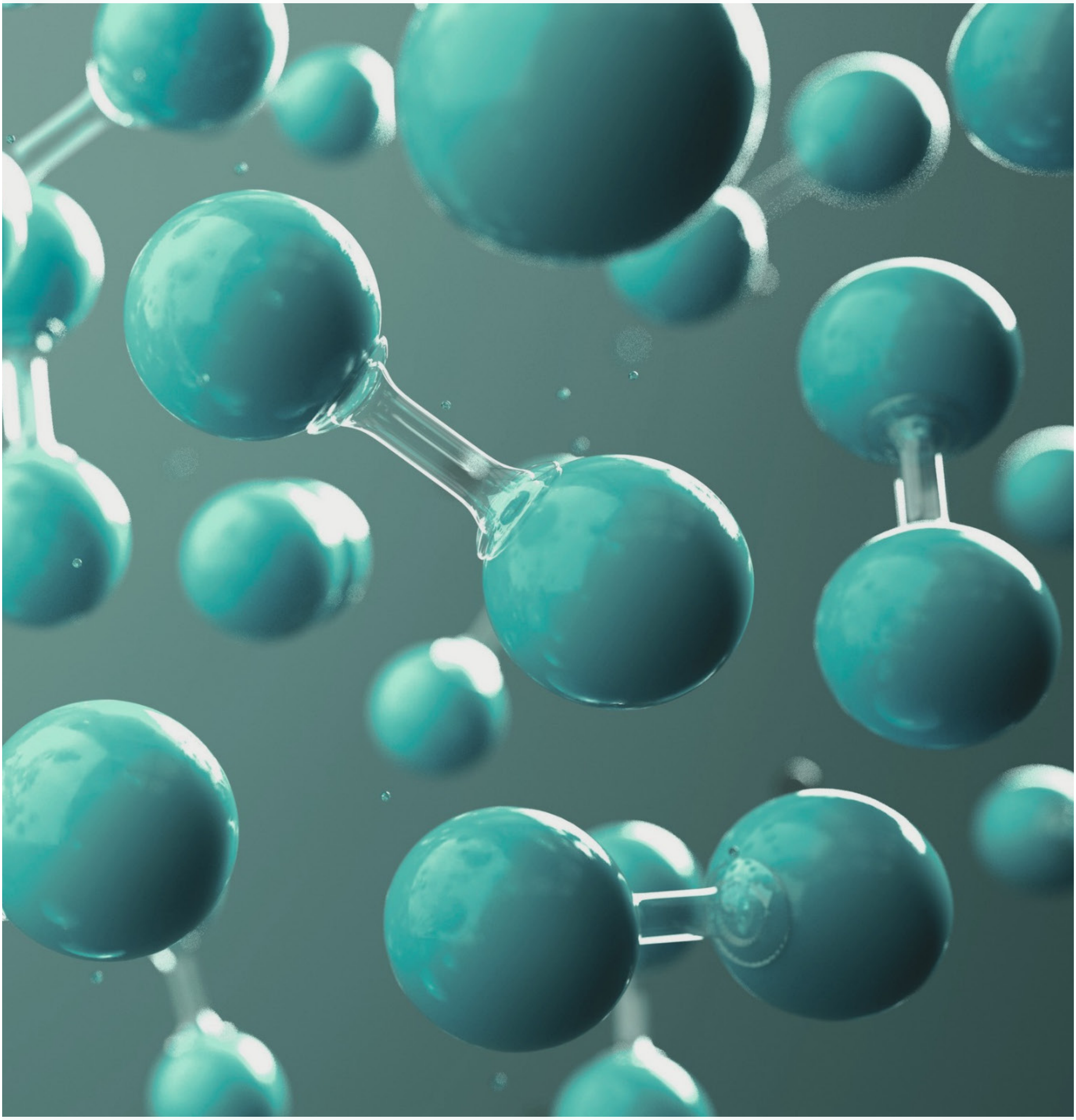
How to deliver on the EU Hydrogen Accelerator



African Hydrogen Partnership

Dii

EU-GCC Cleanergy.Net

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MENA Hydrogen Alliance
An initiative of Dii Desert Energy

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Key Suggestions

This paper analyses the Hydrogen Accelerator proposed in the European Commission's REPowerEU common action plan and suggests concrete additional EU actions that are needed to realise its '20-Mton-hydrogen-target-by-2030', i.e., 10 Mton produced in the EU and 10 Mton supplied via imports. The aim of these efforts in support of 'REPowerEU' is to make the Union 25-50 BCM less dependent on Russian gas.

Table 1 summarises the additional EU actions that are, in our opinion, necessary for successfully carrying out the Hydrogen Accelerator goal.

Table 1: Additional EU H2 actions.

Hydrogen Accelerator 20 MTon by 2030	Proposed Set of additional EU Actions To deliver on the 20 Mton by 2030 hydrogen goal Making EU 25-50 BCM less dependent on Russian gas imports
Decouple supply and demand in time and geography	'Bootstrap' the hydrogen system, i.e., realise the proper hydrogen infrastructure and storage capacity before supply and demand can be scaled up accordingly. • Realise upfront infrastructure, pipelines and logistic chains, including port facilities, connecting potential supply areas and geographical demand areas, i.e., 'hydrogen valleys'. • Realise upfront hydrogen storage facilities. Use these storage facilities in the start-up phase to decouple supply and demand for the ramp-up period. • Let TSOs or other regulated public or private bodies operate these storage facilities in the ramp-up phase and finance the upfront operational costs of these through the European Hydrogen Facility.
Transport, infrastructure and storage facilities	Coordinate and accelerate EU hydrogen infrastructure and storage capacity planning in an integrated manner. • Accelerate the development of an integrated EU hydrogen infrastructure that needs to be ready by 2030. • Accelerate the development of hydrogen storage facilities throughout the EU, with a capacity of about 5-10 Mton, allowing for an early market instrument that decouples supply and demand. • Create a public-private financing scheme within the EU Hydrogen Facility to subsidise the re-purposing and construction of an EU wide hydrogen infrastructure and storage capacity. • The Hydrogen and Decarbonised Gas Market Package legislation should focus on rapid scale-up, expansion, and market creation while avoiding premature barriers such as stricter unbundling rules. **Establish a European Hydrogen Cross-Border Infrastructure and Storage Facility additional to those of Member States that:** • Plans, invests and operates EU cross border pipeline infrastructure across the Mediterranean and the North Sea and port facilities and storage capacity beyond the Union. • Initiates, invests and manages an EU strategic hydrogen reserve equivalent to at least 90 days of net import, which equals approximately 2,5 Mton by 2030.

