The need for a European hydrogen economy

Our vision for an integrated and sustainable hydrogen market model

April 2022

Contents

Hydrogen is key to becoming climate-neutral

As a society, we are in an existential race to reduce greenhouse gas (GHG) emissions and become climate-neutral. Members of the European Union (EU) agreed and signed the Paris Agreement[1] to keep the global temperature increase below 2 degrees Celsius compared to the 1990 level. By 2030, Europe aims to further cut GHG emissions by more than 55% and become climate-neutral by 2050.[2]

The growth of renewable energy and distributed energy resources like solar panels, wind generation units and battery storage are rapidly changing the entire energy value chain, and the pace is only accelerating. Increasingly unpredictable consumption and production patterns make it more challenging to match supply and demand. In addition, growing electrification and the need to transport and distribute energy will exceed the capacity of our grids. Combined with phasing out the use of natural gas in some countries, transporting energy from where it is produced to where it is needed will be one of the industry's major challenges.

It is impossible to accurately predict what our future energy system will look like. We see scenarios ranging from (1) regionally orchestrated reduced energy demands and highly distributed, decentralized, local and community production driven by prosumers on one end to (2) an internationally coordinated approach with large-scale, low-carbon technologies (e.g., offshore wind and large storage) and a strong dependency on transmission and distribution grids on the other end.[3]

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Source: European Commission

From industry to mobility, and from residential heating and energy transportation to balancing the electricity grid, every sector is looking for alternative ways to reduce its GHG footprint and dependencies on fossil fuels. Achieving this requires a high degree of flexibility in our overall energy system. It also involves significant and costly infrastructural changes. Smart solutions are essential to fulfill our energy needs while controlling costs.

Hydrogen, especially green hydrogen, looks promising as part of the solution to reach climate goals and reduce GHG emissions in several industries and markets. Hydrogen can be produced with (excess) wind or solar energy, while burning hydrogen only produces water and energy. Huge investments are being made, but many steps still are needed to lower the cost, accelerate digitalization and mature the market.

CGI is committed to accelerating the energy transition as the digitalization partner for the hydrogen economy based on our deep expertise in energy market liberalization, renewables management, asset data management and license to operate.

In this paper, we discuss the market potential for green hydrogen. We also share our vision for developing a green hydrogen supply chain and moving to a mature and sustainable hydrogen market model in Europe as an integral part of a complete energy ecosystem.

Publication note (April 2022) This paper was written prior to the war in Ukraine. The resulting humanitarian crisis and economic impacts are and will continue to affect the trends discussed in this paper.

What is hydrogen?

Hydrogen is the lightest and most abundant element in the universe. It is also an explosive and clean-burning gas, only releasing water (H_2O) and energy. In its gaseous form, it contains more energy per unit of weight compared to any fossil fuel. Although hydrogen's energy-to-weight ratio is high, its energy-to-volume ratio is low, requiring the development of advanced storage methods to improve energy[4].

Even though no CO_2 is released, it does not mean everything is blue skies and rainbows. Hydrogen, as a gas, is not found naturally on Earth. Therefore, it is not an energy source that we can tap into, as we can with water or wind. Hydrogen is an energy carrier that needs to be produced from other sources. Simply put, hydrogen can be used to store, move and use energy that is extracted from other sources. The conversion process determines how "clean" the hydrogen is. To makes this clear, the industry uses color labels to distinguish production type methods:

