Expert Paper

Enablers for investing in hydrogen in Europe

November 2021

Table of Contents

1. Key messages

i. **Renewable and low-carbon hydrogen can help decarbonise sectors where direct electrification is hard to achieve.**
The EU's strategic objective to install at least 6 GW of electrolysers in the EU by 2024, producing up to 1 Mt of renewable hydrogen and 40 GW by 2030 producing up to 10 Mt[1], is welcomed. Achieving this goal requires a cumulative investment of between €320 and 458 billion by 2030. These figures do not include any additional investment required for upgrading downstream installations.
As stated in the EU Hydrogen Strategy, other forms of low-carbon hydrogen are needed in the short and medium term, mainly to cut emissions from existing hydrogen production quickly and support the parallel and future uptake of renewable hydrogen. We need clear definitions for both renewable and low-carbon hydrogen (e.g. within the EU Gas & Hydrogen Decarbonisation package).

ii. **Stimulate demand for renewable hydrogen with balanced policies that mix incentives and mandates.**
Measures to increase renewable hydrogen use in industry – as proposed by the 'Fit for 55' package – are steps in the right direction, if the availability of renewable energy sources (RES), abatement cost gaps and flexibility to apply the most efficient CO_2 reduction options are considered.
The upcoming Gas & Hydrogen Decarbonisation package should contain the right enablers for low-carbon hydrogen, compatible with the EU's carbon neutrality goal and the 'do no significant harm' principle.

iii. **If there are insufficient renewable hydrogen supplies, all forms of low-carbon hydrogen production must be incentivised for a short to medium-term transitional period.** As long as they are compatible with the 'do no significant harm' principle, all forms of hydrogen production should be backed ahead of any strong uptake of renewable hydrogen to achieve decarbonisation pathways and reach climate neutrality in the EU.

iv. **Predictable carbon prices support the business case for hydrogen.** Volatile carbon prices can cause risk-averse investors to forego investments in clean solutions. Carbon contracts for difference (CCfDs) should be promoted.

v. **We need access to renewable energy at a competitive price**. EU Member States should update their national energy and climate plans to cover any additional demand for RES stemming from the uptake of hydrogen. They should remove any construction and licensing barriers to renewable energy buildout, and cut taxes and levies on electricity to enable direct and indirect electrification. Companies need access to the right tools to prove that they use renewable energy to produce hydrogen. The guarantees of origin (GOs) scheme is a good start and must be further harmonised in combination with Power Purchasing Agreements (PPAs) while ensuring credible traceability.
Take a pragmatic approach on criteria to prove 'additionality', geographical and time correlation, while respecting the energy system's overall efficiency.

vi. **We need time-limited incentives for industrial-scale integrated hydrogen pilot projects; local, decentralised hydrogen production; and associated infrastructure, including CO_2 transportation and storage.**
The cost of low carbon and renewable hydrogen is currently well above the fossil-based hydrogen benchmark cost. Financial and government support for CAPEX and OPEX will be critical to bring these technologies to scale, reduce costs

1 EU Hydrogen Strategy (2020)

and enable commercial deployment, as well as competitive technologies for export. Correlate any financial support with the CO_2 emissions reduction potential of a project.

vii. **We need to foster the development of European partnerships and co-operation between the public and private sector (PPP)** and join forces to define an appropriate regulatory framework, including standards.

viii. **We need public support for R&D and innovation in hydrogen technologies**, combined with talent and skills to make European companies global technology leaders in hydrogen.

ix. **We need an infrastructure and an enabling regulatory framework in Europe to transport and trade both electricity and hydrogen**, building up capacity in a pragmatic and progressive way, depending on the expected evolution of demand.

x. **We need a well-functioning cross-border hydrogen market with a harmonised system of guarantees of origin and foster partnerships with non-EU countries in the mid-to long term**, to guarantee stable access to sufficient renewable and low carbon hydrogen.

xi. **We should look at sector-specific triggers to make the business case for hydrogen** as each sector's needs and potential is different. Several ERT Member companies are taking the lead and are integrating hydrogen applications in their business.

In this paper, the various hydrogen production routes are defined in line with the European Commission's Communication "*A hydrogen strategy for a climate-neutral Europe*"[2].

2 COM(2020)301 – p3 and p4:
'Electricity-based hydrogen' refers to hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), regardless of the electricity source. (...) 'Renewable hydrogen' is hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources. (...)
'Fossil-based hydrogen' refers to hydrogen produced through a variety of processes using fossil fuels as feedstock, mainly the reforming of natural gas or the gasification of coal. (...)
'Fossil-based hydrogen with carbon capture' is a subpart of fossil-based hydrogen, but where greenhouse gases emitted as part of the hydrogen production process are captured. (...)
'Low-carbon hydrogen' encompasses fossil-based hydrogen with carbon capture and electricity-based hydrogen, with significantly reduced full life-cycle greenhouse gas emissions compared to existing hydrogen production.

2. Facts & figures on hydrogen in Europe

Alongside other solutions, hydrogen can contribute to the decarbonisation of both the energy system and various industrial and transport applications. For this to happen, the world needs to cut energy-related CO_2 emissions by 60% until 2050. Hydrogen can play seven major roles in this transformation. In 18 applications in the industry, transportation (heavy-duty mobility) and heating sectors, hydrogen could become the most competitive low-carbon solution in 2030[3].

Today, hydrogen is mainly used as feedstock in industrial processes, mostly in refining and ammonia production (see graph below). Hydrogen represents less than 2% of the EU's energy consumption. In the European Commission's projections, the share of hydrogen in Europe's energy mix will grow to 13-14% by 2050. Considering hydrogen consumption for energy purposes only, the shares in different scenarios range from less than 2% to more than 23% in 2050.

Share of total demand (8.3 Mt) for hydrogen in 2018[4]	
Refinery	45%
Ammonia	34%
Methanol	5%
Other chemicals	7%
Energy	1%
Other	8%
Transport	0%

Annual hydrogen production capacity stood at 9.9 Mt[5] in 2018, with most, around 7.5 Mt, produced on-site as direct feedstock (captive production). Hydrogen production capacity for sales represents only 1.7 million tonnes. Both hydrogen exports and imports are negligible.

Steam Methane Reforming (SMR) is the main production process and more than 90% of the EU's generation capacity uses fossil fuels, mainly natural gas (see graph below). Only two production plants in the EU had carbon capture technology installed in 2018.

The European Union's total installed capacity of electrolysers is around 1 GW[6], representing around 1.6% of total generation capacity.

Hydrogen generation capacity by technology	
Fossil hydrogen	90.6%
Electricity mix electrolysis	1.6%
Renewable hydrogen	0.1%
Low-carbon hydrogen (CCS)	0.7%
By-product	7.1%

Today's hydrogen production creates substantial carbon emissions: production via steam methane reforming, causes 9-10 tonnes of CO_2 per tonne of hydrogen. Globally around 1% of the anthropogenic GHG emissions are caused by hydrogen production.