Hydrogen demand	Set Mandatory Targets with: • 'Fit for 55' replacing 50% of industrial grey hydrogen demand with green hydrogen. • 'Fit for 55' incorporating an increased target for hydrogen usage in the transport sector, i.e., from an initial 2.6% to 5%-10% by 2030. • Set mandatory targets for green steel. **Develop hydrogen demand per geographical area via 'gas-to-hydrogen-conversion' instead of a sectoral approach** • Convert regional 'corridors' that are scheduled to shift from low to high caloric gas to hydrogen instead. • Fast-track the implementation of Important Projects of Common European Interests (IPCEI) and hydrogen valleys with the integrated conversion from gas to hydrogen. • Connect hydrogen valleys across Europe and expand geographically from these valleys while converting from gas to hydrogen.
Hydrogen supply and demand	In order to boost Member States' access to affordable renewable hydrogen, a temporary **Global European Hydrogen Facility** should facilitate the domestic production and EU import of green hydrogen, ramping up to 10 MTon by 2030. • Expand and Europeanise the 'H2Global' instrument initiated by Germany, which has already started implementing its first hydrogen auctions. • As a specific first and priority set of auctions, tender and purchase 2,5 Mton for the EU strategic reserve 2030 under the Global European Hydrogen Facility. • Tender hydrogen storage capacity to store hydrogen for balancing supply and demand. • Execute auctions to purchase hydrogen in geographic areas that can be connected to a hydrogen infrastructure or logistics chain. • Initiate **EU Green Hydrogen Partnerships** backed by country and region-specific tenders. • Execute bidding processes to sell hydrogen to companies and Member States' hydrogen facilities. • Use existing trading platforms to support the creation of market liquidity in the EU.

Source: Authors.

Introduction

Russia's unprecedented military attack on Ukraine has turbocharged the European Union's (EU) clean energy transition. The European Commission has formulated a bold, common action plan entitled "REPowerEU" to achieve independence from Russian gas well before the end of this decade. This action plan consists of three-pillars that will increase the resilience of the EU-wide energy system, i.e.:

I. Diversifying gas supplies via higher LNG imports and pipeline imports from non-Russian suppliers and higher levels of biomethane.
II. Accelerating hydrogen production and imports to 20 Mton by 2030.
III. Reducing faster the EU's dependence on fossil fuels at the level of homes, buildings and the industry, and at the power system level by boosting energy efficiency gains, increasing the share of renewable, and addressing infrastructure bottlenecks.[1]

Via the Hydrogen Accelerator (Pillar II), the Commission proposes an additional 14,4 Mton of renewable hydrogen on top of the 5,6 Mton foreseen under the "Fit for 55" legislative package, i.e., 10 Mton produced domestically (in the EU) and 10 Mton of imports.[2] The Commission argues that this 20 Mton of hydrogen could replace 25-50 bcm of Russian gas by 2030.[3]

This position paper suggests tools and actions that are needed to realise the REPowerEU '20-Mton-hydrogen-target-by-2030' rapidly; this in terms of:

Image: Informaconnect.

- **Infrastructure.**
- **Storage.**
- **Strategic reserve.**
- **Creating 'early demand regions'.**
- **Utilising the H2Global instrument to kick start national hydrogen supply and demand.**
- **Establishing a Europeanised H2Global instrument under the Global European Hydrogen Facility.**
- **Decoupling supply and demand across time and geography.**

Whereas this position paper focuses on the rapid deployment and scaling up of green hydrogen production, imports, and infrastructure, we recognise that a clear regulatory framework (e.g., via the amendment of the EU Renewable Energy Directive and its Emissions Trading System) is a condition sine qua non for realising the RePowerEU's green hydrogen targets. Equally critical, but also beyond the scope of this paper, is the development of an international Guarantees of Origin system. Proper standardisation and certification are necessary to increase investment security, mobilise private capital and facilitate imports.

1European Commission, "REPowerEU: Joint European action for more affordable, secure and sustainable energy" (Strasbourg: European Commission, March 8, 2022), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A108%3AFIN.
2 REPowerEU states that "Other forms of fossil-free hydrogen, notably nuclear-based, also play a role in substituting natural gas".
3 Ibid. Footnote 1.

2. Proposal: What is required for realising the EU’s 20 Mton Hydrogen Accelerator goal by 2030?

Today, small- and large-scale projects within Europe are in development, especially as part of the Important Projects of Common European Projects (IPCEI) initiative. However, planned power-to-hydrogen projects are insufficient to deliver on the 10 Mton target by 2030. Suppose all currently planned power-to-hydrogen projects in Europe are carried out. This would result in 118 GW of installed electrolyser capacity by 2030 while reaching the EU’s Hydrogen Strategy (2020) target of 40 GW in 2027.[4] Although impressive, the REPowerEU Hydrogen Accelerator implies a doubling of the capacity of the currently planned electrolysers. Therefore, the Accelerator suggests a range of measures that are required for securing the ’20-Mton-hydrogen-by-2030’ target:

- Further developing the regulatory framework to promote a European market for hydrogen and support the development of an integrated gas and hydrogen infrastructure, hydrogen storage facilities and port infrastructure.
- Assessing State Aid notification for hydrogen projects as a matter of priority.
- Completing the assessment of the first IPCEI within six weeks of their submission by Member States.
- Supporting renewable hydrogen production and transport pilot projects in the EU neighbourhood, starting with a Mediterranean Green Hydrogen Partnership.
- Working with partners to conclude Green Hydrogen Partnerships and with industry to establish a Global European Hydrogen Facility to boost the Member States’ access to affordable renewable hydrogen.[5]

These measures will undoubtedly positively impact the EU’s ‘hydrogen economy’ and its technology leadership if and when properly implemented. Simultaneously, we argue that much more is needed to obtain the highly ambitious ‘2030 target’.

2.1 Hydrogen Infrastructure: Backbone, ports and logistical chains

An extensive hydrogen infrastructure needs to be ready upfront with public spending driving initial investments in re-purposing natural gas pipelines and the construction of new ones. A specific public-private financing scheme within the Global European Hydrogen Facility should be dedicated to building and repurposing transport infrastructure and storage facilities, especially for hydrogen import. The “European Hydrogen Backbone”, initiated by the majority of European gas TSOs, recommends introducing the establishment of import corridors, including all infrastructure requirements, as a policy objective in the REPowerEU plan.[6]

Hydrogen derivates as a transport vector and fuel and feedstock will need to play a larger role much sooner for the EU’s independence of Russian gas imports to materialise before 2030. This implies that logistical chains will have to encompass ports, tankers, barges, trains and trucks accordingly.

