European Clean Hydrogen Alliance

THE EUROPEAN CLEAN HYDROGEN ALLIANCE

REPORTS OF THE ALLIANCE ROUNDTABLES ON BARRIERS AND MITIGATION MEASURES

October 2021

- TABLE OF CONTENTS -

I. INTRODUCTION………………………………………………………………………. 3

II. EXECUTIVE SUMMARY…………………………………………………………. 7

III. REPORTS OF THE ALLIANCE ROUNDTABLES……………………………. 13

1. Report of the Roundtable Renewable and Low Carbon Hydrogen Production 14
2. Report of the Roundtable Transmission and Distribution 20
3. Report of the Roundtable Industrial applications 28
4. Report of the Roundtable Mobility 30
5. Report of the Roundtable Energy Sector 37
6. Report of the Roundtable Buildings 46

IV. CONCLUSION………………………………………………………………………. 49

V. ANNEXES…………………………………………………………………………… 50

Annex 1 - Mobility Roundtable Roadmap 51

Annex 2 - Buildings Roundtable CEOs Statement 55

This report reflects the work of the European Clean Hydrogen Alliance Roundtables. Proposed mitigation measures to address identified barriers do not necessarily represent the position of individual members of the Alliance Roundtables.

I. INTRODUCTION

This document brings together the reports of the six Roundtables of the European Clean Hydrogen Alliance on the main barriers that impact the roll out of renewable and low carbon production, transmission, distribution and use across Europe, and the most relevant mitigation measures that should be addressed in the short or medium term to guarantee the ambitions of the European Hydrogen Strategy.

Background. The European Clean Hydrogen Alliance was launched in July 2020, as one of the key initiatives of the new European Industrial Strategy and of the new EU Hydrogen Strategy for a climate neutral Europe, to support its important hydrogen production and deployment ambitions and ensure the emergence of a European Hydrogen economy by 2030.

The main deliverable of the Alliance is to build up a pipeline of concrete and viable investment projects along the complete hydrogen value chain, with a view to shift away from fossil fuels, create a clean hydrogen market contributing to growth and jobs, and reducing greenhouse gas emissions.

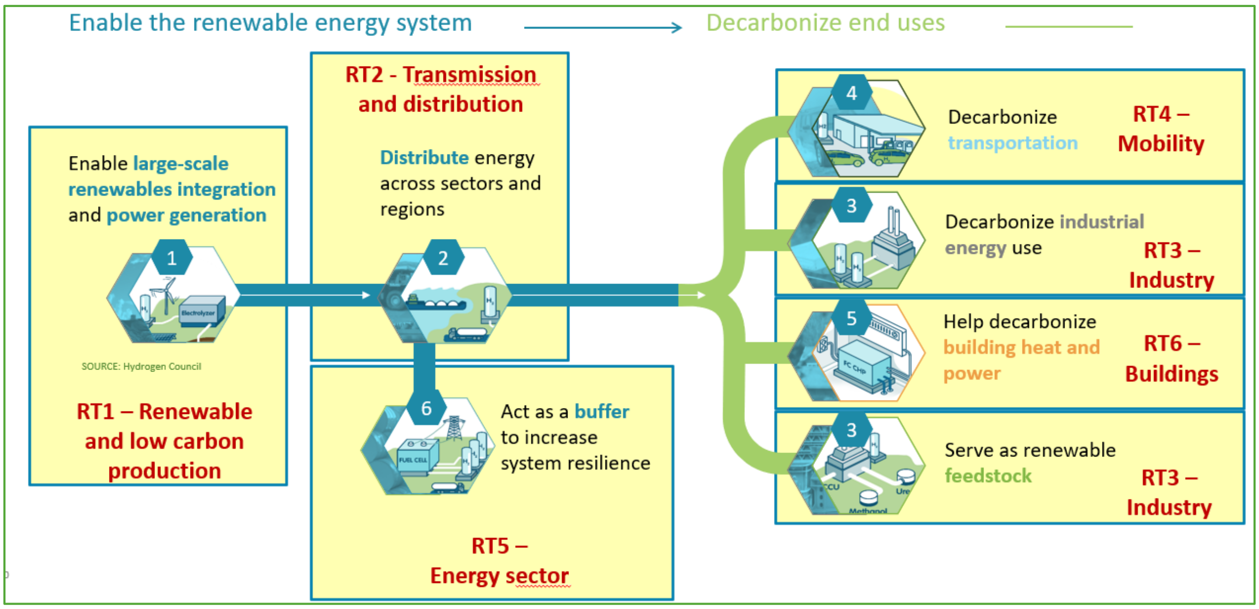
Installing at least 6 GW of renewable hydrogen electrolysers in the EU by 2024 and 40 GW of renewable hydrogen electrolysers in 2030 and ensuring market take up of up to 10 million tonnes of renewable hydrogen under competitive and smooth conditions by 2030 is a very challenging ambition. The pipeline of projects of the Alliance will give visibility to the projects already launched or under preparation, facilitate the cooperation between the members of the Alliance and foster the massive investments, estimated by industry to €430 billion, that will be needed in the coming years.

Due to its nature the Alliance is also set to provide a unique opportunity to identify the multiple obstacles and bottlenecks related to the investment projects and raise awareness of EU and national decision makers of what needs to be addressed in this starting phase to facilitate the roll out and scale up of hydrogen.

The European Clean Hydrogen Alliance has raised an unprecedented interest. Since its launch, more than 1500 stakeholders have joined, and this number is increasing every day in line with the principles of openness and transparency of the Alliance. The members of the Alliance are C-suite level representatives of industry companies with activities in the hydrogen value chain, high level representatives of trade unions, civil society organisations[1], investors, and the research community with an interest in hydrogen, as well as national and regional public authorities involved in hydrogen deployment.

[1] *When joining the European Clean Hydrogen Alliance, NGOs issued a declaration stating that they (i) agree to engage and contribute to the deployment of renewable hydrogen in terms of supply, demand and distribution as they promote the rapid phase-out of the use and production of all fossil fuels in order to reach the objectives of the Paris Agreement.; (ii) thus do not consider fossil fuel based hydrogen as a short- or long-term solution; and (iii) contribute to targeting the use of renewable hydrogen specifically to those sectors and industrial processes which are hard to decarbonise (steel, cement and basic chemicals, aviation, shipping and heavy good vehicles).*

The operational work of the Alliance relies on six thematic Roundtables (RT) that reflect the activities of the entire hydrogen value chain: RT1-Renewable and low carbon Production, RT2-Transmission and Distribution, RT3-Industrial Applications, RT4-Mobility Applications, RT5-Energy Sector and RT6-Buildings.



Position of the Roundtables of the European Clean Hydrogen Alliance in the Hydrogen value chain

The members of the Roundtables and their three co-chairs have been selected and named by the European Commission. Since the Roundtables were kicked-off in February 2021 they have met in numerous occasions at both CEOs and Sherpas level to discuss their vision on the rollout of hydrogen production and use across Europe, design the key elements of the pipeline via the preparation of the project collection that was published in April, and undertake a very thorough discussion on the bottlenecks that impact the scale up of investment projects and their potential mitigation measures.

To ensure the transversality of these works in a real value chain perspective, the facilitating organisations of the six Roundtables (RT1-SolarPower Europe, RT2-ENTSOG, RT3-Cefic, RT4-ACEA, RT5-WindEurope, RT6-EHI) have coordinated regularly to manage interdependencies with the support of Hydrogen Europe and the supervision of the European Commission.

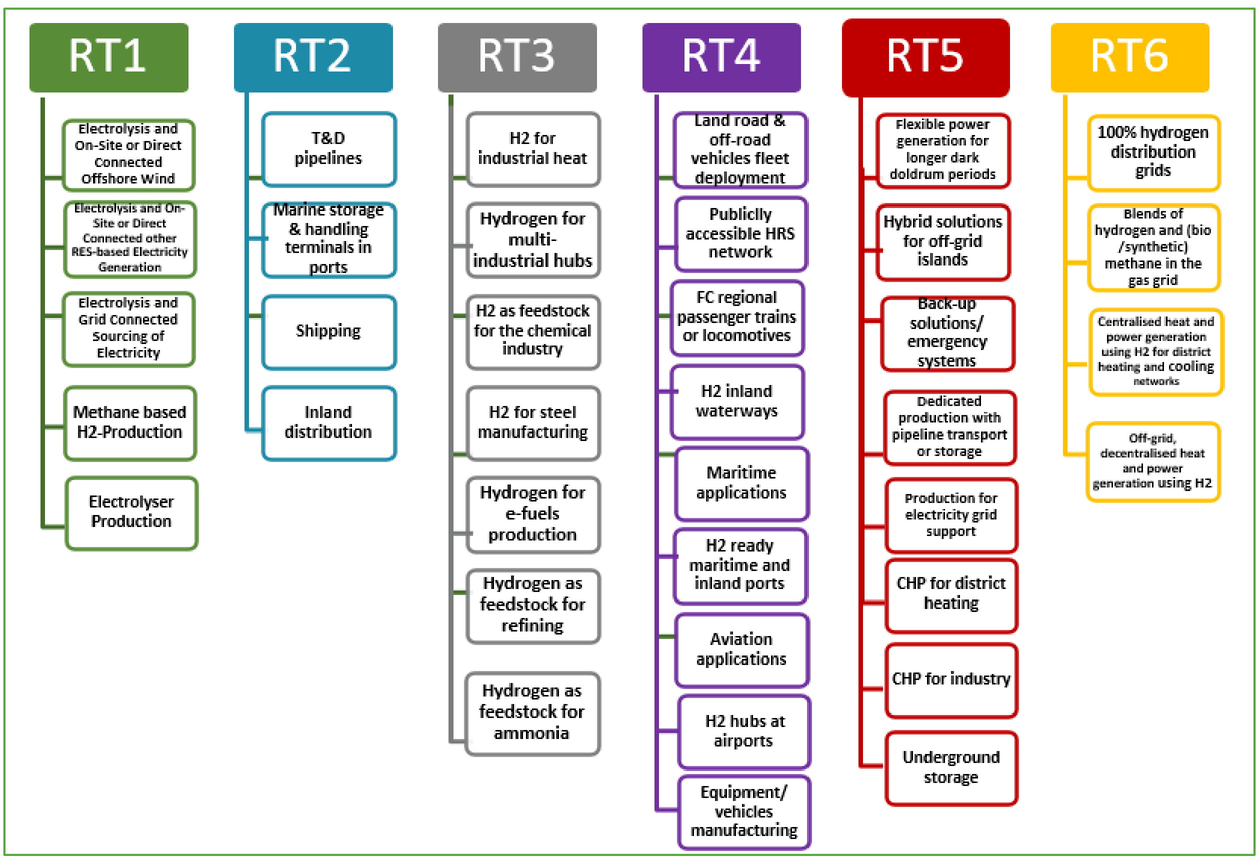
The Roundtables' barriers and mitigation measures reports. The creation of the adequate conditions to stimulate and make viable the roll out of renewable and low carbon hydrogen production, distribution and take up at large scale have been at the core of the Roundtables' debates in the last months as the needed complement to the project pipeline preparations.

The more than 1000 projects submitted to the project collection show indeed that industry is ready to launch ambitious scale up projects and investments, but these require an enabling environment with concrete measures that support the creation of a European competitive hydrogen economy, able to face growing international competition.

To this end, the six Roundtables have proceeded to an in-depth analysis of the most relevant barriers in terms of:

1. Market and end use,
2. Administrative and regulatory,
3. Supply chain, and
4. Technology.

The specific needs and potential mitigation measures have been analysed in relation with the "archetypes" (project models that allowed for combination in the case of integrated projects across the value chain and the Member States) that the Roundtables identified in view of the Alliance project collection:



Archetypes adopted by the Alliance Roundtables

The Alliance Roundtables have organised several meetings and workshops in the last months. All the Roundtables have translated the summary of their works in six reports that give an overview of the concerns expressed by their members and possible mitigation measures in their area of activities. In this exercise, they also have highlighted several cross-cutting issues that would require a common and coherent vision and solutions across the value chain in the views of the Roundtables.

Some variations in the methodology used are due to the specificities of the Roundtables and the diversity of their members.

Other documents adopted by the Roundtables, such as roadmaps and declarations relating to the roll out and deployment of hydrogen, have been added at the end of this document where they have helped to shape and put in perspective the Roundtables' exchanges on barriers and mitigation measures.

II. EXECUTIVE SUMMARY

The reports of the six Roundtables on barriers and mitigation measures underline that, beyond the specific concerns identified and the possible solutions, full-scale industrial deployment requires systemic action along the whole hydrogen value chain.

This means that the offer and demand challenges that have been raised by all the Roundtables, reflecting the chicken and egg dilemma, need to be addressed simultaneously to create competitive market conditions, together with the availability of a hydrogen-ready infrastructure. **Integration, synchronisation, and visibility** appear to be the cornerstones of hydrogen deployment and scale up across the whole value chain.

1. On the offer side, this requires addressing the **availability and affordability of renewable electricity and renewable hydrogen, and also of low carbon hydrogen**. Following most of the Roundtables, this involves the increase of renewable energy sources (RES) ambitions, tackling the administrative barriers related to permitting processes, including for electrolysis manufacturing capacities, support mechanisms to derisk hydrogen production, clear and harmonised definitions for hydrogen and emissions calculations that provide certainty to operators and the administration, as well as opening the option to hydrogen imports.

2. On the demand side, the **stimulation of hydrogen use is key to create a market and provide visibility on the expected uptake** by the industry, the mobility, and the building sectors, in a context where they face additional operational expenditures generated by the too high costs of hydrogen. This applies also to the deployment of hydrogen when used in the energy sector for power generation. Substantial support to cover the costs of hydrogen as well the transformation and scale up of technologies and processes, coherent green procurement policies, and stronger CO2 pricing mechanisms that make hydrogen more attractive, are some of the cross-cutting proposals generally put forward by the Roundtables to address the issue of the funding gap and level playing field of renewable and low carbon hydrogen with other fuels.

