

## Hydrogen integration into the European energy system

### Introduction

The thrust of this chapter is to evaluate the current and planned European Union (EU) measures aimed at enhancing the role of clean hydrogen in achieving the long-term socio-economic viability of a climate-neutral energy system. Given the enduring challenges and the subsequent responses that have been characterising the energy landscape at the European level, the following discussion will adopt a bi-dimensional logic: on the one hand, the existing EU energy governance system will be examined against the most recent steps made by the EU institutions to bolster resiliency and provide flexibility to the system; on the other hand, more specific EU actions targeted at preparing the ground for a hydrogen economy will be analysed in light of the regulatory, infrastructural and cost-effectiveness needs.

The EU and its Member States have realised the importance of translating their vision towards 2040-50 into a roadmap, based on no-regret<sup>1</sup> options consistent with the strategy for 2030 (Fit-for-55), and on all the major decarbonised technologies, such as renewables coupled with energy efficiency, as well as green

<sup>1</sup> No-regret in this context can be understood as taking climate-related decisions or actions that make economic good sense, whether or not a specific climate threat actually materializes in the future.

hydrogen, biomethane, and synthetic fuels. The current system reflects, to a large extent, not only the concern for the supply of imported fossil fuels, but also the traditional distinction in different energy vectors (e.g., electricity, natural gas, etc.) and in different national systems. In the coming years, the European governance of energy will have to evolve towards multi-vector coordination and integration, and multi-level (EU, regional, national, and local) decision-making and governance (Tubiana et al. 2022). The future will imply a more decentralised energy system and, hence, a distributed decision process that must be incorporated into the policy framework to decarbonise Europe by 2050.

Still, the existing framework dates back to the adoption of the Clean Energy Package (published in 2016 and fully adopted in 2019), while the Fit-for-55 package (presented in July 2021), was followed by REPowerEU (published in May 2022), which further increased the Fit-for-55 climate ambitions. These last two frameworks rest on the European Green Deal (outlined in 2019 by the Von der Leyen I Commission), which sets the ultimate target of climate neutrality by 2050. Hydrogen fits into this scenario as a critical enabler of the energy transition, as clearly outlined in the EU Hydrogen Strategy, presented in 2020. The deployment of H<sub>2</sub> in Europe faces important challenges that neither the private sector nor Member States can address alone (European Commission 2020a). The key issue lies in driving (green) hydrogen development past the tipping point, for which a critical mass in investment, an enabling regulatory framework, new lead markets, and sustained research and innovation are needed. These elements - including a large-scale infrastructure network - can only be offered by an EU-wide market and by cooperation with third country partners (European Commission 2020a). If such cooperative approach between policymakers, industry and investors does not emerge and current policies remain in place (business-as-usual approach) hydrogen will see much lower deployment levels, and decarbonisation targets may remain unmet (Fuel Cells and Hydrogen Joint Undertaking 2019).

According to the FCH JU 2019 report, the EU has got several assets that make it particularly well-suited to lead in hydrogen and fuel cell technology. First, it has world-class players along the hydrogen and fuel cell value chains that can drive the development and deployment of hydrogen solutions. Second, it has strong research institutions in hydrogen and well-developed programmes to support research, development, and deployment (RD&D) at the EU, national, and regional levels. Third, the EU is committed to achieving environmental targets, such as increasing renewables, decreasing carbon emissions, and cutting local emissions, and environmental consciousness and awareness is high among its citizens. Fourth, it has an extensive natural gas network, which it can rely on to decarbonise industries and transports.

In view of these challenges, the following discussion is organised along three sections. First, an analysis of the EU regulatory context will be provided, with a focus on the role accorded in the Green Deal to clean molecules and hydrogen in particular. The second section will follow with an in-depth examination of the most recent EU initiatives to address the upscaling of both hydrogen demand

and supply. Finally, the missing piece of the puzzle, i.e. hydrogen infrastructure, will be considered from a regulatory, cost-efficiency and geo-economic perspective in the last section.

## 2.1 Updating the EU's regulatory context to meet the needs of the low-carbon transition

### 2.1.1 The «Clean Energy for all Europeans» Package

The Clean Energy Package (CEP) still represents one of the main legal frameworks on which the existing energy and climate legislation at the EU level is based, while it has been revised through the Fit-for-55 and REPowerEU initiatives. The CEP is only the fourth of the so-called «packages» that have shaped and steadily updated the European energy (mainly electricity and gas) markets. After the «First Energy Package», which consisted of an Electricity Directive (1996/92) and a Gas Directive (1998/30), the energy market liberalisation efforts were coupled with further market integration steps. The «Second Energy Package», adopted in 2003, contained two Directives (for gas and electricity) and one Regulation (on access to the network for cross-border exchanges in electricity), while mandating the creation of independent national regulatory authorities (NRAs). Thanks to this package, households and industrial consumers were free to choose their gas and electricity suppliers, thus fostering competition in the market. Finally, two Directives and three Regulations constituted the «Third Energy Package», adopted in 2009. The updated gas and electricity Directives were accompanied by the Regulation (713/2009) establishing the Agency for the Cooperation of Energy Regulators (ACER), the Regulation (714/2009) on conditions for access to the network for cross-border exchanges, and the Regulation (715/2009) on conditions for access to the natural gas transmission networks (Florence School of Regulation 2020a). An example of the increasing importance accorded to market integration and cross-border cooperation was the creation of the European Networks for Transmission System Operators for electricity and gas (ENTSO-E and ENTSO-G). The CEP contains four Directives and four Regulations, mostly concerning electricity and energy efficiency. Table 5 summarises the eight pieces of legislation contained in the CEP.

The objective of the CEP was thus to make the EU energy market suitable for the low-carbon transition, even though - unlike the previous packages - it did not include specific legislation for the gas sector, focusing instead on electricity. A separate new gas package was indeed foreseen to be put forward by the Commission in 2020, but also due to the emergency spurred by the COVID-19 pandemic and the subsequent policy initiatives (e.g., Next Generation EU), the new gas framework was proposed in conjunction with the Fit-for-55 package, in late 2021, and has been referred to as the «Hydrogen and Decarbonised Gas Market Package». The latter piece of legislation thus provides a sort of complement to the CEP, since it is crucial to create a consolidated framework and provide regulatory certainty to facilitate the integration of low-carbon and renewable gases into the market.

Table 5 – Acts adopted under the Clean Energy Package. Source: own elaboration based on European Commission (2019) and Florence School of Regulation (2020a and 2020b).

Subject of the act	Type of act	Publication on the OJEU	Content of the act
Energy Performance of Buildings	Directive 2018/844	19 June 2018	Member States are obliged to establish a long-term renovation strategy to support the renovation of the national stock of residential and non-residential buildings into a highly energy efficient and decarbonised building stock by 2050; <sup>2</sup>
Energy Efficiency	Directive 2018/2002	21 December 2018	EU-level target of 32.5% for energy efficiency for 2030, compared to a baseline scenario established in 2007, with a possible upward revision in 2023; «Energy efficiency first» principle;
Renewable Energy	Directive 2018/2001	21 December 2018	Binding target of 32% for renewable energy sources in the EU's energy mix by 2030, with a possible review for an increase in 2023;
Electricity	Directive 2019/944	14 June 2019	Rules for the generation, transmission, distribution, supply and storage of electricity (market design); consumer empowerment and protection aspects;
Electricity	Regulation 2019/943	14 June 2019	Principles for the internal EU electricity (wholesale) market and network operation; New bidding zone review process and establishment of regional coordination centres, replacing the regional security coordinators, and complementing the transmission system operators' roles on a regional scope;
Governance of the Energy Union and Climate Action	Regulation 2018/1999	21 December 2018	New governance system for the Energy Union; Each Member State is to establish an integrated 10-year National Energy and Climate Plan (NECP) for 2021 to 2030, with a longer-term view towards 2050; The plan is to outline how the Member State will achieve its respective targets;
Risk Preparedness in the electricity sector	Regulation 2019/941	14 June 2019	Requirement for Member States to prepare plans on how to deal with potential future electricity crises;
ACER	Regulation 2019/942	14 June 2019	Update of the role and functioning of the European Union Agency for the Cooperation of Energy Regulators (ACER); increase in the competence of the ACER in cross-border cooperation;

<sup>2</sup> Buildings are responsible for around 40% of energy consumption and around 30% of CO<sub>2</sub> emissions in the EU, making them the single largest energy consumer in Europe (European Commission 2019).

### 2.1.2 The EU Hydrogen Strategy: A Roadmap for the EU

The Communication<sup>3</sup> presented in July 2020 to the European Parliament and Council by the European Commission referred to as the «EU Hydrogen Strategy» has got at its core the goal of the Commission to significantly reduce the production costs of «green» hydrogen, so as to make it competitive with fossil-based H<sub>2</sub>. The strategy includes however also a long-term geopolitical and industrial ambition: Europe is a highly competitive player in clean H<sub>2</sub> production technologies, and it could reap significant benefits from the development of a global hydrogen market (Grossi 2020)<sup>4</sup>. The difference between the past peaks of interest in hydrogen and today's situation is mainly due to the rapid developments in renewable energy technologies and the subsequent cost decline of renewables, which open new possibilities for hydrogen. The 2020 EU Hydrogen Strategy estimated that cumulative investments in renewable hydrogen in Europe could be up to €180-470 billion by 2050, and in the range of €3-18 billion for low-carbon and fossil-based H<sub>2</sub>, while employing more than 1 million people in the hydrogen value chain (European Commission 2020a). Table 6 summarises the stages into which the Commission decided to divide the H<sub>2</sub> strategy<sup>5</sup>. While the H<sub>2</sub> market is likely to develop through a gradual trajectory and at different speeds across sectors, the policy focus must be initially on laying down the regulatory framework for a liquid and well-functioning market and on incentivising both supply and demand in lead markets (mainly industrial applications and mobility), including through bridging the cost gap between conventional solutions and renewable and low-carbon hydrogen and through appropriate State aid rules (European Commission 2020a).

Table 6 – Phases of the EU Hydrogen Strategy. Source: own elaboration based on European Commission (2020a) and Tarvydas (2022).

	Phase 1: 2020-2024	Phase 2: 2025-2030	Phase 3: 2030-2050
H <sub>2</sub> technology and market maturity	Renewable H <sub>2</sub> use is limited to sectors already employing hydrogen (chemicals)	Gradual integration of H <sub>2</sub> into the energy system and into new applications (steelmaking, trucks, rail, maritime applications)	Technological maturity of renewable H <sub>2</sub> , application in all hard-to-abate sectors and balancing role for renewable-based electricity systems

<sup>3</sup> COM 2020/301 final

<sup>4</sup> As stated by European Commission's President Ursula von der Leyen in her 2023 State of the Union speech, on 13<sup>th</sup> September 2023, the modernisation of Europe's industry goes hand in hand with decarbonisation, and the EU's ambition to promote clean technologies aligns with the hydrogen industry's vision for a sustainable future and supports the «Made in the EU» concept. See: [https://ec.europa.eu/commission/presscorner/detail/en/speech\\_23\\_4426](https://ec.europa.eu/commission/presscorner/detail/en/speech_23_4426).

<sup>5</sup> The electrolyser and production targets set out in the strategy are not legally binding.

	Phase 1: 2020-2024	Phase 2: 2025-2030	Phase 3: 2030-2050
Electrolyser installed capacity	6 GW	40 GW	500-550 GW (max scenario) <sup>6</sup>
Production of renewable H <sub>2</sub>	Up to 1 million tonnes (Mt) <sup>7</sup>	Up to 10 Mt	Up to 70 Mt
Infrastructure	Infrastructure needs for transporting hydrogen will remain limited	The need for an EU-wide logistical infrastructure will emerge	Fully developed EU hydrogen network in place (with connections to non-EU countries)

The rules designed and proposed so far by the EU institutions are targeted at an emerging market that should first establish itself. In 2025, market growth has remained insufficient to meet EU and national targets, as electrolyser capacity only reached 308 MW in 2024, hence way behind the 6 GW target for 2024 and 40 GW for 2030 (European Union Agency for the Cooperation of Energy Regulators 2025).

It is interesting to address the progresses made by the EU from the publication of the H<sub>2</sub> strategy in 2020 up to the time of writing. This can be done by assessing the 20 «key actions» outlined in the document of the EU Hydrogen Strategy, and reported in Table 7, together with the follow-up information about their implementation. These actions are sub-divided into five dimensions: 1) an EU investment agenda, 2) actions to boost hydrogen demand and production, 3) a supportive framework for infrastructure and market rules, 4) promotion of research and innovation in H<sub>2</sub> technologies, and 5) the international dimension.

Table 7 – Key Actions of the EU Hydrogen Strategy. Source: own elaboration based on European Commission (2020a) and European Commission: [https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen/key-actions-eu-hydrogen-strategy\\_en](https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen/key-actions-eu-hydrogen-strategy_en).

Dimension	Key Actions	Follow-up information
An EU investment agenda	Develop an investment agenda to stimulate the roll out of production and use of hydrogen and build a concrete pipeline of projects, through the European Clean Hydrogen Alliance.	Over <b>840 projects</b> have been collected under the Clean Hydrogen Alliance

<sup>6</sup> The same amount of intermittent renewable capacity should be added to provide electricity. The required capacity could be reduced by installing short-term energy storage (batteries). In order to meet electricity demand for green hydrogen production in the EU, installed wind capacity will need to grow by 50% between 2020 and 2030 in the average hydrogen demand scenario (around 40 Mt). In the maximum scenario (around 68 Mt), both solar and wind installed capacity would have to almost triple (Tarvydas 2022).