The production cost of renewable hydrogen is at present far higher than fossil-based hydrogen – and producing hydrogen with carbon capture and storage is slightly more expensive[7]. There is no clear consensus on how relative competitiveness will evolve. Some[8] argue that carbon prices in the range of €55-90/tonne of CO_2 are needed to make fossil-based hydrogen with carbon capture competitive with fossil-based hydrogen, while renewable hydrogen

3 Study "Path to hydrogen competitiveness", from the Hydrogen Council (2020). The seven roles of H_2 are 1- enabling large-scale renewable energy integration and power generation; 2- distributing energy across sectors and regions; 3- acting as a buffer to increase energy system resilience; 4- decarbonising transportation; 5- decarbonising industrial energy use; 6- helping to decarbonise building heat and power and 7- providing clean feedstock for industry
4 Hydrogen Europe (2020), Clean Hydrogen Monitor 2020 – The figures cover the European Economic Area (the EU-27 plus the UK, Norway, Switzerland and Iceland).
5 Excluding by-product hydrogen, generated as part of coke oven gas (COG)
6 Joint Research Centre (JRC), K. Kanellopoulos y H. Blanco Reano (2019), The potential role of H_2 production in a sustainable future power system, p8
7 Agora Energiewende (2021), Making renewable hydrogen cost-competitive, p11
8 COM(2020) 301 – p4

technologies would need CO_2 prices of around €300/tonne in 2030 to reach the break-even threshold. Others[9] say that by 2030 renewable hydrogen will outcompete fossil-based hydrogen with carbon capture in most major markets, and even fossil-based hydrogen in many markets.

The European Union is committed to developing hydrogen for sectors and processes that struggle to cut carbon emissions through direct electrification. The EU's priority is to develop renewable hydrogen. It hopes to install at least 6 GW of electrolysers by 2024 producing up to 1 Mt of renewable hydrogen and 40 GW by 2030 producing up to 10 Mt,[10] which nearly equals all currently existing hydrogen production capacity and is 40 times currently installed electrolyser capacity. Meeting these targets would mean a cumulative investment of €320 to 458 billion by 2030. These figures do not include the additional investment needed to upgrade downstream installations. In the short and medium-term, the European Commission acknowledges that other forms of low-carbon hydrogen, compatible with the 'do no significant harm' principle, are needed, mainly to slash emissions from existing hydrogen production and support the parallel and future uptake of renewable hydrogen.

9 BloombergNEF (2021), Green hydrogen to outcompete blue by 2030
10 EU Hydrogen Strategy (2020)

3. Enablers for the uptake of a hydrogen economy

3.1 A predictable framework

1. Ensure a predictable carbon price

The EU ETS (Emissions Trading System) can play a supportive role in ensuring carbon price stability for clean investment. The EU can make the investment case for low-carbon hydrogen applications by gradually integrating carbon costs in the price of products, solutions and services, regardless of their origin (EU produced or imported). They would become more competitive. However, appropriate measures must be in place to address any risk of carbon leakage.

Carbon price volatility can cause risk-averse investors to forego clean investment. Instruments, like the Market Stability Reserve, have a role to play.

Carbon Contracts for Difference (CCfDs) should be further promoted: they can help close the economic gap between various low-carbon solutions.

2. Ensure access to additional renewable energy for all industry sectors

Member States should update their national energy and climate plans to cover any additional demand for RES to support uptake of hydrogen, removing the construction and permit barriers for renewable energy buildout.

Companies must have access to the right tools to prove that they use renewable energy to produce hydrogen. The guarantees of origin (GOs) scheme is a good start and must be further harmonised – in combination with Power Purchasing Agreements (PPAs) – while ensuring credible traceability.

The EU should take a pragmatic approach in establishing criteria to prove 'additionality', geographical and time correlation. It should also respect the energy system's overall efficiency and avoid any undesired rise in the power system's emissions. It should tackle the principle of additionality in the Renewable Energy Directive (RED II) and the requirement to demonstrate correlation in time and geography between the generation of renewable energy and hydrogen production.

Setting unjustified criteria and/or exclude workable flexibilities can limit operating hours and lead to significantly higher investment costs that would widen the gap with fossil-based hydrogen.

Take account of the fact that RES development can be delayed by lengthy permitting processes and that it takes place not necessarily where industrial demand is located.

3. The EU should remain open to all forms of low carbon hydrogenand provide clear definitions, compatible with the EU's carbon neutrality goal and the do not significant harm principle.

While the central role of renewable hydrogen in the future energy system is clear, the European Commission should also clarify the role of low carbon hydrogen. As certain (energy intensive) industries need a constant supply of hydrogen, a framework and market tools must be ready to ensure an uninterrupted hydrogen supply. The definitions should be based on a lifecycle analysis and a robust GHG emissions methodology. Low carbon hydrogen has an important role to play here at least in the short to medium term and while respecting the 'do no significant harm' principle. Long-term clarity on the role of low carbon hydrogen would cut uncertainty related to investment decisions in technologies such as carbon capture and storage (CCS), which require time and high upfront costs.

3.2 Making the investment case

The cost of low carbon and renewable hydrogen is currently well above the fossil-based hydrogen benchmark cost. Financial and government support will be critical in bringing these technologies to scale, cutting costs and enabling commercial deployment.

To make the investment case for hydrogen, policymakers must:

1. **Provide time-limited incentives for industrial-scale integrated hydrogen pilot projects and associated infrastructure, including CO_2 transportation and storage.** These financial supports should be correlated to a project's potential to cut CO_2 emissions. Incentives could take various forms. For example:

    - Use the **Innovation Fund to support the large-scale demonstration** of pre-commercial technologies including hydrogen and CCS projects, provided they respect the 'do no significant harm' principle. Support from the Innovation Fund should be compatible with other forms of efficient and technology-specific subsidies and based on careful investments.

    - Raise **public funding for hydrogen projects** in line with Next Generation EU and the Multiannual Financial Framework (MFF) funding instruments (such as the Recovery and Resilience Facility, Horizon Europe, Connecting Europe Facility, InvestEU and the Just Transition Mechanism). We need more operating expenditure (OPEX) support, which can be more than 80% of the total cash cost, which should in any case ensure environmentally friendly operating decisions.

    - The **EU's State Aid Guidelines for Climate, Energy and Environmental Protection and Energy (CEEAG)** ensure that support mechanisms take account of the specific needs of renewable and low-carbon hydrogen. Moreover, the guidelines should be revised to cover wider CCS and hydrogen activities including hydrogen infrastructure repurposing, provided that both carbon lock-in is avoided and there are no barriers to deployment of cleaner solutions. The revision should ensure industries are fully compensated for indirect costs like higher power prices (the current rules allow for up to 75%) and provide the framework for new funding tools such as Carbon Contracts for Difference.

    - Funding programmes play an important role. The legal framework for Important Projects of Common European Interest (IPCEI) scheme for hydrogen should be created as soon as possible.

    - The **European Investment Bank (EIB)** and other public financing institutions will play an important supporting role for hydrogen projects. Their criteria for loans, investment and assistance should reflect the EU taxonomy, including the 'do not significant harm' principle.

    The EU should also **provide support for local, decentralised hydrogen production**. Local hydrogen production provides high efficiency by local system integration and can contribute to a fast ramp-up and availability of hydrogen due to lower investment risk and reduced transport costs. Furthermore, local participation and benefits will increase public acceptance.

2. **Take measures to close the cost gap,** we recommend that the EU:

    - **Reviews the Energy Taxation Directive, as proposed in the 'Fit for 55' package** to ensure that the European energy tax framework matches the required uptake of hydrogen. The review should not create undue obstacles for activities such as hydrogen storage and electricity supply to electrolysers.

    - **Takes measures to increase the reach of renewable electricity** including long term and coordinated planning of hydrogen demand and renewable electricity supply as well as anticipatory transmission and distribution build-out.

    - **Removes barriers related to construction and permitting needed for renewable**

energy buildout, and the associated grid expansion, which are the largest bottlenecks for substantial green hydrogen growth.

- **Eliminates any concept costs in electricity prices not directly related to supply.**
- **Take a pragmatic approach in setting criteria to prove 'additionality'**, geographical and time correlation, **while respecting the energy system's overall efficiency** (see point 3.1.2 above).
- **Scale-up electrolysers production** and increase the electrolysers' utilisation rate, which will dilute their unit investment cost (if electricity costs are maintained). The Path to Competitiveness study carried out by the Hydrogen Council foresees that scaling up to 70 GW of electrolysis will lead to electrolyser costs of less than US$400 (€342) per kW.

