require more EU-level guidance to be able to benefit from support mechanisms such as intertemporal cost allocation, and to successfully de-risk their business.

Firstly, it remains unclear how the transition from negotiated third-party access to regulated third-party access will play out. Although the grandfathering clause guaranteeing the validity of negotiated tariffs beyond 2032 provides a limited degree of legal certainty, clear guidance from the EU Commission to national regulatory authorities is urgently needed.

Because the Decarbonisation Package grants temporary flexibility to Member States' national regulatory authorities to develop tariff mechanisms, Member States should also receive more direction on how tariff mechanisms may account for and remunerate the system-wide benefits generated by UHS (e.g. increased network flexibility, avoided network infrastructure costs etc.). This report will provide a detailed overview of possible innovative tariff models in the Economics chapter on financing mechanisms.

2.1.2 | Integrated network and storage capacity planning

> Because hydrogen storage can provide services for and interact with three markets – hydrogen, electricity, and gas – UHS may facilitate the sectorial integration of energy systems, and therefore contribute to an efficient network expansion across energy carriers.

Some studies even indicate that integrating green hydrogen storage may lead to a 60% overall system cost reduction.[14] To harness this added value created by the implementation of UHS, efficient and well-coordinated network planning across energy markets and both on national and EU-level is of the essence.

The Gas Decarbonisation Package provides a first approach to hydrogen network planning as it requires national gas and hydrogen transmission and distribution system operators to submit a Ten-Year Network Development Plan (TYNDP) to the relevant national authorities, and to update it at minimum bi-annually. They are also mandated to closely collaborate with electricity transmission and distribution system operators in order to identify and coordinate potential "joint infrastructure

13 European Commission (2024). Gas Decarbonisation Package Directive Article 37 & 78 (Link) and Regulation Article 8 (Link)
14 IEEE Spectrum (2024) Hydrogen Storage Could Slash Renewables' Cost (Link)
15 European Commission (2024). Gas Decarbonisation Package Directive Article 55 (Link)

requirements" e.g. identifying the ideal location of electrolysers.[15] SSOs are already obliged to assess market demand for hydrogen flexibility services every two years. To streamline processes, these projections must be integrated into network planning procedures in a coordinated way.

Example approach

SSOs conduct a national storage demand survey to predict the demand for natural gas and hydrogen storage over the next 15 years (e.g. using a public platform solution). Based on the resulting findings and existing core network plans, SSOs develop a market forecast which they submit to the NRA. The NRA reviews and approves the forecast, taking external (political) factors like security of supply into account. Once approved, this forecast is used in the TSOs' network development plans and in tenders for hydrogen storage facilities.

Once the market is mature, storage operators allocate storage capacities in a market-based manner, e.g. by way of auctions.

Similarly, on a more European level, the newly introduced European Network of Network Operators of Hydrogen (ENNOH) is required to coordinate EU hydrogen network planning with its electricity and natural gas counterparts, ENTSO-E and ENTSO-G.[16]

Whilst the Gas Decarbonisation Package clearly recognises that coordination across energy carriers is both needed and beneficial for the creation of efficient energy systems, its approach is mostly centred on the coordination of transmission and distribution networks.

Creating and recommending a formalised approach for the integration of UHS across energy systems on both a national and EU-level is therefore highly important. The coordinated planning of UHS infrastructure in tandem with hydrogen and electricity networks can contribute to a thriving hydrogen economy in the future, as well ensure a smooth build-out of RES.

The current provisions – simply outlining that UHS operators must provide information if required by network operators – are insufficiently clear on what value and importance is assigned to storage's integration into overall energy system planning.[17] Clear guidance and recommendations on stakeholder engagement throughout the creation of national and EU-level TYNDPs is therefore urgently required to ensure the added value generated by UHS is reflected in network plans.

16 European Commission (2024). Gas Decarbonisation Package Regulation Article 60 paragraph 3 (Link)
17 European Commission (2024). Gas Decarbonisation Package Directive Art 55 paragraph 1 (Link)

2.1.3 | ENNOH

The Gas Decarbonisation Package introduces a new player on the European stage of energy network operators: the European Network of Network Operators of Hydrogen, or ENNOH. Currently in the process of being established, ENNOH will be tasked with coordinating union-wide hydrogen network development plans independently from the ENTSO for Gas by 1 January 2027.[18]

Storage operators' involvement within ENNOH is strongly limited to the terms proposed by ENNOH for the stakeholder engagement process. In order to guarantee that concerns by storage operators are considered within ENNOH's involvement for EU-level TYNDPs, strong recommendations regarding its drafting process and the inclusion of storage infrastructure are essential. This will ensure a balance between TSOs and SSOs, and guarantee the smart build-out of the European energy system.

2.2 Pathways for market certainty: EU UHS ambitions and KPIs

The decarbonisation of the European energy landscape requires significant European policy maker efforts across the board. In the case of the hydrogen economy, it is probable that policy maker intervention will remain necessary until the market is liquid and mature as well as supported by a wide infrastructure deployment. Currently, investment costs are high and profit margins subject to a high degree of uncertainty, reducing the commercial feasibility of hydrogen-related applications overall. **Whilst both EU and Member State policymakers have taken explicit action to support the construction of a European hydrogen network, as well as to kick-off hydrogen production and usage, UHS has so far not been subject to clear policy or market signals.** This means that although demand appears to be significant (e.g. various H2eart for Europe's members' market consultations have led to an over-reservation of storage capacities[19,20,21]), policy makers have not yet provided the appropriate framework and market signals which would ensure that UHS can be developed securely on a sufficiently large-scale to maximise the impact of its system-wide benefits.

Past developments in the European hydrogen industry have illustrated the positive impact of EU ambitions on the development of hydrogen infrastructure to reduce market uncertainty and encourage both private and public investment.[22] The introduction of ambitions and/or Key Performance Indicators (KPIs) tracking market development continuously would reduce overall market risk significantly, and aid individual stakeholders in appropriately evaluating their activities, as well as encourage both private and public investment.