European governance structures have to reflect this challenge, e.g., via the acceleration of integrated network planning and a shift in focus in the Hydrogen and Decarbonised Gas package towards more rapid hydrogen market creation. Premature barriers through highly sophisticated regulations such as stricter unbundling rules have

4 Hydrogen Europe, “Clean Hydrogen Monitor 2021” (Brussels: Hydrogen Europe, October 22, 2021), https://hydrogeneurope.eu/reports/.
5 Ibid. Footnote 1.
6 Guidehouse, “European Hydrogen Backbone: A European hydrogen infrastructure vision covering 28 countries” (Utrecht: Guidehouse, April 2022), 28, https://gasforclimate2050.eu/sdm_downloads/2022-ehb-a-european-hydrogen-infrastructure-vision-covering-28-countries/.

to be avoided.[7]

2.2. Role of storage, strategic stocks and balancing instrument

Storage facilities for hydrogen and hydrogen derivatives need to be ready upfront so that demand can be met at all times. A substantial storage volume is required due to the intermittent character of renewable hydrogen production and different demand patterns, e.g., base-load for steel, chemical industry and mobility, seasonal fluctuations for electricity balancing and heating. Underground hydrogen storage facilities need to be realised similar to those for natural gas, whereby it needs to be considered that potential storage capacities are unevenly distributed among EU Member States. Current indications of hydrogen storage facilities planning by several national TSOs are insufficient for realising the '20-Mton-hydrogen-by-2030' target. The market alone will not provide the required upfront storage capacity and the necessary volumes. We propose letting national TSOs or other regulated public bodies and companies take ownership and carry out the general operation of hydrogen storage facilities. Regional EU market area managers could subsequently coordinate and balance supply and demand, similar to the Trading Hub Europe. Initially, regional market areas are expected to develop around industrial clusters or 'hydrogen valleys', i.e., where demand-side liquidity and a comparatively high turnover rate can be expected.

Steep increases in gas prices and the war in Ukraine emphasise the geo-economic and geopolitical importance of a strategic energy reserve. As hydrogen imports will play an essential role in the EU's future decarbonised energy system, building a strategic hydrogen reserve is needed. Beyond strategic reserves, additional (commercial) hydrogen storage facilities need to be realised and integrated into the network planning. Whereas with strategic oil reserves, every Member State can install tanks for hydrogen derivatives, underground storage options in empty gas fields, porous rock formations, and salt caverns have to be considered and developed for hydrogen on a European scale. A comprehensive strategic hydrogen reserve at the EU level is realistic because potential storage capacity is not distributed evenly among its Member States. However, an organisation responsible for strategic hydrogen (and gas) reserves does not exist at the EU or national level.

Image: Audio und werbung.

2.3. Create early demand regions with strong pull and spill-over effects

The EU's 'Fit for 55' legislative package proposes new sub-targets for clean hydrogen used either as a feedstock or energy carrier by 2030, including a 50% demand target for industry and an (initial) 2.6% demand target for the transport sector. Hydrogen demand can be created by increasing these mandatory targets in industry and transport fuel and implementing mandatory targets for other industry sectors such as steel.

In parallel, another way of creating demand for hydrogen could be promoted, whereby regions are converted from natural gas to hydrogen and the volumes are clearly defined. Stated differently, we argue that regions scheduled to be converted from low-caloric gas to high-caloric gas (which includes Russian gas) should shift to hydrogen instead. Also, and in order to accelerate demand and the necessary supply chains, IPCEI projects and the scaling up of hydrogen valleys

7 Noé van Hulst and Kirsten Westphal, "Now is the time to get hydrogen off the ground in Europe", March 18, 2022, https://illuminem.com/energyvoices/a08ea94d-6b64-4008-ae4d-657b5117d337.

will need to become the nodes in the evolving hydrogen grid.

In short, and next to further developing a set of deterministic targets and actions that allow for a 20 Mton hydrogen demand by 2030, the EU has to establish a '**Union-wide-schedule-and-geographic-mapping**' on how and which EU regions can be converted from natural gas to hydrogen. This will inform the integrated network planning process and where and how to develop hydrogen infrastructure and storage facilities accordingly.

Regional conversion from natural gas to hydrogen can be expanded across larger regions, including scheduling according to a predefined roadmap. This 'deterministic'v process makes the properly planned expansion of hydrogen demand possible and more optimal than a sectoral 'policy and instrument approach'.

2.4. Kick-start national and inter-regional hydrogen supply and demand

In Germany, H2Global has implemented an auction-based approach to kick start supply and delivery to demand of green hydrogen and which was approved in December 2021 by the European Commission under EU State Aid rules (Box 1)[8].

Box 1: The H2Global Instrument

H2Global is an instrument for the fast and effective hydrogen or Power-to-X (PtX) market ramp-up at an industrial scale. This instrument aims at strengthening the creation of a sustainable hydrogen market, fostering a rapid energy transition and strengthening the EU's energy sovereignty.

How does it work? In the absence of pricing-signals, an intermediary (in this case the HINT.Co) concludes long-term purchase contracts; on the supply side and short-term sales contracts on the demand side for sustainably produced green hydrogen and its derivatives. The intermediary is backed by government support (in this case the German government) that provides these long-term off-take contracts and investors with the necessary investment security and bankability to finance the projects. Shorter-term sales contracts are concluded on the demand side. Potential losses occurring on the level of the intermediary, resulting from the difference between supply prices (generation and transport) and demand prices are compensated by grants. Pricing on the purchase and sales side is carried out via a competition-based bidding process ('double auction mechanism'). In compliance with pre-defined (sustainability) criteria based on the existing EU regulatory framework for the production and transport of the products, the lowest bid price or the largest quantity and respectively the highest sales price in Europe, will be awarded the contract. The short-term sales contracts make it possible to reflect the expected increase in the willingness of buyers to pay and thus in the market prices for the energy sources. The divergence in tenor of the purchase and sales agreements creates a symmetric market premium instrument, which is highly efficient and market-based with the effect that the difference between procurement costs and resale revenues to be compensated with public funds is kept at a minimum (Figure 1).

Figure 1: The Hydrogen Intermediary Company (HINT.CO) as 'mediator' between supply and demand.

Source: H2Global.

8 European Commission. "State Aid: Commission Approves €900 Million German Scheme." European Commission - Press Corner, December 20, 2021. https://ec.europa.eu/commission/presscorner/detail/en/ip_21_7022.

This instrument can efficiently match the production and export potential of several Member States with the import needs of others, i.e., imports within and beyond the EU. Several Member States could collaborate, i.e., team up or integrate their policies and instruments to kick start (inter-) regional hydrogen supply and demand in concert with import and export capabilities. The architecture of the H2Global instrument enables immediate scalability due to its modular approach, which allows each fund provider to customise the use of the instrument according to its specific needs ('window' logic).

Image: Scharfsinn.