3.3 Research & Development

We need continuously improved innovative solutions to manage the wide range of possible applications of hydrogen (e.g. transport and industry systems) and the broad variety of technologies.

Performance, cost, durability and circularity are among the most often-cited technical barriers to the development of fuel cells and electrolysers.

- **Performance** - R&D focuses on developing ion-exchange membranes and electrocatalysts with enhanced efficiency and durability at reduced cost.
- **Cost** - PGMs (platinum group metals) are a large component of the cost, so R&D focuses on increasing the activity and utilization of current PGM-based electrocatalysts.
- **Durability** - R&D focuses on increasing the system lifetime in realistic operating conditions (impurities in the fuel and air, starting and stopping, freezing and thawing, humidity and load).
- **Circularity** – R&D focusses on reducing the net-need for critical raw materials (PGMs) by developing more performant electrocatalysts and recycling processes for metal recovery.

R&D in hydrogen technologies does not stop at fuel cells and electrolysers. It covers a breadth of topics, like hydrogen production, transport & storage, utilisation in transport, heating & industry. This diversity is developed in the Strategic Research & Innovation Agenda (SRIA) produced by Hydrogen Europe for the "Clean H_2 for Europe" IEP (Institutionalised EU Partnership) in Horizon Europe.

European companies can become technology leaders in the field with strong public support in Europe for R&D in hydrogen technologies, combined with the availability of talent and skills as well as pioneering work.

Going forward, we support the set-up and potential upscaling of:

- Horizon Europe's IEP to speed up development and deployment of clean hydrogen technologies.
- Non-IPCEI traditional schemes in Member States / Regions aiming at supporting lab R&D on clean hydrogen technologies (while encouraging cooperation).
- Initiatives aiming at connecting transnational R&D infrastructures and building new ones.
- European Clean Hydrogen Alliance and European Raw Materials Alliance aiming at de-risking and accelerating investments in capacities as well as tackling the issue of critical raw materials.
- International collaboration (such as Mission Innovation) ideally with teams in the EU and other countries working on the same common project.
- International collaboration (such as Mission Innovation) ideally with teams in EU & other countries working on a same common project.

3.4 International partnerships

The EU Hydrogen Strategy aims to develop an EU-based hydrogen value chain and maintain technology leadership within Europe. However, as highlighted in the EU Hydrogen Strategy, with a growing role of hydrogen in the European economy, part of the hydrogen supply could be imported from outside Europe to complement European production, especially in countries with limited options for cost-efficient domestic production.

One notable national example in this field is the German hydrogen strategy, which says imports will be needed because the domestic generation of green hydrogen is not enough to cover all new demand. The German government will develop tools to provide suppliers, consumers and investors in Germany and abroad with the security to plan ahead.

We recommend that the EU:

- **Ensures partnership with non-EU countries** in the mid-to-long term, prioritising geographic proximity and cost-competitiveness, aligned with EU climate and energy policy targets.

- **Develops a well-functioning cross-border hydrogen market** accompanying the evolution of the demand for renewable and low-carbon hydrogen, by means of a full set of new policies and co-operation instruments, [11] with markets playing a central role and it should harmonise the certification systems with shared definitions and methodologies. This will enable efficient investments in production and transport facilities to reach the EU's ambitious goals. Commercial, technical and environmental standards in line with the EU's own regulation must be developed to support this cross-border hydrogen market.

3.5 Timely planning and development of hydrogen infrastructure.

Infrastructure and an enabling regulatory framework in Europe should be developed to transport and trade both electricity and hydrogen in in a pragmatic and progressive approach, depending on the expected evolution of demand. We must leverage the extensive gas networks and retrofit or repurpose them to take hydrogen when there is a clear prospect of demand from sectors that need hydrogen to lower emissions. New pipelines would also be needed, especially in hydrogen clusters.

We need an optimised energy system that links all sectors, helps them decarbonise, and uses integrated planning across energy vectors (electricity, gas, hydrogen, heating) and network operators (transport and distribution). Joint scenario-building and planning can help design the most cost-effective decarbonisation pathways.

In the first phases, dedicated finance must be provided to support the development of hydrogen infrastructure.

We recommend:

- That Member States and transmission system operators (TSOs) develop a new approach to infrastructure planning that incorporates the energy system integration view for the sake of overall efficiency.

- That TSOs continue their studies on safety to determine to what extent blending could be an option in the short term for the hydrogen economy.

- Support pilot projects at TSO and DSO levels.

- That Member States coordinate their efforts, develop a hydrogen infrastructure and, if it is the case, make hydrogen blending compatible with cross-border flows.

- Policy frameworks are defined to facilitate a large-scale deployment e.g. clear and homogeneous permitting processes.

We also need to **develop European guidance on key principles for a market design framework for hydrogen to support the development of an integrated competitive internal EU market for hydrogen**. The revision of the Hydrogen and Decarbonised Gas package should be driven by the overarching EU climate neutrality objective and the Green Deal and closely coordinated with the other elements of the 'Fit for 55' package.

11 For example: the mutual recognition of hydrogen certificates between countries as well as alignment on the definitions of H_2.

4. Uptake of hydrogen: sector-specific enablers

4.1 Industry and the energy system

Nearly all current demand for hydrogen comes from industrial applications (see paragraph 2 above). Hydrogen is a building block for key chemicals, for example, ammonia (including for fertilisers). Oil refining is another large user of hydrogen today. Hydrogen is used here for hydrotreatment, to remove impurities; hydrocracking, to upgrade heavy crude oils; and, in smaller volumes, hydrogen also serves in biorefining.

The availability of renewable hydrogen is essential for several 'hard to abate' industrial sectors to achieve climate neutrality by 2050. For these applications, a baseload flow of hydrogen is required and thus also a steady (renewable) power input to produce hydrogen on-site (if no dedicated hydrogen infrastructure is in place). Excess renewable power, which would otherwise be curtailed, is insufficient.

Hydrogen can also help stabilise the electricity grid via power-to-gas in case of intermittent generation by renewables. Hydrogen offers flexibility; it can be injected in hydrogen or gas grids, to be consumed as molecules, stored, or reconverted back to electricity, e.g. through fuel cells or CCGTs[12]. In short, excess power from renewables can be used, thus avoiding curtailments. Obviously, this only happens during a very limited number of hours, and power-to-gas competes with other flexible options (like batteries, etc). Its future role in this respect will thus depend on its competitiveness vis-à-vis other options.

To help support these systems, governments could consider dedicating public funding to R&D, and small-scale storage pilot projects.

In addition to the key enablers described in previous chapters, we recommend that governments:

- **Prioritise the use of hydrogen for sectors where no alternatives exist.**
- **Ensure green power availability to enable on-site production of climate-friendly hydrogen** using renewable power at industrial sites where conventional methods like steam-reforming could be replaced.
- **Develop sector-specific measures and support schemes to incentivise the decarbonisation of existing hydrogen consumption**. For example, introduce a targeted financial support system for carbon-free production to bridge the gap of competitiveness till a price balance is reached.
- **Develop measures and support schemes to drive industrial demand for renewable and low carbon hydrogen**. For example, targets linked to support schemes, public procurement, voluntary green markets, demand-side mandates, etc. Mandates, subsidies and explicit carbon pricing should be complementary measures.
- **Implement a certification system for renewable and low-carbon hydrogen**. Other voluntary certification schemes could be envisaged for the sake of consumer disclosure.
- **Consider dedicating public funding to R&D, and small-scale storage demonstration projects.**
- **Consider a system of labelling for products using renewable/low carbon hydrogen** e.g. green steel, green chemicals.