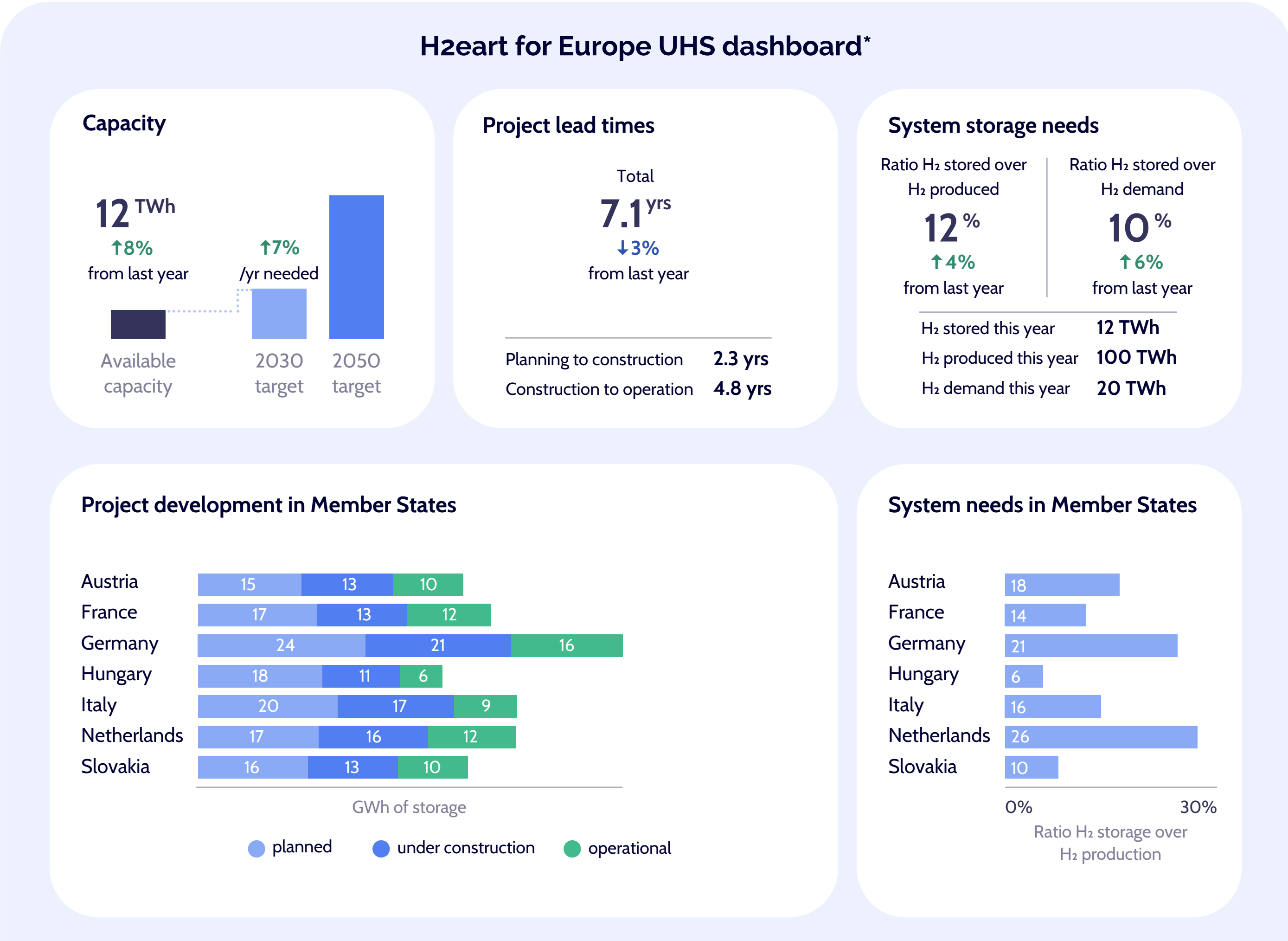
Evaluating the success of policy measures aimed to narrow the identified UHS project gap could take the form of market based KPIs, underpinning the UHS project development ambitions. KPIs may additionally support the development of UHS and must put forward the multi-facetted additional value created through UHS system integration. They may include:

18 European Commission (2024). Gas Decarbonisation Package Regulation Art 61 (Link)
19 EWE (2023). EWE market survey shows great need for hydrogen storage (Link)
20 Gasunie (2023). Successful Open Season: ample interest in hydrogen storage first salt cavern HyStock (Link)
21 Uniper (2024). Uniper market consultation shows high demand for hydrogen storage capacity from 2029 (Link)
22 European Commission (2023). Renewable Energy Directive (Link)

- Overall UHS capacity available (possibly with respect to overall – i.e. 2030 and 2040 – ambitions) on a European level and broken down per Member State;
- Number of UHS projects per Member State per development stage (e.g. planning, construction, capacity, network connection status);
- Average project lead times to commissioning / supply chain stress indicators;
- Ratio of H_2 storage capacity to H_2 production capacity and imports where relevant (on EU-level and on Member State, or even electricity bidding-zone level) to track overall system need for storage;[23]
- Ratio of H_2 storage capacity to H_2 demand (on EU-level and on Member State level) to track overall system need for storage.[24]

These KPIs may be visualised on a dashboard to track their development. Figure 3 provides an illustration with indicative numbers of what such a dashboard could look like.

Figure 3
Example of a UHS dashboard that can be used to track development of KPIs*



* The indicated values are indicative and simply serve to illustrate proposed KPIs.

23 According to H2eart for Europe's internal studies, a need of 0.4 TWh of UHS per GW of electrolysis is estimated.
24 Recommendations based on proposal from Gas Infrastructure Europe (2024). Why European underground hydrogen storage needs should be fulfilled, executed by Artelys and Frontier Economics (Link)

Since the technological development of both UHS specifically and hydrogen-related use cases may still change over time, UHS policy should similarly be open for revision. This particularly applies to KPIs: it is recommended that regular assessments analyse their circumstantial relevancy to determine whether they should be developed further in order to account for new technological (or other) requirements. These regular assessments can also include a market demand registration tool where potential customers can register their current and predicted future market demand so as to include real needs as accurately as possible.

2.3 Removing permitting roadblocks

As with many innovative infrastructure projects, permitting for UHS projects has proven to be a substantial development barrier and strong risk factor. Currently, lead times can exceed up to 10 years for new construction UHS projects.[25]

Consequently, urgent action is needed to remove permitting roadblocks on a national and European level, to clear paths to public financing and to facilitate the construction of UHS projects whilst developing and upholding standardised high safety criteria.

A series of regulatory risk mitigation measures may not only contribute to the timely deployment of UHS across Europe, but also contribute to kick-off of infrastructure solutions with similar risk profiles.

2.3.1 | Adapting PCI methodology to gecognise UHS

Being classified as a "Project of Common Interest" (PCI) under the Trans-European Networks for Energy (TEN-E) regulation largely reduces investment risks for selected projects as they benefit from sped-up permitting and authorisation procedures, as well as may access funding from the Connecting Europe Facility Energy (CEF-E). The most recent and 6th round of projects was the first to recognise hydrogen-based projects, showcasing that hydrogen will play an instrumental role in achieving EU decarbonisation targets.

So far, however, only a highly limited number of UHS projects has achieved PCI status: 4 projects, corresponding to a capacity of 800 GWh i.e. less than 10% of the total planned projects for 2030.[26] This is due to the fact that PCI criteria are largely based on a project's cross-border impact which has oftentimes manifested as providing a physical interconnection between Member States.

Hydrogen storage sites, are commonly geological formations bound to one Member States' geographical territory. This creates the need for UHS project developers to illustrate the cross-border's impact, and will necessitate to complement the CBA (Cost Benefit Analysis) for hydrogen infrastructure PCI criteria, embracing the benefits of UHS.[27] Nevertheless, UHS projects can significantly reduce European energy system costs overall, as well as contribute to a reliable and affordable supply of hydrogen across Europe. It is

25 H2eart for Europe (2024). The role of underground hydrogen storage in Europe (Link)

26 Gas Infrastructure Europe (2024). Why European underground hydrogen storage needs should be fulfilled, executed by Artelys and Frontier Economics (Link)

27 ENTSOG (2023). Single-sector Cost-Benefit Analysis (CBA) methodology – Draft (Link)

therefore recommended that the PCI methodology develops further to include the full value of energy storage projects. In the case of UHS, current shortcomings could be based on the following KPIs:

Table 1
List of proposed KPIs for current PCI methodology[28]

Type of value	Proposed KPIs	Corresponding benefit in existing PCI methodology
System	Levelised Cost of Hydrogen (LCOH)	B2: Social Economic Welfare for hydrogen sector
Arbitrage	Share of hydrogen supply routes, electrolyser load factor	B2: Social Economic Welfare for hydrogen sector
Insurance	Hydrogen production capacities	B5: Reduction in exposure to curtailed demand
Kick-Start	Investments in on-site renewables and electrolysis	B3: Renewable Energy Integration

Ideally, the system cost reduction achieved through UHS would also be included as a metric.