2.5. Auction-based import approach under the Global European Hydrogen Facility

Imports from beyond the EU cannot be realised by each Member State separately due to the lack of storage facilities and an interconnected hydrogen infrastructure with neighbouring countries. Also, integrated infrastructure and storage planning allows for realising long-term import contracts more cost-efficiently. Therefore, it is suggested here to implement an auction-based approach for EU hydrogen and derivatives imports. Hydrogen imports will enable Member States to benefit from the most competitive production costs worldwide while supporting production and export capacity in partner countries and creating EU-oriented infrastructure corridors (or 'interconnectors') and maritime logistical chains. Such a global European hydrogen facility will enable the European Commission to decide flexibly on products, quantities, and criteria according to the particular demands of Member States and tailored to specific (European) technological developments and capacities and those of partner countries.

The swift implementation of a **Europeanised H2Global instrument** is considered a requirement here. The European Global Hydrogen Fund will benefit from the expansion of the already established auction-based and flexible architecture of the H2Global instrument. By bundling market development support in one major instrument, a clearly defined, transparent and replicable approach is established that creates a transparent, singular European hydrogen 'interface' to the outside world. This also strengthens the leverage of the EU Commission's efforts in current and ongoing efforts regarding certification (or 'guarantees of origin') in organisations such as the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). It furthermore supports the establishment of long-term supply partnerships with third parties and the establishment of Euro-denominated hydrogen contracts.

The auction-based instrument is also compatible with the Emissions Trading System (ETS) logic, whereby the incentive to use renewable alternatives is the highest for consumers who need to decarbonise the fastest.

Utilising the H2Global instrument as a set-up for the Global European Hydrogen Facility, creates a 'ready-available' opportunity for a rapid and effective market ramp-up of green hydrogen import and its derivates. We argue that creating any new (elaborate) institutional structure will take precious time that the EU and its Member States cannot afford. Moreover, this invites the creation of different instruments at various stages by different actors that could 'cannabilise' each other.

Regarding imports, the EU will have to rely on pipelines for pure hydrogen and maritime shipping for hydrogen and hydrogen-based derivatives from beyond its borders. Thus, we recommend incorporating all **Green Hydrogen Partnerships** proposed in 'REPowerEU' under the **Global European Hydrogen Facility**.

2.6. Decouple supply and demand across time and geography

An auction-based instrument also allows for developing supply and demand in unison. For example, the demand for hydrogen in steel production requires the installation of new Direct Reduced Iron (DRI) plants. While it takes several years to build such a plant, it requires the immediate and baseload supply of hundreds of thousands of tonnes of hydrogen. Regarding mobility, it takes years to scale up demand because new fuel cell electric vehicles have to come on the market at a reasonable price, with companies replacing their respective vehicle fleet only when their existing one is depreciated and sufficient volumes of affordable hydrogen being available.

This means that hydrogen infrastructure and storage facilities have to be established **before** production needs. In turn, proper production has to be established **before** sufficient hydrogen demand is available, resulting in a significant mismatch between time and geography. Therefore, the upfront realisation of infrastructure, pipelines and logistical chains, including port facilities, is required to connect potential supply areas and geographical demand areas, including the storage facilities, to balance supply and demand and for strategic reserve purposes.

The mandatory targets in industry and for transport fuels, as well as dedicated subsidies to energy-intensive sectors, will lead to large hydrogen 'demand sinks' around industrial clusters 'hydrogen valleys'. This will trigger supply in and outside the EU and result in fixed point-to-point delivery contracts and flows at the cost of the demand side that will carry the still high cost of production and delivery. This comes with challenges for the pipeline infrastructure, such as congestion in pipelines, and for hydrogen storage. Moreover, long-term bilateral contracts result in up-scaling existing production projects and replicating well-known gas industry problems. Even though these singular large deals are an important element in ramping up the production of hydrogen and its derivatives and are necessary to adjust technologies and consumption patterns on the demand side, they do not provide price signals, standard criteria and trading structures. The latter is important to create a level-playing field and incentivise markets. They also do not deliver on diversification. Yet, the EU needs to actively diversify its long-term import relations and build interconnectors with strategic partners.

In summary, the described additional EU actions allow for the '**bootstrapping**' of the Union's common hydrogen system, i.e., temporarily decoupling supply and demand over the coming years while allowing for the built-up and usage of the proper infrastructure and storage facilities for balancing supply and demand and the creation of a strategic reserve. TSOs or other regulated public or private bodies need to carry out a temporary decoupling of production and demand and operate these storage facilities accordingly. The global European Hydrogen Facility could finance these upfront operational costs.

Image: audioundwerbung.

3. Context: What is necessary to deliver on the 20 Mton hydrogen accelerator goal by 2030?

Putting the Hydrogen Accelerator into practice will require a massive ramping up of production, supply and demand via the necessary storage and transport facilities, all made possible by quickly establishing the proper regulatory framework. This section provides the context in which these efforts need to take place, i.e., it presents an estimate of the production capacity and storage plus the hydrogen transport infrastructure needed within and beyond the EU to deliver on the 20 Mton of clean hydrogen target by 2030.

3.1. 2x10 million-ton hydrogen production

Table 2 presents a high-level scenario for the production of 10 Mt of hydrogen in the EU and the import of 10 Mt. Many variations on this scenario are possible. Still, the overall picture is that a large amount of additional solar and wind capacity is needed, together with about **350 GW** of electrolyser capacity.

Table 2: A 2030 scenario for 20 Mton green hydrogen production, 10 Mton in EU and 10 Mton imported.

2*10 million ton green hydrogen	Renewable Resource			Electrolyser		Hydrogen Production	
2030	Capacity	Full load hours	Electricity Production	Capacity	Full-load hours		
	GW	hr/yr	TWh	GW	hr/yr	Million ton	TWhHHV
EU production							
Offshore	30	5.000	150	30	5.000	3	118
Onshore wind	35	3.000	105	30	3.400	2	79
Solar PV	150	1.500	225	125	1.750	4	158
Grid connected electrolysers	Renewable/Nuclear electricity from grid			7	7.000	1	39
Import							
Onshore wind	30	3.500	105	25	4.100	2	79
Solar PV	150	2.100	315	115	2.650	6	237
Offshore wind	10	5.000	50	10	5.000	1	39
Hydropower/Nuclear	8	6.000	51	8	6.000	1	39
Total				**350**		**20**	**788**

Source: Authors.[9]