12 CCGT – Combined Cycle Gas Turbine

4.2 Transport and mobility

4.2.1 Road Transport

Transport represents almost a quarter of Europe's greenhouse gas emissions with road transport alone accounting for about 70% of these. The transport sector is also the backbone of major industries providing jobs and economic growth, so traffic volumes are expected to grow. Decarbonising transport is thus vital.

To decarbonise the transport sector, a two-fold approach will be needed: direct electrification using lithium ion batteries (or new chemistries to come), while for specific mobility segments and use cases (e.g. long haul heavy transport with electric charging limitations), hydrogen-based mobility using fuel cell technology will be needed.

For light-duty vehicles, a steadily falling price of lithium-ion batteries will bring the cost of electric vehicles down and allow them to compete with combustion engine vehicles. Moreover, the energy density of lithium-ion batteries keeps rising, allowing for higher mobility range and faster market uptake. The challenge of recharging time is also being tackled with solid-state batteries looming on the horizon.

For heavy-duty vehicles, such as buses and trucks, which require a long mobility range and have charging limitations (i.e. optimised usable space and fast refuelling), both electric vehicles and fuel cell technology will be relevant. In Europe, the first hydrogen fuel-cell vehicles are already being rolled out and some sources estimate that their number could increase significantly, with at least 60,000 trucks expected to be operational by 2030.[13]

In other mobility segments such as ships and planes, it is unclear if they can be electrified, and several technology options are being trialled: batteries, fuel cells, synthetic fuels or biofuels.

To unleash the full potential of hydrogen for road transport, Europe must:

- **Accelerate the development of hydrogen refuelling infrastructure.** Hydrogen infrastructure is still being built too slowly and availability often depends on national measures and financial support. More well-located refuelling stations will make hydrogen fuel more attractive. We need a real European and global approach to tackle the current obstacles to building a meaningful infrastructure. **The 'Fit for 55' proposals include a target for hydrogen refuelling stations for the proposed Alternative Fuels Infrastructure Regulation**. This goes in the right direction. Once agreed, its implementation will be crucial.

- **Consider fiscal support to consumers and incentives to automakers to build more, affordable and better alternative fuelled vehicles**. These could include time-limited tax credits or rebates on purchases to equalize the total cost of ownership; road tolls based on vehicle CO_2 emissions and kms driven; and preferential access to inner cities with low-emission zones (at the Member State/city level). The inclusion of additional operational expenditures (OPEX) is crucial for rolling out alternative fuel fleets and should be included in the design of funds like the Connecting Europe Facility (CEF).

- **Focus and strengthen public support for innovation to develop cost-competitive, sustainable, circular and high-performance hydrogen-based mobility technologies**. The performance of fuel cell electric vehicles (FCEVs) can be further increased through innovation, while lowering costs and increasing durability. Also, the development of liquid organic hydrogen carrier technology (LOHC) could support a move from compressed hydrogen tanks on board vehicles to a liquid solution.

- **Take a global approach**. International co-operation will be crucial to stimulate investment into renewable and low-carbon hydrogen. Common international standards will help global trade and alliances. Governments

13 ACEA (2021) Heavy-duty vehicles: Charging and refuelling infrastructure requirements

and industry must work together and support a global hydrogen market with the right legal framework and technology.

- **Further develop appropriate EU legislation on CO_2 emissions from transport**. Intensify the targets, further expand the scope of mobility segments to boost demand for H_2-based mobility technologies as proposed by the 'Fit for 55' package.

4.2.2 Aviation

In aviation, the choice of the optimal zero-emission fuel (or form of energy and power) depends on the size of the aircraft and the distance to be covered. Options include electric, hybrid-electric, fuel cells, novel fuels including non-drop-ins such as hydrogen or sustainable aviation fuels (SAF), in order of increasing range capability.

Liquid hydrogen can be used as a fuel for aircraft when it is combusted in a hydrogen-burning engine or reacted in a fuel cell, which powers electric motors. Hydrogen can be also used to produce SAFs (e.g. e-fuels).

Despite its higher gravimetric energy density compared to kerosene, hydrogen's higher volume requires larger volumes for storage, and for the fuel to be compressed or liquefied to make this as effective as possible. In turn, this requires larger tanks aircraft and specific aircraft and fuel system designs. This adds system complexity and weight to the aircraft.

Nonetheless, hydrogen could be a solution to decarbonise flights up to the short and medium range categories (SMR).

The use of hydrogen in aviation will involve major challenges:

- **The exploitation of the full potential of hydrogen will require the redesign of aircraft and propulsion and fuel systems** to address related safety challenges. The modifications will affect the fuselage and wings due to different fuel storage requirements, fuel and thermal management systems and, for the fuel cells solution, the electrical distribution needed to support electric power.
- **Effective storage solutions are key** to unlocking hydrogen's high gravimetric energy density. Storage in the liquid state is currently the most promising option but involves complex tank and fuel systems, and a cryogenic system to keep hydrogen liquid.
- A significant **ramp-up in competitive renewable hydrogen production** (3% current production) will be needed to produce fuel volumes sufficient for the aviation industry sustainably.
- **Hydrogen infrastructure improvements** will include solutions to deliver the fuel to airports (in case hydrogen is not produced on site) and an airport refuelling infrastructure with additional requirements to liquefy hydrogen on-site. The concept of 'hydrogen hubs at airports', starting with hydrogen to decarbonise all airport-associated ground transport, would pave the way to hydrogen availability for aircraft in the 2030 timeframe.
- The use of complex fuels such as hydrogen also comes with potential **operational penalties tied to the logistics** of using the fuel. This could take the form of longer turn-around times and the need for greater on-the-ground infrastructure (e.g. fuel trucks) at airports. It might also affect flight altitudes and routes.

To further build up hydrogen opportunities in aviation, we recommend policymakers do the following:

- **Dedicate public funding for research projects to develop hydrogen-based aircraft configurations and systems**, including key specific components (e.g. light-weighting storage, fuel system design, fuel injection technology, light-weighting fuel cells and advancing cryogenic cooling systems). We also recommend the development of applicable standards and regulations in tight cooperation with the relevant authorities.
- **Support close collaboration inside and outside the aviation ecosystem**, including aircraft manufacturing, airports, infrastructure providers and airliners. A Zero Emission Aviation Alliance, bringing together all the ecosystem

stakeholders in addressing regulatory aspects, required infrastructure and establishing a global outreach will be essential in laying the foundation of the future market

- **Promote the setup of appropriate market measures and policies**, including enablers for the development of hydrogen production and distribution, airport infrastructure and portfolio of solutions to achieve the reduction of the cost of hydrogen and integrate the carbon cost in the price of fossil-based fuels.

- **Support the Clean Hydrogen Alliance** to establish an investment agenda to scale up the hydrogen value chain across Europe, including for aviation.

- **Promote international cooperation** to set global standards and a level playing field to allow hydrogen aircraft to operate globally.

Case Studies

Air Liquide is committed to investing €8 billion in the low-carbon hydrogen value chain by 2035, and a total of 3 GW electrolysis capacity by 2030.

CASE STUDY

Air Liquide

Production · Transport and Storage · Industry · Transport

What role does hydrogen play in your company's strategy?

Air Liquide commitments address the urgency of climate change, targeting carbon neutrality by 2050. Deeply convinced that hydrogen will play a major role in the energy transition, Air Liquide is committed to investing €8 billion in the low-carbon hydrogen value chain by 2035, and a total of 3 GW electrolysis capacity by 2030.