2.3.2 | Granting UHS priority status in network development plans

National network plans may play an important role in the rapid implementation of UHS projects across various types of energy carriers (electricity, gas, hydrogen). **To unlock the full network cost reduction benefits possible with UHS, national TYNDPs must grant UHS priority status and minimise development timelines through streamlined permitting procedures.**

2.3.3 | Applying permitting timelines to UHS

The Gas Decarbonisation Package's Directive provides clear guidance on the allowed timelines for the development for authorisation of "natural gas facilities, hydrogen production facilities and hydrogen system infrastructure", ensuring that these projects are subject to dynamic permitting procedures.[29]

More specifically, Article 8 of the Directive outlines that a permitting procedure for the mentioned infrastructure categories may not exceed two years, and upon the provision of justification may only be extended by one additional year. Furthermore, all applicants must be guided through the authorisation procedure at no cost and have access to so-called "contact points".[30]

It is essential that these permitting criteria are enforced on a national level and made to be applicable to UHS projects. To achieve this, a specific recommendation to apply these guidelines to UHS projects would be instrumental, the current provision and simple reference to "hydrogen

28 Gas Infrastructure Europe (2024). Why European underground hydrogen storage needs should be fulfilled, executed by Artelys and Frontier Economics (Link)
29 European Commission (2024). Gas Decarbonisation Package Directive Article 8 paragraph 1 (Link)
30 European Commission (2024). Gas Decarbonisation Package Directive Article 8 paragraph 5 and 8 (Link)

system infrastructure" is too vague. Additionally, the Directive's provisions allowing for the extension of existing permitting rights for construction and operation of natural gas networks to assets for the transport of hydrogen should also be applied to natural gas and hydrogen storage.

2.4 Developing UHS whilst guaranteeing security of supply

Despite the European Union's strong commitment to phasing out of fossil fuels in the long-term, natural gas is expected to remain an essential part of the European energy mix in the medium term (next 10-15 years). **As a result, the development of UHS projects – some of which may be based on the repurposing of existing natural gas storage sites – must coincide with the maintenance of sufficient natural gas storage capacities to ensure overall European security of supply.**

To ensure that a maximum degree of European energy security is maintained, a high level degree of oversight is essential.

This means that both European and national network plans must identify essential and priority natural gas storage infrastructure, whilst also identifying natural gas storage sites' repurposing potential.

2.5 European hydrogen purity standards to ensure maximum compatibility with use cases

Hydrogen gas purity standards are of relevance for its suitability per use case, but also for its transmission and distribution. Therefore, European hydrogen purity standards would have to ensure compatibility across the value chain against the lowest overall system cost.

Storing hydrogen – even when using hydrogen as a cushion gas – in different storage assets results in varying degrees of impurities. Purification of hydrogen upon withdrawal and before feeding it back into the hydrogen network involves the construction and integration of cost-intensive assets at storage sites for storage operators. At the same time, not all end users will require a high level of purity for their processes.

Therefore, it needs to be clarified which degree of hydrogen purity shall be required and accepted across the value chain. European hydrogen purity standards should be set according to a methodology that considers the needs to scale up the hydrogen value chain in a future-proof way at lowest overall system costs.

2.6 Discounts may encourage use of UHS capacities

Russia's aggression towards Ukraine profoundly changed how European policy makers assess European energy security and propelled the EU-wide classification of gas storage sites as critical infrastructure. Following the winter of 2022, EU policy makers recognised the need to facilitate the filling up of gas storage sites, and consequently proposed the introduction of a 100% discount on capacity-based transmission tariffs at storage entry and exit points.[31]

The discounts introduced in June 2022 in combination with other supporting measures considerably facilitated the filling up of gas storage sites and would incite a similar effect if applied to hydrogen storage sites. Over the course of the energy transition, hydrogen is expected to assume a significant role in decarbonising use cases currently relying on fossil fuels as an energy carrier (power sector, high-heat industry, chemical industry, etc.), and will consequently similarly require provisions which ensure a high degree of security of supply, and therefore European energy security.

Not introducing a discount on the grid access fees for hydrogen storage facilities would also lead to an unreasonable double burden on hydrogen storage customers. This is because they would have to pay grid fees twice, both when injecting into the storage facility and when withdrawing into the grid. The comparable situation was also deemed unfair in the natural gas sector, which is why a mandatory discount was introduced in the network code on harmonised transmission tariff structures for gas. There is no apparent reason to handle this differently in the hydrogen sector.[32]

31 European Commission (2017). Regulation concerning measures to safeguard security of gas supply (Link) and European Commission (2009). Conditions for access to natural gas transmission networks, Article 13 (Link)

32 European Commission (2017). Regulation concerning measures to safeguard security of gas supply, Recital 4 and Article 9 (Link)

03 Economics

Key messages

- **Currently, high market uncertainty undermines the UHS business model** because in the nascent hydrogen market financial risks are high, and rewards are low.
- **Bridging the market development gap:** To ensure that UHS infrastructure is built and connected to the network by the time demand is high, public financial risk mitigation mechanisms are urgently needed for both market development but also UHS-centred research (e.g. the repurposing potential of depleted natural gas fields).
- **Ensuring investment security:** Investment security means guaranteeing – in the long-term – the implementation of a tariff model which, when properly set-up, can ensure yearly revenues that cover costs, as well as an appropriate level of remuneration. This is what the rTPA rules within the Gas Decarbonisation Package are set out to achieve when implemented, however, to bridge the gap between developing & developed market, additional (financing) mechanisms might prove essential in kick-starting UHS project development.
- **Introducing financial risk mitigation mechanisms:** H2eart for Europe proposes a series of financial mechanisms in the form of a "toolbox" that can contribute to a UHS ramp-up by distributing cost (and thus risk) over a long time period and across various actors, and that can therefore ensure intertemporal and system-wide cost allocation.
- **Contracts for Difference and Minimum Revenue Floor:** Financial risk mitigation mechanisms can be CAPEX, DEVEX and OPEX-focussed, and their implementation may differ from Member State to Member State. This report will investigate the concepts of Contracts-for-Difference, Minimum or Regulated Revenue Floor, as well as other design elements such as clawback and amortisation account.
- **Public financial risk mitigation solutions in combination with coordinated capacity allocation will provide security for private (re-)financing**, such as is common with other large infrastructure projects (e.g. wind parks), and speed-up market development to create a competitive and liquid market as soon as possible.

Note: A definition list for this chapter can be found in the appendix.

3.1 Status quo: high market uncertainty undermines UHS business model

The successful kick-off of UHS is tightly interlinked with the success of Europe's nascent hydrogen economy, as well as an EU-wide build-out of RES. Currently – similar to other hydrogen infrastructure projects, e.g. the European Hydrogen Backbone – the development of UHS projects is significantly restricted due to challenges related to the creation of a viable business case, e.g. large investments, long development lead times, value chain coordination and lengthy permitting processes.

Renewable hydrogen production must conform with criteria laid out in the Delegated Acts on Renewable Fuels of Non-Biological Origin' (RFNBO), meaning that it must be produced according to temporal and geographical correlation, and produced with additional renewable electricity. Additional rules on criteria for low-carbon hydrogen are currently in development. At the same time, the development of hydrogen demand is somewhat uncertain, and will depend on various factors, e.g. varying decarbonisation roadmaps per sector or Member State, (inter)national support mechanisms, and the availability of hydrogen transport infrastructure. The market for hydrogen is currently at its inception, and it is unclear at what moment in time there will be a liquid market. However, it is to be expected that – at least initially – the profile for hydrogen demand will be mostly baseload to decarbonise various industries, possibly with a seasonal component for (high temperature) heating purposes as well as ensuring security of supply in the power sector.

3.1.1 | A nascent hydrogen economy means high financial risk and low rewards for UHS

In addition to regulatory and technical risks, financial risks are currently most detrimental for UHS. Financial risks – i.e. a company's ability to generate sufficient cash flow – seriously undermine UHS' business models, and can broadly be linked to demand and price risk.