<sup>7</sup> A kilogramme of hydrogen has an energy value of about 33.3 kWh, so a tonne of hydrogen delivers about 33 MWh and a million tonnes about 33 terawatt hours (TWh).

Dimension	Key Actions	Follow-up information
An EU investment agenda	Support strategic investments in clean hydrogen in the context of the Commission's recovery plan, in particular through the Strategic European Investment Window of InvestEU.	At the end of 2021, 15 EU countries had included <b>hydrogen in their Recovery and Resilience Plans</b>
actions to boost hydrogen demand and production	Propose measures to facilitate the use of hydrogen and its derivatives in the transport sector in the Commission's Sustainable and Smart Mobility Strategy, and in related policy initiatives.	The <b>Sustainable and Smart Mobility Strategy</b> was published in December 2020
actions to boost hydrogen demand and production	Explore additional support measures, including demand-side policies in end-use sectors, for renewable hydrogen building on the existing provisions of the Renewable Energy Directive.	The revision of the RED includes <b>sector-specific targets for renewable H<sub>2</sub></b> in industry and transport
actions to boost hydrogen demand and production	Work to introduce a common low-carbon threshold/standard for the promotion of hydrogen production installations based on their full life cycle GHG performance.	The Hydrogen and Gas package requires the European Commission to adopt a <b>common definition for low-carbon hydrogen</b> (see section 1.4.1)
actions to boost hydrogen demand and production	Work to introduce a comprehensive terminology and European-wide criteria for the certification of renewable and low-carbon hydrogen.	The RED and the revised Gas Directive include <b>certification schemes for renewable and low-carbon hydrogen</b>
actions to boost hydrogen demand and production	Develop a pilot scheme for a Carbon Contracts for Difference programme, in particular to support the production of low carbon and circular steel, and basic chemicals.	The <b>revised EU ETS</b> includes the option to introduce CCfDs <sup>8</sup>
a supportive framework for infrastructure and market rules	Start the planning of hydrogen infrastructure, including in the Trans-European Networks for Energy and Transport and the Ten-Year Network Development Plans (TYNDPs).	The Hydrogen and Gas Package includes <b>coordinated planning for hydrogen infrastructure</b>

<sup>8</sup> CCfDs are contracts between a public administration and a company that set a fixed carbon price over a given period, which reduces the investment risk for companies that want to adopt GHG-neutral technologies, and shares the CO<sub>2</sub> costs between public and private entities. If the market price for emission allowances (EU ETS) is lower than the carbon avoidance costs for the company, the public administration pays the difference to the company. If the carbon price is higher, the company must pay the difference to the public administration. See: <https://cefic.org/media-corner/newsroom/whats-next-for-carbon-contracts-for-difference-and-can-they-really-boost-innovation-in-europe/>.

Dimension	Key Actions	Follow-up information
a supportive framework for infrastructure and market rules	Accelerate the deployment of different refuelling infrastructure in the revision of the Alternative Fuels Infrastructure Directive and the revision of the Regulation on the Trans-European Transport Network.	The <b>Alternative Fuels Infrastructure Regulation</b> (AFIR) and Trans-European Transport Network revision include support for hydrogen refuelling stations
a supportive framework for infrastructure and market rules	Design enabling market rules to the deployment of hydrogen through the review of the gas legislation for competitive decarbonised gas markets.	The Hydrogen and Decarbonised Gas Markets Package includes an <b>enabling framework for H<sub>2</sub> infrastructure and markets</b>
promotion of research and innovation in H <sub>2</sub> technologies	Launch a 100 MW electrolyser and a Green Airports and Ports call for proposals as part of the European Green Deal call under Horizon2020 <sup>9</sup> .	The Horizon2020 call resulted in the financing of three <b>100 MW renewable H<sub>2</sub> electrolysers</b> in Germany, the Netherlands and Portugal.
promotion of research and innovation in H <sub>2</sub> technologies	Establish the proposed Clean Hydrogen Partnership, focusing on renewable hydrogen production, storage, transport, distribution and key components for priority end-uses.	The <b>Clean Hydrogen Partnership</b> was established in November 2021
promotion of research and innovation in H <sub>2</sub> technologies	Steer the development of key pilot projects that support hydrogen value chains, in coordination with the SET Plan <sup>10</sup> .	Hydrogen has been integrated into <b>implementation Working Group on Renewable Fuels</b> under the SET Plan activities
promotion of research and innovation in H <sub>2</sub> technologies	Facilitate the demonstration of innovative hydrogen-based technologies through the launch of calls for proposals under the ETS Innovation Fund.	The first round of the <b>Innovation Fund</b> included 3 large-scale and 5 small-scale hydrogen projects
promotion of research and innovation in H <sub>2</sub> technologies	Launch a call for pilot action on interregional innovation under Cohesion Policy on Hydrogen Technologies in carbon-intensive regions.	The interregional innovation action supported the « <b>European Hydrogen Valley partnerships</b> »
The international dimension	Strengthen EU leadership in international fora for technical standards, regulations and definitions on hydrogen.	The <b>International Partnership for a Hydrogen Economy</b> (IPHE) published a report on GHG emissions associated with H <sub>2</sub> production

<sup>9</sup> Horizon2020 was the EU's research and innovation funding programme from 2014 to 2020 and has been replaced by Horizon Europe (EU programming cycle 2021-2027).

<sup>10</sup> The Strategic Energy Technology Plan (SET Plan) is an instrument (established in 2007) with the goal to improve new and low-carbon technologies and bring down their costs, by promoting cooperation among EU countries, companies, and research institutions.

Dimension	Key Actions	Follow-up information
The international dimension	Develop the hydrogen mission within the next mandate of Mission Innovation <sup>11</sup> .	A « <b>Clean Hydrogen Mission</b> » was launched in 2021 under Mission Innovation
The international dimension	Promote cooperation with Southern and Eastern Neighbourhood partners and Energy Community countries on renewable electricity and hydrogen.	The EU's joint communication on the <b>Southern Neighbourhood</b> has established hydrogen as a new strategic priority, and a hydrogen workshop has been established with the <b>Eastern Partnership</b>
The international dimension	Set out a cooperation process on renewable hydrogen with the African Union.	The « <b>Africa-EU Green Energy Initiative</b> » was launched in 2022
The international dimension	Develop a benchmark for euro denominated transactions by 2021.	Hydrogen was included in a <b>communication to the European Central Bank</b> in 2021

### 2.1.3 The EU Energy System Integration Strategy

The EU strategy on hydrogen is complemented by the Strategy for Energy System Integration (ESI), which was released at the same time, in July 2020. Without adopting a systemic perspective, it is indeed more difficult - if not impossible - to exploit the transformations occurring in one sector to foster advancements in other sectors of the energy system. The latter today is still built on several parallel, vertical energy value chains, which rigidly link specific energy resources with specific end-use sectors (European Commission 2020b). For instance, petroleum products are predominant in the transport sector and as feedstock for industry. Coal and natural gas are mainly used to produce electricity and heating. Electricity and gas networks are planned and managed independently from each other. Market rules are also largely specific to different sectors. According to the ESI strategy, such a model of separate silos is technically and economically inefficient and leads to substantial losses in the form of waste heat and low energy efficiency. This is why emerging technologies, such as renewable hydrogen, can not only contribute to decarbonisation, but can transform the same structure of the energy system, by integrating different energy carriers flexibly and fostering decentralisation.

Energy system integration can be defined as «the coordinated planning and operation of the energy system as a whole, across multiple energy carriers, infrastructures, and consumption sectors» (European Commission 2020b). The main idea behind integrated energy systems, which are also known as «multi-energy systems» or «hybrid energy systems», is to move from a single energy carrier to multiple energy carriers to exploit the synergies from their interplay,

<sup>11</sup> Mission Innovation is a global initiative on clean energy launched at the COP21, which the EU joined in 2016.

thereby increasing the efficiency in the energy resources used (Graditi and Di Somma 2022). In their book *Technologies for Integrated Energy Systems and Networks*, Graditi and Di Somma (2022) define this concept as an integrated infrastructure for all energy carriers with the electrical system as a backbone, characterised by a high level of integration between all networks of energy carriers, coupling of electrical and gas networks, heating and cooling, supported by energy storage and conversion processes. Figure 10 shows such a concept, which links the various energy carriers with each other and with the end-use sectors (households, tertiary sectors, industry and transport).

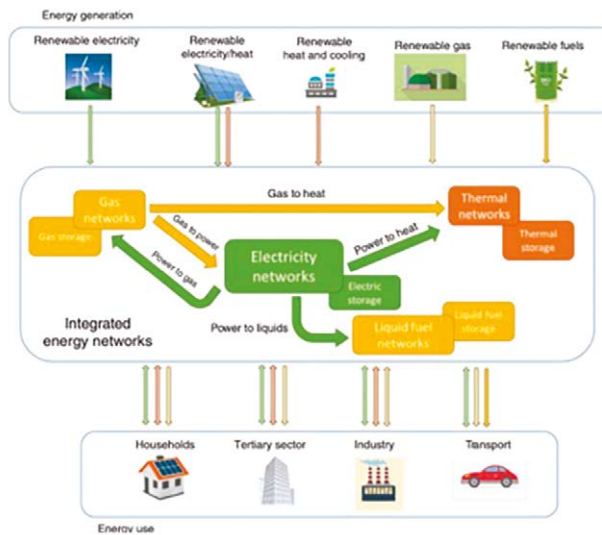


Figure 10 – Scheme of an integrated energy system. Source: Graditi and Di Somma (2022).

Therefore, energy system integration relies on «sector coupling» to achieve full integration. Sector coupling can be defined as «the process of progressively interlinking the electricity and gas sectors - by optimising the existing synergies in the generation, transport, and distribution of electricity and gas - with the ultimate scope to build a decarbonised and hybrid EU energy system» (Florence School of Regulation 2020c). Therefore, despite being limited to electricity and gas, sector coupling is the key to integrate more sectors in the future, given the projected increase in electrification of end-uses, and the enhanced role of clean molecules (mainly biomethane and hydrogen). Power-to-Gas (P2G) technologies, already mentioned in this work, are a typical - and rather new - instrument to foster sector coupling, because they can serve the double purpose of converting curtailed electricity into renewable (or low-carbon) hydrogen (depending on the type of electricity used) for storage or direct use, and even into natural gas (after methanisation) (Florence School of Regulation 2020c). As reported

in Van Nuffel (2018), sector coupling leads to a lower overall cost, mainly because of reduced investment costs, since the lower peaks in electricity demand and supply allow for less reinforcement investments in the electricity transmission and distribution grids and require less gas-based power generation capacity. Hence, also efficiency can be higher in a system with sector coupling, which uses assets in a more economical way. This is why the EU ESI Strategy aims at gradually shaping a new integrated energy system, by putting forward concrete policy measures that have been divided into six main pillars: 1) a circular energy system based on efficiency, 2) increased electrification based on renewable energy sources, 3) renewable and low-carbon fuels in hard-to-abate sectors, 4) empowering consumers' choice, 5) infrastructure integration, and 6) digitalisation for a smarter interconnection.

The pillars of the ESI Strategy have been confronted with numerous challenges. Firstly, the application of the «energy efficiency first» principle must materialise, while the Primary Energy Factor (PEF)<sup>12</sup> can be used as a tool to facilitate comparisons of savings across energy carriers. Secondly, electrification has shown a slower pace, increasing only by 5% in the last thirty years (European Commission 2020b). For this reason, and according to the provisions of the new RED III (see section 2.1.4.2. below), it is crucial to accelerate permitting for installing renewable power capacity and further electrify the energy mix. Part of such newly installed renewable capacity must be used to ramp-up clean hydrogen production, as this molecule is a critical enabler of system integration, and methane-based H<sub>2</sub> with CCS has been facing a too slow growth. This is also because a proper CCS system needs an integrated infrastructure to manage and transport CO<sub>2</sub>. It is important to keep in mind that infrastructure investments typically have an economic life of 20 to 60 years, so there can also be a serious risk of lock-in effects and stranded assets.

#### 2.1.4 «Fit for 55» Package and «REPowerEU» Plan

##### The Fit-for-55 Package

The European Commission presented the «Fit-for-55» Package in July 2021 to implement and achieve the aims of the European Climate Law, which took effect on 29<sup>th</sup> July 2021. The package consisted of thirteen interlinked strategic and legislative proposals to revise existing EU energy and climate laws and six proposals to adopt new legislation. After setting ambitious targets such as climate neutrality by 2050 and a 55% reduction of net GHG emission by 2030, the European Commission also designed an equally ambitious and strict timeline to reach those objectives, which however must consider the possible frictions

<sup>12</sup> The primary energy factor (PEF) indicates the amount of primary energy used to generate a unit of final energy (electrical or thermal), allowing a comparison of the primary energy consumption of products with the same functionality using different energy carriers (European Commission 2020b).

and obstacles enshrined in the EU ordinary and special legislative procedures. As is being demonstrated at the time of writing, final decisions on some of the proposed legal acts have yet to be made, while other acts have been recently adopted or politically agreed upon<sup>13</sup>.