Description of project

For the Air Liquide Normand'Hy electrolysis, AL will install, own and operate a large Siemens Energy PEM electrolyser, with a capacity of at least 200 MW for producing renewable hydrogen to be used in the industry and mobility sectors. Main offtakers will be major refinery players in Normandy. The renewable hydrogen will be compatible with the RED and be qualified as RFNBO. The project will sign a PPA for renewable energy supply from new capacity to be added in France. The project will be integrated within a hydrogen pipeline network with two existing hydrogen production units, accommodating the intermittency of the renewable hydrogen production from the electrolyser thus ensuring reliability and continuity of supply to end users.

What is the size of the project?

The project will be based on the PEM technology from Siemens Energy for a total of at least 200 MW. The project will have the capacity to avoid approximately 250 ktonnes/year CO_2 emissions.

What benefits does the project bring?

- Massive production of renewable hydrogen.
- Spillover effect on the electrolyser industry by providing manufacturing load for key equipment manufacturer, for the industry by collaborating with other IPCEI H_2 projects.
- Contribution to EU objectives to develop the H_2 economy for industry and mobility sectors.
- Contribution to the development of the renewable energy sector by generating a demand of addition of large capacity of solar and wind assets.
- Building a large scale electrolyser for the industry usage will help create competitive sourcing for the nascent H_2 mobility market in the Seine Valley Axis through to the deployment of a low-carbon hydrogen infrastructure.
- Direct and indirect job creation in the Normandy industrial basin.

What are the bottlenecks or key success factors?

- Favourable and stable EU and French regulatory framework for the development of the hydrogen economy in Europe (RED, EU ETS).
- Mobilisation and support of key stakeholders for the success of this first of its kind project in France, starting with Customers, renewable energy suppliers.
- Strong public support from the EU administration through the Innovation Fund mechanism and from the French government and administration (DGE, DGEC, ADEME, BPIFrance) through the IPCEI H_2 and from local authorities (Caux Seine Agglo, Région Normandie).
- Competitiveness of the key technology supplier Siemens-Energy.
- Availability in time and quantity of a competitive renewable energy supply in France.

Find out more:
[Air Liquide Energies]

BASF
We create chemistry

BASF is eager to implement alternative production processes: water electrolysis and methane pyrolysis.

CASE STUDY

BASF

Production Industry

What role does hydrogen play in your company's strategy?

For BASF, the use of clean hydrogen is a key element in reducing greenhouse gas emissions. In Europe, for example, BASF is one of the largest hydrogen producers. Around 250,000 tonnes of H_2 per year are produced decidedly as well as intrinsically or as couple / by-products at our main plant in Ludwigshafen. The gas is a key and irreplaceable raw material. However, the current production technology goes along with high CO_2 emissions.

BASF is therefore eager to implement alternative production processes: water electrolysis and methane pyrolysis.

Description of project

BASF currently develops the methane pyrolysis technology as part of our Carbon Management R&D program in cooperation with partners in a project funded by the Federal Ministry of Education and Research (BMBF). Here, biomethane or natural gas, is split directly into its components of hydrogen and solid carbon. Compared to electrolysis, methane pyrolysis requires only around one-fifth as much electrical energy.Within this project, a test plant has been set up at the Ludwigshafen site. The goal is to analyse whether the procedure is viable for applications on an industrial scale. The test plant is the decisive step for enabling further upscaling to larger pilot plants and industrial applications. Despite technological and economic challenges we expect to have this technology ready for implementation from around 2030 onwards.

What benefits does the project bring?

- As a procedure, methane pyrolysis is flexible and can be conducted with every type of methane.
- Methane pyrolysis has a much lower electricity demand compared to electrolysis. The simultaneous production of high-purity carbon positively influences the economic efficiency. The use of methane pyrolysis thus plays a special role in maintaining industrial value creation in locations with limited renewable energy.
- Solid, high-purity carbon is already used today in various industrial sectors. The uses of carbon are partially linked with environmental pollution, which could be avoided thanks to the purity of our pyrolysis carbon.
- Our pyrolysis carbon is stable, meaning storage is also theoretically feasible. If biomethane is used as a starting material, a solid, bio-based carbon is created. Permanently binding or storing this carbon would permanently remove carbon from the atmosphere (negative emission technology).

What are the bottlenecks or key success factors?

- Aside from the technical hurdles to be overcome to enable the further scale-up of the process, also the political framework is also decisive. The economic efficiency of methane pyrolysis is decisively influenced by the price of electricity from renewable sources. Therefore, electricity from renewable sources must be more cost-effective for use in the chemical industry, and the expansion and integration of renewable energy needs to be advanced.
- It is also important to support technology development with further funding, as well as to ensure a technology-open approach that enables the use of different hydrogen processes. Certification and classification should be based on the environmental impact and CO_2 footprint and there should be equal access to funding programmes and incentive systems.

Find out more:
[BASF - New Technologies]

The planned electrolyser system will be able to generate over one tonne of renewable hydrogen an hour, which will be used in the production of fuels in the refinery.

CASE STUDY

bp

Production Industry Transport

What role does hydrogen play in your company's strategy?

bp has set out an ambition to be a net-zero company by 2050, or sooner, and help the world get to net-zero. bp aims to become a leader in delivering efficient decarbonisation solutions, including clean hydrogen. bp's aim is to capture 10% of the clean hydrogen market in core markets by 2030.

Description of project

Lingen Green Hydrogen is a joint venture project between bp and Ørsted and will produce green hydrogen at bp's Lingen refinery in Germany, displacing 20% of the current grey hydrogen production during phase 1.

The planned electrolyser system will be able to generate over one tonne of renewable hydrogen an hour, which will be used in the production of fuels in the refinery. Green hydrogen will be produced from renewable electricity to power the electrolysis unit. We expect to abate 68 ktonnes of CO_2 per year. The project should become operational by end of 2024.

What is the size of the project?

- The capacity for the Phase 1 electrolyser is 60 MW.
- This will produce 7,090 tonnes/year of green hydrogen.
- The next project phases aim to achieve total electrolyser capacity greater than 500 MW and production of more than 56,000 tonnes/year of green hydrogen by 2026/27, to displace 100% grey hydrogen production and for future synthetic aviation fuel production at the site.

What benefits does the project bring?

- Lingen Green Hydrogen contributes to the sector goals of industry decarbonisation and transport sector targets set out in Germany.

What are the bottlenecks or key success factors?

- In the early stages of the development of a hydrogen market, a robust regulatory framework and access to funding and incentives are required to support project economics and business models.
- Treatment of additionality and renewability, outlined in the Renewable Energy Directive, will have a significant impact on project economics. Stringent treatment of additionality is likely to warrant these projects as uneconomic, rendering them unlikely to move forward.

Find out more:
[Lingen Green Hydrogren - decarbonising industry together]

Around 50 partners from business, science and politics want to create sustainable innovations, trigger economic impulses and strengthen northern Germany as an industrial location.

CASE STUDY

E.ON

Production | Transport and Storage | Industry

What role does hydrogen play in your company's strategy?

Our company is laying the foundation for an economically sustainable market ramp-up for hydrogen and thus for achieving the German and European climate goals. Our activities are increasingly focusing on hydrogen projects, because green hydrogen optimally complements our existing product portfolio and can make a valuable contribution to climate protection.

Description of project

In the *"Living Lab of Northern Germany"*[1], the holistic transformation of the energy system is to be tested and thus contribute to a rapid decarbonisation of all consumption sectors. Distributed across geographical 'hubs' in Hamburg, Schleswig-Holstein and Mecklenburg-Western Pomerania, large-scale concepts for sector coupling are to be developed, with a focus on hydrogen and energy-efficient neighbourhood solutions in the heating sector.

Around 50 partners from business, science and politics want to create sustainable innovations, trigger economic impulses and strengthen northern Germany as an industrial location.

E.ON subsidiary HanseWerk AG[2] is a founding member of the project consortium and plans to build and operate an electrolyser in the Hamburg port area.