3. The **availability and readiness of transport infrastructure and sufficient storage capacities** are also critical points flagged by the Roundtables, that should be quickly addressed to prepare the timely connection between the production and demand centers and unleash the potential that hydrogen can play in the energy sector in terms of decarbonization, flexibility and security of supply. Considering the important investment and timeline needed for deployment, the planification of investments in coordination with the other energy sectors is considered of utmost importance. This should be based on a thorough understanding of the planned production capacity, demand volumes and locations, and ensure hydrogen-readiness to prevent carbon lock-in.

The synchronization of the hydrogen value chain needs to be translated in several measures:

1. A supportive and fit-for-purpose regulatory framework. The missing framework for trading and supply of hydrogen, including for certifications, is indeed identified as a key bottleneck with huge

negative impacts on the market development and the access to finance. The Roundtables have therefore proposed concrete improvements to **complete and align all hydrogen relevant legislation** such as the Renewable Energy Directive (REDII), the Energy Efficiency Directive (EED), the Energy Taxation Directive (ETD), the Emissions Trading System (ETS), and the EU Gas and Electricity Directives, **with the European Hydrogen Strategy ambitions.**

2. **The alignment of subsidy schemes** is a complementary issue largely tackled by the Roundtables, with a view to develop hydrogen-tailored instruments that provide stronger capital expenditures (CAPEX) and operational expenditures (OPEX) support, namely via the new Climate, Energy and Environmental Aid Guidelines (CEEAG) and the Communication on Important Projects of Common European Interest (IPCEI), with a focus on scale-up. **Funding policies** are also encouraged to further adapt to hydrogen deployment needs and the related technological improvements required.

3. Finally, several Roundtables have started pointing out the importance of tackling other challenges that could quickly become bottlenecks, such as the upskilling and reskilling the workforce in line with the expected hydrogen deployments, to avoid shortages of needed occupational profiles.

To complete the setup, the following paragraphs provide an overview of the main points raised by the Roundtables.

Renewable and Low Carbon Hydrogen Production Roundtable. The Renewable and low carbon hydrogen production Roundtable identified an urgent need to speed-up project deployment and reduce costs. This encompasses in particular the need for a massive build-up of renewable electricity generation capacity, synchronised with the build-up of electrolysers.

Lack of demand is a key bottleneck for scaling up further cost-competitive hydrogen production. Demand-side stimulus measures need to be taken, including the creation of lead markets for the use of clean hydrogen, accelerating its use beyond Renewable Fuels of Non-Biological Origin (RFNBOs). Tax incentives, offtake mandates, providing for a level playing field among hydrogen sources and a supportive regulatory environment can all help to spur demand.

The **regulatory framework** needs to be clarified and in line with the Hydrogen Strategy and **administrative barriers** alleviated, to accelerate the roll-out of cost-competitive renewable and low carbon hydrogen. This includes clear rules in the delegated acts for Art. 27 RED II, enhancing national transpositions, clarification of rules regarding hydrogen in the CEEAG and the Energy Trans-European Networks (TEN-E) and the EU Sustainable Finance taxonomy. In addition, establishing a clear and harmonised Guarantees of Origin (GO) and certification system, allowing for easier trade and supply of clean hydrogen between Member States and with third countries, is also necessary. To reduce administrative barriers, the Roundtable recommends establishing fast-track permitting procedures for hydrogen production and electrolyser manufacturing.

The Roundtable also identified a **financing gap**. Mitigation measures include establishing transparent and predictable support schemes (CAPEX and OPEX) capable of delivering the Hydrogen Strategy objectives and based on the EU Sustainable Finance taxonomy. In this sense, the IPCEI is seen as an important but insufficient mechanism. Eliminating double taxation (on electricity and on hydrogen produced) and reducing levies and network tariffs are also necessary steps recommended.

Transmission and Distribution Roundtable. The Roundtable Members identified several barriers currently faced by the Roundtable project promoters. The common barrier identified was that **renewable and low carbon hydrogen is still uncompetitive,** so customers do not have a business case to switch. On the regulatory side, there is **missing operationalization of the Hydrogen Strategy as targets need to be translated to clear volumes and optimized means – hence there is lack of regulation for renewable and low carbon hydrogen and hydrogen carriers, framework for infrastructure planning,** clarity on the principles for access to infrastructure **and lack of synergies between TEN-E and TEN-T,** especially for shipping. For marine storage and handling terminals, there are barriers related to l**and access management - priority access to new energies infrastructure** and **missing framework for capturing the benefits for integrated projects.** Financial barriers mentioned, relate to the **lack of regulation on infrastructure financing**, absence of public grants, **missing clarity on subsidy schemes and allocation of financial support**. Technical barriers identified relate to operational challenges for blending projects, **lack of technical requirements for repurposing, retrofitting and newly built pipelines, lack of investment strategy and prioritization for allocation of R&D&I funding targeting next 5 years, need for technological scale up and** missing **technical standards**.

The collection of projects for the preparation of a pipeline of investment projects for the European Clean Hydrogen Alliance provided additional insight into key barriers and possible mitigation measures for the Transmission & Distribution archetypes, beyond these discussed on the Transmission and Distribution Roundtable. The major concern was the **lack of a functioning international hydrogen commodity market,** which currently translates into **zero transport capacity and no hydrogen imports capacity.** When submitting their projects, project promoters moreover identified a lack of a regulatory framework for transport of hydrogen and hydrogen carriers, **uncertainty on access to infrastructure and capacity management, missing clarity on Transmission System Operators' (TSO) role** and a **missing framework for coordinated infrastructure planning on national and EU level**. To mitigate these, project promoters submitting their projects to the Alliance pointed out that a clear regulatory framework was needed, **based on key principles** such as **Third-Party Access (TPA), non-discriminatory access and open access** where network operators are allowed to operate and invest into hydrogen infrastructure and mutualise network cost. The main barrier for hydrogen uptake identified by project promoters was the **lack of incentives for customers to switch** to renewable and low carbon hydrogen, and they hence proposed a **reliable GOs and certification framework** combined with **public funds and grants** based on technology neutrality, including **support mechanisms** such as Carbon Contracts for Difference (CCfD) schemes, quotas on gas supply, or targets. **Speeding up the development of hydrogen technical standards** and the need to adapt some technical equipment was also highlighted by project promoters. Finally, project promoters proposed to address the **lack of clarity on interoperability rules for blending** with a **clear regulatory framework and detailed gas quality forecasts**. They also believed that for lengthy and bureaucratic **permitting** processes enhanced preparation and update of relevant authorities was needed.

Industrial Applications Roundtable. The Industrial Applications Roundtable identified bottlenecks and potential mitigation options related to scaling up the application of clean hydrogen (i.e. renewable and low-carbon[2]) in its respective areas. The key bottlenecks are a) **bridging the gap between the needed volumes of clean hydrogen** (> 10 millions of tons per year) and current status of production technology (<5'000 tons per year) with a focus on reducing GHG emissions, b) considerably **reducing the cost of clean hydrogen**, and c) **providing a stable regulatory environment** that accounts for the transition that industry needs to go through.

Paramount for a successful transition to a hydrogen economy is **easy access to abundantly available and competitively priced fossil-free electricity** throughout Europe. That would allow build-up of the needed production capacities of clean hydrogen. **An appropriate regulatory framework for CCS (Carbon Capture and Storage) and CCU (Carbon Capture and Utilisation)** for the deployment of related low carbon technologies and products must be ensured.

Mitigation of technological and financial risk needs to be enabled via public funding and state-aid (including OPEX-related tools). Better coordination of the EU and national funding programmes is required, for example through a "single window" approach, and of policies (competition policy, state aid, sustainable finance) to ensure that industry can access funding to enable the transition.
Because there is no one-solution-fits-all, **a clear terminology, as well as a comprehensive certification and verification framework for clean hydrogen** is needed. At the same time a **harmonised calculation methodology** for e.g. LCA (Life Cycle Assessment), GHGs, embodied emissions, needs to be introduced, thereby allowing a fact-based choice for the best solution in a given location.

Mobility Applications Roundtable. There is a broad consensus, among the members of the Roundtable, that the ecosystem is under development and must be **supported by a number of regulatory, fiscal, or non-fiscal measures to positively stimulate technology adoption and foster the initial market volumes deployment to support a suitable infrastructure development.** Being at the end of the value chain, the availability of the infrastructure is indeed seen as a critical point. Mobility applications will be dependent on the results of the progress in upstream areas (production – distribution).

Investment in a new infrastructure (storage & fuelling station) and ensuring an adequate supply of green hydrogen is a significant barrier for potential early adopters of fuel cell powered vehicles. Public support should be available at national and/or EU level to support such investments: covering 50% of CAPEX during the next 5 years. At the EU level, the Connecting Europe Facility should be the main support instrument for hydrogen infrastructure investments for all transport modes.

To lower costs, it is important **to increase the demand for green hydrogen,** which can be done through at the local & regional level: synergies should be investigated when planning hydrogen refuelling infrastructures to serve multiple applications, e.g., various types of road vehicles and trains in cities, or vessels and trucks / trains in harbours – a concept of "multi-purpose hydrogen refuelling stations".

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[2] *In line with the European Clean Hydrogen Alliance Declaration: https://ec.europa.eu/docsroom/documents/43526*

Progress on the **standardisation on hydrogen refuelling infrastructure** for all mobility application is also important to de-risk investments and reduce costs. One of the key areas to unlock the market development potential is seen in standardisation and unified procedures at European level. Definition and standards for certifying low carbon and green hydrogen should be put in place and a clear differentiation between local produced hydrogen and imported hydrogen is needed. Standardization of Hydrogen Refueling Stations (HRS) design and interface and of the building norms for certifying HRS should be envisaged for a European widespread network to develop.

Reducing the Total Cost of Ownership (TCO)-gap through a number of interlinked measures is critical. Especially for commercial vehicles a significant TCO-gap is expected in the initial stage for zero-emission technology and will impact final users in the value chain.

There is a need to reduce operational gap, especially through fuel costs. As the energy costs impacts the production costs of hydrogen by 60-80%, exemption schemes like exemption from grid fees for electrolysis with renewables or labelling and incentives or taxation of green hydrogen could lower the energy costs and help close the OPEX gap.

Energy Sector Roundtable. The Energy Sector Roundtable has ascertained that **there is no sufficient renewable and low carbon hydrogen today**. **The ambitious build-up of wind and solar capacity to produce domestic renewable hydrogen should be accelerated and the fast replacement of coal-fired power generation should be incentivised** to decarbonise power generation and energy demand**.** Sustainable low carbon types and derivates should also be accepted. And while domestic production should be prioritised, imports from outside Europe should also be planned for.

In the power system, hydrogen will play an important role in securing supply and managing residual load, but the price gap with natural gas makes it today economically non-viable. Governments should thus introduce OPEX-centred funding as of today to enable operational learning in power and CHP applications. And remuneration mechanisms should evolve to better value reliability and capability with a focus on zero-carbon emissions. Going forward, any investment in gas infrastructure should be hydrogen-ready to avoid carbon lock-in. There is also a need to revise electricity markets to ensure that the flexibility electrolyser can provide could be utilised, both by managing congestions and providing balancing reserves.

There is no hydrogen transport and storage infrastructure today to enable a large-scale deployment of renewable and low carbon hydrogen across the energy system. The hydrogen infrastructure will need to be planned in an integrated manner, based on enhance coordination between electricity, gas, district heating and hydrogen sectors. Europe should also establish a vision and a planning process for the development of underground hydrogen storage sites, ensuring sufficient storage capacity. The Regulatory framework for investments into the hydrogen grid should allow anticipatory investments in view of the future expansion from hydrogen valleys into an interconnected and meshed grid.

Buildings Roundtable. As reported by the Buildings Roundtable, in the EU buildings are responsible for 40% of energy consumption and 36% of greenhouse gas emissions. As stressed by the EU Commission in its Renovation Wave Strategy, **the building sector is a hard-to-abate sector that requires urgent action.** EU scenarios for a climate-neutral 2050 show that the share of direct electricity in heating for residential buildings is expected to grow to 34%[3]. The remaining heating demand will have to be supplied by non-electric renewable and decarbonized energy.

The large majority of the members of the Buildings Roundtable believe that **hydrogen can play an important part in an integrated energy system that combines electrification and other renewable and defossilised sources of energy** to cut emissions from buildings in the short time-scale available, while NGO members of the Roundtable believe that hydrogen should be used where direct electrification is not possible. However, **there still exist barriers standing in the way of a successful deployment of hydrogen in buildings.** Based on the input provided in the EU Commission's hydrogen project collection in spring 2021, the members of the Buildings Roundtable have identified the main barriers, in terms of market, regulation, funding and financing, technology and supply chain.

One of the main barriers to the use of hydrogen in buildings has been identified in the **insufficient level of synchronisation across the hydrogen value chain.** There is a lack of coordination between (a) sourcing of green hydrogen (b) investments in hydrogen-ready infrastructures and (c) investments in hydrogen end-use equipment. A better connection across energy supply, transmission and distribution and end-use sectors is required to avoid market failure and delays in the creation of an effective European market for hydrogen as indicated by the EU Hydrogen Strategy.

Secondly, the pathway to clean hydrogen is not clear to consumers, inhibiting consumer demand for hydrogen technologies. According to the members of the Roundtable, the absence of a sufficiently strong CO2 price for competing fossil fuel-based alternatives and the lack of incentives to hydrogen-based technologies fail to signal to consumers alternatives to fossil fuels. The current policy framework offers limited technological openness. While the direct use of (green) electricity-based technologies has advantages, the large majority of the Roundtable members believe that an "electrification only" approach does not seem feasible neither at system nor at consumer level in the time frame required by the EU climate targets, as mentioned in the EU Commission scenarios for a climate-neutral 2050.