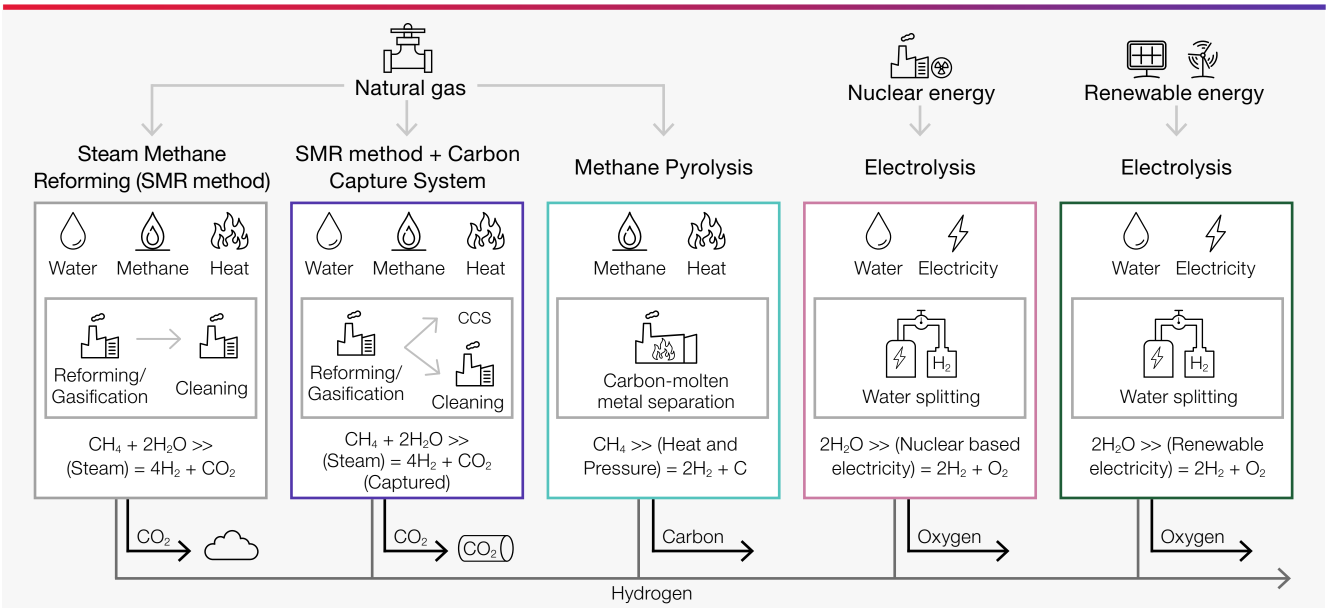


Figure 1: Hydrogen color code based on its production process

Grey hydrogen is produced using natural gas. The vast majority of hydrogen is grey at the moment[5]. The most common production method used is the Steam Methane Reforming (SMR) method[6]. In this process, methane (CH_4) reacts with high-temperature steam to produce hydrogen and release CO_2. The resulting CO_2 emissions are not captured.

Blue hydrogen is produced in the same way as grey hydrogen, but the CO_2 emissions are captured and stored. Converting grey hydrogen production to blue can be an intermediate step to reduce emissions in industries that currently rely on grey hydrogen.

Turquoise hydrogen uses a process called “pyrolysis” to split methane into hydrogen and carbon. There are no CO_2 emissions in this process, and it produces two valuable products, hydrogen and solid carbon. The latter can be used for various applications like manufacturing car tires. This technology is currently in the experimentation phase[7].

Pink hydrogen is produced through electrolysis by using nuclear energy to split water into hydrogen and oxygen. No CO_2 is produced in this method. The fission products, which are around 4% of the by-products, are nuclear waste and require disposal[8].

Green hydrogen is produced through electrolysis by using electricity from renewable energies to split water into hydrogen and oxygen. No CO_2 is produced in this method.

Hydrogen's market potential

Due to its versatility, hydrogen has the potential to reduce GHG in different sectors and segments, including the industrial sector, utilities, transportation and residential heating.

Industry feedstock

Currently, industry makes up the bulk of hydrogen demand, using it as raw material or feedstock for many industrial processes such as in the chemical industry or as reactant to remove impurities. This hydrogen is mainly sourced from fossil fuels (i.e., grey hydrogen). As an intermediate step, the industrial sector can first move to blue hydrogen by capturing CO_2 with existing grey hydrogen production facilities. In parallel, we see significant investments in setting up electrolyzers close to industrial cores (for example, by Shell[9], BP[10] and Total[11]) to transition to green hydrogen in the longer term.