Some of the changes proposed through the «Fit-for-55» Package are not limited to one specific sector or sub-sector, but are intended as cross-sectoral regulatory acts, that contribute to integrating the energy system to other sectors. Figure 11 provides an explanatory overview of those linkages between sectors and shows the legislation proposed to realise the objectives of the EU Climate Law. The key areas of action of Fit-for-55 are the energy, buildings, and transport sectors. Some links between the key proposals imply, for instance, that the revised Gas and Hydrogen Regulation and Gas and Hydrogen Directive (both part of the «Hydrogen and Decarbonised Gas Market Package») refer to the revised Renewable Energy Directive (RED) for the definition of renewable gas. In turn, both the RED and the Energy Performance of Buildings Directive (EPBD) refer to definitions included in the revised Energy Efficiency Directive (EED)<sup>14</sup>. The latter and the proposal for a Social Climate Fund (SCF) refer to each other with respect to the use of the fund<sup>15</sup>. Finally, the Energy Taxation Directive (ETD)<sup>16</sup> refers to the definitions in the revised RED and in the new Alternative Fuels Infrastructure Regulation (Erbach and Jensen 2022).

<sup>13</sup> Among the key proposals for new and updated legislation, the European Parliament and the Council of the EU formally adopted the revised Renewable Energy Directive in October 2023; the new Energy Efficiency Directive was formally adopted in July 2023, as well as the Fuel EU Maritime Regulation and the ReFuelEU Aviation to decarbonise maritime and air transport applications; the new Alternative Fuel Infrastructure Regulation (AFIR) was also adopted in July 2023, which is also relevant for hydrogen integration in the transport sector; the new ETS was adopted after two years of negotiations in line with the objectives of the EU Climate Law; finally, the Hydrogen and Decarbonised Gas Markets Package, which is one of the cornerstones of the EU hydrogen policy, was formally adopted in April 2024.

<sup>14</sup> The Fit-for-55 proposal to amend the EED provided for an increase of the Union's binding energy efficiency target for final and primary consumption of at least 9% in 2030 compared with the projections of the 2020 reference scenario, thus expressing the target in a different manner in comparison to the EED adopted under the Clean Energy Package (32.5% compared to 2007 scenario), and representing raised ambitions. The energy efficiency target has been further increased by the REPowerEU Plan (see next paragraph).

<sup>15</sup> As part of Fit-for-55, the European Commission proposed to create a Social Climate Fund to address the social impacts that might arise from the revised Emission Trading System, that has been extended to the buildings and road transport sectors.

<sup>16</sup> The initial ETD (Directive 2003/96/EC) was aimed at providing a harmonised framework for imposing taxation on energy products and electricity in the EU Member States. Its proposed revision focuses on the structure of the tax rates (based on the real energy content and environmental performance of fuels and electricity, rather than on volume) and on broadening the taxable base (by including more products and abolishing some of the current tax exemptions) (Schlacke *et al.* 2022).

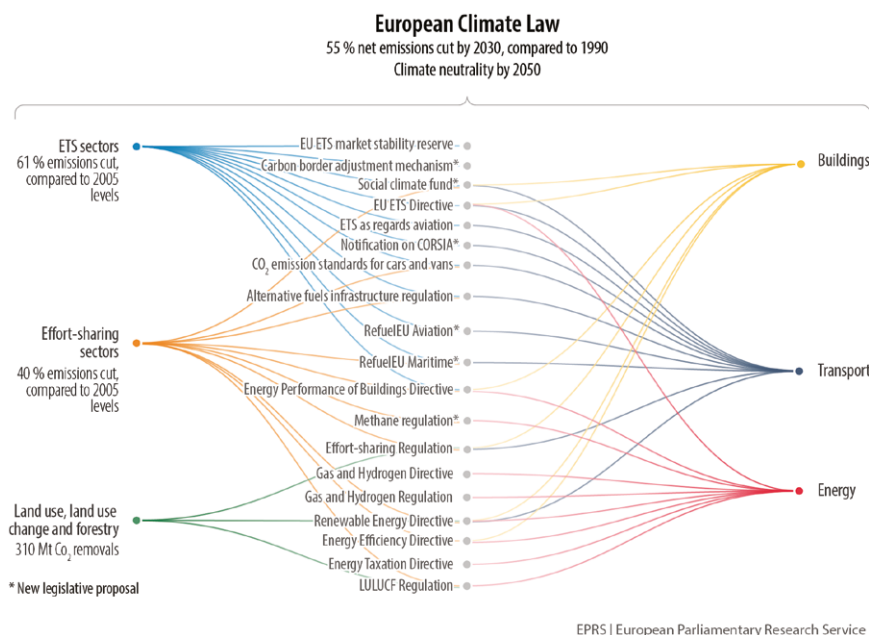


Figure 11 – The «Fit-for-55» Package. Source: Erbach and Jensen (2022).

### The REPowerEU Plan

While the legislative proposals introduced with the «Fit-for-55» Package were being negotiated by the EU institutions, the European Commission published the REPowerEU Plan on 18<sup>th</sup> May 2022, to respond to the energy market disruptions sparked by Russia’s war against Ukraine<sup>17</sup>. This initiative included actions in four key areas, which had been also affected by the tightening of energy supply chains and increased gas prices since late 2021. The plan includes efforts targeted at diversifying and securing the EU’s energy supplies, as well as saving energy and boosting renewables. The updates that REPowerEU has brought to Fit-for-55 are aimed at preserving and strengthening the EU’s climate policy trajectory, including enhanced targets for green and low-carbon gases, such as biomethane and hydrogen. Table 8 gives an overview of the main amendments put forward with REPowerEU concerning the Fit-for-55 legislative proposals. Besides the short-term measures taken to fill gas storages and diversify the energy supply away from Russian fossil fuels, the REPowerEU Plan has focused on a series of targeted amendments to the RED, the EED, and the EPBD. Since all three directives were already in the process of being revised as part of Fit-for-55, the amendments are meant to feed into this ongoing process of legislative revision.

<sup>17</sup> COM 2022/230.

Table 8 – Main legislative updates of REPowerEU. Source: own elaboration based on European Parliament (2023a).

Legislative act	Fit-for-55 Package	REPowerEU Plan
Renewable Energy Directive <sup>18</sup>	RES in final energy consumption: <b>40%</b>	RES in final energy consumption: <b>45%</b>
Energy Efficiency Directive <sup>19</sup>	Energy Efficiency target: <b>9%</b> reduction in primary energy consumption by 2030 compared to 2020	Energy Efficiency target: <b>13%</b> reduction in primary energy consumption by 2030 compared to 2020
Energy Performance of Buildings Directive	All new buildings must be zero-emission buildings by 2030; existing buildings must be transformed into <b>zero-emission buildings by 2050</b>	Additional obligation for Member States to ensure new buildings are <b>solar-ready</b> and to install solar energy installations on buildings, covering all new residential buildings from 2030

Given the scope of this thesis, the REPowerEU Plan will be mentioned in the light of the initiatives targeted at developing hydrogen, even though some other major changes have been rolled out by the European Commission to strengthen the EU energy system. One critical measure is represented by the mandate to add a «REPowerEU chapter» in the National Recovery and Resilience Plans (NRRPs), thus also increasing the financial resources to bring about decarbonisation<sup>20</sup>. Furthermore, boosting the industrial low-carbon transition and the use of renewables are two key areas of action, as well as investments in energy infrastructures and interconnections.

#### 2.1.4.1 Hydrogen and Decarbonised Gas Market Package

The revision of the Gas Directive (2009/73/EC) and the Gas Regulation (2009/715/EC) is part of the «Hydrogen and Decarbonised Gas Market Package» (HDGMP), proposed by the European Commission in December 2021. Two years after, in December 2023, the EU's legislative institutions managed to agree on a final version of both the Directive and Regulation, both of which were formally adopted in early 2024, with the aim to create a favourable regulatory environment for the uptake of the so-called «clean molecules». In 2021, power and heating generation represented the largest share of natural gas use in the EU at roughly 31% of overall consumption, while around 24% of gas was used by households, and a further 23% by the industry sector (European Council 2023). The EU's total natural gas consumption was around 343 billion cubic

<sup>18</sup> The revised Renewable Energy Directive (RED III) was formally adopted by both Council and Parliament in Autumn 2023 (see section 2.1.4.2).

<sup>19</sup> After the EU Parliament and the Council of the EU had adopted the new rules to reduce final energy consumption at EU level by 11.7% in 2030, the new EED entered into force in late 2023.

<sup>20</sup> This aspect will be discussed in Chapter 3 when analysing Italy's hydrogen policies.

metres in 2022 (Statista 2023)<sup>21</sup>. A significant amount of this demand is likely to be electrified in the future as it is typically more efficient in the context of a renewable-dominated energy mix. Within this context, projections for the gas sector broadly envisage a diminished overall role for molecules (Olczak and Piebalgs 2019). However, there is likely to still be a requirement for significant volumes of molecular energy. This is due in part to the physical properties of energy in such a form. According to the TYNDP 2022 Scenario Report<sup>22</sup>, current national policies show a large role for methane with very limited evolution of the demand until 2030, when the methane demand will decrease with the implementation of the strategy of some Member States which see the uptake of their hydrogen demand (ENTSO-E and ENTSO-G 2022). Figure 12 clearly shows that the current share of fossil gas consumption will have to be almost completely replaced by clean molecules (biogas, hydrogen, and e-gases) by 2050.

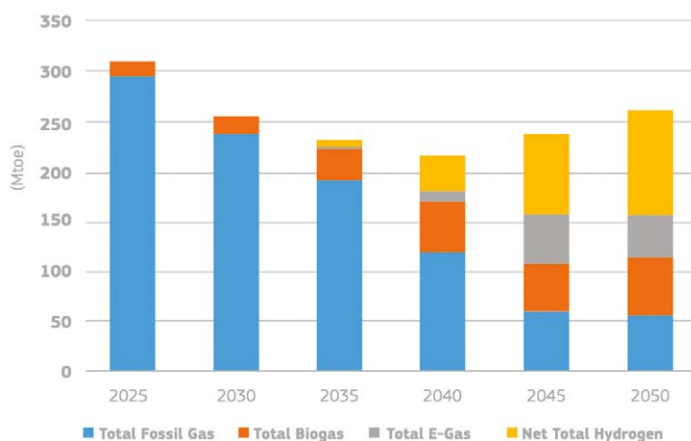


Figure 12 – Total consumption of gaseous fuels in 2050 [Mtoe]<sup>23</sup>. Source: European Commission (2021a).

The Commission's initial proposal set two main goals. On the one hand, the package had to establish the legislative base for the decarbonisation of gas markets, and on the other hand, it was aimed at creating a hydrogen market (Tanase and Anchustegui 2022). These objectives will contribute to putting Europe at the forefront in terms of regulatory innovation in an area that is expected to be a vital component of the energy transition. The latter goal includes the crea-

<sup>21</sup> Currently, some 300 Mtoe (350-400 bcm) of gaseous fuels are consumed in the EU per year, of which 95% is natural gas.

<sup>22</sup> TYNDP refers to the Ten-Year Network Development Plan, prepared jointly by European Network of Transmission System Operators for electricity (ENTSO-E) and gas (ENTSO-G) every two years.

<sup>23</sup> 1 Mtoe = 1.11 billion cubic metres (bcm) of natural gas.

tion of regulatory incentives towards a fit-for-purpose infrastructure where hydrogen can be cost-effectively transported from production to consumption (Tanase and Anchustegui 2022). Table 9 summarises the key areas of revision of the rules within the HDGMP, as proposed by the European Commission at the end of 2021.

Table 9 – Key areas of revision in the European Commission’s HDGMP proposal. Source: own elaboration based on Tanase and Anchustegui (2022).

Area of revision	Proposal of the European Commission
Infrastructure	Adaptation of the Gas Directive and Gas Regulation to accommodate renewable and low-carbon gases (including hydrogen and biomethane) and to <b>enable the repurposing of the existing gas infrastructure</b> for their transport, storage and import.
Market design	Design of a <b>hydrogen and market framework</b> (third party access, tariffs, unbundling, ban of long-term gas supply contracts after 2049).
Inter-TSO cooperation	Creation of the <b>European Network of Network Operators for Hydrogen (ENNOH)</b> to promote a dedicated hydrogen infrastructure, cross-border coordination, interconnector network construction, and elaborate specific technical rules.
Cross-border cooperation	<b>5% cap for hydrogen blend</b> at cross-border interconnection points from 1st October 2025.
Consumers’ protection	Consumer protection rules modelled on the ones applicable to electricity markets, <b>facilitating supplier switching, price comparisons</b> , and getting accurate data on consumption.
Renewable certificates	A <b>certification system for renewable and low-carbon gases</b> in line with the rules of the Renewable Energy Directive applicable to renewable gases.
Security of energy supply and gas storage	Measures to cover renewable and low-carbon gases, as well as introducing additional provisions on critical areas, namely <b>cybersecurity and supply disruptions</b> ; Development of a <b>strategic approach to gas storage</b> by incorporating storage considerations into energy risk assessments.

One critical aim of the HDGMP is to ensure a more integrated network planning between electricity, gas and hydrogen networks, as emphasised in the EU Strategy for Energy System Integration. According to the Commission, at the national level, there may continue to be two separate network plans for gas and electricity, but both will need to be developed on the basis of a joint scenario covering electricity, gas and hydrogen, as this helps to ensure that there is a common vision between different energy vectors in the future (European Commission, 2021a)<sup>24</sup>. The initial HDGMP proposal introduced an additional

<sup>24</sup> The network plans should also provide transparency on network parts that will not be needed anymore or could be used for transporting hydrogen in the future, as well as providing indications for the optimal size and location of power-to-gas facilities such as electrolyzers.

national network planning for hydrogen and an EU-wide ten-year network development plan, which would include the modelling of an integrated network, build on national hydrogen network plans, national investment plans, cross-border interconnectors, and identify gaps in investments. The revised Gas Directive, as agreed by the EU legislators, requires gas TSOs and hydrogen network operators to prepare every two years a ten-year network development plan for methane and H<sub>2</sub>, while hydrogen distribution network operators must cooperate with electricity and natural gas distributors to develop a network plan every four years (Council of the European Union 2023c).