[3] *In depth analysis in support of Commission Communication COM (2018) 773 and Impact Assessment for the 2030 climate target plan.*

European Clean Hydrogen Alliance

III. REPORTS OF THE ALLIANCE ROUNDTABLES ON BARRIERS AND MITIGATION MEASURES:

1. ***Report of the Roundtable Renewable and Low Carbon Hydrogen Production***
2. ***Report of the Roundtable Transmission and Distribution***
3. ***Report of the Roundtable Industrial applications***
4. ***Report of the Roundtable Mobility***
5. ***Report of the Roundtable Energy Sector***
6. ***Report of the Roundtable Buildings***

1. Report of the Roundtable Renewable and Low Carbon Hydrogen Production

The Renewable and Low Carbon Hydrogen Production Roundtable has focused on the bottlenecks and mitigation measures below relating to the 'archetypes' agreed by the Roundtable.

i. Clean and low carbon hydrogen production projects across all Archetypes share the following bottlenecks

Topic	Bottleneck	Mitigation Measures
Market & End-Use	Lack of demand for clean H2 – clean H2 has to compete against much cheaper traditional (fossil-based) H2 with low (ETS, ESR) or no (leakage list) carbon costs	Stimulate end-use of clean H2: clarify priority sectors RED II H2-application; introduce tax incentives, offtake mandates, develop appropriate policies to stimulate offtake of clean H2 (RED II, taxonomy), establish level playing field among H2 sources; foster clusters with large-scale H2 off-takers, foster clean H2 through public procurement in hard-to-abate sectors
Financing & Funding Gaps	Limited access to finance due to clean H2's lack of competitivity (e.g. no project financing) – staid aid is required but currently limited	Enlarge subsidy & funding schemes for innovation w/ stronger transparency on various mechanisms ▪ Pilot financing and first-of-its-kind (e.g. via EU ETS Fund and IPCEI) ▪ Financing of large and mature H2 projects in hard-to-abate demand (e.g. via EIB) include OPEX subsidies ▪ Coverage along the value chain (e.g. incl. synfuels)
	Unclear outlook for public support hinders financing of long-term projects	Establish stable & visible long-term support schemes compatible with the EU legislative framework
	State aids focus largely on R&D, rather than scaling-up production	Enlarge the scope of support schemes beyond R&D to cover demand side needs for hard-to-abate H2 projects
	State Aid Guidelines are unclear on the interplay between support mechanisms for the different parts of the value chain	Clarify State Aid Guidelines (EEAG) – support should account for entire H2 value chain
	Dependency of clean vs. commercially available H2 cost gap on volatile CO2	Introduce schemes to de-risk clean H2 production (e.g. CCfDs, double auctions, support to compensate for the free

Topic	Bottleneck	Mitigation Measures
	prices introduces risk additionally hampering financing	allowances that grey H2 currently receive which provides a competitive advantage)
Administrative & Regulatory	Missing RED II delegated acts and incomplete national transposition	EU COM: issue delegated acts; Member states: accelerate national transposition
	Unclear definitions for clean hydrogen	Develop clear and transparent criteria linking to the EU Taxonomy for sustainable finance and based on homogenous boundary definitions and resulting carbon footprint
	Missing H2 trading & supply framework – incl. Guarantees of Origin	Specify & enact a coherent, efficient & harmonised GO framework that includes the various types of hydrogen
	Cumbersome permitting for clean H2 production	Establish permitting priority (in line with RES electricity projects)
	European environmental regulations apply hydrocarbon-related safeguards to all H2 production (including renewable)	Clearly differentiate between safeguards related to the production and storage of H2 as such, from those related to the methane needed to produce H2 in the 'traditional' way ("grey H2")
	Lack of H2-related knowledge with regional/local administrations	Awareness raising & efforts coordination (EU / national / municipal & local levels)
	Insufficient reg./loc. permitting capacity delaying H2 projects	Step up support for regional/local administrations regarding H2 and RES-e permitting
	Missing framework for using H2 infrastructure	Clarify provisions for infrastructure retrofitting and blending in the TEN-E
Supply Chain	Potential lack of H2 infrastructure (various transport vectors)	Strengthen existing (e.g. CEF) and set-up new schemes supporting H2 infrastructure; emphasis and support H2 production on-site of demand
Technology	Challenges of long distance H2-transport	In-depth evaluation of multiple transport means

ii. Electrolysis-based Hydrogen Production, related Bottlenecks and their Mitigation

All hydrogen production projects based on electrolysis share some specific bottlenecks

Topic	Bottleneck	Mitigation Measures
Administrative & Regulatory	Double taxation of electricity and electricity based H2	Review of EU and national tax legislation aiming to avoid double taxation
	Missing link between Electricity and H2 Guarantees of Origin	Integrate Electricity and H2 GO systems and allow PPAs for clean H2 production

Topic	Bottleneck	Mitigation Measures
	Insufficient regulatory framework for hybrid RES generation projects	Expand regulatory coverage and ease permitting process for hybrid-RES project setups
	Cumbersome permitting for direct connections	Establish permitting priority in line with the RES Directive
	Lack of clarity on electricity sourcing requirements due to missing RED II delegated acts – strict electricity sourcing requirements or respective uncertainty can (and sometimes already do) challenge project economics and hamper development	(a) Issue RED II delegated acts soon; (b) observe the aim of supporting the growth of additional RES capacity to ensure the growth of a clean H2-industry (in line with EU strategy) as well as the emission reduction when specifying RED II electricity sourcing requirements;
Supply Chain	High electrolyser cost (CAPEX)	Incentives to scale-up electrolyser manufacturing
	Current and expected shortage of electrolyser stacks	Ramp-up electrolyser production
	Necessity for additional RES-e generation capacity	More ambitious RES targets and quicker realisation of these targets
	Grid tariffs can damage business cases for grid connected electrolysers	Introduce tariff systems incentivising optimised electrolyser location with low tariffs
	Levies on electricity can damage business cases for grid connected electrolysers	Relief Electrolysers from levies for low/no carbon electricity
	Potential of electrolysers to provide grid balancing services is often not (sufficiently) remunerated	Adequate remuneration of grid balancing services by electrolysers
Technology	Performance, efficiency, and lifetime of the electrolysers	Further R&D, easier access to test platforms to assess electrolyser properties

iii. Hydrogen Production based on Direct Gasification of Biomass or Waste or other Innovative (non-Electrolysis) Technologies, related Bottlenecks, and their Mitigation

Topic	Bottleneck	Mitigation Measures
Financing & Funding Gaps **Administrative & Regulatory**	Direct gasification is currently not sufficiently acknowledged in relevant regulations, which leads to slow market uptake among waste treatment companies. This lack of clarity creates barriers in other areas (e.g. access to finance, permitting procedures)	The role of non-recyclable waste and biomass in hydrogen production need to be reflected appropriately in all relevant regulations (RED II, waste directive, State Aid Guidelines)
Other Areas	Underestimated advances in Research, Development in thermal treatment of waste for clean Hydrogen and Execution regarding the integration of new, novel as well as mature components for new applications	Increased efforts needed to support the alternative technologies and demonstration projects already set-up by EU Universities such as KTH Stockholm, TU-Freiberg, IEC, EVT, and by dedicated corporates.

iv. Methane-based Hydrogen Production, related Bottlenecks and their Mitigation

Topic	Bottleneck	Mitigation Measures
Market & End-Use	Unclear valorisation of the usage of solid carbon resulting from Pyrolysis	Research on sustainable / climate effective solid carbon usage
Administrative & Regulatory	Unclear role of retrofitting for existing SMR within EU H2 strategy	Define a decarbonisation roadmap for existing H2 production
	Difficult permitting and obtaining of rights of way for CO2 capture, transport, and storage	Develop CO2 infrastructure in parallel with new H2 infrastructure. Simplify CO2-infrastructure related permitting and adapt Gas Directive
	Unclear role of Methane-based H2-production in the hydrogen strategy	Clarify the role of Methane-based H2-production in the hydrogen strategy
	Unclear requirements for life cycle (impact) assessment (LC(I)A) across technologies	Develop clear and transparent criteria for LCA and LCIA methodologies as part of the EU Taxonomy
Supply Chain	The need for developing CO2 infrastructure (transport & storage) in parallel to upscaling H2 production is crucial. The role of retrofitting existing infrastructure also needs clarification	Clarify the role of CCS and CO2 infrastructure as enablers for H2 production in the regulatory framework and R&D support. Clarify targets for retrofitting and for the role of low carbon hydrogen

Topic	Bottleneck	Mitigation Measures
	Need to increase capacities for RES-based electricity and bio-Methane for Methane pyrolysis	More ambitious RES targets and quicker realisation these targets
Technology	Various optimisation issues regarding the generally mature technology of steam reforming + CCS	Clarify the scope of future Horizon Europe calls and the revisions of State Aid Guidelines with regard to Methane based H2-production processes.
	Various integration and co-production potentials for hybrid solutions (H2 + power & heat production, etc.)	Provide public funding for new developments and optimisation of integrated concepts for increased value propositions of co-production Recognise and provide public funding for the development of hybrid solutions taking into account several technologies
Other Areas	Scepticism about natural gas as feedstock for clean H2 production	Open and technology neutral fact-based assessments followed by discussion of different H2 production technologies (electricity and fuel demand, availability, CO2-avoidance cost…) is crucial

v. Electrolyser Manufacturing (incl. Giga Factories), related Bottlenecks and their Mitigation

Topic	Bottleneck	Mitigation Measures
Market & End-Use	Missing clarity on market (and demand) evolution	Clear strategy (implementation) and regulation to provide clarity; incl. accelerated transposition of EU-level measures into national legislation
Financing & Funding Gaps	Difficult financing for scaling-up electrolyser manufacturing in an environment with little current demand for the end-product	Dedicated financing facilities for electrolyser manufacturing (e.g. IPCEI and ETS IF)
Administrative & Regulatory	Over-burdened permitting for electrolyser manufacturing plants with environmental regulation intended for (large) industrial sites	Relax permitting requirements for electrolyser manufacturers
Supply Chain	Lack of mass production capacities for electrolysers – along the whole supply chain (materials, equipment, systems, …)	EU Commission: Support investment in Open Access pan-European Technology Platforms; Research community and Industry: engage in such platforms; up-stream industry: scale-up production; Strategic planning + recycling, alternative processes

Technology	Long time to market of technology developments	Open Access pan-European Technology and Research Platforms; technology openness (inclusion of all currently available technologies)
	Ongoing R&D efforts are still required to continue improving technologies in parallel to scaling up towards the Giga-factory level, thereby providing for the cost reduction for mass market deployment	Ensure coordination between R&D, Joint undertakings, and industrial application inter alia by the ECH2A

2. Report of the Roundtable on Transmission and Distribution

I. Introduction:

The gradual hydrogen market ramp-up will lead to increasing need for hydrogen infrastructure to transport, store and import large-scale hydrogen volumes. At the same time, investments in a wide range of transmission, distribution and other infrastructure solutions are key to enable the deployment of a well-functioning and mature hydrogen market. This requires involvement of both public and private parties and a flexible and open regulatory framework for hydrogen infrastructure in the beginning. There is a need to develop a regional, national, and transnational pipeline network as well as marine export and import facilities and non-grid transport options, taking into account system integration. The EC should encourage a broad use of hydrogen across all sectors. Clear mapping of demand for hydrogen from priority sectors, for processes which cannot be otherwise decarbonised, may help prioritize public investments in infrastructure if needed. This is to avoid the risk of stranded pipeline assets due to planning processes which do not adequately plan hydrogen networks to match priority demand and address public acceptance. Applying a minimum set of sound regulatory principles, such as a neutral operator, transparency, and non-discriminatory Third-Party Access, should ensure that hydrogen investments are done "future proof" and contribute to increasing the liquidity of the hydrogen market.

The Transmission & Distribution Roundtable generally share a common understanding on the role, configuration and contribution of the future EU hydrogen transport, distribution and storage system based on 5 key principles:

1. "Hydrogen as enabler - at the heart of energy system and sector integration, linking electricity and gas infrastructure needed, hydrogen will make the system more sustainable, reliable, cost-efficient and flexible."
2. "Hydrogen transportation, distribution and storage system will be based on multiple modes and technologies."
3. "Hydrogen Transport, Distribution and Storage Infrastructure to handle renewable and low carbon hydrogen will contribute to achieve the objectives of the EC's Hydrogen Strategy and the EU Green Deal".
4. "The necessary hydrogen infrastructure should be developed in a view to create an EU wide market on a non-discriminatory, transparent basis."
5. Enabling solutions for intra EU trade and non-EU imports of hydrogen are needed to implement the targets defined under the Hydrogen Strategy and long-term carbon neutrality objective."

II. Barriers of the Transmission and Distribution Roundtable:

The Transmission and Distribution Roundtable has focused on the *list of barriers* currently faced by the project promotors, organised per archetypes as agreed within Transmission and Distribution Roundtable:

- Transmission and distribution pipelines,
- Maritime storage and handling terminals (including),
- Shipping
- Inland Distribution

The problems listed below are collected from the CEOs and Sherpas. This list of barriers is organised by archetypes and can be of regulatory, financial, and technical nature. The overall comment to the list also includes **the strong need for training and competencies of staff that needs to deal with logistics, maintenance etc.**

i. Common barriers for all the T&D archetypes:

Regulatory Barriers:

Barrier 1. Renewable and low carbon hydrogen is still uncompetitive, so customers do NOT have a business case to switch.