Industrial heat

High temperatures are often needed for melting and drying within the process industry, such as in steelmaking. Emission-free alternatives for medium (100-400 degrees Celsius) and high (>400 degrees Celsius) temperatures are limited, and hydrogen offers the most promising alternative to provide high-grade industrial heat.

With growing renewable energy production due to more offshore wind and solar farms, the challenges of balancing production and consumption and transporting the energy through the electricity grid are growing. Hydrogen can help balance the grid and act as a buffer system by providing flexible power generation, long-term energy storage and long-distance energy transport.

Electricity supply and transport

Sector coupling between electricity and hydrogen will become more and more relevant as the need for large-scale flexibility services continues to increase. Hydrogen has the potential to play a significant role in this area. However, conversion losses will need to be addressed. With every conversion comes energy loss. With current technologies and costs, it is difficult to make a business case when a significant amount of (green) energy is lost during conversion and reconversion. In the future, when green energy becomes abundant or expanding electricity infrastructure too costly, conversion losses may become irrelevant.

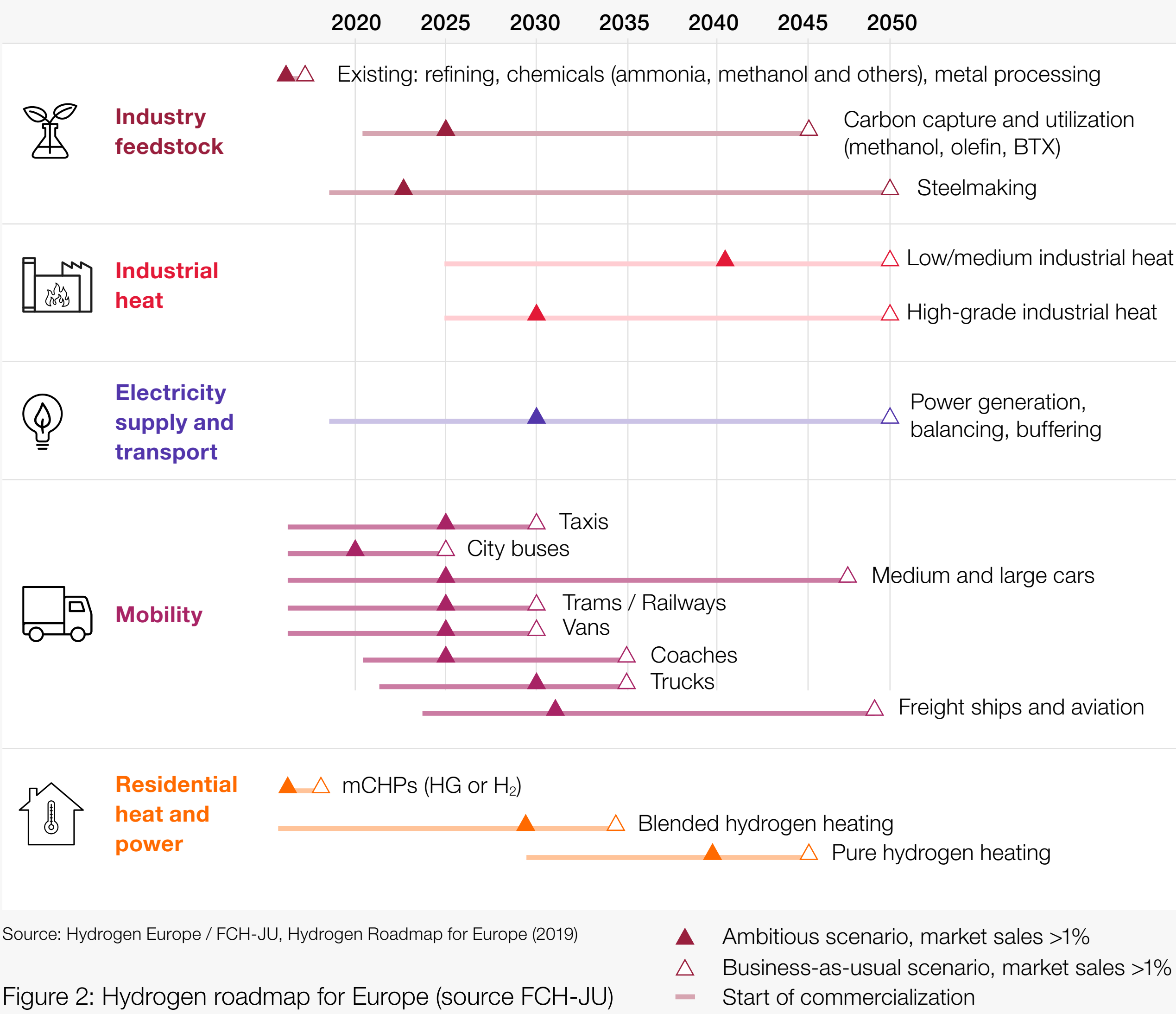
Mobility

Hydrogen for mobility is a complex topic. Due to its high energy-per-weight and low energy-per-volume characteristics, hydrogen is a promising alternative for heavy-duty and long-haul road transport as well as shipping, rail and aviation. For cars, battery electric vehicles (BEVs) are the likely way forward thanks to advancements in battery technology and charging infrastructure. For specific use cases (e.g., taxis) or regions, fuel cell EVs are an attractive alternative.

Residential heat and power

Hydrogen is a low-carbon option for decarbonizing buildings. As a first step, hydrogen can be mixed with the existing natural gas to lower CO_2 emissions. In the longer run, fuel cells for combined heat and power (FC-CHP) and boilers for heating can be used.