1 German name: „Norddeutsches Reallabor"

2 E.ON SE holds 2/3 (66.7%), eleven districts of Schleswig-Holstein hold 1/3 (33.3%) of the shares.

What is the size of the project?

- Living Lab of Northern Germany in total:
    - Investment volume: €300 million
    - Funding by Federal ministry of economics: €52 million
    - Electrolyser capacity: 42 MW
- Subproject of HanseWerk AG within the Living Lab of Northern Germany:
    - Electrolyser capacity: 25 MW
    - Hydrogen production: 2,900 tonnes/year

What benefits does the project bring?

Subproject of HanseWerk

- Provision of green hydrogen for decarbonisation of industrial and mobility applications in Hamburg in a local value chain.
- Reduction of CO_2 emissions of 34,000 tonnes/year.[3]
- Via an optimised storage and operational management concept, the integration of renewable energies into the electricity market is promoted and, at the same time, a continuous hydrogen demand can be covered.

What are the bottlenecks or key success factors?

- Green hydrogen is still not competitive with grey hydrogen, existing incentives are not sufficient to convince end users.
- No uniform definition for green hydrogen yet respectively upcoming legislation restricts the criteria too much, especially for one user group.
- The implementation of the project will depend on the upcoming legislation at EU level, more specifically the definition of green hydrogen which will be set by the upcoming Delegated Act.

NRL
Norddeutsches RealLabor

3 Compared to steam methane reforming

We are already involved in 40 green hydrogen projects in 10 countries.

CASE STUDY

ENGIE

Production | Transport and Storage | Industry

What role does hydrogen play in your company's strategy?

ENGIE is a front-runner in the development of an industrial-scale hydrogen economy worldwide.

Our ambition is to enable the industrial and heavy-duty mobility players to reach their carbon-neutrality objectives.

We are already involved in 40 green hydrogen projects in 10 countries.

By 2030, ENGIE expects to:

- Develop a green hydrogen capacity of 4 GW;
- Have 700 km of dedicated hydrogen networks and 1 TWh of storage capacity;
- Operate more than 100 refuelling stations.

Description of project

HyNetherlands

In the context of the Dutch government's ambition to reach carbon neutrality, we are working, together with Gasunie as a strategic partner, on a **large-scale hydrogen project** on the site of the ENGIE Eems power plant in the province of Groningen (Eemshaven industrial site). The electrolyser is to be built in a stepwise approach: 100 MW in 2025, an additional 750 MW end 2020s and an additional 1 GW in the 2030s. ENGIE develops the electrolyser and Gasunie the required transport infrastructure (hydrogen backbone).

The objective is to decarbonise the region's **chemical industry** (methanol and fuel production industries), by providing renewable hydrogen, and the Northern Netherlands' rail sector by converting the full fleet of e.g. regional diesel passenger trains.

The project of 100 MW green hydrogen is expected to be operationally ready by 2025.

What is the size of the project?

The numbers below refer to the 100 MW electrolyser:

- Electrolyser capacity at full load: 20,000 Nm^3/h
- Expected production of hydrogen: ~ 11.8 ktonnes hydrogen per year

What benefits does the project bring?

- Avoided emissions (CO_2): an estimated 2 $MtCO_2eq$ over a 10-year operation period. 1.2 Mt p.a. once fully operational by 2035.

The hydrogen is intended to be used by off-takers to:

- produce e-methanol through processing of captured carbon;
- use as fuel.

Once the hydrogen backbone and hydrogen storage are realised by Gasunie, a larger variety of off-takers throughout the Netherlands can benefit from the produced hydrogen from the HyNetherlands project to decarbonise their operations.

Find out more:
HyNetherlands: a green hydrogen chain

What are the bottlenecks or key success factors?

In order to realise a large-scale hydrogen project, various building blocks must be in place:

- **Legislation:** the regulatory framework must be 'fit for purpose' and take into account the state of play of the hydrogen market. This is particularly true for the rules that apply for the use of hydrogen in the Dutch transport market and the REDII delegated act that will be issued by the European Commission.
- **Off-take market:** market participants should have an incentive to use green hydrogen. This requires e.g. a (European) CO_2 tax.
- **Availability of infrastructure:** the hydrogen backbone and salt caverns for the storage of hydrogen must be timely in place.
- **Subsidies:** Sufficient subsidy (in terms of budget) must be available to support hydrogen projects to get off the ground and schemes must be in line with the maturity of the technology. The first is an issue for the Dutch upscaling fund and the second for the Dutch exploitation scheme SDE++.

The main goal of the project is to test the implementation and operation of electrolyser systems linked to existing hydrogen production plants

CASE STUDY

Eni

Industry

What role does hydrogen play in your company's strategy?

Hydrogen is one of the elements that Eni will leverage to reach carbon neutrality by 2050. Eni's strategy comprises all low-carbon and renewable hydrogen production pathways to progressively replace the existing consumption in Eni's refineries and biorefineries as well as for the decarbonisation of hard-to-abate sectors and mobility.

Description of project

Eni is evaluating the feasibility of a green hydrogen project connected to one of its biorefineries, in partnership with another company. The main goal of the project is to test the implementation and operation of electrolyser systems linked to existing hydrogen production plants (steam methane reformer) and to demonstrate the technology's potential to reduce greenhouse gas emissions of biorefineries across Europe. The electrolyser will be located within the Gela biorefinery's boundaries and will be powered by grid electricity via a virtual PPA (the electricity energy is produced by PV plant). This project will be Italy's first industrial deployment of green hydrogen in biorefining processes.

What is the size of the project?

Polymer electrolyte membrane (PEM) electrolyser with 20 MW of capacity. Expected hydrogen production is about 1,200 tonnes/year (under nominal conditions).

What benefits does the project bring?

- The avoided CO_2 will be around 11,000 tonnes/year.
- A contribution to further development of the green hydrogen value chain (i.e. electrolyser technologies) and the demand for high-skilled jobs both at local and EU level.

What are the bottlenecks or key success factors?

- A well-defined regulatory framework is needed to encourage and manage the proper development of the hydrogen market.
- Approval of appropriate and detailed supporting mechanisms to ensure full coverage of investment costs, Opex expenditures, and a fair remuneration, as market revenues are currently insufficient to adequately support most decarbonisation investments due to a still low CO_2 price.
- Permitting to build and operate the facility will be also an essential requirement.
- Partnerships represent an enabler to promote hydrogen valley by creating large and integrated projects.

The battery storage system and 35 MW of generating capacity will be dedicated to green hydrogen production, through a dedicated underground electric line.

CASE STUDY

Iberdrola

Production | Transport and Storage | Industry

What role does hydrogen play in your company's strategy?

Technological development over these past years has made electricity the backbone of a decarbonised energy model with the combination of renewable power generation and demand electrification. However, some industrial uses as well as hard-to-abate sectors will need other technological developments, and this is where we see green hydrogen playing a key role.

Description of project

The project consists of a 100 MW solar PV plant and a 5 MW / 20 MWh lithium-ion battery storage system. The battery storage system and 35 MW of generating capacity will be dedicated to green hydrogen production, through a dedicated underground electric line. Renewable electricity will feed a 20 MW PEM electrolyser which will be located within the fertiliser facility premises at the Fertiberia Puertollano plant. The electrolyser produces 360 kg of hydrogen/hour and 2800 kg of oxygen/hour. Hydrogen will be used to produce ammonia and oxygen produced as a by-product of electrolysis will be used entirely in a nitric acid unit, to improve its greenhouse gas emissions and energy efficiency.

What is the size of the project?

Once completed, it is expected to reduce natural gas requirements at the Fertiberia Puertollano facility by over 10%. The estimated H_2 production rate is about 1000 tonnes/year. The project will generate up to 700 jobs and provide scale in the region to consolidate its position as a hydrogen hub. The required investment will be around €150 million.