- *Price risk* refers to how high prices for UHS services during ramp-up of the hydrogen ecosystem might deter potential storage clients.
- *Demand risk*, on the other hand, refers to the fact that hydrogen storage system operators will not make enough revenue to cover their costs due to a low volume of sales (also known as *volume risk*) and low prices. This situation is to be expected during the ramp-up of the European hydrogen economy.

To ensure the system integration of UHS, these risks cannot fully be transferred on individual projects, especially as both demand and price risk are largely beyond the control of the storage developer and linked to the overall degree of development of the European hydrogen market.

High financial risks might be acceptable for some storage companies if rewards were high. However, this is currently not the case. The hydrogen demand is currently low, as is the demand for hydrogen storage, but is expected to grow based on market consultations of SSOs. With increased production and demand for hydrogen, demand for hydrogen storage will grow and potential revenues are expected to rise.

To ensure UHS facilities are market-ready and connected to the hydrogen network by the time demand is high, risk-mitigating financial support mechanisms are essential to remove investment barriers. Currently, no viable UHS business models exist without financial support during market development.

Financial risk mitigation mechanisms are needed to develop the storage market to a mature, and self-sustainable market. These mechanisms should focus on mitigating demand risk, which will unlock investments and ensure sufficient supply of hydrogen storage at lowest cost for society.

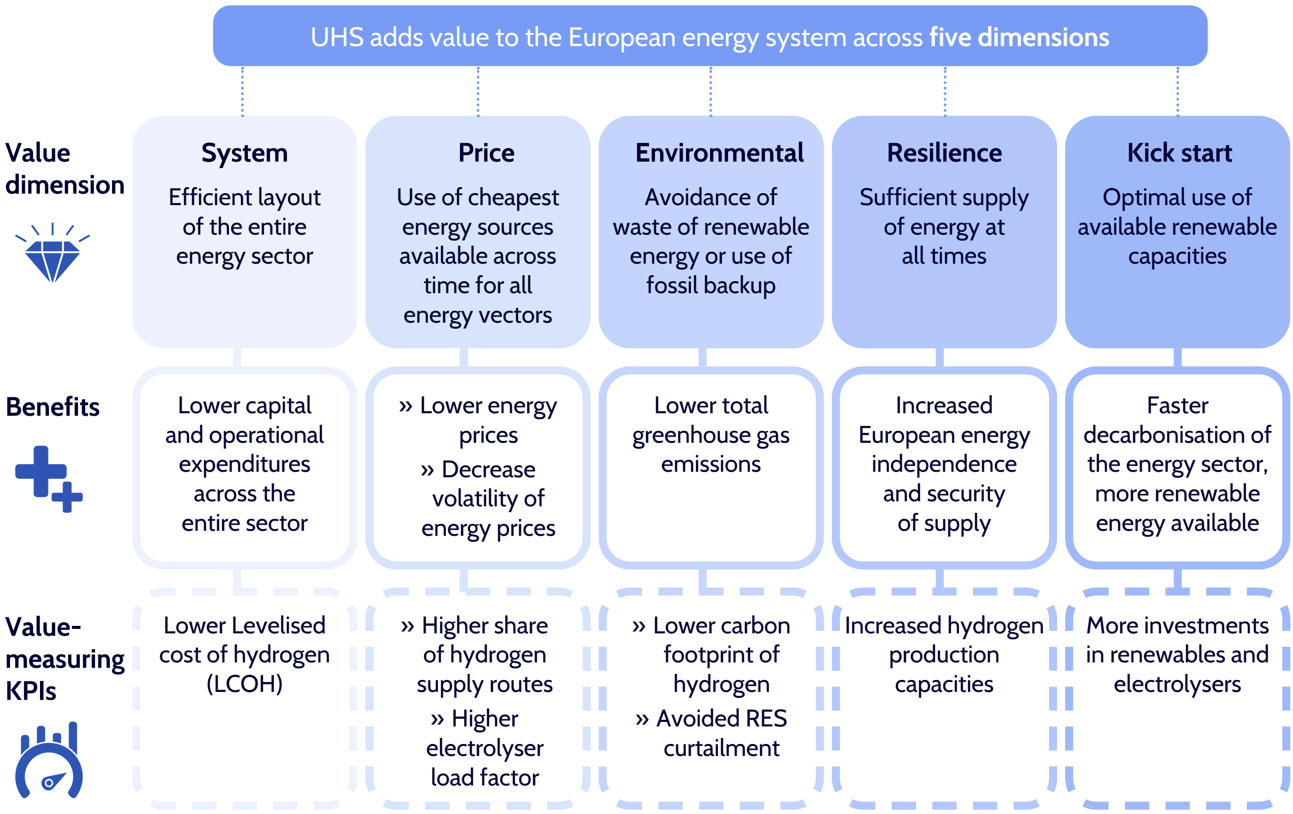
3.1.2 | Financially remunerating added value of UHS

The aforementioned GIE publication explains how UHS can bring benefits to energy systems overall – ranging from reducing RES curtailment to bringing down overall system development costs – and introduces different types of value added (system, arbitrage, environmental, insurance and kick-start).[33]

For the creation of a successful future business model of UHS, it will be important to monetise these different values properly to stimulate build-out and tap into the related benefits.

The lack of a business case for UHS is related to the monetisation of future operation of UHS assets, as well as support mechanisms. To assess the future market and operation of UHS, one could compare the characteristics of underground natural gas storage (UGS) with the possible future utilisation of UHS. The natural gas market is a liquid, international market with continuous trading and flows. The natural gas production is relatively continuous, and products are well-defined. Also, utilisation and prices are tracked and forecasted, and the demand has a clear, seasonal demand profile.

Figure 4
The five value dimensions through which UHS can provide benefits to the European energy system, and KPIs that could be used to measure these



Note: this figure is closely adapted from: Gas Infrastructure Europe (2024).[27]

33 Gas Infrastructure Europe (2024). Why European underground hydrogen storage needs should be fulfilled, executed by Artelys and Frontier Economics (Link)

When looking at the differences as described above, it becomes evident that UHS may be operated in a different way than natural gas storage. As described in H2eart for Europe's first report, hydrogen storage is a way to connect electricity and gas systems, where hydrogen can be used to store (renewable) electricity and then later also used as a dispatchable electricity source. UHS therefore also has other system benefits, such as the reduction of renewables curtailment and grid congestion issues. On the other hand, natural gas is not a means to store electricity, but is used as a dispatchable power source. These differences in supply and demand and utilisation could result in different seasonal and inter-seasonal spreads and a different valuation of the storage products (from hourly to seasonal).

To properly monetise UHS assets, a specific approach will be needed that recognises the value of the operation of UHS in the broader energy system. The KPIs as described in Figure 4 above would have to be calculated in a comprehensive manner and linked to the financial support mechanisms available. This will enable the UHS sector to de-risk their investments and create a future business model for storage operators. On an asset level, this will help to create certainty for the business case and incentivise storage operators to develop UHS assets for the benefit of the future energy system.

3.2 H2eart for Europe's Toolbox of financial support mechanisms: mitigating risk and creating a valid business model

- **Financial support instruments need to focus on lowering financial risk and increasing rewards** for UHS storage operators to unlock private investments in the short term. This means bridging the gap between developing & developed market by providing a certain level of guaranteed income.
- **Many types of financial support are conceivable:** measures can focus on DEVEX, CAPEX, or OPEX, be public-private agreements or policy-based, or consist out of various combinations of these options.
- **The EU should develop a toolbox of support instruments out of which Member States can construct their ideal support model.** Because UHS projects will likely operate in different ways, and because infrastructure is commonly planned on a national level, support instrument requirements will vary per Member State.
- **The measures currently most discussed are Contracts-for-Difference and Minimum Revenue Floors.**

Financial support instruments can be designed on both an EU and Member State level. EU support often consists of lump-sum payments that are policy-based or auctions, and not project-specific. This can unlock some initial UHS investment but cannot mitigate demand risk in the long-term. Financial support instruments must therefore also be designed on Member State level to effectively improve the business case for UHS.