1.1 Missing customer incentives for switching.
1.2 Missing clarity on the evolution on EU ETS/CO2 taxation to determine competitiveness of renewable /low carbon hydrogen
1.3 Missing clear definitions and carbon footprint thresholds for renewable/ low carbon hydrogen to apply coherently across all EU policies relevant for hydrogen
1.4 Missing robust certificates/guarantees of origin framework for renewable and low carbon hydrogen to allow efficient trade "across borders and sectors" and for proving reliable sustainability standards (climate value) of hydrogen. Certification is key to justify a higher price for low carbon and renewable hydrogen and renewable hydrogen. As long as there is not one European certification framework, customers will have no incentive to pay a higher price for renewable or low carbon than for grey hydrogen.
1.5 Missing international competitiveness if no carbon adjustments are clearly made.
1.6 Renewable energy capacity and associated renewables targets are not high enough to allow for sufficient production of additional renewable hydrogen.
1.7 Missing clarity over taxation (taxes and levies) of energy used in electrolysers, to reflect electrolysers treatment as a conversion facility, not as end-user.
1.8 The temporal and spatial correlation between produced renewable electricity and the electrolysers (as per Delegated Act implementing Article 27 of REDII) could bring very strict obligations which would totally undermine the business case for renewable hydrogen production, obliging to oversize the electrolyser and associated hydrogen storage and negatively impacting the business case of the project.

1.9 Missing agreed framework to declare levelised cost of hydrogen from projects. This would allow a better understanding of estimated costs from across a broad spectrum of projects at different stages of their development, which in turn could be used to spot and incentivise cost and carbon reductions.

1.10 Lack of operational performance data to inform Opex estimates for project investment cases.

1.11 Missing market regulation and a trading platform (hydrogen exchange) for hydrogen trading and a market pace for H2 Guarantees of Origin at scale for the purpose of trading between producers, storage, and consumers. Importance of importing green hydrogen from outside Europe is underestimated by the European Union. EU Member States are competing for import streams worldwide, no coordinated approach by the EU, despite the geopolitical dimension of importing and diversifying new energy flows (as was the case with oil and coal for example).

ii. Archetype 1: Transmission & Distribution pipelines

Regulatory Barriers:

Barrier 2: The missing operationalization of the Hydrogen Strategy: targets need to be translated to clear volumes and optimized means.

2.1 Missing regulatory basis for planning, construction, and operation of hydrogen infrastructure – retrofitted repurposed and newly built.
2.2 Missing framework for a coordinated infrastructure planning on a national level and EU level between hydrogen, gas, and electricity both for pipes and underground storage, preferably under TEN-E regulation.
2.3 Lack of regulatory framework for P2G-facilities (including concerning siting, sizing, constructing and operations, ownership, taxation).
2.4 Lack of EU framework for EU Regulatory-Sandbox promoting R&D and new business models to promote innovation, scaling up, system adaptation and optimization for technology.
2.5 Lack of clear, region-specific mapping of hydrogen demand in priority sectors undertaken by European Commission
2.6 Missing clarity on the principles for access to infrastructure and operations:

2.6.1 Clarity needed for Third-Party Access as a core principle for hydrogen infrastructure. Lack of set of core regulatory principles for hydrogen infrastructures to be applied from the outset – e.g. pertaining to unbundling/neutral operator, transparency, and non-discriminatory Third-Party Access (TPA).'

2.6.2 Uncertainty to be addressed over the evolution of regulation for hydrogen markets to guarantee investments.

2.6.3 Missing vision for how the regulatory framework for gas and hydrogen will be developed to capture the synergies and interactions between H2 and existing EU gas legislation.

2.6.4 Lack of understanding of comprehensive approach TSOs/DSOs and other public and private parties' future roles and if/how they can be eligible to conduct the decarbonisation activities for the future hydrogen economy.

2.6.5 Blurry expectations for future unbundling rules related to natural monopoly activities. Uncertainty about who and how can operate hydrogen networks

2.7. Missing clarity on regulatory solutions for hydrogen blending:

2.7.1 Missing well developed EU framework permitting for injecting hydrogen into existing natural gas grids.

2.7.2 Missing framework for gas system operators TSOs/ DSO to connect local hydrogen producers and blend hydrogen into grids or repurpose grids to pure hydrogen.

2.7.3 Absence of the guidelines towards guarantees of origin/certificates and measuring methods to track and trade hydrogen blends.

2.7.4 Hydrogen blending/deblending infrastructure is not eligible according to current draft of TEN-E Regulation proposal.

Financing Barriers:

Barrier 3. Lack of regulation of infrastructure financing, subsidy schemes application, allocation of financial support: where in the supply chain to co-invest? How to attract financing from the financial markets and get bankable projects?

3.1 Missing clarity on state aid: need for a renewable hydrogen dedicated chapter in the State Aid Guidelines revision

3.1.1 Missing clarity on how to finance the development of hydrogen network (tariffs, handling of Regulatory Asset Base, mutualization between gas and hydrogen networks, alternative funding mechanisms, etc.)

3.2 Uncertainty of regulatory treatment of financing R&D activities for operators based on arrangements approved by market regulator

Technical Barriers:

Barrier 4. Operational challenges for blending

4.1 Missing framework for cross border gas/hydrogen dual gas quality handling at TSO level

4.2 Missing coordination across value chain for the gas quality and quantity management (e.g. maintaining a steady gas flow poses a challenge and set clear guidance on acceptable purities)

4.3 Missing EU technical gas quality standards for pipelines: Clear European Regulations (EN 16726) concerning the relevant important physical parameters such as Wobbe Index and Relative Density should be harmonized and need to be defined.

4.4 Missing harmonization for pipelines and transport integration: also, limiting and strict European Regulations (EN 16723-1 and EN 16723-2) concerning the applications (CNG cars e.g.) need to be adapted to allow more than 2% of hydrogen blending in grids where CNG filling stations are connected.

Barrier 5. Lack of technical requirements for repurposing, retrofitting and newly built pipelines

5.1 Absence of technical standards for repurposing of existing gas grids or building hydrogen ready grids (e.g. missing requirements for compatibility and qualification of materials (piping and accessories) for 100% H2);

5.2 Need to develop safety, operational and maintenance requirements in the various activities and interventions on assets including possible de-blending in case transport of gas to sensitive end-users;

5.3 Missing interoperability and operational rules for repurposed system management (e.g. Develop mechanisms to control energy balances at TSOs and DSOs level).

5.4 Need to define a hydrogen purity level for pure hydrogen pipelines (either repurposed or newly built).

5.5 Missing framework for reverse flow facilities between TSOs and DSOs.

5.5 Lack of clear declarations of the suppliers of infrastructure elements regarding the possibility of cooperation with hydrogen components in the future.

iii. Archetype 2: Marine storage and handling terminals in ports (including hubs)

Regulatory Barriers:

Barrier 6: Land access management - priority access to new energies infrastructure

6.1 Missing EU Green Deal compatible rules for managing scarcity of available land for new energies accommodation and terminals development.

6.2 Missing process and criteria for determining what parties should be granted access to land by port authorities.

6.3 Lengthy permitting processes and Environmental Impact Assessments.

6.4 Missing processes for streamlined public acceptance management.

Barrier 7: Missing framework for capturing the benefits for integrated projects (involving different modes of transport, hybrid projects – electricity, gas, hydrogen projects).

7.1 TEN-E framework does not allow for integrated hydrogen / CCS projects. No synergies between TEN-E and TEN-T projects at the moment. TEN-E, TEN-T corridors are not integrated.

7.2 Current standards and processes not agile/fast enough to integrate hydrogen applications (e.g. For instance the EN 17339 is a state of art standard but not listed in the ADR and therefore cannot be used for the moment for H2 applications).

7.3 Missing regulatory framework provided to recognize the role of dedicated hydrogen storages as well as reuse of gas infrastructure

Barrier 8: Barriers related to hydrogen carriers: Ammonia:

8.1 Missing regulatory framework for using ammonia as an energy vector and energy storage, also missing regulatory and stimulating framework for other hydrogen carriers

8.2 Clarification of rules for ammonia transportation on different modes of transportation as hydrogen carrier

8.3 Lack of EU harmonization of authorization process for ammonia production, storage, use as fuel, etc hindering scaling up of multi-country projects

8.4 Missing framework for certificates/guarantees of origin and transformation of the same (from green hydrogen to green ammonia, and from green ammonia to green hydrogen).

Barrier 9: Barriers related to Liquid Organic Hydrogen Carriers and/or other hydrogen carriers:

9.1 Very limited reference to hydrogen carriers in TEN-E and importance of import facilities and related infrastructure in ports is underestimated.

Financing Barriers:

Barrier 10: The absence of public grants to projects that enable reduction of CO_2 emissions for participants outside the project (at beginning and/or end of the value chains) will be a barrier to the market development.

10.1 Missing framework for integrated and hybrid projects to accelerate market uptake of H_2 technologies.

10.2 Missing regulations and higher incentives for infrastructure solutions to transport, export, import, store and distribute renewable hydrogen (compared to low carbon, especially below agreed CO_2 footprints).

10.3 Higher incentives for transporting green hydrogen and make clear regulations

iv. Archetype 3: Shipping

Regulatory Barriers:

Barrier 11: Lack of synergies between TEN-E and TEN-T, not promoting technologies for shipping hydrogen

Barrier 12: Missing clear regulations and higher incentives for shipping green hydrogen

Barrier 13: No standards (safety, certification) for H2 as cargo, but also for import terminals, storage, etc.

Financing Barriers:

Barrier 14: Pending approvals for H_2-based technologies to achieve sufficient maturity

14.1 Design of the EU grant programs for innovative projects, currently not sufficiently capturing TRL scale assessment of technologies application at industrial levels, but crucial to foster market uptake.

14.2 The absence of sufficient public grants to R&D and innovation pilots projects

14.3 absence of funding for ‘mobile equipment’ under EU financing programmes (CEF relates to infrastructure, not the funding of ships)

Technical Barriers:

Barrier 15: Lack of investment strategy and prioritization for allocation of R&D&I funding targeting next 5 years

15.1 Missing Investing in R&D&I to accelerate the development of H_2 applications for different shipping segments for the first commercial solutions to be available in the market in the next 5 years.

v. Archetype 4: Inland Distribution

Regulatory Barriers:

Barrier 16: Regulatory framework for safe onward transportation for the various technologies is either lacking or hindering further distribution.

Financing Barriers:

Barrier 17: Missing clarity on subsidies for e.g. the mobility sector to be provided such that both heavy duty transport, cars, train, and barging can accelerated be stimulated.

Technical Barriers:

Barrier 18: Lack of availability of sufficient Hydrogen Fuel Stations to accelerate the change from fossil to zero carbon.

Barrier 19: Technological scale up.

Barrier 20: Training and competencies of staff that needs to deal with logistics, maintenance etc.

III. Analysis of the project collection data from the transmission and distribution archetypes on barriers and mitigations measures

As part of a collection of hydrogen projects from members of the European Clean Hydrogen Alliance in April/May 2021, the European Commission gave project promoters submitting their projects the opportunity to highlight barriers that they believed complicated their projects, and to propose mitigating measures. This sub-chapter summarises the input collected as part of this exercise, beyond those discussed on the Transmission and Distribution Roundtable.

A majority of project promoters that submitted projects for their inclusion into the project pipeline of the Alliance highlighted the lack of functioning H2 market – no supply and no demand, which currently translates into no H2 imports and minimal transport capacity. On the regulatory side, a majority of these project promoters mentioned a missing regulatory framework for transport of H2 and H2 carriers. In addition, they identified uncertainty on access to infrastructure and capacity management, missing clarity on the role of TSOs on ownership, operation of H2 networks, and a missing framework for coordinated infrastructure planning on national and EU level. Some project promoters mentioned that the renewable and low carbon hydrogen market needs to be structured and organized by a clear regulatory framework and be based on key principles such as non-discriminatory Third-Party Access. Some project promoters mentioned that network operators should be allowed to operate and invest into H2 infrastructure and RAB (for TSOs operating H2 and methane systems) with a combined cost recovery mechanism, as cost mutualization ensures reasonable network tariffs for early hydrogen customers. Some project promoters moreover mentioned that NRAs should be obliged to recognize costs linked to repurposing/retrofitting of existing pipelines to H2. In addition, wider implementation of EU regulatory sandboxes was seen by some project promoters as a way to bring flexibility for projects. For shipping and marine transport many project promoters identified missing permits for building and operation of the projects and missing regulation for maritime storage and transport of H2 carriers. Some project promoters also identified the need for clarification on import, excise tariffs of H2 carriers and excise administration.

On the market side, there are no market incentives available and no clarity on mechanisms to finance the hydrogen networks and other parts of the infrastructure, according to project promoters. They believe that mechanisms need to be carefully assessed in relation to the impact on H2 cost and stakeholders involved. Some project promoters suggested support mechanisms such as Carbon Contract for Difference, quotas on gas supply, or even targets. Another barrier for H2 uptake identified by project promoters was the lack of incentives for customers to switch form fossil fuels to renewable and low carbon hydrogen, hence establishing a reliable GOs and certification framework was proposed as a relevant mitigation measure. In addition, lack of clarity on evolution of EU ETS and CO2 taxation was identified as significant market barrier by project promoters to foster demand and production. For H2 carriers it was mentioned by project promoters that H2 terminal activities are only viable with large enough quantities on regular basis, there is lack of incentives on offtake side to pay sufficient premium for imported green H2, current price for green ammonia and methanol is not yet competitive, and the current LH2 market is oligopolistic with very few actors.

On the financial side, for many projects the CAPEX investment is high whilst the economic viability uncertain due to uncertain market developments – demand risk and price of H2. Hence project promoters see an investment risk in implementing large scale projects. European and national public funds can reduce the financial burden for consumers, according to project promoters. Though project promoters identified that financial mechanisms and State aid guidelines are unclear, while in some non-EU neighboring countries, e.g. Ukraine, access to such EU funding is limited. In summary, several project promoters agreed that public funds and grants are needed to mitigate the risks of financing such projects, but there needs to be technology neutrality in grant distribution and availability of funds not just for large but also SME companies.