A key challenge is the substantial cost of the electricity required to produce, compress, store and transport hydrogen. The success and speed of hydrogen adoption in different markets lie in our ability to optimize the hydrogen supply chain to reduce the cost. The pace of hydrogen adoption in these various markets will differ, as is depicted by the FCH-JU Hydrogen Roadmap (Figure 2). With industry currently making up the bulk of hydrogen demand, it offers a lot of potential to move to low-carbon hydrogen alternatives as a first phase. Mobility is a possible next phase, with a focus on long-haul and heavy transport. The final phase could focus on hydrogen-based residential heat and power, and coupling with the electricity sector to help solve congestion challenges and balance supply and demand.



Source: Hydrogen Europe / FCH-JU, Hydrogen Roadmap for Europe (2019)

Figure 2: Hydrogen roadmap for Europe (source FCH-JU)

Our vision of a hydrogen future

Developing a green hydrogen supply chain

Meeting Europe's 2050 climate goals requires developing and moving to a green hydrogen supply chain, in which hydrogen is primarily produced by renewable energy at scale. Different scenarios are conceivable here, ranging from very distributed to a highly coordinated, integrated approach.

We see several drivers influencing the green hydrogen supply chain:

- **Large and heavy industries** are speeding up their GHG reduction and investing in their own renewable energy generation and electrolyzers to produce hydrogen for their own industrial and mobility uses.
- **Gas transmission system operators (TSOs)** are re-evaluating their role in the future due to the declining need for natural gas and are looking at ways to utilize their assets. This has resulted in a joint vision by over 20 European gas TSOs to move toward a European Hydrogen Backbone[12].
- **Countries** with (potentially) substantial amounts of renewable energy, like Iceland[13], Spain[14] and Finland[15 16], are setting national ambitions for large volume hydrogen production (e.g., offshore windfarms with offshore electrolyzers[17 18 19]) and export.
- **Prosumers** are driving local renewable energy production, with a low(er) need for transmission capacity when they store and use this energy themselves or in a local community. If this trend continues, it could evolve to local hydrogen generation, especially as the cost of electrolyzers goes down.