What benefits does the project bring?

The Puertollano project will serve as a reference for future developments in the manufacturing of commercial scale electrolyser equipment, the management of power generation from variable renewable sources to deliver a firm hydrogen supply, and the integration of green hydrogen supply within an existing fertiliser production site.

The project will reduce the environmental footprint of the existing Fertiberia plant and allows manufacturing green fertilisers in a very competitive market. The displacement of a natural gas-based processes and the technical modifications in the ammonia and nitric acid production, will avoid emissions of almost 40,000 tonnes CO_2/year.

Find out more:
[Iberdrola builds the largest green hydrogen plant for industrial use in Europe]

[Green hydrogen: an alternative that reduces emissions and cares for our planet]

What are the bottlenecks or key success factors?

Producing green hydrogen from renewable electricity sources is challenging due to:

- Daily and seasonal fluctuations;
- Incorporating the green hydrogen and oxygen into the conventional ammonia production line adds another level of operational complexity;
- Coupling variable generation with continuous ammonia production.

Three components have the largest impact on competitiveness:

1. cost of the electrolyser,
2. the cost of the electricity and
3. the plant capacity factor.

We see large improvement potential in electricity costs as generation costs in renewables keep on decreasing.

Electrolyser investment costs will show a typical learning curve evolution with large cost reductions as volumes increase. Given the size and number of projects announced, progressing along the learning curve can happen very quickly. Capacity factors will also increase, driven by technological evolution.

Considering uncertainty associated with future developments, we see a potential cost reduction between 35% and 60%, which could make green hydrogen competitive by 2030.

Shell is exploring the possibility to boost the hydrogen economy in the Netherlands with the construction of the Shell Hydrogen Holland I facility, which will be Europe's largest renewable hydrogen production facility.

CASE STUDY

Shell

Production Industry Transport

What role does hydrogen play in your company's strategy?

Shell believes that hydrogen has a critical role to play in delivering energy, whilst reducing greenhouse gas (GHG) emissions. We plan to invest in integrated hydrogen hubs to serve industry and heavy-duty transport, alongside Shell's own demand from our energy and chemical parks. Both low-carbon and renewable hydrogen will be crucial. Shell would like to utilise our unique integration opportunities and capture a double-digit share of global clean hydrogen sales.

Description of project

Shell is exploring the possibility to boost the hydrogen economy in the Netherlands with the construction of the Shell Hydrogen Holland I facility, which will be Europe's largest renewable hydrogen production facility. Shell hopes to make a final investment decision in the winter of 2021. The power for this electrolyser will be directly sourced from an offshore wind farm off the Dutch coast and connected to the Port of Rotterdam. Green hydrogen could be produced for the industrial and the transport sectors. Its first main user will be the Shell Pernis refinery, where green hydrogen will replace grey hydrogen used to produce of transport fuels.

What is the size of the project?

- Potential 200 MW electrolyser.
- Approximate 55 tonnes/day of green hydrogen.
- Approximately 40 km pipeline connecting the electrolyser to the industrial hub in the Port of Rotterdam.

What benefits does the project bring?

- Reducing the GHG footprint of road transport fuels and enabling zero-carbon mobility.
- Building an end-to-end hydrogen value chain, including the generation of renewable electricity, hydrogen production through the electrolyser and the transport and supply to industrial and mobility customers.
- This project demonstrates the key value chain scale, contributing to reduce the costs of future projects through learning by doing.

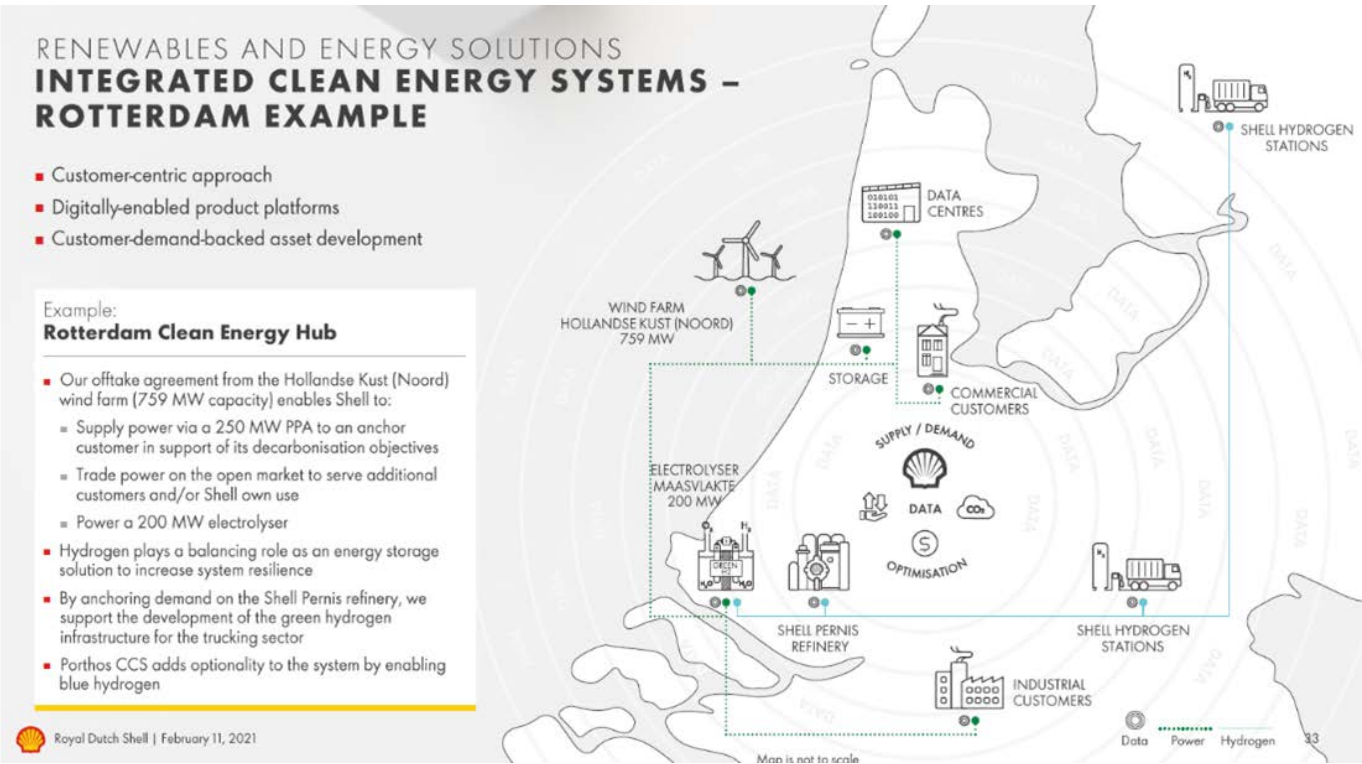
What are the bottlenecks or key success factors?

For the Holland Hydrogen I project, the most important bottlenecks are:

- Implementation of the Renewable Energy Directive to recognise the role of renewable hydrogen to deliver both renewable energy and reduce GHG emissions;
- Access to funding for the first few industrial scale demonstration projects and associated infrastructure;
- Timely hydrogen transportation infrastructure planning and construction;
- Supply of affordable renewable electricity;
- Upscaling of electrolysis manufacturing capabilities.

The 'Fit for 55' package provides an opportunity to overcome these challenges.

Find out more:
Wind As Energy Source For Green Hydrogen Factory In Rotterdam



TotalEnergies and ENGIE are working together to design, develop, build, and operate the Masshylia project, France's largest renewable hydrogen production site based on solar energy.