On the technical side, several project promoters highlighted the need to speed up development of H2 technical standards as currently the biggest barrier is lack of such standards (e.g. for vessel tank pressure, tank typology, standard for bunkering of compressed H2 for maritime applications, standard for using ammonia as shipping fuel, and others). Project promoters also identified some technological barriers for H2 transport in pipelines and that adaptations for sensors, compressors, and valves are needed. In addition, there is missing clarity on interoperability rules for blending, according to project promoters. To mitigate this issue, some project promoters stressed the need for clear regulatory framework on H2 allowance, interoperability rules and the need for detailed forecasts (H2 content, Wobbe Index & calorific value). On the technology development side, some technologies were flagged by project promoters as requiring more research (e.g. polymers, liquefaction cycle, ammonia cracker, etc) and it was mentioned that more testing of equipment in H2 setting under operating conditions is needed.

On the value-chain side, permitting was highlighted by project promoters as lengthy and bureaucratic process, hence detailed preparation with frequent and timely involvement and update of all authorities was proposed by some project promoters.

3. Report of the Roundtable Industrial applications

The Industrial applications Roundtable report focused on the pain points and mitigation measures common to all the “archetypes” agreed by the Roundtable. Below there is a summary of the report, whereas the complete version, with a detailed description of the archetypes, barriers, and mitigation measures, can be found on this link[4].

i. Pain points common for all mentioned archetypes:

- Lack of clear terminology, as well as a comprehensive certification and verification framework for clean hydrogen.
- Growing demand for low carbon products but resistance to pay the necessary premium to cover the additional cost.
- Current cost of renewable and low carbon hydrogen is too high.
- Current availability of renewable and low carbon hydrogen is low.
- Current availability of affordable and abundant renewable electricity is low.
- Current availability of hydrogen-related infrastructure is low.
- Technological risk during process scale-up to commercial size.
- Lack of prioritisation from the EC on the sectors/functions that hydrogen should be primarily destined for from now to 2030.

ii. What do we need to enable a faster transition and to keep investments in Europe?

- Support for investments that scale-up production and demand for renewable and low carbon hydrogen.
- Mitigation of technological and financial risk via public funding and state-aid (OPEX-related).
- A stable regulatory environment that accounts for the transition that industry needs to go through.
- Visibility as to how the upcoming sustainable product policy initiative and the other circular economy provision will influence the amounts of intermediary products and final products required by the market.

[4] *https://ec.europa.eu/growth/system/files/2021-11/RT3%20Archetypes%20barriers%20mitigation%20options%20final_0.pdf*

iii. Mitigation options common for all mentioned archetypes

- Secure access to and availability of sufficient and competitively priced renewable electricity, also by combining European and international infrastructure solutions in the most efficient forms.
- Support and drive investments in appropriately sized (from local to highly interlinked, high capacity and digitalised) electricity, and dedicated hydrogen grids.
- Create an effective toolbox of demand-side measures to drive markets for low-GHG-impact basic materials, energy-efficient processes, etc.
- Introduce a harmonised calculation methodology for e.g. LCA, GHGs, embodied emissions.
- Encourage mandatory green/sustainable public procurement targets/policies prioritising the use of secondary and low-GHG-impact materials or products.
- Support uptake of corporate renewable Power Purchase Agreements (PPA) and facilitate a European scheme for CCfD (Carbon Contract for Difference).
- Describe transition pathways for specific industrial ecosystems, offering a better bottom-up understanding of the scale, cost, long-term benefits, and conditions of the required actions to accompany the twin transition, leading to an actionable plan in favour of sustainable competitiveness.
- Ensure an appropriate regulatory framework for CCS and CCU for the deployment of related low carbon technologies and products.
- Implement better coordination of the EU and national funding programmes, for example through a “single window” approach, and of policies (competition policy, state aid, sustainable finance) to ensure that industry can access funding to enable the transition.
- Effective and appropriate protection against risk of carbon-leakage must be ensured.

iv. Potential of the suggested archetypes

- Reduction of large amounts of greenhouse gas emissions (several 100 million tons/a).
- Preservation of industrial sites and employment while transitioning to climate-neutral manufacturing.
- Preservation of the making industry in Europe, thereby ensuring a certain level of independence.
- Maintain technological leadership in Europe (vital for a resource-restricted region).

4. *Report of the Roundtable Mobility*[5]

The Roundtable Mobility has discussed several times on different levels, including roundtable CEOs, the key challenges ahead of the ecosystem [1]. Based on the discussions between the RT members, following key blocks of barriers/bottlenecks/challenges were identified, as well as number of possible mitigation measures to accelerate the ecosystem development.

i. *Market*

There is a broad consensus that the ecosystem is under development and in a number of areas, the market development must be supported by number of regulatory, fiscal, or non-fiscal measures. The key area to unlock the market development potential is seen in the area of standardisation.

Challenges/barriers and mitigation measures:

- Low carbon and green hydrogen production and trade
  - Definition and standards for certifying low carbon and green hydrogen as well as LH2 - Liquid Hydrogen - either as an end product or for logistics reasons.
  - Differentiation between local produced H2 and imported H2 (e.g. through different branding or fiscal support)
  - Setting Exchange for green hydrogen to establish a reference price.
  - Setting up a certification system of carbon capture and reuse taking into account different levels of GHG reduction based on the carbon source for synthetic fuels/chemicals.
  - Standardization and certification of 100% Sustainable Aviation Fuel (SAF/e-fuels) based on H2.
  - Definition of standards and unified procedures at European level to obtain the necessary permits for the construction of hydrogen production sites: would create clarity and accelerate market development

- Hydrogen storage and transport
  - Construction/Building norms for hydrogen storage in gaseous and liquid form.
  - Norms for hydrogen transportation in tunnels and handling liquid hydrogen (filling nozzle, volume debits, etc.).
  - Standardization in the factor of safety/pressure limits in hydrogen transportation.

- Design, engineering, validation, and market introduction of hydrogen powered vehicles

[5] *This report is not supported by T&E due to different perspective on the future development of the mobility part of the value chain.*

- Development of (international) standards for vehicle on-board hydrogen storage (350bar, 500 bar, 700bar, liquid), safe integration of on-board H2 storage and hydrogen propulsion systems and refuelling infrastructure & process in road and rail transport. In rail the upcoming IEC 63341 will be the reference.
- Potential revision of Rail Interoperability and Safety Directives.
- It should be ensured that fluoropolymers used in the hydrogen and hydrogen vehicle and supply industry are exempted from the planned PFAS ban taking safe collection and recycling into account.

- Hydrogen Refueling Stations (HRS)
  - Standard for certifying HRS (to avoid certification by each hydrogen car manufacturer or by member state), especially valid for HDV and buses.
  - Standardisation of HRS design and interface.
  - Multi-user HRS design, e.g. HRS which can serve trucks, busses and passenger vehicles.
  - Safety standards at airports and aircraft handling.
  - Construction/Building norms for HRS.

- Applications
  - New aircraft safety standards but also safety standards at airports and aircraft handling.
  - Recognition of the technological and design specificities of zero emission vehicles' architecture.
  - Safety standards and classification for hydrogen, ammonia, and methanol powered ships.
  - Defining technical requirements towards zero-carbon shipping with the IMO.
  - Standardisation of fuel cell modules for heavy duty applications e.g. "StasHH mission" project
  - Methanol and Ammonia norms for utilization as transport fuel e.g. using experience based on different national or EU projects.

ii. Funding and financing

The business case of investment projects in mobility applications are primarily driven by the cost of H2 and the cost of emitting CO2. Therefore, fiscal, and regulatory incentives should focus both on facilitating the availability of green H2 at a competitive price and on increasing the price of emitting carbon.

Challenges/barriers:

Reducing the TCO-gap through a number of interlinked measures is critical. Especially for commercial vehicles a significant TCO-gap is expected in the initial stage for zero-emission technology and will impact final users in the value chain. Different actions are needed to reach parity with diesel. That will also positively stimulate technology adoption and foster the initial market volumes deployment to support a suitable infrastructure development.

There is a need to reduce operational gap, especially through fuel costs. As the energy costs impacts the production costs of H2 by 60-80%, exemption schemes from system and transport costs of the energy costs can close the OPEX gap. This should be supported by a number of fiscal and non-fiscal measures.

Possible mitigation measures:

Transversal measures need to be taken to promote the uptake of low carbon hydrogen:

- Boost and incentivize the public demand to accelerate the deployment of zero-emission mobility. Set up higher targets for (publicly procured) zero-emission vehicles in the framework of the Clean Vehicle Directive as well as strengthened CO2 emission standards, investigate the possible inclusion of a zero-emission mandate for vehicles.
- Introduce CFDs or subsidies on CAPEX and OPEX (no reimbursable advances), both on production and infrastructure (storage, HRS, applications in different transport modes) and for the use of H2 applications (user perspective/e.g. OPEX support for e-fuels in aviation).
- Carbon pricing and introducing polluter pays principle (e.g. through reviewed level Energy Taxation Directive excise duty, based on CO2 intensity of the fuel, unless the sector – such as aviation – is already part of EU ETS), road tolls based on vehicle CO2 emissions, preferential access to inner cities with low-emission zones or introducing "guarantee of origin" principle on carbon sources for e-fuels to reflect GHG (reduction) impact of re-utilized CO2.
- Exemption from grid fees (systems and transport fees) for electrolysis with renewables
- Clear and harmonized traceability and labelling of origin of hydrogen
- Labelling and different incentives or taxation of green hydrogen: from renewables, from renewables produced in smart grid function.
- Need for financial support on all the hydrogen value chain, including storage (e.g. electrolysis in Germany still suffers from the renewable energy law, which increases energy prices by almost 7 Cent/kWh. The production of energy on the other hand is subsidized). Need to review the De Minimis regulation and encourage member states to use this instrument as well as other instrument which would contribute to the shift towards hydrogen mobility.
- Clear elaboration of rules for project definition, funding, and execution under the parallel initiatives of:
  - Clean Hydrogen Partnership / Clean aviation / Europe's Rail support/foster common roadmaps and funding calls between European Partnerships on hydrogen mobility to improve the competitiveness of FC solutions across all modes.
  - Other Horizon Europe-supported projects.
  - IPCEI Hydrogen.
  - ECH2A.
  - Innovation Fund.
  - ERDF: Cohesion Fund and the European regional development Fund.
  - Ocean Fund.

iii. Regulatory issues

Standardisation and infrastructure availability are identified clearly as key areas, where regulatory measures need to be taken to boost the ecosystem development. As indicated in the chapter related to financing, lowering TCOs is key to steer the market development. Besides those key challenges, additional ones could further boost the deployment of hydrogen applications in a number of mobility areas:

Challenges/barriers and mitigation measures:

- Integration of externalities in transport cost structure (e.g. increasing the price for CO2 emissions in ETS, establishing an adjacent ETS system for road transport) - important, especially for aviation: idea is to shift to alternatives, e.g. important to avoid new levies, earmark all revenues from transports modes, no double-charging for CO2 emissions (cf. decarbonisation efforts in aviation: should focus on SAF).
- Increasing share of renewables in all transport modes as indicated in the 2030 Climate Target Plan and additional incentives in form of sub-targets or multipliers for hydrogen. RED III should further ensure a level playing field in terms of accounting towards the renewable transport target for BEVs and FCEVs based on their engine efficiency. Focused REDII review to stimulate supply in the transport sector, considering stimulating measures for low carbon and green hydrogen or synthetic fuels.
- SAF blending mandate with blending obligation incl. a sub-target for new technologies such as e-fuels is necessary but needs to be carefully designed (ReFuelEU Aviation) and applying strict sustainability criteria under the recast of the Renewable Energy Directive (RED). Earmarking of EU ETS revenues for SAF projects, incl. hydrogen projects (esp. E-fuels).
- Revision of EEAG: reduce the constraints linked to national aids on mobility sector.

iv. Infrastructure/supply chain

With respect to the mobility applications, being at the end of the value chain, availability of the infrastructure is seen as a critical point. Mobility applications will be dependent on the results of the progress in upstream areas (production – distribution).

Challenges/barriers:

Regulatory framework for the infrastructure is essential to speed up the ecosystem development. The expected review of the Alternative Fuels Infrastructure Directive (AFID) should set a framework for the massive, coordinated deployment of H2 applications across all modes.

Investment in a new infrastructure (storage & fuelling station) and ensuring an adequate supply of green hydrogen is a significant barrier for potential early adopters of fuel cell powered vehicles. Public support should be available at national and/or EU level to support such investments: covering 50% of CAPEX during the next 5 years).

At the EU level, the Connecting Europe Facility should be the main support instrument for H2 infrastructure investments for all transport modes.

To lower costs, it is important to increase the demand for green H2, which can be done through at the local & regional level: synergies should be investigated when planning H2 refuelling infrastructures to serve multiple applications, e.g. various types of road vehicles and trains in cities, or vessels and trucks / trains in harbours – a concept of "multi-purpose hydrogen refuelling stations".

Progress on the standardisation on H2 refuelling infrastructure for all mobility application is also important to de-risk investments and reduce costs.

An overview on H2 refueling points of all transport modes should be built and maintained. This will require regional and local planning efforts as well as advanced monitoring on EU level in order to monitor progress in the implementation of the milestones fixed (e.g. number of electrolysers installed, number of HRS etc.) as well as improve consumer information.

Possible mitigation measures:

- Road and off-road
  - Speed up deployment of refuelling stations through the Alternative Fuels Infrastructure Directive and Regulation on the Trans-European Transport Network (TEN-T); The inclusion of hydrogen and hydrogen-based technologies should be made mandatory as part of in National Infrastructure Roll our Plans. The inclusion of mandates for FCEV along TEN-T corridors should be considered to ensure a backbone infrastructure along main highways by 2030
  - Synergies between the Trans-European Transport Networks (TEN-T) and the Trans-European Networks for Energy (TEN-E) should be explored; both new infrastructure projects as well as hydrogen transport (including pipelines, maritime, road, off-road and other) solutions, intermediate storage and associated infrastructure projects should be encompassed in the framework of TEN-E.