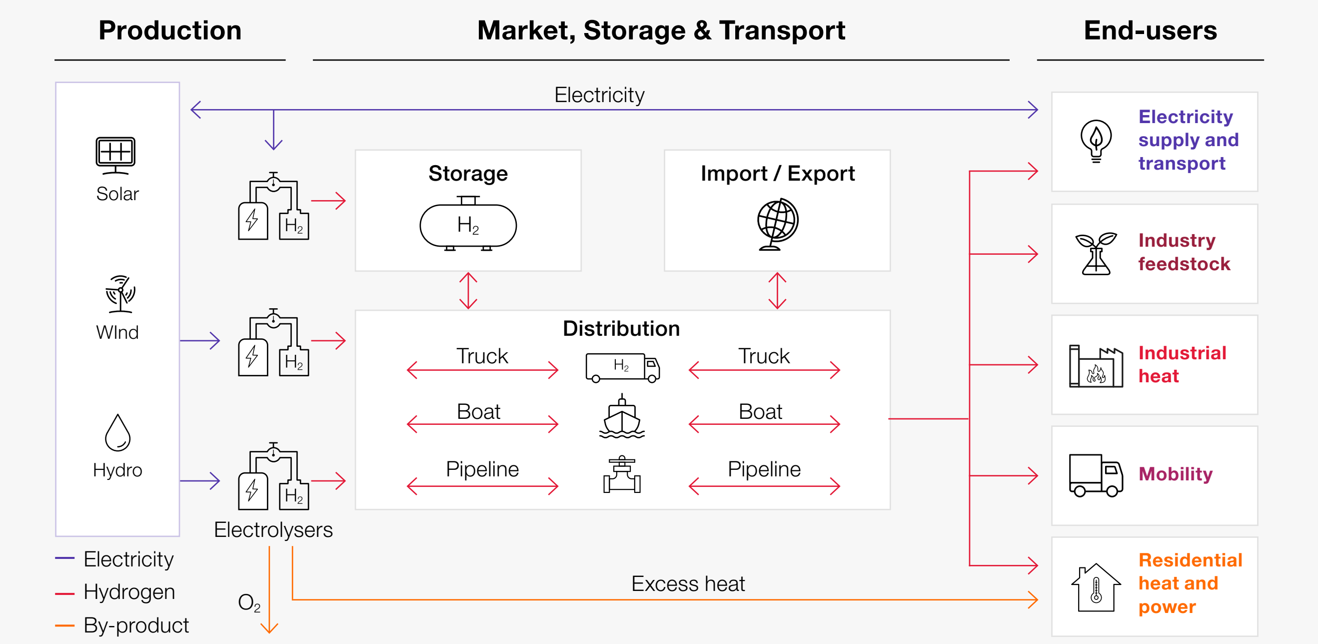


Figure 3: Simplified view of a green hydrogen supply chain

In our view, key aspects for this future market include support for multiple infeed points and hydrogen colors, connection to different markets through a mixed private and public pipeline infrastructure in an international market and efficient use of the side-flows of hydrogen production.