CASE STUDY

TotalEnergies

Production Industry Transport Energy System

What role does hydrogen play in your company's strategy?

TotalEnergies is looking into the production of clean hydrogen (blue or green) in its commitment to get to net-zero by 2050. TotalEnergies has already been working on the development of concrete use cases for the decarbonisation of industrial processes as well as for mobility.

Description of project

TotalEnergies and ENGIE are working together to design, develop, build, and operate the Masshylia project, France's largest renewable hydrogen production site based on solar energy. The electrolyser will be located at La Mède biorefinery and will aim to decarbonise hydrogen used as a substitute for steam methane reforming in industrial processes.

An innovative management solution for the production and storage of hydrogen will be implemented to manage the intermittent production of solar electricity and the biorefinery's need for continuous hydrogen supply.

The two partners aim to begin construction of the facilities in 2022, following the completion of the advanced engineering study, with a view to production in 2024, subject to the necessary financial support and public authorisations.

What is the size of the project?

Photovoltaic panels with an approximate capacity of 110 MW will be installed near the site and will supply a 40 MW electrolyser. Initially, all the hydrogen produced will be consumed by the biorefinery site as a substitute for the grey hydrogen produced through steam-methane reforming (without capturing or storing the CO_2 emitted) which is currently being consumed. The project could produce up to 15 tonnes of renewable hydrogen per day by addressing other usages such as mobility or other industries.

What benefits does the project bring?

The Masshylia project should:

- avoid emissions up to 33,5 ktonnes CO_2/year;
- demonstrate the economic advantages of renewable hydrogen and its integration into the local ecosystem and at the European level;
- create a centre of expertise on industrial security H_2 with the ENSOSP;
- use the la Mede site as an incubator H_2 Platform to test new technologies.

What are the bottlenecks or key success factors?

- **Secure business model and cope with legislative constraints:**
    - Compliance with RED II delegated acts;
    - Cost competitiveness (CAPEX & efficiency);
    - Public support mechanisms (IPCEI, etc.).
- **Tackle technological challenges:**
    - Valorise infrastructure and existing assets (pipes, storages…);
    - Permitting (RES , H_2 plant…);
    - RES intermittency management.
- **Expand beyond the biorefinery needs:**
    - Replicability;
    - Develop skills and competences;
    - Establish a Masshylia hub by scaling up production and uses + connecting with other hubs at European scale.

Find out more:
[TotalEnergies and Engie partner to develop France's largest site for the production of green hydrogen from 100% renewable electricity]

umicore

Umicore is investigating advanced materials technology facilitating the storage & transport of hydrogen, as well as the refueling of fuel cell electric vehicles (FCEVs) to accelerate the deployment of hydrogen-based mobility

CASE STUDY

Umicore

Transport and Storage | Transport

What role does hydrogen play in your company's strategy?

Umicore has more than 30 years of experience in developing and producing, in Germany and South Korea, the electrocatalyst advanced materials used in PEM-based fuels cells (turning hydrogen into energy) or in PEM-based electrolyzers (converting energy into hydrogen). At Umicore's recycling facilities, the critical metals (PGMs) contained in electrocatalysts can be recovered and re-injected into the hydrogen economy.

Description of the project

Umicore is investigating advanced materials technology facilitating the storage & transport of hydrogen, as well as the refueling of fuel cell electric vehicles (FCEVs). This long-term technology is called LOHC (for liquid organic hydrogen carrier). LOHCs absorb and release hydrogen through chemical reactions. Hydrogen is absorbed into the LOHC using a hydrogenation catalyst (based on platinum group metals). The LOHC liquid is stored and conveyed safely and cost-efficiently to refueling stations using regular means of transport at ambient temperature and pressure. FCEVs can then be refueled directly and quickly with hydrogen-rich LOHCs. The hydrogen is then released onboard (using a dehydrogenation catalyst) and converted back into energy via the fuel cell.

What benefits does the project bring?

- Facilitated storage and transportation of hydrogen (today based mainly on compressed liquid hydrogen, stored at either high pressure (350-700 bar) or very low temperature (-253°C) using existing conventional networks.
- Facilitated refueling of FCEVs (like conventional vehicles) using existing refueling infrastructure (LOHCs stored and dispensed at ambient temperature and pressure).
- Acceleration of the development of the hydrogen economy through more convenient and cost-competitive technologies.

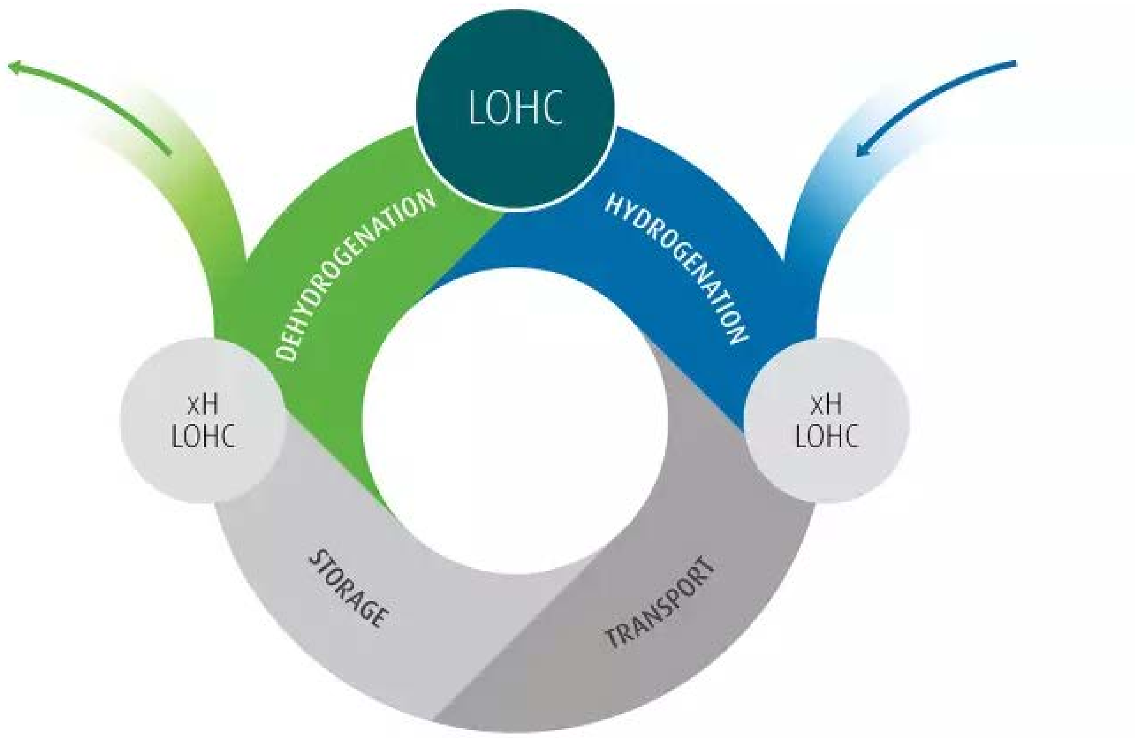
What are the bottlenecks or key success factors?

- Current catalyst system for the dehydrogenation process (hydrogen release from the LOHCs) is not compatible with current FCEVs' requirements for on-board applications.
- New catalysts are needed to operate at lower temperatures and pressures.
- Long-term R&D collaboration programmes being put in place with academic and industrial partners to alleviate the bottlenecks of the dehydrogenation process.

Find out more:

Umicore's position in catalysts to support the green hydrogen economy

LOHC technology: accelerating the deployment of hydrogen storage and fuel cell electric vehicles



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This paper has been prepared by the Energy Transition & Climate Change Working Group of the European Round Table for Industry.

More info and previous papers to: https://ert.eu/focus-areas/energy-and-climate-change/

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