Infrastructure is thus the keystone of the future development of an integrated hydrogen market. The European Commission assumes that there will be two gaseous networks: a methane-based infrastructure, which will evolve from the current natural gas-based system to one which uses more biomethane and synthetic methane; and a hydrogen-based infrastructure, which will complement and partly replace the current natural gas one (Barnes 2023). This is why also a separate organisation for hydrogen operators (ENNOH) was included in the initial proposal, and it has been kept in the final agreement between the Council and Parliament (Council of the European Union 2023d), even though the latter institution had insisted on expanding the role of the already existing ENTSO-G to also cover hydrogen network operators, thus becoming an “ENTSO-G&H” and avoiding the creation of the ENNOH (European Parliament 2023b). Although we could claim that integrating those operators into the already existing ENTSO-G would have been faster and could have provided benefits from common expertise, the revised legislation requires ENTSO-G to also prepare the hydrogen network plans for a transition period (until 2027) until the ENNOH is established (Council of the European Union 2023d). The creation of a new separate entity to coordinate future hydrogen operators could be also justified by the fear (mostly felt by the Council) that having one single ENTSO-G&H might give an incentive to incumbent (natural gas) operators to exclude potential new entrants, thus distorting the market to their advantage.

Regarding hydrogen networks, the Commission initially proposed to abolish tariffs at interconnection points between different Member States from 2031 (Barnes 2023). Given that tariffs would have been equal to zero, the national regulatory authorities (NRAs) should have agreed a system of financial compensation for cross-border H<sub>2</sub> infrastructure, because tariffs are usually the essential means through which network operators recover their revenue and thus enable the physical flow of gas in the system. Cross-border tariffs reflect the cost of moving gas from one network in one country to another. The proposal to remove such tariffs on hydrogen networks was based on the Commission’s idea that cross-border transport tariffs hinder trade<sup>25</sup>. However, as we pointed out,

<sup>25</sup> This element is known as «pancaking issue», which refers to the accumulated effect of cross-border tariffs on the delivered price of natural gas or hydrogen that crosses several borders from point of entry into the EU grid to point of delivery. For example, depending

removing those tariffs will require several network operators to agree revenue-sharing mechanisms which would be complex.

As a result, the EU's co-legislators agreed that for the hydrogen market every national regulatory authority must consult the neighbouring NRAs on the draft tariff methodology and submit it to the Agency for the Cooperation of Energy Regulators (ACER), while each Member State, and thus every NRA, will maintain the right to set its own tariff (Council of the European Union 2023d). The revised Gas Regulation adds the possibility for EU countries to merge adjacent entry-exit systems - i.e. the different zones of the gas network - to achieve regional integration where tariffs can (but do not have to) be abolished at the interconnection points. When choosing such option, the regulatory authorities may approve a common tariff and an effective compensation mechanism between TSOs for the redistribution of costs on account of the abolished interconnection points (Council of the European Union 2023d). The legislators also agreed on a series of discounts on tariffs for renewable and low-carbon gases accessing the natural gas system, concerning:

1. the injection from production facilities, with a discount of 100% for renewable and 75% for low-carbon gas;
2. the injection to and withdrawal from storage facilities, with a 100% discount in the Member State where the renewable and low-carbon gases were first injected into the system;
3. the interconnection points between Member States, with a discount of 100% on the capacity-based tariffs<sup>26</sup> for all network users, after one year from the entry into force of the revised Gas Regulation, and only after providing the respective TSO with a proof of sustainability, based on a valid sustainability certificate in accordance with the Renewable Energy Directive II.

Regarding hydrogen blending at interconnection points in the gas grid, the Parliament and Council agreed on a 2% instead of a 5% H<sub>2</sub> share, as had been initially proposed by the Commission. Some experts have argued that the supply of renewable hydrogen will be so limited in the early years that it is better to focus its use on hard-to-electrify sectors such as heavy industry, rather than «waste» it by blending it into natural gas flows (Barnes 2023). Moreover, at present, the permitted proportion of hydrogen in gas transmission networks varies significantly from one EU Member State to another. For instance, only 0.5% is allowed in Sweden, 4% in Austria, 5% to 10% in Germany and up to 12% in the Dutch gas grid (Zemite et al. 2023).

on the contractual path chosen, LNG delivered and regasified at Rotterdam could be sold to a customer in the Slovak Republic. Such gas would pay an entry tariff into the Dutch grid, then exit and entry tariffs as it went from the Dutch to the German grid, and so on from the German to Czech grid, and from the Czech grid to the Slovak grid. The Commission sees pancaking as a barrier to trade (Barnes 2023).

<sup>26</sup> Those tariffs are charges based on the transport capacity of the gas infrastructure rather than solely on the volume of gas consumed by users.

The revised Gas Directive includes a reference to «low-carbon hydrogen», thus potentially opening the way to the so-called blue H<sub>2</sub>. The 9<sup>th</sup> recital states that «In line with the EU Hydrogen Strategy, the priority for the Union is to develop renewable hydrogen produced using mainly wind and solar energy». It nonetheless continues stating that «Low-carbon fuels (LCFs) such as low-carbon hydrogen (LCH) may play a role in the energy transition, [...] particularly in the short and medium term to rapidly reduce emissions of existing fuels, and support transition of the Union's customers in hard-to-decarbonise sectors in which more energy or cost-efficient options are not available». A more precise - even though incomplete - definition of «low-carbon hydrogen» is provided by Article 2 of the revised Gas Directive, where such type of H<sub>2</sub> is included in the concept of «low-carbon gas» which meets a «greenhouse gas emission reduction threshold of 70%» (Council of the European Union 2023c)<sup>27</sup>.

As a final item in the revision of the gas package, the issue of unbundling - the separation of energy supply generation from the operation of the transmission network - should be mentioned. In its initial proposal, the Commission suggested a horizontal unbundling model, i.e. when a hydrogen network operator is part of a company active in transmission or distribution of natural gas (or electricity), it must be independent at least in terms of its legal form and must ensure that accounts are kept separate between the two activities (Tanase and Anchustegui 2022). After 2030, however, the Commission proposed the Ownership Unbundling (OU) model, i.e. the highest degree of unbundling, which prevents a company that owns and operates a network from being active in the other (competitive) segments of the hydrogen or gas supply chain. Such a proposal would nonetheless prevent transmission system operators (TSOs) in several Member States from owning and operating a hydrogen network after 2030, with the effect of disincentivising investments into hydrogen and its supporting infrastructure. This is also why the Council of the EU and the European Parliament decided to allow other, less restrictive, unbundling models to apply to hydrogen networks, and they agreed to allow Member States not to apply the OU model under certain conditions (Council of the European Union 2023c)<sup>28</sup>.

The integration of clean molecules in the EU's energy mix still faces limitations and bottlenecks. First, replacing fossil gas with biomethane or hydrogen does not completely solve the issue of lifecycle GHG emissions. Clean molecules can also be climate forcers, characterised, for instance, by fugitive emissions. Secondly, the aspect of lifecycle emissions involves an opportunity cost, con-

<sup>27</sup> On 8 July 2025, the European Commission published a delegated act (EU 2025/2359) on low-carbon hydrogen, which operationalises the formal definition of low-carbon H<sub>2</sub> and explains how to calculate the required 70 % GHG emissions savings compared to the use of unabated fossil fuels (European Parliament 2025).

<sup>28</sup> One possible unbundling model is the Independent Transmission Operator (ITO), which allows the vertically integrated company to maintain the ownership of the transmission network, but it requires the company to comply with some rules aimed at ensuring the independence of its other businesses in the supply chain (e.g. a type of legal unbundling).

cerning the allocation of scarce resources (e.g. renewable electricity) to different uses, such as electrolysis to produce green hydrogen, or the electrification of transport applications. That is why different EU initiatives aimed at decarbonisation may end up competing for the same renewable electricity. Thirdly, the cost-effectiveness of clean molecules and the speed at which they can be scaled largely depend on the cost and availability of renewable electricity, as well as the support schemes introduced by governments. Unsubsidised, renewable hydrogen typically remains uncompetitive with fossil H<sub>2</sub> in most of the circumstances.

#### 2.1.4.2 Renewable Energy Directive III

The Hydrogen and Decarbonised Gas Markets Package is strongly linked with the proposals set out in the revised Renewable Energy Directive (RED). After the adoption of RED II (Directive 2018/2001), the European Commission expanded its scope with the proposals included first in Fit-for-55, and then in REPowerEU. The latter plan indeed raised the required share of renewable energy sources (RES) in the EU's final energy consumption to 45% by 2030, and the Commission included measures to accelerate permitting procedures for new RES power plants, whereas Member States would be required to designate «renewables go-to areas» suitable for RES installations (European Parliament 2023a). The proposal also included a series of higher EU and national targets for different sectors (transport, industry and buildings) and the promotion of (renewable) hydrogen consumption in transport and industry (European Parliament 2023d). The European Parliament adopted the more ambitious RES targets (including sector-specific targets) proposed by the Commission, reaching a provisional agreement with the Council on 30<sup>th</sup> March 2023. The two co-legislators formally adopted the RED III (Directive 2023/2413) in September (Parliament) and October 2023 (Council)<sup>29</sup>. Table 10 outlines the content of the main items agreed upon by the co-legislators regarding the RED.

Table 10 – Key elements of the Renewable Energy Directive III. Source: own elaboration based on Council of the European Union (2023b).

Items	Measure
RES target in EU final energy consumption	Agreement to raise the share to <b>42.5% by 2030 with an additional 2.5% indicative top up that would allow to reach 45%</b> .
Transport sector target	Possibility for member states to choose between: a binding target of <b>14.5%</b> reduction of <b>greenhouse gas intensity</b> in transport from the use of renewables by 2030 or a binding share of at least <b>29%</b> of <b>renewables</b> within the final consumption of energy in the transport sector by 2030

<sup>29</sup> After the entry into force of the Directive, Member States have got 18 months of time to transpose it into national law.

Items	Measure
Transport sector sub-targets	<b>5.5%</b> for <b>advanced biofuels</b> and <b>renewable fuels of non-biological origin</b> (mostly renewable hydrogen and hydrogen-based synthetic fuels). Within this target, there is a minimum requirement of <b>1%</b> of <b>renewable fuels of non-biological origin (RFNBOs) in 2030</b> .
Industry sector target	Increase in the use of renewable energy annually by <b>1.6%</b> . <b>42%</b> of the <b>hydrogen</b> used in industry should come from RFNBOs by 2030 and <b>60%</b> by 2035.
Buildings sector target	Indicative target of at least a <b>49%</b> renewable energy share in 2030.
Heating and cooling	Binding increase of <b>0.8%</b> in RES per year at national level until 2026 and <b>1.1%</b> from 2026 to 2030.
Permitting	Member states will design <b>renewables acceleration areas</b> where renewable energy projects will undergo simplified and fast permit-granting processes. Renewable energy deployment will also be presumed to be of « <b>overriding public interest</b> », which will limit the grounds of legal objections to new installations

Most importantly, for the purpose of our discussion, the revised Renewable Energy Directive contains the definition of renewable gas, including renewable fuels of non-biological origin (RFNBOs). The rules to comply with in order for an RFNBO to count towards the EU's policy targets have been defined in two critical Delegated Acts to the Renewable Energy Directive, published by the European Commission in February 2023, and formally adopted in June 2023<sup>30</sup>. As the number of implemented production projects increased and improvements were made in the generation of RFNBOs, an issue emerged on the end-uses of those fuels and energy carriers, concerning the availability of sufficient renewable electricity to produce them.

#### – First Delegated Act<sup>31</sup>

RFNBOs are the subject of the first Delegated Act (DA), which defines when hydrogen, hydrogen-based fuels and other energy carriers can be considered RFNBOs. These were first defined in the 2018 Renewable Energy Directive (RED II) as «liquid or gaseous fuels which are used in the transport sector other than biofuels or biogas, the content of which is derived from renewable sources other than biomass»<sup>32</sup>. However, the Commission proposed to count RFNBOs towards the EU's renewable energy targets regardless of the end-use sector in which they are used, thus expanding the scope for hydrogen develop-

<sup>30</sup> The final texts are unchanged from the draft acts adopted by the Commission on 13<sup>th</sup> February 2023. The rules formally enter into force 20 days following their publication in the Official Journal.

<sup>31</sup> Commission Delegated Regulation 2023/1184

<sup>32</sup> Article 2.36 of the Renewable Energy Directive II (Directive 2018/2001).

ment. Article 1 of the new RED III amends the previous definition, describing RFNBOs as «liquid and gaseous fuels the energy content of which is derived from renewable sources other than biomass». Gaseous renewable H<sub>2</sub> produced by feeding renewables-based electricity into an electrolyser is therefore considered an RFNBO, whereas liquid fuels, such as ammonia (NH<sub>3</sub>), methanol, or e-fuels, are considered RFNBOs when produced from renewable hydrogen (European Commission 2023a).