- **Multiple infeed points**: Instead of feeding in hydrogen at one point with top-down distribution through a transport and distribution grid, the future model must allow for a large number of decentralized infeed points.
- **Support for different hydrogen colors and variances**: The infrastructure will need to cater for multiple hydrogen colors and variances. We envision end-users requiring information about the origin of their consumed hydrogen, for example, to report on their own GHG footprint. This makes it important to know how much of which type of hydrogen is produced or imported, including the characteristics of its energy source. It likely will require some form of certification and tagging of hydrogen volumes. Additionally, the quality of hydrogen (e.g., the amount of impurities) may become a factor to be considered.
- **Multiple markets**: As explained above, different markets can benefit from using hydrogen. The future model must be able to support all these markets, with different types of end-users, from wholesale to retail.
- **Mixed private and public infrastructure**: Although initially, green hydrogen is likely to be produced close to where it is used (e.g., at industrial clusters), potential economies of scale in hydrogen production might drive large-scale hydrogen production and transport. A mature hydrogen gas pipeline infrastructure can be justified to connect producers with consumers at scale, especially when volumes and distances extend beyond what is feasible with trucks. This pipeline infrastructure is likely to be a mix of private and public infrastructure with existing pipelines reused as much as possible.
- **International market**: With hydrogen production at scale, countries aiming to export hydrogen and the TSOs' ambitions to create an international hydrogen backbone in Europe[20], there is an opportunity to create a pan-European hydrogen market. We can speed this up by aligning regulatory frameworks, market roles, processes and information exchanges across borders.
- **Use of side-flows**: When hydrogen is produced through water electrolysis at scale, it becomes interesting to use and commercialize its by-products such as heat and oxygen. For example, around 20% of the energy used for electrolysis is transformed into heat. Feeding this heat into a heat infrastructure could increase energy efficiency from 80% to over 98%[21]. More research is needed on the commercialization of these side-flows.

How do we get there?

Moving toward a pan-European green hydrogen economy is a marathon, not a sprint. It is critical to drive the cost down. Complicated questions need to be answered, for example, if it is economically viable to have a widespread physical infrastructure, where and how to realize it and keep it safe, how to make the transition within each segment, and how to grow to a mature market where electricity, natural gas and hydrogen coexist, interact, and this is accepted by the society.

Currently, several countries are planning or executing various practical hydrogen research initiatives. These “hydrogen valleys”[22] comprise local, national or internationally funded projects that bring together industry and research institutions to run pilot projects across (parts of) the hydrogen value chain. In the coming years, we will continue to see regional initiatives focused on specific parts of the green hydrogen value chain and on one or multiple market segments.

In essence, each hydrogen valley is creating its own mini-market in a local energy system, in which hydrogen is produced, transported, stored and consumed. Within these valleys, different concepts can be tried, and specific research questions can be answered. Data and technology will be key, as companies will need to make business critical decisions. Having insight into and controlling electrolyzers, storage and transmission units will deliver the data to support decision-making and act on market signals.

The European Hydrogen Strategy[23] foresees a roadmap with a phased approach for ramping up the production and use of hydrogen. A condition for the broad use of hydrogen as an energy carrier is the availability of an infrastructure that connects supply and demand. European hydrogen valleys are planned to be connected by a gas pipeline network of 4,225 miles (6,800 kms) by 2030, comprising a mix of existing and new pipelines[20]. The initial focus will be on connecting industrial hubs to make intra-hydrogen valley exchange possible.