- Rail
  - 70.000 km of railway lines in Europe would remain unelectrified under the current EU legal framework. Fuel cell propulsion provides a technical alternative to diesel for such lines.
  - Member States should define decarbonation roadmaps for their non-electrified rail infrastructure, contributing to the 2050 objective of 90% reduction in CO2 emissions.
  - Rail projects synchronise infrastructure and rolling stock (vehicles) investments for a given transport services. Thus, rail projects can guarantee a predictable, geographically localised, long term (20 years and more), significant (up to several tons per day) demand for green H2, contributing to local or regional transition strategies.
  - The deployment of HRS for regional passenger train applications is currently the most promising market segment.

- Maritime
  - A coherent international regulatory framework is needed to support the development of the sector. R&D and first technological exploitations are necessary to support the development of a regulatory framework at IM level.
  - Ports can be at the core of the European hydrogen backbone as well as local and regional hydrogen valleys. Integrated infrastructure concepts of hydrogen production and distribution for maritime and other use, also using coastal and offshore renewable electricity. A broader EU/IMO harmonised regulation will be necessary to enable the building of larger ships and to create the conditions for designing ships with innovative components at cost competitive conditions.
  - In regions with scattered industry and population, such as the Baltic Sea region, hydrogen and e-fuel supply is expected to build on network of hydrogen and e-fuel ports.
  - Build-up of port infrastructure prerequisite to attract inland waterways ships, yachts, coastal shipping to transition to hydrogen propulsion.

- Aviation
  - To advance hydrogen propulsion technology infrastructure requirements need to be taken into account (ideally, at global level but realistically in this context on a European level). To enable hydrogen aviation flights through Europe a hydrogen hub network on relevant European airports has to be established. In best case also in liquid form.
  - Develop airports into hydrogen hubs to serve local non-aviation users (mobility, logistics, etc.) as first step to start building up hydrogen infrastructure at airports before the service entry of hydrogen aircraft. This is also relevant to use hydrogen for ground operations equipment.

v. Others

There is a number of measures that can further stimulate the development of the hydrogen ecosystem. The key challenges and possible mitigation measures identified are following:

- Transversal and holistic view on production of core components like fuel cells and ICE adapted to the use of hydrogen and hydrogen-based fuels.
- Establishing mode-specified project development assistance (PDA) schemes to support hydrogen end-users, especially in maritime sector.
- Support the use hydrogen and hydrogen-based fuels in off-highway applications with their specific operational profiles and conditions.
- Provide EU or national public support to support investments in new or modernized railway rolling stock.
- Systems and applications developed, designed, and manufactured in Europe should have a preferred status.

- It is surprising that the EU Smart and Sustainable Mobility Strategy refers correctly to hydrogen passenger cars, but that Fuel Cell PCs are being neglected in the national plans of the Member States. The Commission should make best efforts to correctly synchronize plans.
- A cost-efficient way for green hydrogen produced in Europe should be established, in line with circular economy and EU energy independency considerations.
- To accelerate creating green hydrogen society by fast implementation of green hydrogen value chain, following examples of supporting measures could be used:
  - Green hydrogen certificates in the first number years to support the start of green hydrogen production.
  - Subsidies for first number of millions of tons of green hydrogen storage/transportation infrastructure.
  - Subsidies for first number hydrogen refuelling stations.
  - Subsidies to entities that declare building the whole green hydrogen value chain from production, storage to hydrogen refuelling stations.
- Within the different EU budgets, earmark the amounts for H2 (infrastructure, incentivization of vehicles, H2 production, h2 distribution, etc.
- Public-private partnerships such as Zero-emission Valleys should be replicated throughout Europe as well as clear blueprints to facilitate replications.
- Synchronization needed between different H2 valleys projects to favor connecting the dots between regions and creating a seamless hydrogen deployment starting with regions, than connecting them at national than European levels…
- The link to the other hydrogen initiatives has to be ensured, like Hydrogen Europe and the Hydrogen Council and the national hydrogen strategies.

5. Report of the Roundtable Energy Sector

I. Introduction- A common Industry vision

Europe's energy system will change significantly - carbon-neutral by 2050 means nothing less. We, the members of the Energy Roundtable, cannot predict the future and what the energy system will look like in 2050.

However, we are convinced that five trends are inevitable and will guide the transformation of the energy system from today to 2050.

1. Europe's primary energy consumption must become carbon neutral. Variable renewable energy will play the most important role in this transformation. Coal phase-out should be accelerated.
2. Direct electrification and the conversion of renewables into hydrogen and its derivatives will ensure access to carbon-neutral energy for all consumers.
3. With more variable renewable energy and more electrification, in addition to demand-side response, dispatchable and flexible capacity to manage the residual load and to provide long-term storage will gain in importance.
4. In the power system, molecules will continue to play an important role in securing supply and managing residual load. Molecules must gradually become carbon-neutral, rather sooner than later.
5. Integrated infrastructure planning based on enhanced coordination between electricity, gas, district heating and hydrogen sectors is necessary, to develop a cost-efficient energy infrastructure that will enable carbon-neutrality on time.

The European Union needs to act now, because in the context of energy system, tomorrow investments will determine the energy system of 2050. And albeit the pathway is long and stony, the momentum is right.

II. The energy barriers and mitigation measures

The Energy Roundtable has focused on the challenges and opportunities that hydrogen brings for the decarbonization of the energy sector, with a special focus on the power sector and the decarbonization of the residual load, the integration of the existing and future generation, and transmission and storage infrastructure.

The following four questions have steered the work of the Energy roundtable and set the structure of this paper:

1. How to decarbonise the residual load with renewable and low carbon hydrogen?
2. How to benefit from the efficiency gains of combined heat and power generation?
3. How to produce renewable-based hydrogen aligned with energy system needs, be it 24/7 or to use surplus renewable generation?
4. How to ensure system flexibility through sufficient hydrogen storage and transport infrastructure that is resilient and minimizes costs to society?

In the following sections, we identify the key barriers policy makers need to address to allow Europe reach carbon-neutrality by 2050 with a system as reliable and affordable as today's. We propose solutions how policy makers can surmount the existing barriers and ensure that Europeans don't lose out in terms of reliability and affordability of their energy supply on the pathway to carbon neutrality.

A summary of the solutions presented in this paper are the following:

Hydrogen in the Energy System	Recommendations
1 Incentivise a fast replacement of coal-fired power generation and Triple wind and solar PV installed capacity by 2030	1. **Create a sufficiently high and predictable CO2 price along with a policy toolbox to** phase out coal 2. **Increase investments on wind and solar capacity to triple capacity by 2030** 3. **Accelerate permitting procedures for wind and solar and power grids**
2 Accelerate the deployment of renewable and low carbon hydrogen	1. **Scale H2 production in a technology-open manner,** to create a liquid and cost-competitive hydrogen market that is accessible to all sectors 2. **Accept renewable and sustainable low-carbon hydrogen types and derivatives,** prioritizing EU production but including imports from outside the EU 3. **Make hydrogen transport & storage infrastructures ready** to enable its use across the entire energy system.
3 Enable a hydrogen market and technology to decarbonise the residual load	1. **Design remuneration mechanisms** that better value reliability and capability with a focus on zero-carbon emissions 2. **Mandate H2-readiness levels** for gas infrastructure investments to avoid carbon lock-in 3. **Create OPEX-centered funding as of today** to enable operational learning in power and CHP applications 4. **Adapt the electricity market** to value the flexibility potential of electrolysers, including congestion management and frequency response services
4 Accelerate the development of a hydrogen grid and underground storage infrastructure	1. **Foster an integrated infrastructure planning** based on enhanced coordination between electricity, gas, district heating and hydrogen sectors. 2. **Develop a European vision and planning process for development of underground hydrogen storage sites, ensuring sufficient storage capacities** 3. **Facilitate anticipatory investment on hydrogen infrastructure** to enables the later integration to an overarching meshed hydrogen grid.

1. Power Generation and CHP: Decarbonising the residual load

Today, coal is still a significant energy source to produce electricity and heat. Renewable energy sources (RES), in particular wind and solar power are Europe's energy sources of choice to become carbon-neutral by 2050. With the right infrastructure, they can energize our societies with electricity, heat (e.g. with heat-pumps) and hydrogen (via electrolysis).

The phase-out of coal-fired power generation is a massive opportunity to take out a large amount of CO_2 of the electricity system; this along with an ambitious scale-up of renewables are the best way to decarbonize power generation.

But as renewables don't provide electricity at all times, dispatchable capacity and demand-side response complement them by contributing to reliability and generation adequacy: dispatchable capacity delivers energy for the residual load and to cover dark doldrums. Gas-fired power generation and Combined Heat and Power (CHP) are cost-efficient and available technologies to do so. CHP has the additional advantage of reaching fuel utilization levels of more than 90%.

Especially where governments are pushing for a significant change in electricity supply over a short period of time (e.g. an accelerated phase-out of coal energy), investments in capacity will be soon necessary to ensure a reliable energy supply at all times - and these investments must pay off. The value of these investments is not to produce baseload electricity, but to deliver energy in a flexible manner, be it as electricity or heat. In that sense, providing such resource adequacy with renewable and low carbon sources is a capability complementary to renewable power generation, and currently not sufficiently valued in every electricity market across Europe. Consequently, flexible gaseous-fired power generation and CHP will support and complement the development and operational regime of renewable energy without hampering their development. In addition, both can progressively shift to renewable or carbon-neutral fuels (e.g. clean hydrogen, biomethane, e-ammonia) to enable a fully decarbonized and highly resilient energy system.

Decarbonising the residual load in a way that keep the system reliable and resilient face significant barriers that need to be overcome to reach carbon-neutrality. It is all about three overlapping elements:

1. To replace coal-fired power generation with technologies of similar reliability capabilities and higher operational flexibility as quickly as possible
2. To develop renewable capacity faster to effectively reduce the fuel consumption of thermal capacity.
3. To increase the share of renewable and low carbon hydrogen and other renewable and low carbon gases such as biomethane to 100% to reach fully decarbonized energy systems.

This section will take a closer look to the barriers related to the shift from fossil gas to renewable and low carbon hydrogen in the power system. The summary puts this into perspective and takes a complete view on all three elements.

a. Insufficient availability of hydrogen

Today, clean hydrogen is insufficiently available. According to Agora Energiewende[6], Germany's electricity system will require 102TWh of gas in 2025 and 133TWh in 2035 to provide dispatchable capacity for the electricity system. To replace todays fossil-based 133 TWh with renewable hydrogen, Germany would need to install 75GW of offshore wind and peak power for electrolysis. A full replacement of gas with

[6] Prognos, Öko-Institut, Wuppertal-Institut (2020): Klimaneutrales Deutschland. Studie im Auftrag von Agora Energiewende, Agora Verkehrswende und Stiftung Klimaneutralität

renewable hydrogen by 2030 is not realistic nor sensible, in particular if this hydrogen was to be produced in Europe.

Therefore, it is paramount to rapidly scale up **the production and storage of renewable and low carbon hydrogen within** and outside of the European Union **and to bring down costs aiming at a liquid and competitive market for clean hydrogen that is accessible to all sectors.**

CHP should play a key role in the market ramp up for re-electrification near district heating networks, providing heat as a by-product, because it saves hydrogen fuel consumption in the range of up to ~30% compared to stand-alone electricity production and heat provided by a boiler. The high fuel utilization rate of CHP plants of 90% and beyond are of tremendous value because the relatively high power to gas to power conversion losses are the main cost driver of this solution.

In addition to high efficiency, CHP is a highly flexible technology: it can provide higher electricity output to meet the electricity residual load by taking the heat from a connected heat storage; and it can provide heat-only with a back-up boiler, whenever electricity demand is met by renewable energy sources. Small-size CHP plans can be built very fast and could be located near the point of use, providing power where demand grows (e-charging stations and heat pumps) and providing heat to heating networks.

Regulators must ensure that CHP operations are fully compatible with the energy system transformation and not lead to curtailment of renewable sources because they run in a base-load approach.

Solutions

1. Accelerate coal-phase out and triple wind and solar PV installed capacity by 2030.
2. Provide a clear pathway to a liquid market for renewable and low carbon hydrogen that can be accessed by all sectors, where cost-efficient.
3. Accept renewable and sustainable low carbon hydrogen types and derivatives, prioritizing EU production but including imports from outside the EU where needed to contribute meeting the 2030 climate ambition based on their renewable origin and CO_2 performance.
4. Prioritize opportunities where the costs of switching to clean hydrogen are closest to what the market is ready to pay as this accelerates scaling and cost reductions.
5. Make hydrogen transport & storage infrastructures ready to enable its use across the entire energy system.
6. Initiate demonstration projects before 2030 to demonstrate application and early value chains.

b. Lack of mandatory hydrogen-readiness or zero-carbon readiness requirements to prepare today for fully decarbonized security of supply by 2050

Considering the lack of renewable and low carbon hydrogen today, policy makers need to ensure that investments in security of supply today will not lock-in carbon by 2050. Otherwise, the EU will face the risk that new investments in gas-fired power generation that will take place over the next decade are not 2050-compatible, or that initiatives of individual Member States will fragment the European Energy Market. The industry (e.g. through associations including EU Turbines and EUGINE) is working on a proposal on how to determine hydrogen-readiness based on thresholds for additional investments needed to reach different H2-readiness levels.

Solution

- Quickly create a legal framework for investments in hydrogen readiness and zero-carbon readiness and consider make hydrogen or zero-carbon readiness mandatory for all new investments in gas infrastructure.

c. OPEX-centred R&D support

Preparing for repowering with clean hydrogen also requires operators to gain operational experience with the new technology to reduce risks and to ensure they will be able to deliver on security of supply. Today, gaining this operational experience means operating at a loss, because clean hydrogen is still 5 to 10 times more expensive than natural gas. Today's EU funding schemes are inadequate for such real-life testing because the funding gap is insufficiently covered.