The first DA is also known as «Additionality Delegated Act» because the rules that it sets out aim to ensure that RFNBOs are only produced from «additional» renewable electricity, which is generated at the same time and in the same area as the production of RFNBOs<sup>33</sup>. Unless the electricity system is already largely decarbonised, it is indeed crucial to match the electricity demand for hydrogen production with additional renewable electricity generation (European Commission 2023a). If H<sub>2</sub> production were not matched by additional RES electricity, the additional electricity demand of electrolysers (used to produce H<sub>2</sub>) could lead to increased fossil-based power generation, thereby increasing - rather than decreasing - emissions. According to the RED II, as of 1<sup>st</sup> January 2021, RFNBOs are indeed counted towards the EU's renewable energy targets if they deliver GHG emissions savings of at least 70% compared to fossil fuels (Erbach and Svensson 2023)<sup>34</sup>.

Because the Renewable Energy Directive provides for a default rule on grid electricity used to produce RFNBOs, the «Additionality DA» acts as a sort of «derogation», providing two scenarios in which the RFNBOs can be considered fully renewable (i.e., produced with renewable electricity). These two scenarios have been introduced by the Commission mainly because currently (and in the near future), given the 70% GHG emissions reduction requirement, the GHG intensity of the electricity grids in most EU Member States is too high, i.e. not fulfilling the emissions saving requirement of the RED<sup>35</sup>. The default rule included in the RED states that the share of RFNBOs corresponds to the average share of renewable electricity on the electricity network of the country in which the RFNBO production is located. Table 11 outlines the two scenarios under which the first DA allows the hydrogen (RFNBO) produced to be counted as fully renewable.

<sup>33</sup> To improve the readability of this section, we may use «hydrogen» to mean «renewable fuels of non-biological origin», and «electrolyser» instead of «installation producing renewable liquid and gaseous fuel of non-biological origin», as used in both delegated acts.

<sup>34</sup> This corresponds to around 3.38 kg of CO<sub>2</sub> per kg of hydrogen. Besides setting the 70% threshold for RFNBOs, Article 25.2 of the RED II also requires the Commission to adopt a delegated act on GHG savings and calculation of lifecycle emissions by 1<sup>st</sup> January 2021, which it did with a two-year delay, when it published the second DA in February 2023 (see below).

<sup>35</sup> This situation might change by 2030, when in 10 EU Member States it will be possible to produce hydrogen from grid electricity with an emission factor below the 70% GHG reduction threshold (Hydrogen Europe 2023).

Table 11 – Scenarios under the Additionality Delegated Act to count hydrogen produced as fully renewable. Source: own elaboration based on Directive 2018/2001 (RED II) and Baker McKenzie (2023).

References in the legal acts	Provisions
Default rule - RED II (Art. 27 par. 3)	«Where electricity is used for the production of renewable liquid and gaseous transport fuels of non-biological origin, [...], <b>the average share of electricity from renewable sources</b> in the country of production, [...], shall be used to determine the share of renewable energy» No further requirements needed
«Direct line» setup - First DA (Art. 3)	The RFNBO (H <sub>2</sub> ) production facility is <b>connected directly to a new renewable electricity installation</b> and does not use grid electricity. The renewable electricity installation must be <b>connected via a direct line to the RFNBO production plant</b> (electrolyser) and have come into operation at most <b>36 months</b> before the RFNBO production facility.
«Grid connection» setup - First DA (Art. 4)	The RFNBO production facility (electrolyser) is connected to the grid, but the <b>electricity used is «demonstrably» renewable</b> .

While the off-grid option is the simplest approach to ensuring that the electricity used to produce hydrogen is 100% renewable<sup>36</sup>, it becomes more difficult to ensure that the electricity taken from the grid comes from renewable sources, because it is usually generated by a mix of renewable, nuclear and fossil sources (Erbach and Svensson 2023). Therefore, the first DA outlines four alternative options under which it can be demonstrated that grid electricity used in the electrolyser is renewable (Baker McKenzie 2023):

1. Where the electrolyser is located in a bidding zone<sup>37</sup> containing a 90%+ level of renewables, and the number of its production hours is capped at the same percentage of the year (the maximum number of operating hours for the electrolyser operation is determined by multiplying the renewable energy share in the electricity mix by the number of hours in a year);
2. Where the RFNBO production plant is located in a bidding zone in which the emission intensity of electricity generation is lower than 18 gCO<sub>2</sub> eq/MJ (i.e., a low-carbon bidding zone), it relies on electricity produced under a renewable power purchase agreement (PPA) and it complies with «temporal» and «spatial» correlation requirements set out in the Delegated Act (see below);

<sup>36</sup> Despite being simpler, this off-grid approach limits electrolyser operation to the periods when renewable electricity can be produced (i.e., intermittency), or requires additional investment into electricity storage (Erbach and Svensson 2023).

<sup>37</sup> i.e., a region in which the same electricity price is applied. In the EU, bidding zones are usually entire Member States, except for Sweden, Denmark, and Italy, which are divided into several bidding zones (Erbach and Svensson 2023).

3. Where the RFNBO is produced with electricity consumed during an imbalance settlement (i.e., the electricity is consumed during a period of curtailment of RES electricity);
4. All other grid situations (default option) in which the renewable electricity is procured via a renewable PPA, and «additionality», «temporal» and «spatial» correlation requirements are met.

Taking the current European electricity system into account, options 2 and 4 (both involving the conclusion of a PPA with a renewable producer) will be the most common. It is important to explain the three requirements (additionality, temporal and spatial correlation) that are present in those two scenarios, as well as in the off-grid option with the electrolyser directly connected to the renewable power plant. Table 12 reports the three criteria as set out in the first DA, showing for each criterion to which scenario they apply. As a general rule, and to facilitate the early ramp-up of hydrogen infrastructure, the Commission's DA introduces a transitional phase with relaxed rules, i.e. the rules on additionality will not apply until 1<sup>st</sup> January 2038 for the renewable power plants that came into operation before 1<sup>st</sup> January 2028. This is mainly because the planning, permitting processes and installation of new additional renewable power takes time and could result in delays in the deployment of electrolysers, limiting the potential to create economies of scale (European Commission 2023a).

Table 12 – Criteria of additionality, temporal correlation and spatial (geographical) correlation. Source: own elaboration based on Baker McKenzie (2023) and Erbach and Svensson (2023).

References in the first Delegated Act	Provisions	Scenario of application
Article 5 - Additionality	Hydrogen producers have to make sure that the electricity used for the production of hydrogen is matched by the production of renewable electricity: showing that the producers generate <b>RES electricity corresponding to the amount of hydrogen</b> they claim as renewable or through a <b>renewable PPA</b>	<ul style="list-style-type: none"> <li>· <b>Off-grid</b> (direct line) option</li> <li>· On-grid option number <b>4</b> (default option)</li> </ul>
Article 6 - Geographical correlation	Hydrogen producers have to ensure that the <b>additional renewables are located in the area where hydrogen is produced</b> . The renewable power plant must be located either: <b>in the same bidding zone</b> as the electrolyser; or in an <b>interconnected bidding zone</b> with electricity prices equal or higher than the electrolyser's bidding zone; or in an <b>offshore zone interconnected</b> with the electrolyser's bidding zone.	<ul style="list-style-type: none"> <li>· On grid option number <b>2</b></li> <li>· On-grid option number <b>4</b> (default option)</li> </ul>

References in the first Delegated Act	Provisions	Scenario of application
Article 7 - Temporal correlation	<p>Hydrogen producers must make sure that <b>renewable electricity generation and hydrogen production coincide temporally</b>:                      Until 31<sup>st</sup> December 2029, hydrogen has to be produced in the same <b>calendar month</b> as the RES electricity under a PPA;                      From 1<sup>st</sup> January 2030, hydrogen has to be produced during the same <b>one-hour period</b> as the RES electricity when the electricity price is below 20 €/MWh<sup>38</sup>.</p>	<ul style="list-style-type: none"> <li>· On-grid option number <b>2</b></li> <li>· On-grid option number <b>4</b> (default option)</li> </ul>

### – Second Delegated Act<sup>39</sup>

This Delegated Regulation (the «Methodology Delegated Act») establishes a methodology for calculating the lifecycle GHG emissions savings achieved from using RFNBOs and recycled carbon fuels (RCFs), given the 70% emission reduction criterion foreseen by the RED II<sup>40</sup>. For the purpose of our discussion, we will focus the following analysis on RFNBOs only, and hydrogen in particular. The methodology established by the second DA defines the total lifecycle emissions from the use of RFNBOs as the sum of emissions from the supply of inputs (including electricity, processing, transport and distribution, and combustion of the fuel in its end use) minus any emissions savings from carbon capture and storage (Erbach and Svensson 2023). More precisely the formula used to calculate GHG emissions from production and use of RFNBOs is the following<sup>41</sup>:

$$E = e_i + e_p + e_{td} + e_u - e_{CCS} \quad (6)$$

where  $E$  are the total emissions from the use of the fuel (gCO<sub>2</sub>eq/MJ of the fuel)<sup>42</sup>,  $e_i$  the emissions from supply of inputs<sup>43</sup>,  $e_p$  the emissions from processing,  $e_{td}$  the emissions from transport and distribution,  $e_u$  the emissions from

<sup>38</sup> Member States may also start applying the hourly rule from July 2027, after notifying the Commission.

<sup>39</sup> Commission Delegated Regulation 2023/1185

<sup>40</sup> Recycled carbon fuels are defined under the 2018 Renewable Energy Directive as «liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin, [...] or from waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations.

<sup>41</sup> Retrieved from Annex to the Commission Delegated Regulation (EU) 2023/1185.

<sup>42</sup> 1 MJ (Megajoule) corresponds to around 0.2 kWh, or 1 kWh is about 3.6 MJ.

<sup>43</sup> Within the supply of inputs, there are «rigid» inputs and «elastic» inputs. Rigid means that the supply of those inputs does not increase with increasing demand, while elastic means that the supply expands with increasing demand (e.g. crude oil, crops...).

combusting the fuel in its end use, and  $e_{\text{CCS}}$  the emission savings from carbon capture and storage (CCS). Emissions from the manufacture of machinery and equipment are not considered by the Annex to the Methodology Delegated Act (Official Journal of the European Union 2023). Instead, to calculate emission savings from production and use of RFNBOs, the Annex specifies that they shall be calculated as follows:

$$\text{Savings} = (E_{\text{F}} - E)/E_{\text{F}} \quad (7)$$

where  $E$  represents the total GHG emissions from the use of RFNBOs, and  $E_{\text{F}}$  the total emissions from the fossil comparator. The latter has been established by the European Commission at a value of 94 gCO<sub>2</sub>eq/MJ for RFNBOs. Therefore, the reference point set by the second DA means that the total lifecycle GHG emissions from the production and use of RFNBOs (or RCFs) must not exceed 28.2 gCO<sub>2</sub>eq/MJ (which is equal to the fossil fuel comparator minus the 70% saving, as established by the RED II).

There are several ways to reduce CO<sub>2</sub> emissions in the life cycle of RFNBOs. According to Jones et al. (2023) the two main ways of reducing the lifecycle GHG emissions are (i) to use inputs that are associated with avoided emissions (such as captured CO<sub>2</sub>) and (ii) use carbon capture and storage during the process for making the fuel. It is important to note however that CCS after the fuel's combustion is not considered in the methodology. For renewable fuels incorporating carbon (notably e-fuels, sustainable aviation and maritime fuels), ensuring that the source of carbon used as part of the production process is associated with avoided emissions is absolutely critical for them to meet the 70% savings requirement (Jones et al. 2023). This is because, chemically speaking, the combustion of these fuels at the point of use produces the same GHG emissions as if they were derived from fossil fuels (Jones et al. 2023).

Given that RFNBOs are produced both via a direct connection to a renewable power plant and via grid electricity, it is important to analyse the methods to assess the emission intensity of the electricity grid, as provided by the second DA. Recital n. 11 of the act states that if the electricity used to produce RFNBOs is taken from the electricity grid, it is therefore not considered as fully renewable, and the average carbon intensity of the electricity consumed in the Member State where the RFNBO is produced should be applied. The delegated act requires the operators to use one of the three alternative methods - set out by the Regulation and outlined in Table 13 - to calculate the carbon intensity of the electricity grid<sup>44</sup>.

<sup>44</sup> The emission intensity is expressed either in gCO<sub>2</sub>eq/MJ or in gCO<sub>2</sub>eq/kWh of electricity generated. The emission intensity of the grid of the major EU countries (as of 2020) is (in gCO<sub>2</sub>eq/MJ): Germany = 99.3, France = 19.6, Italy = 92.3, Spain = 54.1, Poland = 196.5 (Official Journal of the European Union 2023).

Table 13 – Methods to attribute greenhouse gas emissions values to the electricity taken from the grid not qualifying as fully renewable. Source: own elaboration based on Annex to the Commission Delegated Regulation (EU) 2023/1185.

1. Calculation based on bidding zones	The GHG emission intensity is determined at the level of countries or bidding zones - if the required data are publicly available.
2. Calculation based on full load hours	The GHG emissions values are attributed depending on the number of full load hours (FLH) that the electrolyser is operating: <ul style="list-style-type: none"> <li>- Where the number of FLH is equal or lower than the number of hours in which the marginal price of electricity was set by renewable or nuclear power plants, grid electricity used for RFNBOs is given a GHG value of <b>zero gCO<sub>2</sub>eq/MJ</b>.</li> <li>- Where this number of FLH is exceeded, grid electricity is attributed a GHG emissions value of <b>183 gCO<sub>2</sub>eq/MJ</b>.</li> </ul>
3. Calculation based on the marginal unit producing electricity	The GHG emissions value of the marginal unit generating electricity at the time of RFNBO production in the bidding zone may be used.