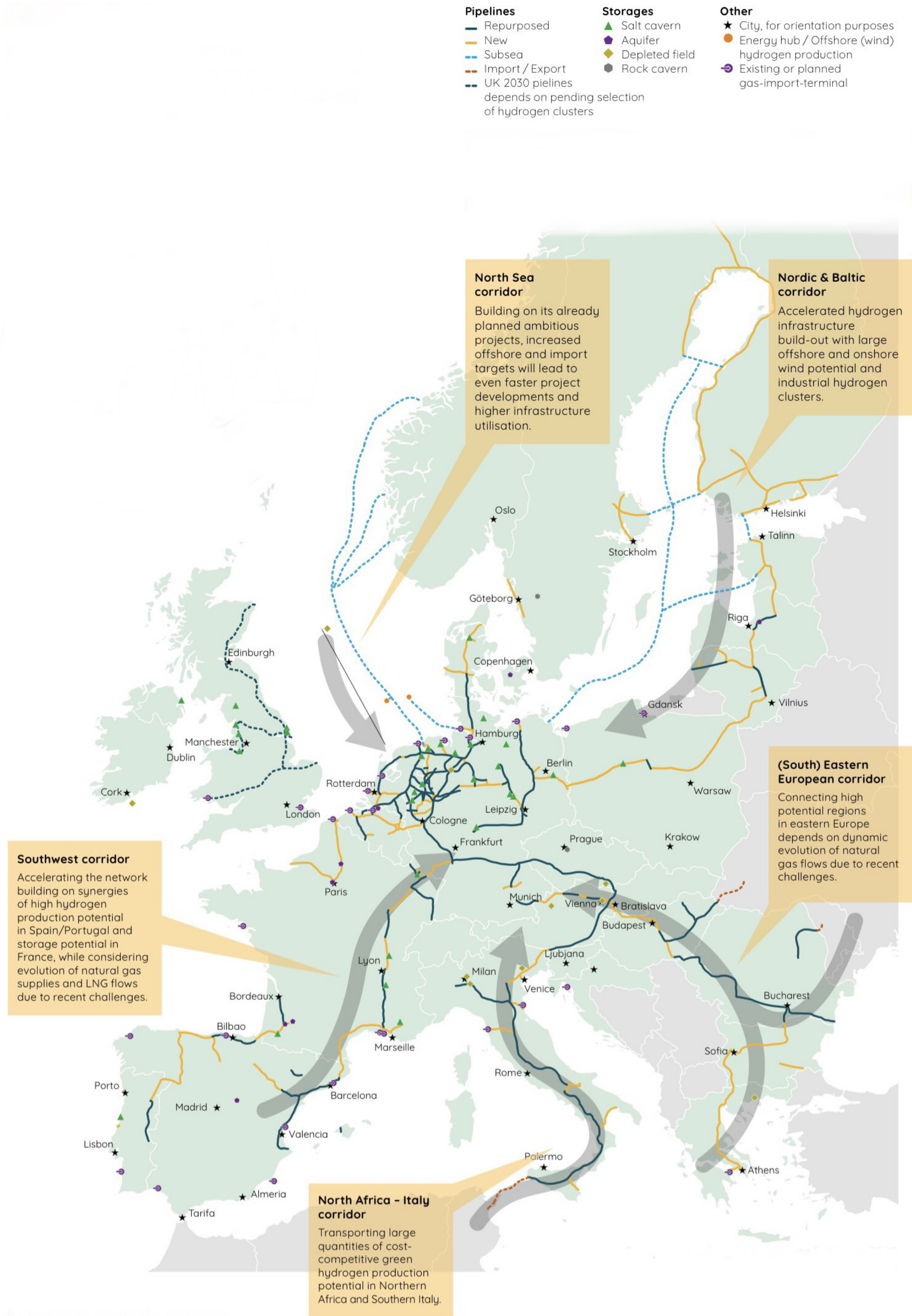
3.2. Required hydrogen transport infrastructure

Transporting 20 Mton of hydrogen across an interconnected European market, including 10 Mton of imports, requires a dedicated transport pipeline infrastructure with interconnections to North Africa, the Middle East, and the North Sea territory beyond the EU.

Responding to the Commission's REPowerEU proposal, the TSO-initiated European Hydrogen Backbone (EHB) has presented an updated, extended, and accelerated plan involving 31 energy infrastructure companies from 28 countries. Figure 2 shows this accelerated EHB vision by 2030, which includes five emerging pan-European hydrogen supply and import corridors that connect industrial clusters, ports, and hydrogen valleys to regions of abundant hydrogen supply – and support the European Commission's ambition to promote the development of a 20 Mton renewable and low-carbon hydrogen market in Europe.

9 This scenario is based on green hydrogen production only. However, part of the hydrogen could be replaced by hydrogen from other sources.

Figure 2: Accelerated and updated 2030 European Hydrogen Backbone network that supports the REPowerEU ambitions.



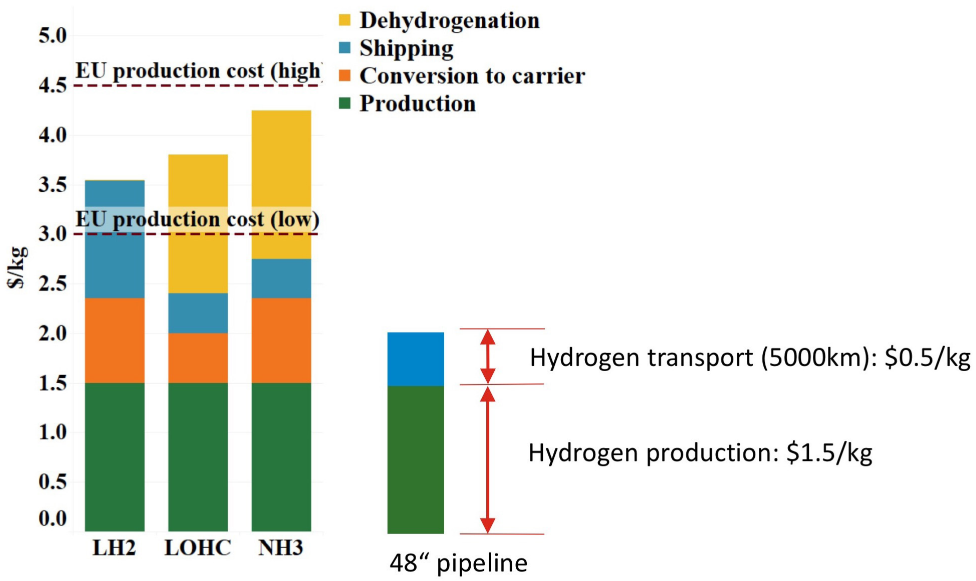
Source: Guidehouse (2022).[10]

10 Guidehouse. "European Hydrogen Backbone: A European Hydrogen Infrastructure Vision Covering 28 Countries." Utrecht: Guidehouse, April 2022. https://gasforclimate2050.eu/wp-content/uploads/2022/04/EHB-A-European-hydrogen-infrastructure-vision-covering-28-countries.pdf.