Solution

EU funding calls need to include hydrogen testing and repowering in real-life operations. These calls need to be centered around the main OPEX components (fuel) and cover 100% of the fuel price gap between natural gas and clean hydrogen.

d. The cost gap with fossil solutions

Electricity generated with fossil gas (including the CO2 price) is by far less expensive than with green hydrogen. The levelized cost of electricity with green hydrogen at 4€/kg translates into approx. 214 €/MWh for a combined cycle power plant[7]. The levelized cost of electricity with natural gas with a CO_2 price of 50€ is 55€/MWh[8]. Bridging this gap and creating price parity will require a CO_2 price of 525€/tCO2. If the costs fall to 2€/kg of green hydrogen, 235€ t/CO_2 are sufficient to create price parity (assuming the same price for natural gas). Utilities will face difficulties to pass on these costs to the consumer as they are in competition with various retailers. How can they be encouraged to complete a fuel-switch towards clean hydrogen? And what is the right pathway, knowing that costs for hydrogen and the fuel consumption in gas-fired power generation will decrease significantly towards 2050?

Solution

1. Support early demonstration projects to demonstrate operational and technological feasibility
2. To ensure investments in decarbonizing the residual load as soon as sufficient renewable and low carbon hydrogen is available, policy makers should analyse these mitigation options:
   - A market design that better values reliability and capability with a focus on zero-carbon emissions
   - Adapt support schemes to allow operations of increasingly decarbonized CHP and power generation. (e.g. a mix of investment incentives and contracts for difference)

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[7] Considering: power plant utilisation of 4,500 full load hours with a 61% efficiency (LHV), 25 years lifetime, a capex of 650€/kW, WACC of 7%, variable O&M costs of 0.20c€/kWh and fix annual costs of 20€/ kW. The cost of hydrogen includes transport, storage, and distribution.

[8] Considering a fuel price of 1.25c€/kWh and a CO2 fuel intensity of 0.20gCO2/kWh. Other assumption on CAPEX, OPEX and operation parameter are those indicated in the previous footnote.

2. How to produce renewable-based hydrogen aligned with energy system needs, be it 24/7 or to use surplus renewable generation?

a) Valuing flexibility from electrolysers

Producing renewable hydrogen can provide significant flexibility to the energy system: located strategically, electrolysers can produce hydrogen at times when the renewable production exceeds grid export capacity avoiding curtailment of wind and solar energy, especially with hydrogen infrastructures (transport and/or storage) available.

Electrolysers can also serve as variable load, following signals from electricity transmission system operators to provide frequency reserves such as FCR or as a FRR, voltage control and even synthetic inertia, as today other technologies already offer (e.g. power generators, demand-response, battery storage). Some of these capabilities have been tested and demonstrated in various European projects.

In many countries however congestion is dealt with through bilateral contracts between the TSO and large power plants operators, limiting the access to other ‘’smaller’’ market players such as electrolysers operators and other forms of energy storage.

Today electrolysis (power-to-gas) is considered as energy storage in European legislation[9]. Storage systems are still today largely double-charged with electricity grid tariffs, when using and then re-injecting electricity in the grid. Even though this situation is improving, electrolysis requires more regulatory certainty on the conditions under which it can be considered a storage technology.

Solutions:

1. Value the congestion management potential of electrolyser and other resources also at local level, by developing competitive and open markets when possible or at least remunerating the service
2. Avoid double-charges for storage technologies and implement the European electricity directive by including electrolysis and underground hydrogen storage in the energy storage definition at national level, also in the context of the revision of the gas package at the end of 2021
3. Adapt pre-qualification rules to give electrolysers access to frequency response markets

[9] According to the Electricity directive Article 2 (59) ‘energy storage’ means, in the electricity system, deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier.

b) System flexibility without a hydrogen grid or storage infrastructure

Large hydrogen consumers such as refineries and ammonia production plants rely on an almost constant 24/7 hydrogen supply. For such use cases the electrolysers would ideally connect directly to a hydrogen grid and/or to a hydrogen storage site The storage capacity of an integrated storage infrastructure would provide the H2 production full flexibility in their operations profile. But underground storage sites (e.g. salt caverns) are not available everywhere.

Without a hydrogen grid and/or hydrogen underground storage infrastructure, alternative storage technologies are required to avoid stress to the grid and limit the resulting costs to society. The first option is hydrogen storage tanks and over dimensioning the electrolyser. The second and probably cheaper option could be to build electricity storage and over dimension the contracted renewable production. This option can deliver additional benefits in terms of grid services and flexibility to the grid but the technologies today (batteries) present important size limitations for 100MW+ loads.

Solutions:

1. Ensure all Member State implement European legislation with regards to the use of electric storage at grid level. This should include clear rule on how electric storage could provide grid services (FCR and FRR reserves, voltage control, etc.)
2. Explicitly recognize the role of electrical storage in RED2 as a means of complying with time correlation requirements for renewable hydrogen production (through the delegated act)

3. Integrated Infrastructure Development

A prosperous but carbon neutral Europe will see additional demand for energy transport and energy storage. A system dominated by renewable energy cannot always generate carbon-neutral energy in the same moment and at the same location where it will be used. Additional means to transport and store energy will broaden Europe's options for a successful, cost-efficient transition to carbon neutrality. Therefore, an important part of the solution will be a well thought-through infrastructure for clean hydrogen that is planned and optimized in coordination with other energy infrastructures and that appropriately considers the evolution of different generation and demand options.

The conversion of existing natural gas grids to hydrogen grids is a good opportunity to early develop an interconnected-hydrogen system and should be evaluated for each specific case. Repurposing existing underground gas storage sites such as salt caverns also offer opportunities for future hydrogen storage systems, allowing to store energy for longer time periods and offering the power system a great amount of flexibility. When repurposing gas infrastructure, some challenges need to be addressed. First, the initial low demand for the renewable and low carbon hydrogen will affect the economics of operating the new infrastructure. Secondly, different hydrogen users will require different levels of hydrogen purity. These are affected by the hydrogen production technology and the transport and storage solutions.

In some cases, blending might provide a transitional solution for some industrial users and grid operators within specific distribution grids, although its emission reduction potential is limited[10] and it is not free of technical and regulatory challenges both for the end-users and the grid operators.

Tamper-proof tracing technologies must also be part of the future hydrogen infrastructure. The tracing technology should trace the renewable origin and/or the CO_2 footprint of low carbon hydrogen (and their derivatives) across the entire value chain covering all sectors, conversion steps and final products. This transparency is very important for the acceptability of off-takers

In many cases the development of renewable and low carbon hydrogen production and application will start in local or regional clusters where, for instance demand for hydrogen is already existing (e.g. chemicals) and where hydrogen generation is available. An immediate start in these clusters will kick-start necessary technologies and application scale. However, this requires sufficient renewable potential in their proximity or sufficient electricity transport capacity from renewable production centers to the clusters. These clusters will grow, and they will be better connected as the demand for hydrogen grows.

A transport and storage infrastructure for hydrogen connecting renewable electricity generation with consumption/clusters will be an important option because of the following reasons:

- Also regions far away from renewable resources need access to decarbonized energies.
- Hydrogen grids with large underground hydrogen storage can allow for seasonal storage of renewable energy
- Hydrogen grids allow imports of renewable and low carbon hydrogen from within and outside the EU.
- Fluctuations in hydrogen production and demand needs to be balanced between different regions and over time
- A competitive European market for hydrogen can only be developed based on an interconnected network that also provides security of supply by giving access to multiple supply sources
- When the energy will be needed in the form of hydrogen anyhow, e.g. for the decarbonisation of hard-to-abate applications within sectors where direct electrification is neither technical possible/feasible or cost-efficient, hydrogen grids will be able to directly supply consumer needs (thus avoiding further reconversion between energy carriers).

If energy consumption is to be transitioned from today's usage of fossil fuels to renewable hydrogen – in particular for those hard-to-abate sectors – there is one central question:

> *Is it more cost-efficient to transport and store the energy in form of electrons from the wind and solar generation to the centers of demand and convert it there into hydrogen, or is it more cost-efficient to convert electricity to hydrogen close to the sources of wind and sun and to transport and store it then via a dedicated hydrogen network to the centers of demand?*

There are strong indications that the infrastructure for the transport of a certain amount of energy in the form of hydrogen can be five to ten times cheaper than the infrastructure for the same amount of energy

[10] *Carbon-free steel production: Cost reduction options and usage of existing gas infrastructure. Source: European Parliamentary Research Service, April 2021*

in the form of electrons if the off taker uses the hydrogen directly. This changes if the molecule is reconverted into heat or electricity due to additional reconversion losses. Evidence also suggests that the costs for repurposing an existing methane pipeline to hydrogen are generally estimated to represent only 10 – 25 % of the costs of a comparable newly constructed hydrogen pipeline. It could be done faster and will create less public acceptance issues.

We strongly recommend setting up and integrated infrastructure planning process based on enhanced coordination between electricity, gas, district heating and hydrogen sectors to develop a cost-efficient, secure energy system that will enable carbon-neutrality on time. This cooperation will ensure a consistent picture of possible futures scenarios developed by different sectors, accounting for diverse types of energy generation and consumption over time and over space.

We also recommend developing a European vision and planning process for development of underground hydrogen storage sites at locations that have the technical potential (e.g. salt carvers) and that can provide a positive contribution to the overall energy system optimisation.

First hydrogen infrastructure investments e.g. in hydrogen clusters should be planned in a way that enables the integration of different demand and hydrogen clusters to an overarching meshed hydrogen grid later. The necessary anticipatory investments should be made possible.

The role of existing gas TSOs and DSO in developing the European future hydrogen grid – with respect to the framework for repurposing the existing natural gas infrastructure to hydrogen – should be timely clarified.

6. Report of the Roundtable Buildings[11]

The Buildings Roundtable has focused on the barriers and mitigation measures below.

i. Market

Barriers	Mitigation measures
• Pathway to clean H2 not clear to consumers • Lack of sufficiently strong CO2 price • Low synchronization btw. a) sourcing of green H2, b) investments in H2-ready infrastructure and c) investments in H2-ready end-use equipment	• Create incentives for consumers to switch to green appliances, e.g. by means of fiscal incentives • Strengthen CO2 pricing mechanisms[12] • Synchronize end users with H2 production, transmission & distribution

ii. Regulation

Barriers	Mitigation measures
• Limited technological openness ("electrification only") • Little consumer awareness of H2-readiness of end-use appliances, weakening consumers' demand for H2-ready technologies • Gas appliance regulation not yet adapted to use of H2 (standardization & certification) • Lack of a wholistic systems approach to buildings, with respect to heat and power self-consumption and production. • Complex and costly power grid connection for cogeneration systems	• Allow for technological openness & mix of different technologies in buildings (incl. electric heat pumps, H2 boilers, hybrids, fuel cells etc.) • Establish EU targets for production & distribution of decarbonized and renewable gases as part of RED III • Revise eco-design & energy labelling ➢ From 2025 onwards, appliances should be technically able to work with blends of up to 20% (2029: 100%)

[11] The mitigation measures of this report are not supported by EEB and ECOS due to different perspectives on the future development of the buildings part of the value chain.

[12] SPP- distribucia flagged the need to address the social impact of a CO2 pricing system for buildings via adequate fiscal incentives policies.

• Missing incentives for buildings to contribute towards power system resiliency, via grid tariffs, access to VPPs, support for self-consumption	➢ Energy label should show what equipment is ready to use H2 by means of a pictogram (as of 2023) • Adapt gas appliance regulation to particularities of H2

iii. Funding and financing

Barriers	Mitigation measures
• Insecure funding and financing environment due to weak policy signals in favour of H2 in buildings • Public Funding biased towards other technologies better known to policymakers	• Promote building technologies as H2-ready to attract positive funding and financing, incl. state aid • Allocate funding to broad range of technologies, incl. end use applications such as H2-ready appliances / appliances operating with blends • Move from CAPEX to OPEX support to close cost gap of using green H2

iv. Technology

Barriers	Mitigation measures
• Low awareness that heating technologies are H2-ready • Certification and standardization processes for H2-ready technologies time consuming and not yet finalized	• Raise awareness that sector is ready for large-scale demonstration projects and commercialization, focus on technology use, cost reduction and efficiency improvements

v. Supply chain

Barriers	Mitigation measures
• Low synchronization btw. a) sourcing of green H2, b) investments in H2-ready infrastructure and c) investments in H2-ready end-use equipment • Limited focus on Europe • Challenge to upskill and reskill installers profiles to new needs	• Synchronize end users with H2 production, transmission, and distribution • Build up secure and robust European and global supply chains and import infrastructures • Invest in reskilling and upskilling of workforce

vi. Others: barriers related to the hydrogen supply chain tackled in the scope of other Alliance Roundtables

The members of the Roundtable "Buildings" mentioned the following as bottlenecks which impact the building sector. As these are tackled by the work of other Roundtables of the Clean H2 Alliance, this group refers them to those Roundtables.

Barriers	Mitigation measures
• Strong focus on production and use of green H2, e.g. in EU taxonomy • Low regulatory incentives for repurposing and retrofitting of gas infrastructure • Uncertainty about future H2 volumes, costs, and prices • Too narrow focus on EU market	• Define low carbon H2 as taxonomy-aligned • Support end use applications regardless of which "colour" of H2 is used, at least for transitional period until large volumes of green H2 become available • Use revision of EU Gas Directive and EU Gas Regulation to incentivise repurposing and retrofitting of existing gas infrastructure • Create favourable investment environment for electrolysers (e.g. by lowering energy-related taxes & levies) • Develop EU import strategy for green H2 to increase availability

IV. CONCLUSION

The adoption of the Fit for 55 Package on July 14th, has marked another milestone in the decarbonization of the EU economy, and the role that hydrogen, and in particular renewable hydrogen will play. While the *detailed assessment of the proposals is still ongoing by the members of the roundtables, the reports* compiled in this document and the related inputs received during the Alliance project collection can provide a valuable reference framework for this analysis and the continuation of the discussions with the EU and national decision makers in the final quarter of the year 2021, including in view of the upcoming gas package.