UHS projects face different geological, infrastructures, and operational challenges. This creates variation in what type of financial support is needed to reduce risk and unlock investment. Specific support instruments (e.g MRF and CfD) must therefore be designed on a Member State level.

The EU can provide financial risk mitigation concepts to Member States that correspond to UHS risk profiles, and thus support Member State-level support instrument design and implementation. Figure 5 proposes such a toolbox from which Member States can select specific financial support elements to design their financial support models.

It is evident that financial support for UHS will demand large-scale funding in the near future whilst the system benefits of UHS infrastructure will only come into play once storage assets are fully integrated across networks. This is a problem that exists for many energy-related investments, and for which Member States have developed approaches to allocate costs fairly across all generations that will profit from current financial support (i.e. intertemporal cost allocation).

Figure 5
H2eart for Europe's proposal for a toolbox of financial mechanisms

This toolbox breaks down subsidy mechanisms into elements that can be combined to design financial support measures for UHS on Member State or project level. It is not by definition complete nor are all tools exclusive; other tools are conceivable and some of these tools might overlap.

What?

Fixed subsidy tools

Fixed subsidies can lower CAPEX and/or DEVEX costs & barriers, and can be combined with dynamic subsidy tools.

Lump-sum

Fixed amount of money. These subsidies exist often on EU level. Variants can be:

One-time payment
Lump-sum payment paid out once.

Periodic payout over lifetime
Subsidy paid out in periods over a project's lifetime.

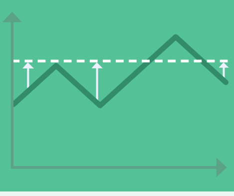
Loans
Conditional loans with infrastructure-specific favourable conditions (e.g. EU Just Transition Mechanism).

Dynamic subsidy tools

Dynamic subsidies can help lower volume and price risk.

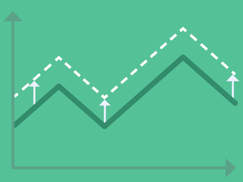
Tariffs

Compensates a project for an income difference between the market price or revenue and some agreed income.



Premium

Subsidy on top of the market price or revenue.

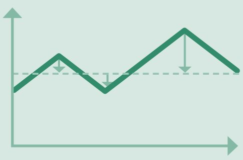


Tariffs and premiums may be revenue-based or price per unit-based. This affects to what degree they provide return-on-investment (ROI).

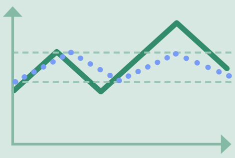
Add-ons

Additional mechanisms may apply to limit the share of risk taken by the subsidy provider or subsidy recipient.

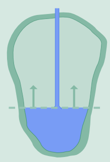
Clawback
Some part of the revenue is returned to the subsidy provider once revenue or price/unit exceeds a pre-defined level.



Income cap & floor
Used to constrain a dynamic subsidy. Note: A tariff is a floor by definition. A payout option for a revenue floor is though anchor bookings.



Minimum availability
For a financial incentive, SSOs ensure a minimum storage availability per year.



+

Who?

Allocation mechanisms

Project-specific
Subsidy is arranged forprojects individually. A subsidy can be designed to fit the needs of both the subsidy provider and storage operator.

Public policy
The level of subsidy is set out in rules from public policy. Any project that adheres to these rules can receive funding.

Auction
The subsidy is allocated to the storage operator that offers the best benefits: e.g. best price per unit, revenue, or other parameters.

+

How?

Pay-out method

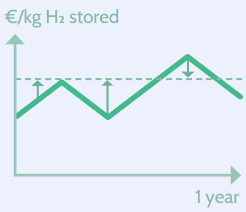
Fund
Financial support is paid out of a state or EU-fund which runs until a pre-defined point in time or until the fund's limit is reached.

Amortisation account*
Support is paid through an account that is drained during market ramp-up, and then gradually replenished after market development by skimming off revenue exceeding a pre-set limit (i.e. clawback).

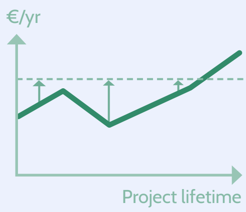
=

Examples of Financial Support Measure Designs

Contracts-for-Difference (CfD)
A CfD scheme is a price/unit-based tariff with clawback. This guarantees storage operators a certain ROI whilst ensuring risk is shared between subsidy provider & recipient.



Minimum Revenue Floor (MRF)
A MRF scheme is a revenue-based tariff that can include clawback. This ensures a guaranteed minimum yearly revenue for a storage facility in a nascent hydrogen economy, and thus de-risks UHS.



Note: The German financing mechanism for the core hydrogen network is also called 'amortisation account'. According to the definitions in this report, however, said financing mechanism consists out of a CfD mechanism with an amortisation account as pay-out method. Our version of the amortisation account can also be combined with e.g. an MRF as it is simply a pay-out method.

As many financing mechanisms variants are conceivable, an assessment of their suitability prior to implementation is crucial both on EU and Member State-level. Criteria such as policy effectiveness, administrative complexity, or incentive creation (Table 2) are often instrumental in determining a mechanisms' suitability, and must sometimes supersede other aspects, such as e.g. determining the mechanism with the lowest financial cost to subsidy providers.

The answers to table 2's questions are likely to differ between Member States due to different geological, political, and regulatory environments. **It is therefore important that storage operators and subsidy providers co-create the design of financing mechanisms to ensure overall maximum effectiveness.**

Table 2

Assessment criteria for financing mechanisms for UHS

Effectiveness	Funding cost efficiency	Practicalities
Does the mechanism create sufficient investments to enable storage ramp-up?	To what extent does the model avoid over-promotion or disproportio-nate profits for storage operators?	Is the administrative burden for the provider and receiver of the financial support appropriate?
Are economic challenges and risks (e.g. demand and price risk) adequately addressed with this mechanism?	To what extent does the mechanism incentivise efficient operation, growth, and transition to a market model without financial support in the long term?	Does the mechanism integrate suf-ficiently well into existing regulatory framework and financing mechanisms?
Does the mechanism create a stable investment framework for storage operations with cal-culable income and returns?	To what extent does the mechanism affect project value (such as NPV, ROI, etc.)?	Is the financing mechanism compatible with storage operation (e.g. monetisation of various user requirements)

3.2.1 | Lump-Sum DEVEX or CAPEX Support

DEVEX or CAPEX financial support in the form of a (possibly one-time) fixed subsidy can support a reduction of investment costs for UHS projects, and therefore kick-off construction in a smooth and timely manner. Although grants can be the most-effective form of lump-sum support, loans with appropriate repayment plans and conditions may result in a similar effect whilst being more low-impact for public financial resources.

However, this type of financing fails to address demand risk as it does not ensure the long-term development of a UHS market.

There are several EU funds available for UHS projects, such as the Innovation Fund, Connecting Europe Facility, and Horizon Europe (Table 3). Only two UHS projects have partly received European funds thus far, but seven more are expected to follow after recently obtaining a PCI (Project of Common Interest) status, allowing them to obtain funds more easily.