The hydrogen infrastructure can then grow to become a pan-European network, with a length of almost 53,000 km by 2040, largely based on repurposed existing natural gas infrastructure. Moreover, figure 2 shows possible additional routes that could emerge, including potential offshore interconnectors and pipelines in regions beyond that of the EHB.[11]

The import of 10 Mton of hydrogen requires an intercontinental and cross-border offshore transport infrastructure of pipelines and shipping routes. Regarding distances of up to 5.000 km, pipeline transport is cheaper than shipping (Figure 3).

Figure 3: Hydrogen transport cost over a distance of 5.000 km via shipping (example of Saudi Arabia to Europe) versus pipeline.

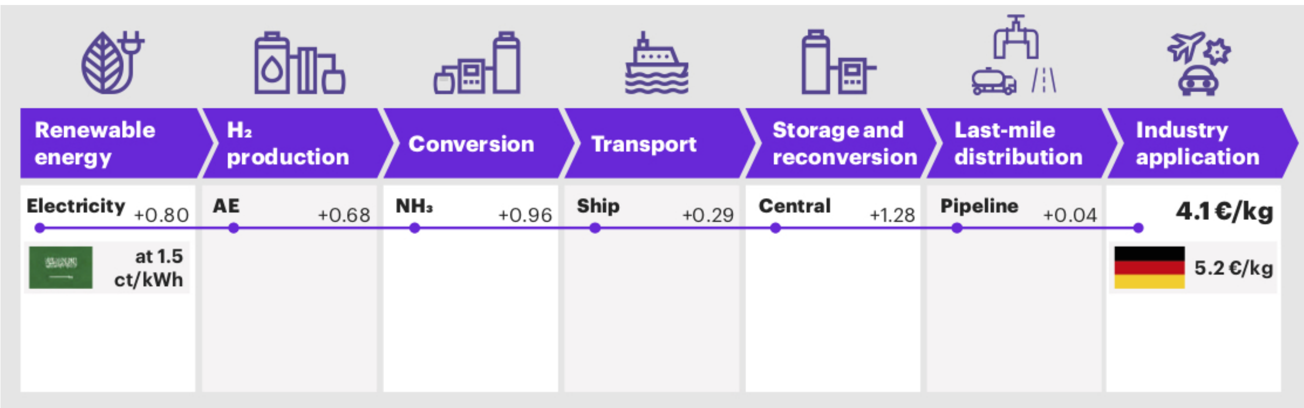


Sources: Adapted from Braun and Shabaneh (2021) and ILF (2021).[12]

We argue that the import goal of 10 Mton of hydrogen creates sufficient volume for a feasible business case for pipeline transport. A 48-inch hydrogen pipeline operating at 80 bar has a transport capacity of 15-20 GW hydrogen (HHV) and can transport between 1,5 and 2,5 Mton per year, (depending on the full load hours).

Additionally, there is a rationale to import hydrogen and hydrogen derivatives by ship. The motivation for this import option is that hydrogen can be imported from areas with even lower production costs from even further away (Figure 4).

Figure 4: Modeling green hydrogen import cost via ammonia from Saudi Arabia to Germany by 2025 (EUR/kg H2).



Source: Wietfeld et al. (2021).[13]

11 Grinschgl, Julian, Jacopo Maria Pepe, and Kirsten Westphal. "A new hydrogen world: Geotechnological, economic, and political implications for Europe." SWP Comment. Berlin: German Institute for International and Security Affairs, December 16, 2021. https://www.swp-berlin.org/publikation/a-new-hydrogen-world.
12 Jan Frederik Braun and Rami Shabaneh, "Saudi Arabia's Clean Hydrogen Ambitions: Opportunities and Challenges," Commentary (Riyadh: KAPSARC, June 30, 2021), https://www.kapsarc.org/research/publications/saudi-arabias-clean-hydrogen-ambitions-opportunities-and-challenges/.
13 Wietfeld, Axel et al. "Competitiveness of Green Hydrogen Pathways for Germany in 2025." Uniper / Kearney, October 2021. https://emvg.energie-und-management.de/filestore/newsimgorg/Illustrationen_Stimmungsbilder/Studien_als_PDF/Competitiveness_of_green_hydrogen_import_pathways_for_Germany_in_2025.

Secondly, hydrogen import by ship is economically feasible from multiple (exporting) countries, creates ‘flexibility in supply’ and avoids a ‘lock-in’ with a limited number of suppliers. Thirdly, due to already established technology, available infrastructure, the existing ammonia market, and ongoing R&D progress, this paper makes a case for shipping hydrogen as ammonia. Imported ‘green’ ammonia can replace ammonia produced in the EU from gas and directly used in combustion processes such as diesel engines in ships or gas turbines for electricity production.

Table 3 presents a range of feasible options regarding volumes and transport modes required for hydrogen import for the EU Hydrogen Accelerator initiative. Hydrogen imports by ship, primarily in the form of green ammonia, are possible from destinations worldwide. Hydrogen import by pipeline is especially foreseen from countries in the Mediterranean region, the North Sea and beyond.

Table 3: Feasible options for EU import of 10 Mton hydrogen by 2030.

Import 10 MTon	Hydrogen Volume Mton/year	Transport Mode	From Countries
Ammonia	*2-3 Mton Hydrogen (= 11-17 Mton Ammonia)*	*Ship*	*Australia, Chile, Morocco, Namibia, Oman, Saudi Arabia, Uruguay.*
Hydrogen	*4-6 Mton*	*NEW pipeline: Saudi Arabia-Egypt-Cyprus-Greece-Italy*	*Middle East and North Africa.*
		Re-Purposed pipeline: Algeria-Tunisia-Italy	
		NEW or Re-purposed pipeline Morocco-Spain	*Algeria, Egypt, Libya, Morocco, Saudi Arabia, Tunisia.*
Hydrogen	*2-3 Mton*	*NEW-Re-purposed pipeline: Norway-North Sea-Germany*	*Connecting North-Sea, Norway, UK.*
		NEW-Re-purposed pipeline UK-North Sea-Netherlands	
		NEW-Re-purposed pipeline UK- Belgium	
Total	**8-12 Mton 315-473 TWhHHV**		

Source: Authors.

The Mediterranean Sea contains existing gas infrastructure to import natural gas from Algeria and Libya to Europe (Figure 5).