Beyond the regulatory framework, though tightly linked to it, discussions are also expected to accelerate in the Roundtables concerning the access to EU and national funding as well as financing. The opportunities flagged by the Funding Compass of the Alliance, presented in the June Hydrogen Forum, will be further analysed against the Roundtables hydrogen deployment needs. The specific technological bottlenecks raised in the reports will also be addressed with timely discussions with the new Clean Hydrogen Joint Undertaking to optimize synergies between the EU support to hydrogen research and innovation activities and the Alliance scale up projects.

Additional exchanges with public and private banking institutions are also expected to provide substantial guidance on the key bankability considerations that potential lenders are likely to take into account, how risky they evaluate the barriers identified by the Roundtables and the potential delays in the needed investments.

These works should close the first-year contributions of the six Roundtables on the enabling conditions of the Alliance project pipeline. As the project pipeline has been thought to be an evolutive tool that embeds investment projects as they develop, the related debate concerning the bottlenecks and mitigation measures is expected to pursue and remain extremely relevant in the coming years, at least until the new regulatory framework for hydrogen is settled.

V. ANNEXES

Annex 1 - Mobility Roundtable Roadmap
Annex 2 - Buildings Roundtable CEOs Statement

ANNEX 1- Shared roadmap perspective of the Mobility Roundtable[13]

The common vision of the development of the ecosystem in all transport modes and the number of applications to be in place (demand side), should provide clear indication for the supply side (production and distribution) of the value chain, what amount of hydrogen will be requested and demanded in the transport sector and help to define priority areas throughout the foreseen decades, where hydrogen use should be incentivized and used.

A critical pre-requisite is to reduce cost of hydrogen for the final consumer (task of the other RT, especially production). In order to reach a customer acceptance and price attractiveness, an ambitious target of €5/kg@2024 and €3/kg@2030 is set for the green hydrogen (5th class/99.999%) pump cost, which would require significant regulatory push and full exploitation of economies of scale.

The table below summarizes the outlook that industry considers realistic under current policy framework and technology development (baseline development without considering additional policy incentives aggregating EU-wide use of hydrogen applications in different transport modes):

While an increase of the market share of FC vehicles is expected across all modes, the current deployment speed remains insufficient to match with the EU ambitions in terms of CO2 emission reduction, particularly when considering the objective of *"Scheduled collective travel under 500 km should be carbon-neutral by 2030 within the EU"* as put forward by the Smart & Sustainable Mobility Strategy in December 2020.

What	2021-2025	Milestone 1	Milestone 2
Cars[14] 2-3 wheelers	10,000/year	2027: 100,000/year	2030: 750.000/year (5% share new vehicles)
City and interurban buses (Type I and type II) and coaches	>1,000 in operation (including interurban buses) >500 coaches	2027: >5,000 in operation (including interurban buses) > 2000 coaches	2030: 15,000 buses 1000 FC coaches
Trucks[15]	>500	2026: 10,000	2030: 10,000/year
Off-Highway Mining trucks: Construction: Agriculture:	 2025: 10 demos >500 >100	 2027: >50 2027: >2,000 2027: >250	 2030: 100/year 2030: 10,000/year 2030: 2,000/year
Trains (in service or ordered)	2025: >100	2027: >200	2030: >1,000

[13] *This document is not supported by T&E due to different perspective on the future development of the mobility part of the value chain. The different views were not bridged during number of meetings.*

[14] *Based on the CO2 LDV Regulation requirements and benchmarks. In line with the COM estimates of at least 30 million ZEVs in operation by 2030 (source: Smart & Sustainable Mobility Strategy (SSMS)) as well as ACEA estimates and Hydrogen Europe Technology roadmaps (https://www.hydrogeneurope.eu/sites/default/files/20200703%20Final%20Draft%20updated%20SRIA%20HE-HER.pdf)*

[15] *Based on ACEA estimates to meet CO2 HDV Regulation requirements – around 200.000 ZEV HDV (>16t GVW) in operation in 2030*

Small ships (≤5000 GT)	15 demos, 16 in service or ordered	2027: 100 in service or ordered	2030: >150
Larger vessels (>5000 GT)	First demos	First prototypal vessels 2027: 10 demos on active routes	2030: 50 Scale up after 2030
Aviation	Demonstrators (e.g. Cessna/Pipistrel size pilots, possible eVTOL (1-2 person)	Shortly before 2030 – in-flight demonstrations and frequent pilot regional routes (<500 km)	Post 2030: 10-20 aircraft/year (<20seater) sold for regional lines By 2035: large commercial aircraft (>100 seats) 2035: commercial transport aircraft
Required:			
Hydrogen refuelling stations (HRS) for road transport	Continued expansion of public HRS networks (for LDV, HDV and buses), if possible multi-purpose HRS	2025: 1500	2030: 3700 public[17]
HRS for rail	5 to 10	>15	>50
Ports and airports as hydrogen and e-fuel hubs	Demonstrators (2-3 pilots)	Ports 2027: 5018 ports featuring hydrogen or e-fuel supply to ships/vessels Airports 2025: 10 airports featuring hydrogen or e-fuel supply to air crafts Pilot GH2 and LH2 dispensers for small aircraft	Ports 2030: 100 Airports 2030: 50 2035: LH2 refuelling infrastructure at airports
Feedstock			
LH2	Development of a performing liquefaction technology – first industrialisation 2025	Industrialisation of liquefaction technology – industrialisation by 2030	~3.5 Mt/y are estimated in 2035
E-fuels	Production system maturation and ramp-up	Aviation: 0,5% e-fuel in 2025	Aviation: 2,5% e-fuel in 2030

With respect to the technology development and cost reduction:

i) **Passenger cars**: Today, components of the fuel cell vehicle, such as the fuel cell, hydrogen tank and battery, account for about half of the vehicle's TCO, while hydrogen fuel accounts for roughly 25 % of

[16] According to Flexens sector analysis, in the beginning of 2021 in Europe, the first two passenger ships (≤5000 GT) using hydrogen as the main power source in fuel cells are under construction in Norwegian projects: MF Hydra and MF Hidle. Several investment projects on small ships and at least one on large vessel (DFDS project in Denmark, >5000 GT) are under preparation. Several ICE suppliers are also developing hydrogen, ammonia, or methanol compatible ICEs. Earlier hydrogen use has been demonstrated in boats and as an auxiliary fuel in ships.

[17] https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

[18] According to Flexens market analysis, in the beginning of 2021, hydrogen and e-fuel supply is being planned to numerous European ports along maritime hydrogen projects and hydrogen valley projects. Ports are expected to become hubs for the European hydrogen backbone and sea transport of hydrogen and e-fuels.

Estimate figures depending on the enabling conditions.

costs. By 2030, these components are expected to make up approximately 30 % of the TCO and hydrogen fuel around 15 %, and the overall TCO to drop by up to 50 %. The key cost reduction factors include the cost reduction in the fuel cell powertrain and of hydrogen supplied at the pump, accounting for more than 90 % of the cost reduction until 2030[19].
With an annual production volume of 200,000 vehicles, a decrease in the cost of the fuel cell system would be estimated at around 45 %, rising to as much as 70 % with an annual production of 600,000 vehicles. A cost decrease of approximately 55 % for the hydrogen tanks is projected at global production of 600,000 vehicles per year.

ii) **Trucks**: The majority of the cost reductions from 2020 to 2030 will result mainly from cuts in hydrogen fuel cost, which will account for about 80 % of the TCO reduction for MDT and HDT, and roughly 60 % for the LCV[20]. This follows a cost reduction of about 50 % for hydrogen delivered – from approximately EUR 7 to 10 per kg in 2020 to about EUR 3-4 in 2030, assuming the large scale-up envisioned. A cost reduction of roughly 70 to 80 % for the fuel cells would be possible given an annual production volume of 150,000 vehicles.

iii) **Buses**: For coaches, the cost is divided due to the larger motor and higher total fuel usage: the powertrain accounts for about 12 % and fuel approximately 40 %. The lower cost of equipment is the other major cost-reduction driver. Reaching 2,500 vehicles per year will cause fuel cell costs to decline by roughly 65 % to about EUR 80 to 100 per kW[21]. A further production increase to 20,000 vehicles annually will yield additional cost improvements of around 30 %. This will lead to a total fuel cell cost reduction of about 80 % in total compared to 2020 levels.

iv) **Off-road vehicles**: Non-road mobile machinery for Construction, Agriculture, Mining but also Trains and Ships are likely to adopt fuel cell technology from on-highway applications, esp. trucks. In the long run, attractivity and willingness to adopt hydrogen fuelled propulsion will depend on scale achieved in fuel cell production or availability of h2 engines. Cost of hydrogen, too, are decisive as they represent up to 30-40 % in the case of Mining trucks.

v) **Trains:** Today the fuel cell system accounts only for about 3 to 5 % of the train TCO, equivalent to 10 to 15 % of the train purchasing cost. Cost improvements in these components and sub-systems should target to bring the combined cost share of the fuel cell system and tanks to approximately 2 to 4 % of the RS cost: a decline of about 70 %. Significant cost improvements are also required and anticipated for the infrastructure part (refuelling stations), but the main driver to improve the TCO of fuel cell trains will be the decrease in the cost of green H2. Fuel costs present the biggest single position within TCO, making it especially important to achieve near diesel-parity quickly.

vi) **Airplanes**: There are two axes of development: hydrogen-based synfuel and hydrogen-powered aircraft.

a. There are three main cost drivers of hydrogen-based synfuel. The first and most important cost

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[19] https://www.fch.europa.eu/sites/default/files/FCH%20Docs/201211%20FCH%20HDT%20-%20Study%20Report_final_vs.pdf
[20] https://www.hydrogeneurope.eu/sites/default/files/20200703%20Final%20Draft%20updated%20SRIA%20HE-HER.pdf
[21] https://www.fch.europa.eu/sites/default/files/FCH%20Docs/201211%20FCH%20HDT%20-%20Study%20Report_final_vs.pdf

driver is the cost of hydrogen feedstock. Carbon feedstock is the second important cost driver and the cost depends greatly on the source of carbon. According to some estimates, the carbon feedstock from industry processes based on fossil fuels or biomass is estimated to cost EUR 25 per ton of carbon. The cost of direct air capture is expected to decline, also depending on the cost of renewable electricity available. Depending on the technology maturity, according to some estimates could fall below EUR 100 per ton of carbon[22]. The third important cost element is the fuel synthesis plant itself; a cost-reduction potential of about 40 % is estimated for the plant itself from 2020 to 2030 due to scaling up plant capacity.

b. A major cost driver for hydrogen airplanes (fuel-cell or hydrogen combustion-based) will be the on-board LH2 storage tanks and the hydrogen distribution system. Cost reductions on these items can only be expected when liquid hydrogen becomes common on-board vehicles, so around 2030. The other major cost driver is hydrogen production and liquefaction, as well as the build-up of the necessary airport infrastructure.

vii) **Ships**: - technological challenges for small and large vessels are relevant to safety control as well as the storage and power generation systems, aiming to increase the volumetric efficiency of the innovative systems.

The increase of nominal power for fuel-cell-based power generation systems must reach the required levels of large vessels (>30MW), whilst solving technical and safety challenges for their installation onboard. Scalability of high-power fuel cell systems and large capacity storages must lead to significant cost reductions. Due to the high importance of fuel for the ship operator TCO, the majority of the cost reductions are driven by lower-cost hydrogen fuel, accounting for more than 90 % of the reduction in costs until 2030. To meet demand in both short-sea and deep-sea shipping, an extensive network of marine ports supplying hydrogen and e-fuels efficiently must be developed.

Commercial shipping, need additional incentives to be able to switch away from Diesel which is currently e.g. in Germany being procured exempt from Energy tax, e.g. 56 ct/l below regular pump prices. At the same time, fuel costs already represent high share of TCO. Switch to Hydrogen at current price level is prohibitive and even above stated target cost of 3€/kg H2 would still represent a huge burden on an industry that faces intense international competition. Within non-commercial shipping, e.g., chartered yachts enjoy similar tax breaks on Diesel, but have lower operating hours thus lower overall weight of fuel costs which could lead to an earlier adoption of new technologies such as hydrogen powered fuel cells and engines.

[22] *Other sources provide much broader range of the estimated costs: https://www.transportenvironment.org/sites/te/files/publications/2020_Report_RES_to_decarbonise_transport_in_EU.pdf.*

ANNEX 2 - The views of the Buildings Roundtable' CEOs - A Statement of the European Clean Hydrogen Alliance corporate members (26/03/2021)[23]

- We, the undersigned CEOs of European companies covering local energy companies and system providers, heating, and cogeneration technology manufacturers as well as district heating providers, members of the European Clean Hydrogen Alliance Roundtable for Buildings, are fully committed to the climate neutrality goals of the EU for 2050;

- As stressed by the Commission in the Renovation Wave Strategy, buildings are a hard to-abate sector and require urgent and significant efforts. We believe that market transformation towards carbon-neutral buildings will be a challenging but fundamental step to reduce CO2 emissions to the level required in time for 2050 and to successfully enable a European hydrogen economy;

- An integrated energy system approach is needed to cut emissions from buildings in the short time-scale available, which means renewable and defossilised gases, including hydrogen should work alongside electricity, as complementary and necessary components of a cost-optimal defossilisation of buildings, bedded in an efficient and resilient energy system;

- We provide the technologies, know-how and infrastructure that can support the development and ramp up of clean hydrogen for buildings; our technologies are ready for hydrogen; hydrogen in buildings - including via blends in the existing grids, will provide a stable demand - hence security to scale up investments in the early phase of the hydrogen economy;

- We should anticipate the transition of the gas mix up to 2050; the sooner we synchronise end-use with hydrogen production, transmission, and distribution, the lower the costs will be;

- This is why we joined the Clean Hydrogen Alliance initiated by the European Commission and why we strongly support its goals for a climate neutral world. Today, we commit to making the investments necessary via a pipeline of projects to ramp up the use of clean hydrogen technologies and make buildings contribute towards a net-zero emissions economy by 2050.

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[23] *This statement reflects the views of the CEOs of the industry stakeholders members of the Buildings Roundtable.*