Table 3
EU funds relevant for UHS projects

Fund	Target projects	Relevent UHS projects
Innovation Fund	Low-carbon demonstration projects. Scoring is based on: emission reduction, innovation, maturity, replicability, and cost efficiency.	None yet, but UHS project are eligible
Connecting Europe Facility – Energy	Cross-border projects that lower costs compared to a project executed by an individual MS. Scoring is based on: urgency, maturity, quality, impact, and catalytic effect. Only projects with PCI status can apply.	Not received funding, but 7 UHS projects are eligible through PCI status, for example: Hystock (NL) and Storage GeoH2 (FR)
Horizon Europe – Cluster 5: Climate, Energy, & Mobility)	Research and innovation projects that help reduce climate change, achieve SDGs, and boost EU competitiveness and growth. Specifically calls for energy storage projects, but bid criteria are call-specific.	EUH2STARS (AUT), FrHyGe (FR)
Just Transition Fund	Support regions most negatively affected by the energy transition. Focus is on up- and reskilling workers, investments in SMEs, R&D, environment, clean energy, job creation, and transformation of existing carbon-intensive installations. Bid criteria are MS-specific.	Subsidies are governed on regional level, but might be open to UHS (such as in NL)
InvestEU – Sustainable infrastructure	Projects that address market failures or investment gaps and need EU to get off the ground, and that achieve a multiplier effect.	

3.2.3 | Variants of dynamic financing mechanisms: Contracts-for-Difference (CfD) and Minimum Revenue Floor (MRF)

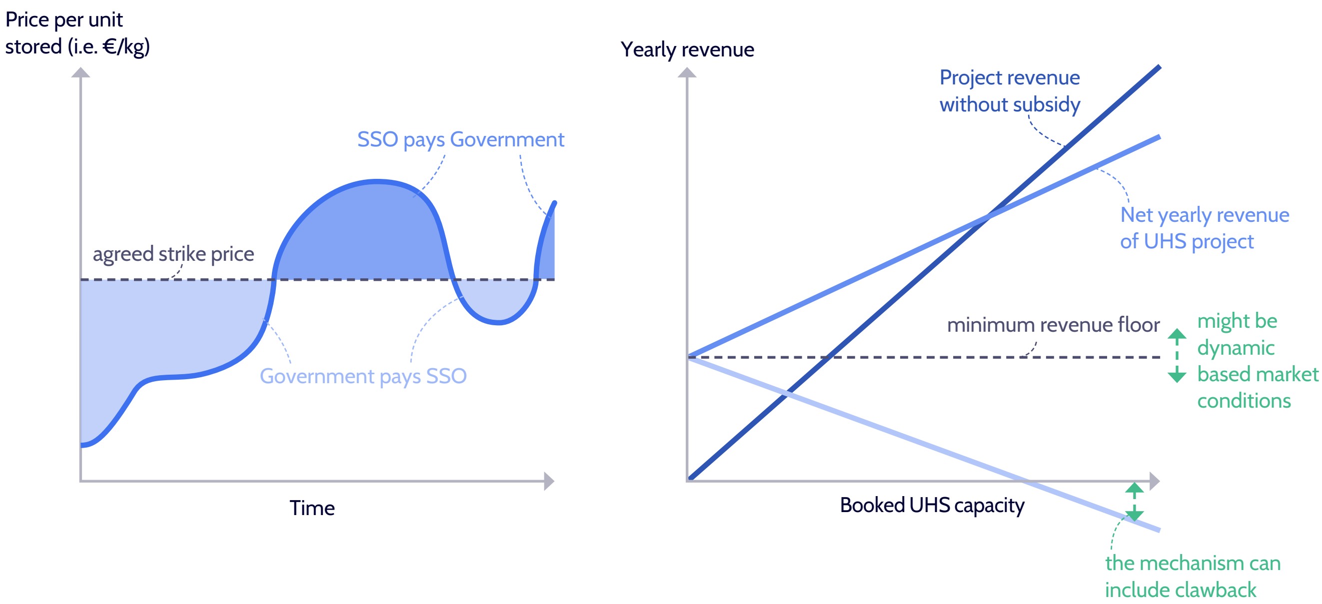
Various toolbox elements can be combined to design financing instruments. Two common dynamic financing instruments are Contracts-for-Difference (CfD) and Minimum Revenue Floor (MRF).

A CfD scheme is a price per unit-based tariff with clawback (Figure 6-a). It ensures that a storage facility receives an agreed price (strike price) per unit of hydrogen stored so that it can cover its CAPEX, OPEX, and have an adequate return-on-investment (ROI). If the revenue per unit stored is lower than the strike price, the government provides a subsidy. If the revenue per unit stored is higher than the strike price, the storage operator pays back the government so that risk is more evenly divided between government and storage facility.

A CfD scheme mitigates the price risk, but does not mitigate the volume risk, because it does not guarantee a minimum total revenue.

An MRF scheme is a revenue-based tariff that guarantees a minimum yearly revenue so that a project can cover its CAPEX, fixed OPEX, and an adequate ROI, even if no storage services are sold (Figure 6-b). As service sales increase, the subsidy goes down, but net revenue increases, such that growth is incentivised. An MRF scheme could also include a clawback mechanism, where the government recovers its costs after a certain level of sales. A downside of this mechanism is that the risk is mostly at the government side, which might make it difficult to agree on the level of the MRF. In the United Kingdom, the government is specifically considering this financial support instrument to finance UHS.[34]

Figure 6
a) Illustration of a contracts-for-difference scheme (CfD)
b) Illustration of a minimum revenue floor scheme that can include clawback



34 UK Department for Energy Security & Net Zero (2023), Hydrogen transport and storage infrastructure: minded to positions (Link)

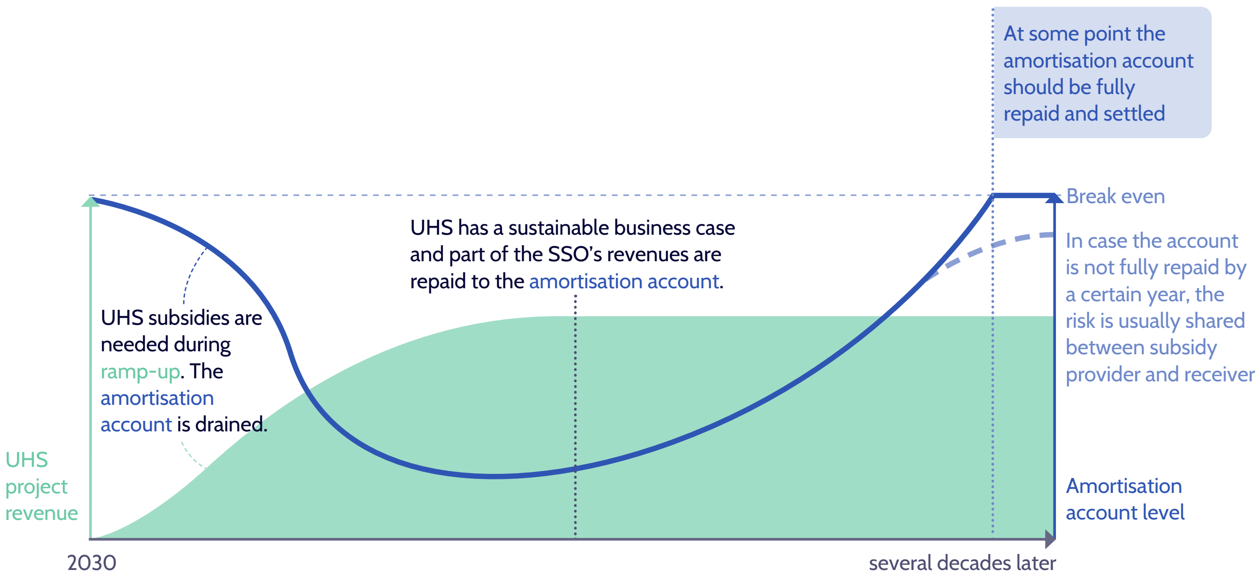
3.2.4 | Clawback and Intertemporal Cost Allocation: A Case Study of Germany's Amortisation Account for the Hydrogen Network

To finance the construction of the planned core hydrogen network, Germany will introduce an amortisation account: a bank account from which subsidies are paid in the early unprofitable phase of the hydrogen network, and which be replenished over time when the hydrogen network is profitable (Figure 7). Ideally, the amortisation account is settled up by 2055. In case of failed market take-off by 2055, hydrogen network operators will stand responsible for up to 24% of subsidy payments. The German government is considering a similar setup to spread out investments in the electricity grid.