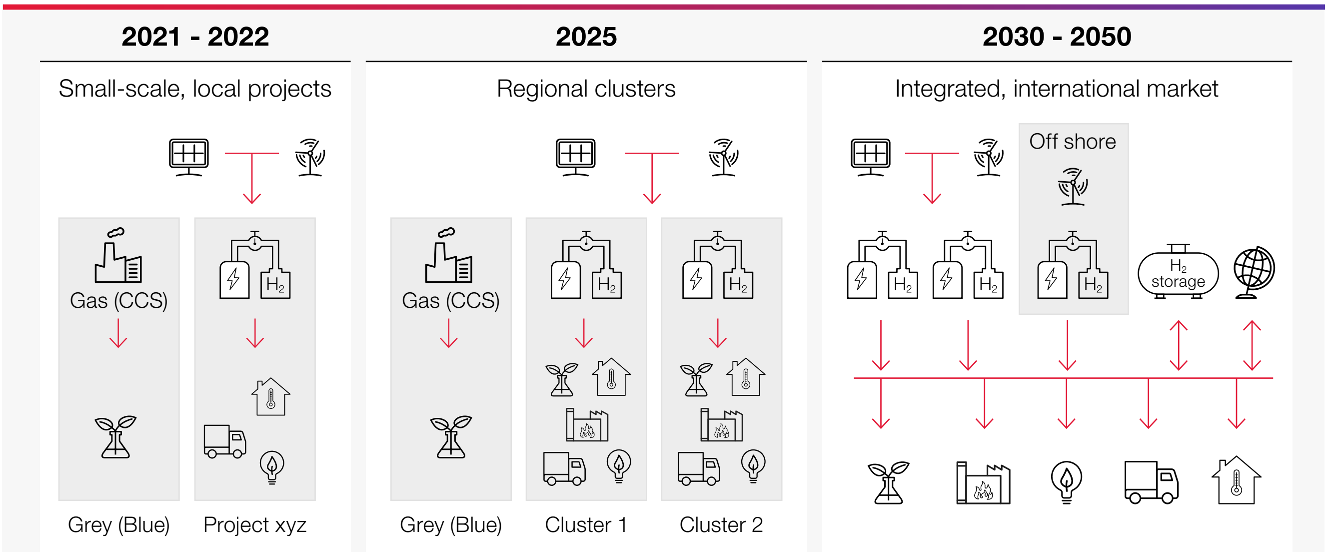


Figure 4: From small-scale projects and regional clusters to an integrated, international market

Design of a hydrogen market model

As the European Agency for Cooperation of Energy Regulators (ACER) also identified, the future development of infrastructure for transporting hydrogen raises questions about the possible need to regulate this infrastructure and the market[24]. Hydrogen is greenfield and can profit from the experiences of European regulations for existing gas and electricity markets. ACER proposes a gradual approach to regulate hydrogen networks that facilitates the dynamic nature and values the benefits of repurposing existing gas assets. The regulatory framework will be based on clear principles like unbundling, third-party access, transparency, non-discrimination and monitoring and oversight by the relevant regulatory authority. Temporary exemptions are to be allowed, for example, for B2B point-to-point pipelines.

The European Commission presented and published the first proposals for regulations and directives.[25] These will provide the conditions to make the shift from fossil natural gas to renewable and low-carbon gases, including hydrogen, and create an environment for a hydrogen market model.

Furthermore, a new governance structure will be introduced to promote a dedicated hydrogen infrastructure, cross-border coordination and interconnector network construction, and elaborate on specific technical rules called the European Network of Network Operators for Hydrogen (ENNOH).

As hydrogen production scales, the hydrogen market is expected to mature, with companies fulfilling one or more market roles, ranging from production, storage and transport to end-users.