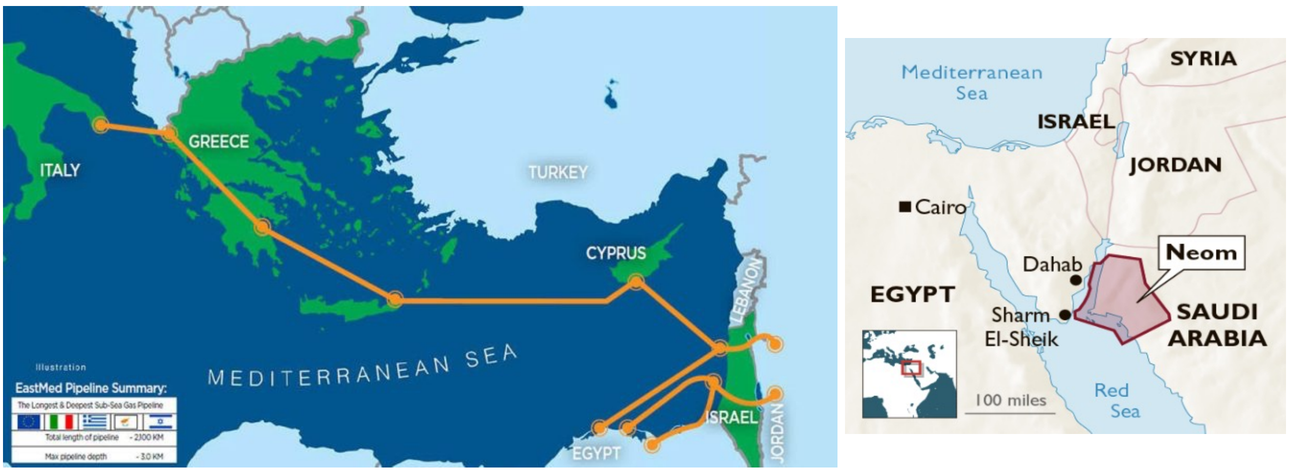
Figure 5: Existing natural gas pipelines from North Africa to Europe.

Source: [Wikipedia](https://en.wikipedia.org).

In the short-to-medium term, this gas infrastructure should be re-purposed for hydrogen. We suggest re-purposing the Trans-Mediterranean pipeline between Algeria, Tunisia, and Italy to increase the required capacity. Between Morocco and Spain, either the re-purposing of the Maghreb-Europe pipeline or a new hydrogen pipeline should become operational before 2030.

In the Eastern part of the Mediterranean Sea, natural gas has been found under the seabed in Egypt, Israel, Turkey, and Cyprus territories, concessions for exploration have been granted. A gas pipeline through the Mediterranean Sea is foreseen to transport this gas to Europe by connecting Egypt, Israel, Cyprus, Crete, and Greece to Italy. To comply with the aims and ambitions of the EU Green Deal and Hydrogen Accelerator, we propose to designate and develop this 'EastMed pipeline' as a hydrogen pipeline. The 'Mediterranean' natural gas can be converted to hydrogen and solid carbon, e.g., via methane pyrolysis, and fed into the EastMed pipeline. The EastMed hydrogen pipeline can be linked to dedicated hydrogen facilities in the NEOM city-state in the north-west of Saudi Arabia.[14] From Italy onwards, 'EastMed' can connect to the hydrogen backbone (Figure 6).

Figure 6: Proposed EastMed Pipeline and the location of the new 'city state' NEOM in Saudi Arabia.



Sources: Israel Ministry of Energy in Journal of Petroleum Technology and thetimes.co.uk.

14 The acronym NEOM is a combination of the Greek neos ('new') and the first letter of the Arabic word for 'future', mustaqbal. NEOM has recently started with the construction of the 'Helios' green ammonia plant. This project will use approximately 4 GW of renewable power from solar, wind and storage in order to produce 1.2Mt of green ammonia annually by 2026.

3.3. Required Hydrogen Storage Capacity

Hydrogen demand and supply need to be balanced with long-term storage, e.g., seasonal fluctuations. Estimating how much hydrogen storage capacity is required is difficult, but it will certainly not be less than the present-day gas storage capacity.

Next to this, hydrogen and ammonia are the only energy carriers in a sustainable energy system that can be used for strategic energy reserve purposes. So, if a similar obligation of 90 days of net hydrogen imports is to be kept as a strategic reserve, a hydrogen storage capacity of 25% of net imported hydrogen needs to be realised.

Applying a storage principle similar to natural gas, an initial EU-wide hydrogen storage capacity of approximately 25% of total demand is needed, i.e., 5 Mton (197 TWhHHV) of hydrogen by 2030. And if the '90-days-of-net-imports' principle is applied, a strategic hydrogen reserve of 2,5 Mton by 2030 is needed. Table 4 summarises the storage capacity needs by 2030.

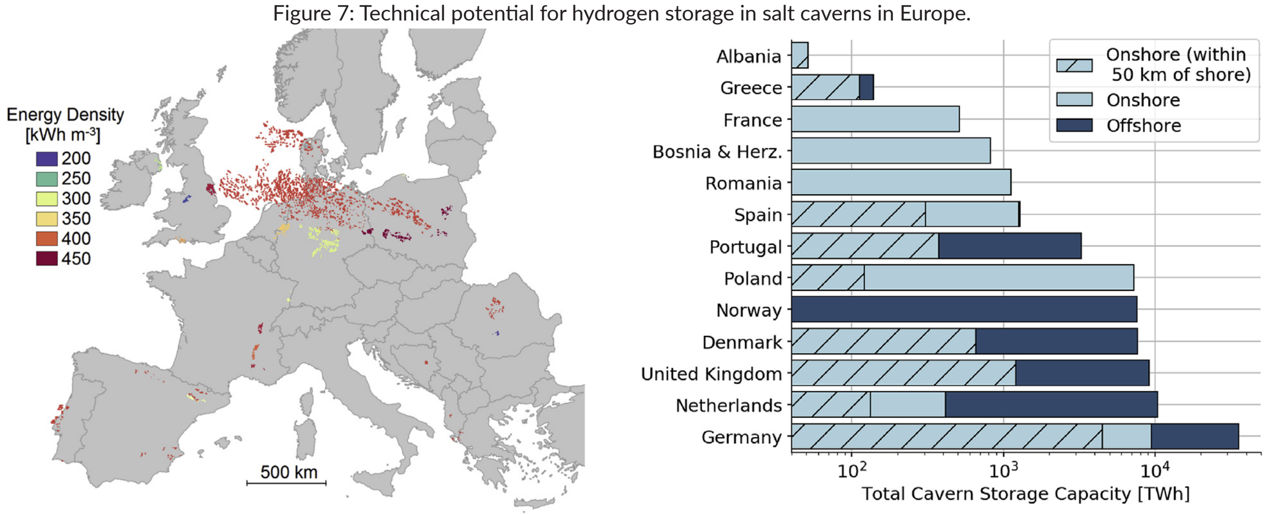
Table 4: Hydrogen storage capacity needs for 20 Mton hydrogen demand and hydrogen storage capacity needs for the strategic reserve of 10 Mton hydrogen import by 2030.