An important component of the amortisation account is a clawback mechanism. Clawback is a mechanism where if revenues are high enough after a mature market has developed, some part is repaid to a subsidy provider. This way a subsidy provider can regain some or all of the investment costs. Similar approaches could be developed for UHS, where initial subsidy costs are recouped after a mature UHS market has developed.

Figure 7

Illustration of an amortisation account from which subsidies are paid in the early phases of UHS development, and then settled after several decades of clawback.



04 Implementation

Key messages

- **The benefits of UHS for the energy system necessitate its prompt implementation and scale-up.** Alliance members are advancing with UHS projects at various development stages, facing challenges related to policy, technical feasibility, and market understanding.
- **Operators encounter challenges with site feasibility and complex permitting procedures.** To overcome this, substantial research and site characterisation are required, often taking significant time and resources, while there is no clear line of sight on a viable business case.
- **The lack of standardised hydrogen and UHS guidelines complicates permitting.** Developing clear standards and learning from pilot project learnings can help accelerate the streamlining of permitting processes.
- **Understanding market requirements through consultations and Open Seasons is critical** for planning UHS capacities and ensuring system flexibility, reflecting future energy system needs.

The implementation and scale up of UHS must start as soon as possible to realise benefits for the energy system. In chapter 2 and chapter 3, the requirements from a policy level, as well as means to increase the financial viability of UHS are described. Whilst there are still a lot of uncertainties and hurdles to overcome, members of H2eart for Europe are already advancing with their UHS projects. These projects are at various stages of development and are running into different types of challenges in terms of implementation.

Overall, challenges are linked to three levels of implementation. Firstly, there are some that are situated at the European and/or Member State level. These are mostly related to market uncertainty, the development of (international) value chains of hydrogen and security of supply. Secondly, various challenges on a project level have emerged, such as site feasibility and permitting procedures. Lastly, all SSOs are working to understand the market and make plans for their sites and future operation. This will be reflected at company-level.

4.1 Lacking high-level vision for UHS translates into overall market uncertainty

During the development of individual projects, SSOs are currently running into problems that are related to unclarity in policy and strategy documents on national or European level. This ambiguity stems from the lack of a clear vision on the needed storage volumes and the structured and integrated planning of UHS in relation to natural gas, hydrogen and electricity infrastructure. As addressed in chapter 2 (Policy & Regulation), a clear view on UHS volumes will be required to implement (no-regret) UHS infrastructure in Europe.

Within the development of individual UHS projects of repurposing natural gas storage for hydrogen, security of supply is seen as a concern. National regulatory authorities and permitting bodies ask storage operators to show that this repurposing does not negatively affect SoS. On a European, national, but even regional level, the coordinated phase out of natural gas assets needs to be mapped out for efficient planning of UHS.

The coordinated implementation of UHS is also closely tied in with the development of the hydrogen sector overall. Recent auctions (conducted by e.g. the EU Hydrogen Bank and H2Global) show that there is a lot of interest to scale up hydrogen supply and demand.[35] This scale up coincides with an increasing need to bring both domestic and imported hydrogen from production to demand centres. The role of infrastructure and its timely implementation is more and more recognised as a key factor in the transition to net-zero.

4.2 Project-level implementation risks

H2eart for Europe members are already progressing with both pilot-, as well as (small) commercial-scale UHS projects, as indicated in the alliance's first publication.[36] From these project developments, several learnings may be identified that can help accelerate the implementation of UHS projects. These take-aways concern the actual (technical) feasibility of projects as well as permitting procedures, in which SSOs are highly dependent on external authorities and legislative bodies. National authorities can also contribute to the successful identification of a UHS location in proximity to other hydrogen infrastructure.

4.2.1 | Site and project feasibility

A detailed site screening process is necessary to assess whether an underground storage location is suitable to store hydrogen. Screening intensity varies per type of storage (salt cavern, depleted field, aquifer or lined rock cavern) and per actual storage site.

A location's technical suitability depends on the geological setting and the structural integrity of cavern/reservoir and cap rock, the presence of water in rock pores, residual hydrocarbons, and other impurities. This means that for both the development and operation of a storage site, a cost-intensive amount of testing will be needed. All sites and fields will need to be characterised individually to understand the suitability for future hydrogen storage. European research projects such as HyUSPRe and HyStories have helped identify the necessary screening parameters which can determine a location's suitability, and the resulting assessment criteria can now form the basis for a standardised approach across Europe.[37]

35 European Commission (2024). European Hydrogen Bank auction provides €720 million for renewable hydrogen production in Europe (Link) and H2Global (2022). 900 million euros for the market ramp-up of green hydrogen (Link)
36 H2eart for Europe (2024). The role of underground hydrogen storage in Europe (Link)
37 HyUSPRe (2023). (Link) and Hystories (2024). Hystories - Hydrogen Storage in European Subsurface (Link)

SSOs have observed notable differences in screening steps necessary between various storage types. For newly leached salt caverns developed for hydrogen storage, technical challenges such as appropriate choice of materials, development of robust cavern shapes, and thorough site screening processes remain. The repurposing of existing salt caverns previously used for natural gas similarly requires a comprehensive assessment process.

Utilising depleted gas fields and aquifers involves several challenges that require thorough investigation. Essential tests for site characterisation include cavity integrity, material suitability, operational procedures, and microbiological assessments. The outcomes of these tests can significantly impact the economic viability of the storage site, potentially necessitating additional purification units or the replacement of components such as valves, compressors, and pipelines.

The development of these sites takes time and resources for the storage operator in a currently uncertain market. In the nascent hydrogen market, it may be wise for storage operators to first develop smaller sites, or sites that are in proximity of national hydrogen infrastructure plans. However, regardless of these conditions, there is the need for a clear line of sight on a viable business case, as described in chapter 3, to develop sufficient UHS assets across Europe.

4.2.2 | Permitting procedures

Chapter 3.4 provides detailed recommendations for shortening permitting procedures to scale up UHS in Europe. This subchapter, however, aims to provide insight into the permitting procedure from Heart for Europe's members.

Alliance members have already initiated or are engaged in various permitting procedures for UHS assets across different jurisdictions. **These experiences reveal a significant lack of reference standard procedures and criteria for UHS, particularly regarding material use and on-site equipment.** While standards such as API and ESMA exist for natural gas assets, similar guidelines for hydrogen and UHS are absent, complicating and slowing down the process of securing permits.

It is crucial to develop and finalise these guidelines promptly to simplify and expedite permitting procedures. Additionally, several SSOs have been permitted to develop pilot or research projects under specific "regulatory sandbox" conditions within their jurisdictions. These conditions allow for the safe and secure testing and operation of assets. The insights gained from these projects should be utilised to streamline and simplify permitting procedures, minimising delays effectively. by providing a starting point for the setting of reference standards.