## 2.2 The EU's most recent initiatives to upscale renewable and low-carbon hydrogen

### 2.2.1 REPowerEU: The Hydrogen Accelerator

Among the other aspects included in the REPowerEU Plan the European Commission launched the so-called «Hydrogen Accelerator», aimed at complementing the EU Hydrogen Strategy, and increasing the EU's ambitions on renewable hydrogen, envisaging a total investment range of €335-471 billion only by 2030. A new target of 10 million tonnes (Mt) of renewable hydrogen imports into the EU by 2030 has been established, together with the target of 10 Mt of domestic renewable H<sub>2</sub> production (European Commission 2022b). Of this domestically generated hydrogen, about 6.6 Mt was already considered in the Fit-for-55 scenario, therefore REPowerEU has increased the internal production by 3.4 Mt. At the external level, the 10 Mt of H<sub>2</sub> import are subdivided into 6 Mt of renewable hydrogen and 4 Mt of ammonia.

Since 1 Mt of hydrogen has an energy value of around 33 TWh, this means that at least 350 TWh of additional renewable electricity generation will be required to produce 10 Mt of H<sub>2</sub> per year by 2030. To have an estimate, this compares to 541 TWh of solar and wind generation in the EU27 in 2020, while the total EU27 gross electricity generation (including hydro, fossil fuels, and nuclear) was of 2781 TWh (Barnes 2023). On the demand side, the REPowerEU Plan rests on some critical assumptions regarding hydrogen usage within the EU. Figure 13 compares the projected hydrogen use by sector in 2030, as estimated by the Fit-for-55 Package first, and then by REPowerEU.

The Commission assumes a reduction in natural gas demand by industry of 35 bcm between 2021 and 2030, based on increased energy efficiency and a switch to alternatives such as electrification and hydrogen. Out of the 35 bcm reduction in natural gas demand, 27 bcm is expected to be replaced by 8 Mt/y of hydrogen, with 2 Mt/y replacing oil and coal use (Barnes 2023). **The use of hydrogen in industrial heat, for example, is planned to increase 4.5-fold compared to the Fit-for-55 targets.** A more than **2.5-fold increase is envisaged in the transport sector.**

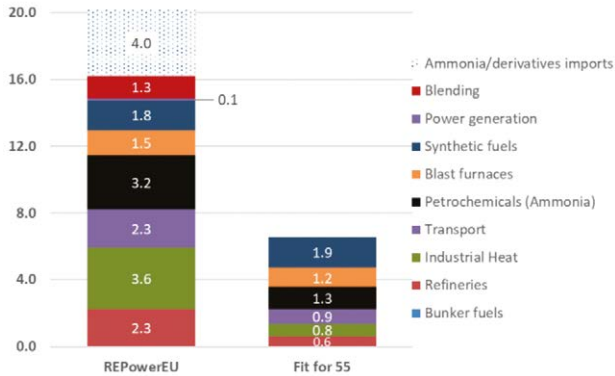


Figure 13 – Hydrogen use by sector in 2030 [Mt of H<sub>2</sub>]. Source: European Commission (2022b).

The expected drop in natural gas use can raise the potential for repurposing existing gas pipelines for hydrogen transportation. Although cross-border hydrogen infrastructure is still in its infancy, the basis for planning and development has already been set by the inclusion of hydrogen infrastructure in the revised Trans-European Networks for Energy (TEN-E) (European Commission 2022c). Given the 10 Mt import target, several «hydrogen corridors» have been identified and partnerships with third countries have been established. Studies indicate that until 2030 the imports of hydrogen into the EU are most cost-efficient via pipelines from the neighbourhood and in the form of ammonia through ships over long distances (European Commission 2022b)<sup>45</sup>.

The REPowerEU Hydrogen Accelerator also includes several policy initiatives and legislative proposals that have been integrated into the current revision process of key energy legislation (e.g. the Hydrogen and Decarbonised Gas Markets Package and the Renewable Energy Directive). Besides the already mentioned sub-targets for RFNBOs under the RED for industry and transport, and the adoption of the two hydrogen Delegated Acts, the REPowerEU Action Plan also includes the regular reporting on the uptake of renewable hydrogen

<sup>45</sup> The aspect of hydrogen import routes will be analysed in detail in Chapter 3.

in key sectors (starting in 2025), the proposal to double the number of the so-called Hydrogen Valleys<sup>46</sup>, the scale-up of electrolyser manufacturing, whose details are outlined in the «Electrolyser Declaration», and the mapping of the hydrogen infrastructure needs<sup>47</sup> (Conti and Kneebone 2022). In addition, as was reported in the section covering the progresses of the EU Hydrogen Strategy, the 840 investment projects collected under the European Clean Hydrogen Alliance, include the production of H<sub>2</sub> (the installation of over 50 GW of electrolysers), transportation and usage of hydrogen by industry, mobility applications, energy systems and buildings (European Commission 2022b). The discussion on the Important Projects of Common European Interest (IPCEI) on hydrogen, and the need to fast-track them, will be addressed in the section 2.5 on H<sub>2</sub> funding flows.

### 2.2.2 The European Hydrogen Bank

After the announcement made by Commission's President Ursula Von der Leyen in her State of the Union speech in September 2022, the European Commission presented the European Hydrogen Bank (EHB) through a Communication in March 2023<sup>48</sup>. The EHB is an instrument, implemented by the European Commission, consisting of two financing mechanisms to support renewable hydrogen production within the EU and internationally, while providing data on hydrogen demand, supply, flows and prices and playing a coordination role to facilitate the blending with the existing financing instruments (such as the EU funds) to support hydrogen projects (European Commission 2023b). This initiative has been spurred mainly by the need to close the current investment gap - estimated at around €90-115 billion - and connect future renewable hydrogen supply with the EU's demand objective, including imports of H<sub>2</sub> from international producers.

Today, Europe hosts over 30% of proposed hydrogen investments globally, but while the first final investment decisions (FIDs)<sup>49</sup> took place in 2022, a vast

<sup>46</sup> Hydrogen Valleys bring together - in a limited geographical area - all the elements of renewable hydrogen production, storage and end-use into an integrated ecosystem. Hydrogen valleys can vary in size and scope thus proving to be very flexible in adapting to local energy needs (European Commission 2022b).

<sup>47</sup> The European Commission in the 36th European Gas Regulatory Forum (in May 2022) mandated several associations of energy sector operators (ENTSOG, EUROGAS, GIE, GEODE, GD4S and CEDEC) to visualize all hydrogen infrastructure projects collected under different existing processes in the form of a map. The latter, which can be consulted here (<https://www.h2inframap.eu>), is continuously updated with the latest information on new investment projects.

<sup>48</sup> COM 2023/156

<sup>49</sup> FID is the point in the capital project planning process when the decision to make major financial commitments is taken. At the FID point, major equipment orders are placed, and contracts are signed for Engineering, Procurement and Construction (EPC). See: <https://www.mckinseyenergyinsights.com/resources/refinery-reference-desk/fid/>.

majority of hydrogen investments in Europe are still at the planning stage (European Commission 2023b). This can be traced back to two main reasons: on the one hand, investors need regulatory certainty and therefore the regulatory framework mentioned in the previous sections should be quickly finalised, and on the other hand, more demand visibility is needed. This is part of the so-called chicken-or-egg dilemma, whereby the demand from customers will not materialise until there are no appropriate infrastructures that supply hydrogen, but without that demand, investors will not finance hydrogen infrastructures, which in turn means zero demand. Table 14 reports the European Commission's estimated investments needed to achieve the target of 10 Mt of domestic (EU) hydrogen production and to enable the imports of an additional 10 Mt from third countries.

Table 14 – Estimated investments needed to achieve the target of 20 Mt/y of green hydrogen and derivatives (billion €). Source: European Commission (2023b).

Type of investment	Amount needed (billion €)
Electrolysers	50-75
Internal (EU) pipelines	28-38
H <sub>2</sub> storage	6-11
Additional renewable electricity <sup>50</sup>	200-300
International H <sub>2</sub> value chains	500

Given the H<sub>2</sub> investment challenges mentioned so far - electrolyser manufacturing capacity, hydrogen production capabilities, expansion of H<sub>2</sub> demand in new sectors, and development of dedicated infrastructure - there currently remains a «green premium» in terms of higher costs for those choosing hydrogen over fossil fuels. The green premium is the additional cost of choosing a clean technology over one that emits more GHG (i.e. the difference between the costs of the two technologies), and therefore it helps to see which barriers still need to be overcome (Breakthrough Energy 2022). According to the European Commission, the targeted use of public resources to finance the green premium can leverage private sector investments and reduce the risk of investing in renewable hydrogen production. Around €1 billion is estimated to be required to enable 0.04-0.06 million tonnes of renewable hydrogen production capacity per year, and after 2025, the market premium is expected to decline due to decreasing production costs and increased demand for green products produced with renewable hydrogen (European Commission 2023b).

<sup>50</sup> The target of 10 Mt of renewable hydrogen production will require around 150-210 GW of additional renewable installed capacity generating electricity at low cost (European Commission 2023b).

## The structure of the European Hydrogen Bank

The EHB's structure consists of a «domestic» and an «international» pillar. Regarding the first dimension, the domestic pillar supports the scale-up of hydrogen production within the EU, with supply-side auctions allocating fixed premium payments to hydrogen producers (see in detail below). The goal of the international pillar is instead to secure diversified imports of renewable hydrogen (and derivatives) from outside the EU, both with fixed premium payments to international producers and with other funding options that are currently being explored by the European Commission. Given that several Member States have been developing strategies to support the import of hydrogen from third countries<sup>51</sup>, the Commission is studying how best to design the international leg of the European Hydrogen Bank, considering that imports of H<sub>2</sub> will fall within the scope of the Carbon Border Adjustment Mechanism (CBAM) from 2026<sup>52</sup>.

As regards the proposed activities under the EHB, there are four pillars that can be summarised as follows. First, the creation of a domestic market will be initially supported by the EU Innovation Fund (see next paragraph). Second, H<sub>2</sub> imports into the EU will be supported by green premium auctions. Third, transparency and coordination activities will include assessments on demand, H<sub>2</sub> flows, infrastructure needs and cost data. The fourth pillar of activities is divided into two subjects: the use of existing EU financing instruments, and the existing international financing instruments (concessional loans, guarantees).

### The first pilot auction and the «Auctions-as-a-Service» mechanism

The Innovation Fund allocates funds through a pilot auction directed at the production of renewable hydrogen, as defined in the Commission's Delegated Acts on RFNBOs. Through such market-based tools, the European Commission transfers the funds after interested projects have submitted a bid, in order to receive support, in form of a fixed premium per kg of hydrogen produced, for up to 10 years of operation. The Commission has indeed decided to allocate funds using auctions for three main reasons: 1) because of the successful use of auctions to support renewable power projects in several EU Member States, which have helped lower the price of renewable energy, 2) the efficient allocation of

<sup>51</sup> In 2021-2022, EU Member States and companies have signed hydrogen cooperation Memoranda of Understanding (MoUs) with at least 30 countries around the world. On behalf of the EU, the European Commission has signed MoUs and/or Partnerships with Egypt, Japan, Kazakhstan, Morocco, Namibia and Ukraine (European Commission 2023b).

<sup>52</sup> The mechanism has a 3-year transitional period starting from 1<sup>st</sup> October 2023, with emission monitoring, and actual surrendering of CBAM certificates (payments) will start in 2026/27 (Hydrogen Europe 2022). Although not part of the initial European Commission proposal, the CBAM will also apply to hydrogen, together with cement, iron and steel, aluminium, fertilisers, and electricity. The inclusion of hydrogen in the EU CBAM was a result of the interinstitutional negotiations between the European Commission, the European Parliament, and the Council (Marcu *et al.* 2023).

support, which creates competition between producers and provides payments based only on certified and verified H<sub>2</sub> production, and 3) the reduced costs for the public and the lower risks, that can attract more private capital (European Commission 2023c). The auction funded by the Innovation Fund under the umbrella of the EU Hydrogen Bank was launched on 23<sup>rd</sup> November 2023, awarding up to €800 million to renewable H<sub>2</sub> producers in the European Economic Area (European Commission 2023c)<sup>53</sup>.

One significant novelty of this initiative is the so-called «Auctions-as-a-Service» (AaaS) mechanism, put in place by the Commission to enhance the scope of the support to H<sub>2</sub> production. Although the RFNBO Delegated Acts provide a uniform basis for the certification of renewable hydrogen across Europe, support schemes can vary considerably between Member States (European Commission 2023b). That is why the Commission has proposed to extend the Innovation Fund auctions as a platform to Member States, enabling them to use their own resources for projects on their territory, by relying on an EU-wide auction mechanism and select the most competitive projects (European Commission 2023b). Hence, through «Auctions-as-a-Service», the Commission would run a single auction, which would first clear the Innovation Fund budget, and then the remainder of the financial support can be supported by Member States themselves.

#### Connecting «H2Global» and the European Hydrogen Bank

The EU also decided to link the EHB with «H2Global», Germany's support scheme for renewable hydrogen. The latter, which is an auction-based instrument, has been financed by the German Government with €900 million for the first «funding window», and its implementation is managed by the H2Global Foundation (*H2Global Stiftung*), whose subsidiary, HINT.CO (*Hydrogen Intermediary Network Company*) uses the funding provided to compensate for the difference between supply and demand prices (European Commission 2023d). European Commissioner for Energy Kadri Simson (2019-2024) and German Federal Minister for Economic Affairs Robert Habeck (2021-2025) agreed to link the EHB with H2Global during a bilateral meeting on 31<sup>st</sup> May 2023 with the aim to expand this approach to other Member States and to jointly develop a European auction targeting international hydrogen imports (Habibic 2023). Thus, it can be argued that the international pillar of the European Hydrogen Bank has been taking shape. As emphasised by the CEO of Hydrogen Europe (a major EU hydrogen industry association), such a step was needed to remain credible with the implementation of the EU Hydrogen Strategy, since the EU will need more hydrogen than it can domestically produce in the required timeframe (Collins 2023).