Hydrogen Storage	Storage Capacity 2030		Storage Options
	Mton	TWhHHV	
To balance hydrogen supply and demand, weekly to seasonal. Principle: 25% of hydrogen demand	5	197	Salt caverns Empty gas fields Ammonia tanks
Strategic hydrogen reserve Principle: 90 days of net hydrogen import	2,5	98	Empty gas fields Salt caverns Ammonia tanks
Total	7,5	295	

Source: Authors.

There is considerable potential for hydrogen storage in salt caverns in Europe. However, the potential is unevenly distributed among the EU Member States (Figure 7). Regarding suitable locations for salt caverns, in the eastern part of the Mediterranean Sea, especially near Italy, Greece, and Cyprus, salt formations could be ideal for creating salt caverns for hydrogen storage (Figure 8).

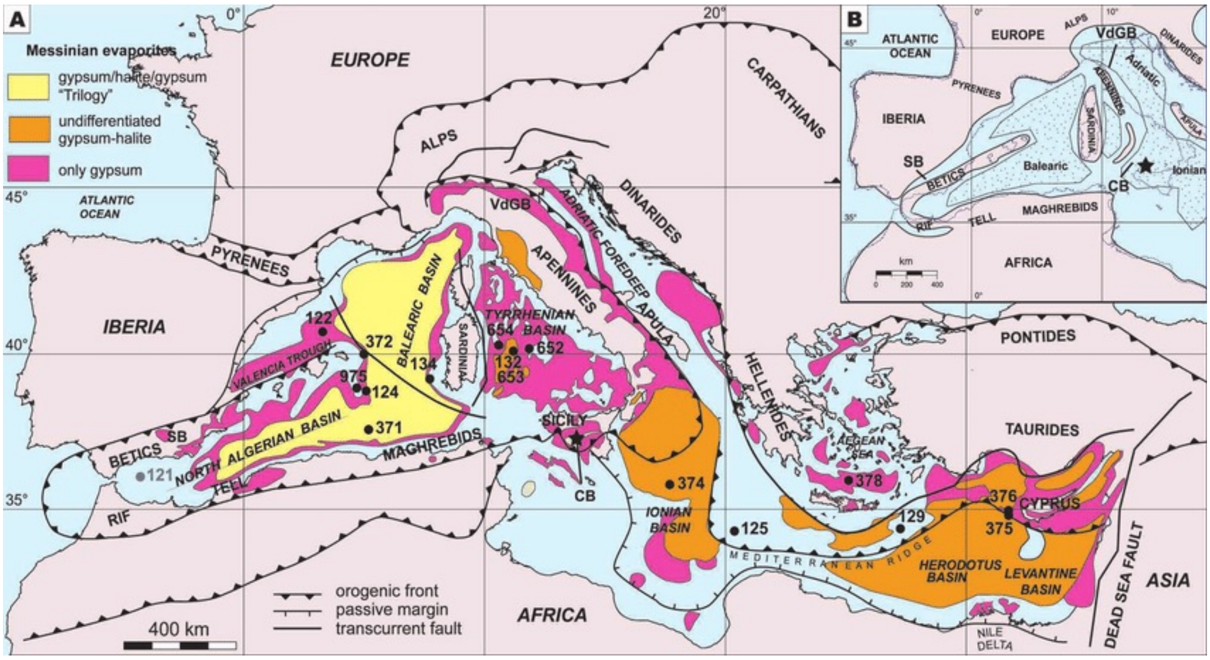
Figure 7: Technical potential for hydrogen storage in salt caverns in Europe.



Source: Caglayan et al. (2020).[15]

15 Caglayan, Dilara Gulcin, Nikolaus Weber, Heidi U. Heinrichs, Jochen Linßen, Martin Robinius, Peter A. Kukla, and Detlef Stolten. "Technical Potential of Salt Caverns for Hydrogen Storage in Europe." International Journal of Hydrogen Energy 45, no. 11 (February 28, 2020): 6793–6805. https://doi.org/10.1016/j.ijhydene.2019.12.161.

Figure 8: Salt formations underneath the Mediterranean Sea, especially the halite formations are suitable to create salt caverns.



Kuruda et al. (2014).[16]

Hydrogen storage capacity in an empty gas field is much larger than in a salt cavern. In a salt cavern, up to 6.000-ton of hydrogen can be stored. In an empty gas field, storage capacity is a factor of 10 to 100 higher. And whereas empty gas fields exist, salt caverns have to be created. Also, storage costs in empty gas fields are, on average, over a factor of 10 cheaper than storage in salt caverns.

Under the North Sea, empty gas fields could be potentially used for hydrogen storage. There are possibly suitable empty or nearly empty gas fields for hydrogen storage, especially in the Dutch, British and Norwegian parts of the North Sea. Especially the Dutch part of the North Sea, there is considerable hydrogen storage potential in empty gas fields and salt caverns.

16 Kuroda, Junichiro, Toshihiro Yoshimura, Hodaka Kawahata, Francisco J. Jimenez-Espejo, Stefano Lugli, Vinicio Manzi, and Marco Roveri. "Evaporation of Marine Basins: A Review of Evaporite Formation and Messinian Salinity Crisis." The Journal of the Geological Society of Japan 120, no. 6 (2014): 181–200. https://doi.org/10.5575/geosoc.2014.0016.

Conclusion

To summarise, this position paper has suggested additional EU tools and actions needed to realise the REPowerEU's Hydrogen Accelerator '20-Mton-hydrogen-target-by-2030 rapidly'.

The tools and actions we've suggested here include:

- '**Bootstrapping**' the European hydrogen system to realise the proper hydrogen infrastructure and storage capacity before supply and demand can be scaled up accordingly.
- Establishing a **European Hydrogen Cross-Border Infrastructure and Storage Facility** (additional to those of Member States).
- Developing hydrogen demand per geographical area via 'gas infrastructure-to-hydrogen infrastructure-conversion'.
- Creating a temporary **Global European Hydrogen Facility** to facilitate the domestic production and import of green hydrogen.
- Establishing a Europeanised **H2Global instrument** under the Global European Hydrogen Facility.

To make the Union less dependent on Russian gas, putting the Hydrogen Accelerator into practice will require the fast implementation of these and other measures mentioned here, all made possible by quickly establishing the proper regulatory framework.

Image: Rafael Classen

Green Planet is a state-of-the-art multi-fuel station where fuels for all passenger and cargo transportation are available.

It is one of the larger hydrogen filling stations in Europe, supported by regional, national and European funds. The green hydrogen that is tanked here comes from electrolysers. The hydrogen is transported by tank trailers that supply other H2 filling stations besides Green Planet.

Photo by Justin Jin for Hydrogen Europe

African Hydrogen Partnership

Dii

EU-GCC Cleanergy.Net

H2Global

MENA Hydrogen Alliance
An initiative of Dii Desert Energy