4.3 Understanding market needs – market consultations and open seasons

An important aspect of implementing UHS is a thorough understanding of market players' needs. To achieve this, H2eart for Europe SSOs have initiated Market Consultations and Open Seasons in various countries. These tools are crucial for assessing storage requirements, such as the capacities needed per company, and injection and withdrawal demands. These metrics help gauge the flexibility needs of UHS assets and their operation within a future hydrogen and energy system.

Currently, market consultations are viewed as a “wish list” from potential customers. However, in the future, binding results from these consultations could inform and financially support well-founded investment decisions. This would aid storage operators and governments in improving energy system planning on European, national, and regional levels.

Initial results from the market consultations by H2eart for Europe members have already yielded intriguing insights. Different potential future users have varied responses regarding their needs. The future interaction between hydrogen producers, infrastructure, and demand remains uncertain. Since electrolysers will operate based on fluctuating renewable electricity, it is unclear who will handle flexibility bookings. This might necessitate a combined product of production and storage to stabilise and balance hydrogen supply to offtake parties, posing contractual challenges caused by unbundling requirements.

Additionally, market consultations have reaffirmed the role of UHS in the future energy system, as outlined in our first publication.

Market actors have identified UHS as vital for stabilising hydrogen supply from intermittent renewable energy and acting as a bridge between the electricity and gas systems. The results indicate high flexibility, provided through several cycles per year are desired, with flexibility being a primary requirement for UHS in the future energy system.

Nevertheless, to efficiently utilise UHS for capacity and flexibility needs, tender procedures will be essential. To account for the EU-specific situation of an integrated market, capacity and tender procedures must include a cross-border approach to also facilitate bilateral contracts in cases where a storage site’s users are located geographically close but not in the same Member State.

In combination with the evaluation of market development through KPIs as suggested in Chapter 2.2, market needs could also be assessed through a market demand registration tool where potential customers can register their current and predicted future demand. This would allow a representation of real needs as accurately as possible.

05
Conclusion & recommendations

Underground hydrogen storage (UHS) is pivotal for the future of Europe's energy system, providing a critical solution to balance the intermittency of renewable energy sources. The transition to a decarbonised energy system hinges on effective storage solutions, and UHS stands out due to its scalability, safety, and potential to leverage existing infrastructure. This report thoroughly examines the multifaceted challenges and opportunities associated with the implementation and scale-up of UHS across Europe.

Policy and regulatory landscape: UHS ambitions as well as clarification of policy ambiguities needed

The regulatory framework for UHS is evolving, with the Gas Decarbonisation Package marking a significant step forward. However, the current framework must be developed further to fully kick-start a robust and viable UHS market. The package introduces a phased approach to tariff setting but lacks detailed guidance for the transition period, which creates uncertainty. Furthermore, while it emphasises the need for coordinated network planning, it does not provide clear directives for integrating UHS into these plans.

This gap underscores the need for additional policy measures, including the establishment of EU and Member State UHS ambitions. Additionally, the development of clear and standardised guidelines for UHS is critical.

Economic viability and financial mechanisms: financial risk-mitigation mechanisms are needed for UHS kick-off

Economic uncertainties pose significant investment barriers to the scale-up of UHS. The nascent state of the hydrogen market means financial risks are high and rewards are uncertain. Without public financial support, the business case for UHS remains weak. The report highlights the necessity of financial mechanisms to mitigate these risks and provide incentives for investment. Proposed mechanisms within the framework of a "toolbox" include Contracts-for-Difference and Revenue Floors. These mechanisms can distribute costs and risks over a longer period, effectively de-risking UHS project development as well as encouraging private investment.

Financial support instruments are especially essential during the ramp-up phase, where the market is not yet mature. In return, public financial risk mitigation can ensure that UHS infrastructure is in place when demand starts ramping-up by 2030 and stabilising by 2050, aligning supply with market needs.

Implementation: ambitious UHS projects testify to high demand and practical barriers

Despite regulatory and economic challenges, SSOs are advancing with ambitious UHS projects, demonstrating the feasibility and potential of this storage solution. However, they encounter several obstacles, particularly related to site feasibility and permitting procedures.

The lack of standardised guidelines complicates permitting, but leveraging learnings from pilot projects can provide valuable insights to streamline these processes. SSOs' proactive efforts in progressing UHS projects highlight the readiness of the industry, but the role of policymakers remains crucial in creating an enabling environment for these initiatives to thrive.

Market consultations conducted by H2eart for Europe alliance members have confirmed the strategic role of UHS in the future energy system, as well as proven to be critical tools for understanding the needs of market players and planning UHS capacities accordingly. While current consultations serve as a preliminary wish list from potential customers, binding results in the future could inform well-grounded investment decisions, aiding both storage operators and governments.

Concluding Remarks

The integration and scale-up of UHS are essential for Europe's transition to a sustainable energy system. The benefits of UHS extend across the power sector and the hydrogen ecosystem, underscoring the need for an integrated vision that encompasses both electricity and gas systems. While SSOs are making significant strides, the full realisation of UHS's potential hinges on coordinated efforts from policymakers, the establishment of clear regulatory frameworks, and the implementation of robust financial support mechanisms. Urgent action is needed to address economic uncertainties, streamline permitting processes, and ensure timely development of UHS infrastructure, paving the way for a resilient and optimised European energy system.

Appendix

Because of a growing number of terms for financing mechanisms and their components, there is a strong need to clarify terms and definitions used in order to avoid confusion. The below definition list is not meant as an authoritative inventory for these terms but rather serves to bring clarity to this report. In the near-future it would be preferable for UHS industry players and policy makers to agree on common definitions.

Term	Definition in this report	Comment
Lump-sum	Fixed amount of money which could be a one-time payment, paid periodically, and could be a loan. Includes both CAPEX and OPEX support.	
Revenue-based subsidy	Subsidy is based on the revenue of a project over a certain timeframe (often 1 year). Tariffs and premiums can be both revenue-based and unit price-based.	Tariffs and premiums can be revenue-based or unit price-based.
Unit price-based subsidy	Subsidy is based on the price per unit (e.g. €/kg H_2 stored).	Tariffs and premiums can be revenue-based or unit price-based.
Tariff-based subsidy	Fixed agreed unit price or yearly revenue. A tariff-based subsidy compensates a subsidy receiver for the difference between the market price or yearly revenue and the tariff.	
Premium	Subsidy on top of the market price or yearly revenue. Can be an agreed percentage or fixed premium.	
Gainshare	Repayment of some part of the yearly revenue or unit price to the subsidy provider when the unit price or yearly revenue goes above a certain price or revenue cap or above the tariff.	Gainsharing can be used to gradually repay and eventually settle an amortisation account (see below).
Anchor bookings	Financing mechanism that guarantees a minimum (virtual) booked capacity for a storage operator. This is an approach to guaranteeing a minimum revenue for a storage operator.	
Amortisation account	A bank account set up by a subsidy provider that is depleted during market ramp-up and gradually replenished after market development until it is settled (often after several decades).	Is sometimes confused as a financing mechanism. Rather, it is a method to facilitate the payment of a financing mechanism.
Contracts of Difference (CfD)	Financing mechanism that compensates the unit price difference between the market price and an agreed tariff (sometimes called 'strike price'). Includes gainsharing, which means that if the unit price goes above the agreed tariff, the subsidy receiver repays the difference to the subsidy provider.	Is sometimes confused as a component of a financing mechanism. Rather, a CfD is a self-contained mechanism that consists of several components: it is a unit price-based subsidy that includes gainsharing.

EWE

gasunie
crossing borders in energy

HGS
Powered by MVM

nafta

OMV

rag
ENERGY STORAGE

RWE

snam

storengy

TERĒGA

uniper

VNG
Gasspeicher