<sup>53</sup> Bids had to be submitted until 8<sup>th</sup> February 2024, after which the applicants were informed about evaluation results as early as April 2024 and signed the Grant Agreements within nine months after the call closure.

### 2.2.3 An overview of hydrogen funding in the EU

The last part of this section dedicated to hydrogen-specific policy initiatives looks at the spectrum of the funding sources that support the scale-up of clean hydrogen in the EU. The adoption of the two Delegated Acts on RFNBOs has contributed to better channelling EU funds towards renewable hydrogen and to guiding the approval of national state aid schemes for hydrogen projects. Significant investments for the production of renewable hydrogen are also being channelled through the National Recovery and Resilience Plans, as more than €10 billion have been assigned so far under the Recovery and Resilience Facility, and several Member States have been able to provide public funding to hydrogen projects via the Important Projects of Common European Interest (IPCEI). The EU Innovation Fund has been providing resources both for renewable H<sub>2</sub> (through fixed-premium auctions) and electrification in industry. The Commission has also allocated an additional €200 million for Hydrogen Valleys, as part of REPowerEU, and has been supporting the work of the Clean Hydrogen Partnership<sup>54</sup> to which it provided €1 billion under Horizon Europe (European Commission 2023a).

The funding sources for clean hydrogen also come from the European Investment Bank (EIB) and the InvestEU fund, which aims at mobilising private investment. The latter fund as well as Cohesion Policy funding (mainly through the European Regional Development Fund) and the Just Transition Fund (JTF), mentioned in the European Hydrogen Bank Communication, will provide support to Member States and regions for investments in the whole hydrogen value chain. In addition, the EIB has committed to exceed 50% of its overall lending, by 2025, for climate action and environmental sustainability, and it is also one of the «implementing partners» of the InvestEU fund, together with the European Bank for Reconstruction and Development and the Nordic Investment Bank. In the past decade, the EIB provided over €1 billion in financing directly linked to hydrogen projects, and this was recently complemented by the EIB's REPowerEU €30 billion package which aims to mobilise up to €115 billion by 2027 of investments leading to decarbonisation of the EU industry (European Commission 2023b).

#### Mapping hydrogen funding flows in the EU

For the purpose of this work and given the articulated nature of the different sources of EU funding for hydrogen projects, it is essential to mention the

<sup>54</sup> The Clean Hydrogen Partnership (legally known as the «Clean Hydrogen Joint Undertaking») is the successor of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), which it has replaced since 2021. The members of this public-private partnership are the EU (represented by the European Commission), the fuel cell and hydrogen industries (represented by Hydrogen Europe) and the research community (represented by Hydrogen Europe Research). Retrieved from: [https://www.clean-hydrogen.europa.eu/about-us/who-we-are\\_en](https://www.clean-hydrogen.europa.eu/about-us/who-we-are_en)

different channels and sources, in order to establish a general framework, without specifying the functioning and implementing stages of each single funding programme. Figure 14 shows the revenue flows from the origin of the funds (at the top) or the revenue-generation mechanisms (e.g. the EU ETS), down towards different major funds and programmes, i.e. massive budgets with significant but cross-sectoral ambitions (e.g. the Cohesion Fund or Next Generation EU), and from there, the financial resources flow down into smaller and more specific «secondary» funds and mechanisms more closely related to energy sector decarbonisation (Kneebone 2023).

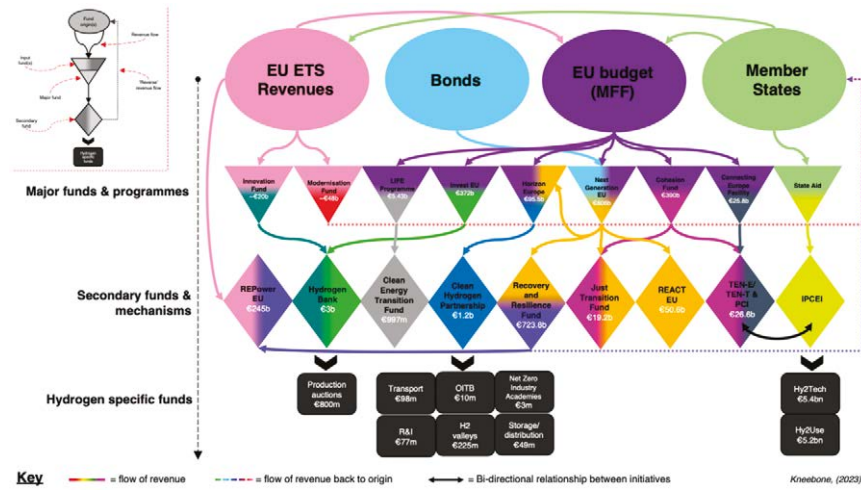


Figure 14 – Hydrogen funding instruments and flows in the EU (billion €). Source: Kneebone (2023).

As can be seen in the figure, the main funding sources are represented by the EU long-term budget (the Multi-Annual Financial Framework 2021-2027), the EU ETS revenues, the bonds through which the EU borrows on financial markets, and the resources of single Member States. The latter follow an essentially straight path since the EU countries’ own resources can be directed towards the IPCEI projects in form of state aid (after the approval of the European Commission). It is of course important to consider that a large part of the EU budget is also financed by the Member States. The EU MFF feeds six main programmes (LIFE, InvestEU, Horizon Europe, Next Generation EU, the Cohesion Fund and the Connecting Europe Facility), some of which are directly managed by the European Commission, then providing resources for more targeted funds, such as the Just Transition Fund, REACT EU, the TEN-E and TEN-T, as well as the European Hydrogen Bank and REPowerEU. These last two funding sources are also supported by other mechanisms. Revenues from the ETS then flow partly into REPowerEU, but they also flow into InvestEU and the EU Inno-

tion Fund, which in turn feed the EU Hydrogen Bank, a critical tool to enable better coordination between funding programmes and to provide clarity to potential project developers.

#### The Important Projects of Common European Interest in the hydrogen sector

Launched by a declaration signed by 22 EU Member States and Norway in December 2020, IPCEI are State aid schemes for supporting projects in infrastructure or research, development and innovation (R&D&I), which are carried out by the private sector and are supported by the funds of the Member States. According to the European Commission (2021b), IPCEI are meant to make a very important contribution to sustainable economic growth, jobs, competitiveness and resilience, as well as to overcome market or systemic failures or societal challenges that prevent a project from being carried out in the absence of the aid. It is important to consider that IPCEI do not have budgets in of themselves but are rather vehicles for accessing finance (Kneebone 2023). Therefore, the European Commission plays a key role in this regard since it is tasked with approving the State Aid funding for IPCEI.

As of 2024, the IPCEI on hydrogen include two sets of projects approved in 2022 (*Hy2Tech* and *Hy2Use*), one adopted in February 2024 (*Hy2Infra*) and one in May 2024 (*Hy2Move*)<sup>55</sup>. *Hy2Tech*, approved in July 2022, involves 35 companies from fifteen Member States. The latter will provide up to €5.4 billion in public funding, while expecting to unlock an additional €9 billion in private investment and the creation of approximately 20000 direct jobs (European Commission 2022d). *Hy2Use*, approved by the Commission in September 2022, includes 35 companies from thirteen Member States, which will provide up to €5.2 billion in public funding in the coming years, thus expecting to unlock around €7 billion in private investments (European Commission 2022e). Whereas *Hy2Tech* covers mainly H<sub>2</sub> generation, fuel cells, storage and end-use applications, *Hy2Use* supports research and innovation and first industrial deployment of hydrogen technologies. The third and IPCEI, *Hy2Infra*, complements the first two by supporting the gradual emergence of an EU-wide hydrogen transmission infrastructure starting from different regional clusters. While expecting to unlock €5.4 billion in private investments, public funding for this IPCEI totals €6.9 billion, which will be provided by the seven Member States (including France, Italy and Germany) that notified the project to the EU (European Commission 2024). The last IPCEI (*Hy2Move*) will provide up to €1.4 billion in public funding, unlocking an additional €3.3 billion in private investments, and it will cover mainly hydrogen integration into road, maritime, and air transport, as well as high-performance fuel cells and advanced refuelling stations.

<sup>55</sup> Among the IPCEI approved in other sectors there are projects related to microelectronics and communication technology sectors, and also batteries.

### 2.3 A pan-European hydrogen network as a key component of the decarbonised European energy system

This section is aimed at analysing how the future hydrogen transmission network - the key enabler of a hydrogen market in Europe - can be most effectively developed, also considering the need to connect integrated network planning to reasonable assumptions and existing EU laws. H<sub>2</sub> infrastructure planning indeed presents a number of challenges, which are mostly linked to a technological and institutional misalignment, both of which must be addressed. The first misalignment is given by the complexity in planning a network where hydrogen transport will include parts of the gas and power networks. The tendency to centralise the architecture and planning process of power and gas networks (because of their natural monopoly characteristics) determines instead the institutional misalignment. To overcome the technological misalignment the existing sector-specific energy infrastructure planning processes will need to be enhanced with cross-sectoral mechanisms, that allow coordination of hydrogen-driven energy infrastructure expansion with the development of hydrogen infrastructure in other sectors (Palovic and Poudineh 2022). On the other hand, given that several hydrogen delivery options (mainly in the transportation sector) have a decentralised nature, there will be the need for new mechanisms to account for hydrogen investments outside the natural monopoly setting, thus overcoming the institutional misalignment (Palovic and Poudineh 2022). Table 15 outlines three approaches on how to integrate hydrogen into the energy transport infrastructure planning in Europe, avoiding the two misalignments. Whereas the first two approaches are one the opposite of the other, the third one (regulatory) represents a compromise between the other two.

Regulators play a critical role in guiding policymakers on the future development of gas and hydrogen networks. Despite having a different scope, the regulators' sphere of action is complementary to policymaking. The analysis on the most recent EU legislative initiatives and policy proposals, especially concerning the Hydrogen and Decarbonised Gas Markets Package, has shown that regulators must ensure that basic principles of network management and operation (e.g. network access, cost-reflectivity, efficiency, monitoring) are upheld. However, while the transition to renewable and low-carbon gases (e.g. biomethane) can largely be based on the existing gas market, the hydrogen market model does not have prior patterns nor predecessors. Therefore, adaptation and flexibility are even more crucial, particularly given the lumpiness of such infrastructural investments<sup>56</sup>. The emergence of a new hydrogen network will mainly depend on the location of renewable power plants that provide clean electricity to electrolyzers and the emergence of demand centres, but it will also be driven by the potential H<sub>2</sub> import routes from the neighbourhood and from repurposed LNG

<sup>56</sup> Lumpiness refers to the fact that this type of investments (especially gas transmission lines) entails chunky expenditures of equipment that cannot be installed piecewise, due to its highly integrated structure or technology (Jiao and Zhang 2022).

terminals. There are many infrastructure trade-offs regarding how and from where energy is transported across Europe, provided that planning and operation can be tightly coordinated, as the more energy transport capacity, the more costs can be reduced (Neumann et al. 2023).

Therefore, we will attempt to both examine a concrete example of the above-mentioned approaches to network infrastructure planning at the European level and address the potential development of a hydrogen network in Europe. First, an in-depth examination of the ENTSO-G Ten-Year Network Development Plan (TYNDP) for gas and hydrogen will be carried out. Secondly, the recent «European Hydrogen Backbone» initiative will be analysed as a complementary, bottom-up effort to the centrally developed TYNDP.

Table 15 – Approaches for hydrogen transport infrastructure planning. Source: own elaboration retrieved from Palovic and Poudineh (2022).

Type of approach	Centrally Coordinated Approach	Market-Based Approach	Regulatory Approach
Characteristics	<ul style="list-style-type: none"> <li>- Central planner who coordinates infrastructure expansion across different sectors</li> <li>- New, neutral institution or common information platform that promotes exchange among stakeholders</li> <li>- Integrated scenario planning for transmission networks<sup>57</sup></li> <li>- Example in the EU: ENTSO-G and ENT-SO-E network development plans</li> </ul>	<ul style="list-style-type: none"> <li>- Market-driven energy infrastructure development</li> <li>- Cross-sectoral coordination is decentralised</li> <li>- Coordination is optimised by individual stakeholders responding to price signals at energy markets</li> <li>- Possibility for merchant transmission investments (MTIs)<sup>58</sup></li> <li>- Most infrastructure projects are backed by long-term contracts between investors and gas or electricity shippers<sup>59</sup></li> </ul>	<ul style="list-style-type: none"> <li>- Classical network governance mode</li> <li>- Hydrogen-driven investments are based on the social benefit to the entire system</li> <li>- Coordination with providers of alternative mode of transport if those are socially more preferable</li> <li>- Regulated operators of network infrastructures are driven towards the socially optimal behaviour when the consequences of their decisions are priced</li> </ul>

<sup>57</sup> Given the locations of the expected energy production and demand, future energy transportation needs are identified and allocated to different sectors by the central planner.

<sup>58</sup> Merchant Transmission Investments are profit-motivated investments in transmission (cross-border) infrastructure undertaken by non-regulated market players. They are often thought to be the second-best option when regulated investment fails to develop at a suitable pace, but they can also lead to partial un-regulated monopolization of the network, which increases the risk of anti-competitive effects (De Hauteclocque and Rious 2011).