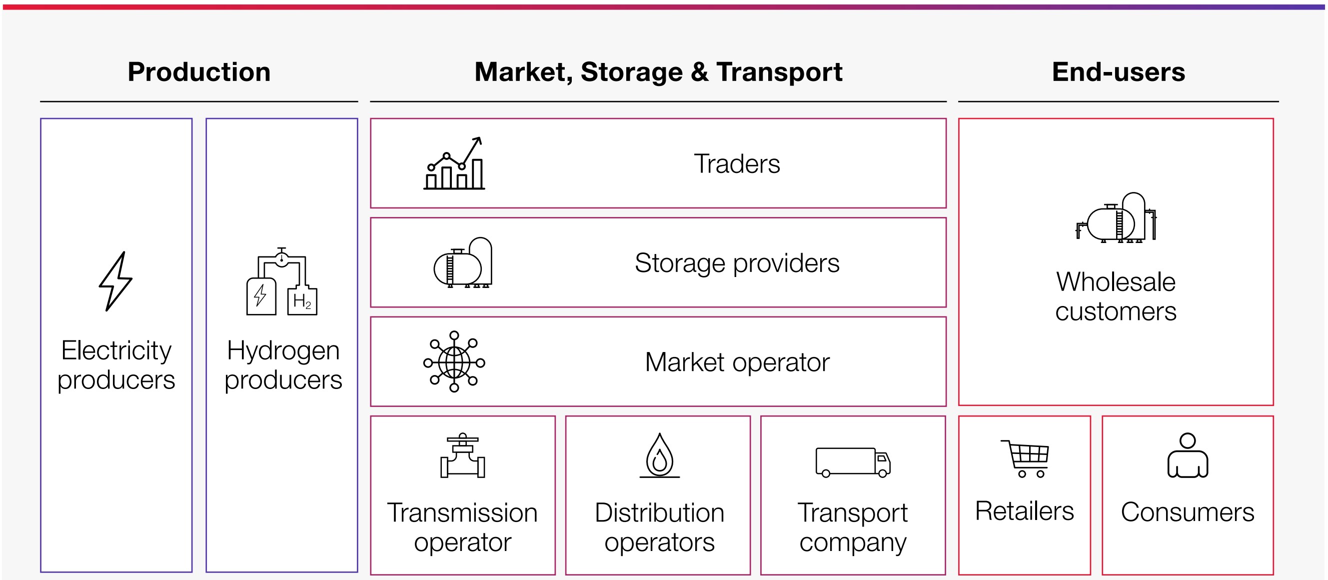


Figure 4: Our view of the high-level hydrogen market roles

On the production side, **electricity producers** are responsible for producing the electricity, for example, by using offshore or onshore wind farms and solar farms. **Hydrogen producers** operate an electrolysis plant to produce hydrogen. As the need for large-scale flexibility services for the electricity grid increases, sector coupling between electricity and hydrogen becomes more relevant. A single company will likely fulfill both the role of an energy producer and hydrogen producer to operate in both markets and make the best use of the renewable energy they produce with innovative optimization mechanisms. For example, this would be done by combining offshore wind with offshore electrolysis to produce hydrogen with the excess capacity or in times of curtailment, or by providing large-scale flexibility services to the electricity market.

Traders engage in forecasting, buying and selling hydrogen in one or more hydrogen markets and provide the crucial link for transactions between producers and end-users. **Storage providers** offer hydrogen storage capacity, for example, to optimize renewable energy and hydrogen production. Storage providers can be separate entities, or combined with, for example, hydrogen producers or customers.

As interconnections grow, we see a potentially vital role for a **market operator** to facilitate the hydrogen market by providing transparency, a level playing field and clear market processes for contracts, metering data and financial settlements.

Transmission operators are responsible for developing, operating and maintaining the hydrogen transmission network to transport hydrogen over long distances. **Distribution operators** are responsible for operating, maintaining and developing the hydrogen distribution network in a given area. We envision current natural gas transmission operators fulfilling the role of hydrogen transmission operators and repurposing existing assets where possible. The transport and distribution of hydrogen likely will be executed by a mix of public and private organizations. For areas without a hydrogen distribution or transmission infrastructure, a **transport company** will move hydrogen from one location to another using lorries, trucks or ships.

We see **large-volume industrial customers** who have direct access to the wholesale market being end-users. Initially, large industries are likely to have their own production and distribution facilities. As hydrogen production scales, we expect large-volume customers to (also) acquire hydrogen at the wholesale level. **Small-volume consumers**, who need hydrogen for their cars or trucks or for residential heating, will acquire hydrogen through a retailer. This **retailer** accesses the wholesale market through their trading partner.

Serving as your digitalization partner

CGI serves the entire energy value chain from production, generation and transmission and distribution operators to suppliers and central market operators. We focus on the end-to-end needs of our clients, providing industry-focused consulting, systems integration and managed services, accelerated by intellectual property to help them navigate the energy transition and remain competitive.

With our deep expertise in energy market liberalization, renewables management, asset data management and license to operate, we help you accelerate the energy transition as your digitalization partner for the hydrogen economy.

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