<sup>59</sup> In the energy domain, a shipper can be defined as person (entity) that buys an energy commodity from producers or importers, transports this commodity through the network, and sells it to its customers. Retrieved from: <https://www.edfenergy.com/large-business/glossary>.

Type of approach	Centrally Coordinated Approach	Market-Based Approach	Regulatory Approach
Main advantages	<ul style="list-style-type: none"> <li>- Better addresses investment risks</li> <li>- Better addresses network externality effects</li> </ul>	<ul style="list-style-type: none"> <li>- Possibility for cross-sectoral infrastructure competition</li> <li>- Better deals with technological uncertainty</li> </ul>	<ul style="list-style-type: none"> <li>- Incentive to cost minimisation</li> <li>- Regulated operators are free to cooperate with other hydrogen infrastructure investors</li> </ul>

### 2.3.1 ENTSO-G Ten-Year Network development plan

The Ten-Year Network Development Plan (TYNDP) provides an overview of the European gas infrastructure and its future development, by mapping the integrated gas network according to a range of development scenarios (ENTSOG 2023a)<sup>60</sup>. For the first time, in the TYNDP 2022, ENTSOG developed a dual gas system modelling approach considering both methane and hydrogen networks simultaneously, thus adjusting the TYNDP to include REPowerEU ambitions with respect to hydrogen infrastructure development. The parallel policy-based infrastructure assessment was developed by ENTSOG together with the TSOs to incorporate additional infrastructure needs required to comply with the relevant policy objectives, such as the 2030 hydrogen imports targets defined by the REPowerEU Plan (ENTSOG 2023a). The approach developed by ENTSOG in the TYNDP 2022 refers to both the existing natural gas infrastructure and the planned natural gas and hydrogen infrastructure. Both types are interconnected, allowing to capture interactions between the two gases and assess the role of the transmission system of both fuels in satisfying demand under different conditions.

For the purpose of this work, it is essential to outline the planned and ongoing hydrogen projects, also considering the potential repurposing of gas transmission lines. Today in the EU and the UK around 205 000 km of gas pipelines exist (ENTSOG 2023b), as shown in Figure 15. Given that, unlike methane, hydrogen infrastructure levels can only be defined with the consideration of planned projects, the TYNDP 2022 defines two contrasted hydrogen infrastructure levels (ENTSOG 2023c):

- Level 1 is a project-based infrastructure level, composed of all hydrogen projects submitted by project promoters to the TYNDP 2022 (including infrastructure submitted as «hydrogen-ready») as well as H<sub>2</sub> projects submitted to the first Projects of Common Interest (PCI) selection process under the revised TEN-E Regulation<sup>61</sup>;

<sup>60</sup> The EU Gas Regulation 715/2009 (revised under the Hydrogen and Decarbonised Gas Markets Package) requires ENTSOG to develop the TYNDP every two years.

<sup>61</sup> The Projects of Common Interest are energy infrastructure projects, such as electricity or gas interconnectors, that link the energy systems of the different EU countries and can

– Level 2 is defined as a policy-based infrastructure, composed of hydrogen infrastructure level 1 and additional infrastructure assumptions needed to enable the EU policy objectives for hydrogen.



Figure 15 – Transmission length in the EU and UK in 2022 [km]. Source: ENTSOG (2023b).

#### Hydrogen infrastructure projects included in the TYNDP 2022

After introducing a new infrastructure project category in the TYNDP 2020 for «Energy Transition Projects», ENTSOG decided to develop this category into four different new single project categories, thus allowing for sector-specific insights and displaying development trends (ENTSOG 2023a). The 2022 TYNDP includes 216 investments (in 26 countries) relevant for these four categories, which are: 1) new or repurposed infrastructure to carry hydrogen (HYD), 2) projects for retrofitting infrastructure to integrate hydrogen (RET), 3) biomethane development projects (BIO), and 4) other infrastructure-related projects (OTH). Hydrogen infrastructure projects can be further sub-divided into three groups, namely on-shore and off-shore H<sub>2</sub> transmission pipelines, newly constructed or repurposed liquefied hydrogen terminals (including for hydrogen derivatives, such as ammonia), and hydrogen storages. Overall, 359 investments are covered by the TYNDP 2022 out of which 143 are natural gas projects, 153 are HYD, 13 RET, 11 BIO and 39 OTH (ENTSOG 2023a). Table 16 outlines the 153 HYD investments for each of the three groups (pipelines, liquefied H<sub>2</sub> terminals, and storages).

therefore benefit from accelerated permitting procedures and funding.

Table 16 – Investments in the HYD (hydrogen) infrastructure category in the TYNDP 2022. Source: own elaboration based on ENTSOG (2023b).

Number of investments	Type of investment	Description of the investments
45	Pipelines	investments related to the repurposing of existing pipelines for hydrogen use
45	Pipelines	investments related to the construction of on- or offshore pipelines to enable the transport of pure hydrogen
3	Storage	investments related to the repurposing of existing storages to enable the storage of pure hydrogen
12	Storage	investments related to the construction of storages to enable the storage of pure hydrogen
12	Liquefied H <sub>2</sub> terminals	investments related to new liquefied hydrogen terminal including hydrogen embedded in other chemical substances with the objective of injecting the hydrogen into the grid
7		investments related to equipment or installation essential for the hydrogen system to operate safely, securely and efficiently or to enable bi-directional capacity, including compressor stations
23		investments related to hydrogen production with network related function
2		investment that enables the production, reception, injection, transportation, or end-use supply of hydrogen
4		other hydrogen related investments
153	Total	

As can be derived from the above table, the highest share of H<sub>2</sub> investments falls into the category of construction and conversion of existing infrastructure to transport and store 100% hydrogen. From the TYNDP 2020 to that of 2022, investments in the four energy transition categories (HYD, RET, BIO, OTH) have increased, thus showing the willingness of project promoters to commit to the EU's decarbonisation targets. According to ENTSOG (2023b), the increase in investments over the last two years stems from the need of industries and societies in the EU to reduce their GHG emission in the near-to mid-term future, and from the provisions set out in the recently adopted acts and initiatives at the EU level, aiming at enhancing the deployment of renewable gases along with renewable electricity. Figure 16 shows the number of investments per country and the type of infrastructure of the four new categories, and Figure 17 illustrates the status of those projects, included in the TYNDP 2022. Such investments are mostly in the «less-advanced» stage, whereas the other two stages are the «advanced» and the «final investment decision» (FID) stage.

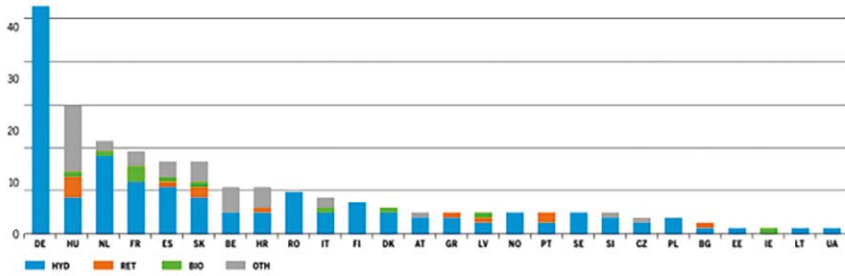


Figure 16 – Number of investments per country and type of infrastructure. Source: ENTSOG (2023b).

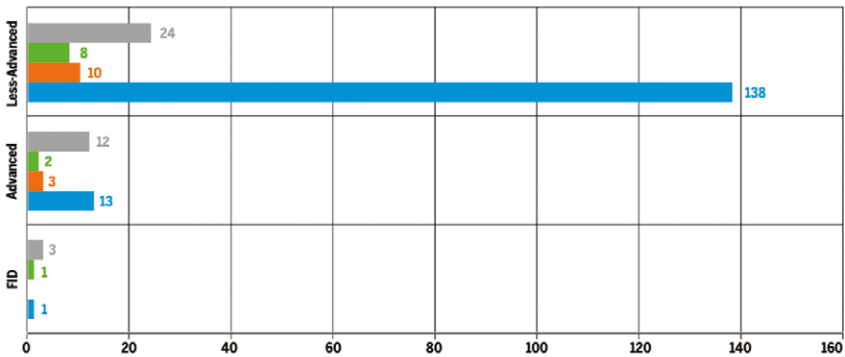


Figure 17 – HYD, RET, BIO and OTH investments by maturity status<sup>62</sup>. Source: ENTSOG (2023b).

### The TYNDP 2024

The latest TYNDP foresees capital investments exceeding €210 billion, approximately 80% of which are dedicated to hydrogen, and the remaining 20% is mainly allocated to natural gas (ENTSOG 2025). Out of the 326 projects included in ENTSOG’s TYNDP 2024, more than 200 focus on hydrogen (in the TYNDP 2022 they were 153). Nearly 80% of the 110 new projects introduced in the 2024 cycle are hydrogen-related, representing a twofold increase compared to TYNDP 2022 (ENTSOG 2025). This development highlights the EU’s strategic commitment to establishing a hydrogen backbone and prioritising regional interconnections and renewable energy integration.

<sup>62</sup> HYD (blue), RET (orange), BIO (green), OTH (grey).

### 2.3.2 The European Hydrogen Backbone Initiative

With the current 33 member companies participating<sup>63</sup>, the European Hydrogen Backbone Initiative (from now on «the Initiative») aims at defining the critical role of hydrogen infrastructure in the EU's decarbonisation effort and in the creation of a liquid and competitive renewable and low-carbon hydrogen market. The Initiative was conceived in 2020 and it has been developing transmission scenarios, connecting hydrogen supply and demand in Europe, towards 2030 and 2040. By examining its regular reports, it is possible to understand the importance of having a new regulatory framework able to ensure hydrogen integration, and to connect the dots with the previously outlined elements, such as the emergence of two parallel gas transport networks, one dedicated to hydrogen, and the other to (bio)methane. The Initiative estimates that around 30 000 km of hydrogen pipelines will be commissioned by 2030, and around 57 600 km by 2040 (European Hydrogen Backbone 2023). Table 17 summarises the envisioned length of the future hydrogen network, as projected by the Initiative.

Table 17 – Envisioned length of the EHB network [km]. Source: own elaboration based on European Hydrogen Backbone (2023).

Year	Overall length	Length of repurposed pipelines	% repurposed pipelines
2030	32616	16864	51.7
2040	57662	34290	59.5

While ongoing multiple studies are investigating to which extent it is technically feasible and economically efficient to use the existing natural gas infrastructure for the transport of hydrogen, according to Grote et al. (2022), about 70% of the total onshore pipeline length in Europe could possibly be reused or repurposed for the transport of hydrogen. Although repurposed pipelines will represent a clear majority of the overall network, the increase in total pipeline length for the 2040 network is mainly due to the newly built pipelines (European Hydrogen Backbone 2023).

Previous analyses of the Initiative have shown that a hydrogen pipeline can transport some 65 TWh of hydrogen per year (Van Rossum et al. 2022). This result is based on two assumptions: 1) a pipeline can transport around 13 GW of hydrogen (capacity), and 2) a load factor of 5000 hours in a year is considered. By multiplying the capacity (13 GW) by the time (5000 hours), we obtain 65000 GWh, that correspond to 65 TWh. This means that transporting 10 Mt (or 330 TWh) of hydrogen, as set by the REPowerEU import target, would require approximately five (65 TWh multiplied by 5) large-scale pipeline corridors towards Europe.

<sup>63</sup> As of 2023, the participating companies (mainly TSOs) are: Amber Grid, Bulgartransgaz, Conexus, CREOS, DESFA, Elering, Enagás, Energinet, Eustream, FGSZ, FlusSwiss, Fluxys Belgium, Gas Connect Austria, Gasgrid Finland, Gassco, Gasunie, GASCADE, Gas Networks Ireland, GRTgaz, National Gas Transmission, NET4GAS, Nordion Energi, OGE, ONTRAS, Plinacro, Plinovodi, REN, Snam, TAG, Teréga, Transgaz, Transitgas AG and the TSO of UA. See: ehb.eu.

## Costs of an expanded H<sub>2</sub> network

Since the publication of its first infrastructure report, the European Hydrogen Backbone has steadily revised its cost estimations on the development of a dedicated H<sub>2</sub> network within the span of 15-20 years up to 2040. The two fundamental cost components are CAPEX and OPEX. Given that here the cost estimations and the economic analysis are limited to the transmission part of the hydrogen market, it is interesting to outline the evolution of both the CAPEX and OPEX values, and the so-called levelized cost of hydrogen transport (LCOT).

While a cubic meter of hydrogen contains only one third of the energy of a cubic meter of methane at the same pressure (lower «energy density» of H<sub>2</sub>), this does not mean that three times as many pipelines are required to transport the same amount of energy, because the maximum energy capacity of an H<sub>2</sub> pipeline can be increased up to 80% of the energy capacity it has when transporting natural gas (Wang et al. 2020). There can be variations across regional gas networks concerning operating pressures, pipeline diameters and compression system designs, which would impact cost estimates. However, the European Hydrogen Backbone has taken an infrastructure-driven view (as opposed to designing parameters for a specific system demand) and has selected a generic network design, thus obtaining cost ranges that are deemed representative of the EU-average (Wang et al. 2020). Table 18 reports the evolution of the CAPEX and OPEX estimations of the Initiative up to 2040. Initially, operational costs were lower than expected, and they remained quite stable in subsequent estimations. Instead, capital expenditure, which is split into the pipeline costs and the compression cost component, progressively increased (also due to the rising inflation and market disruptions).

Table 18 – Evolution of CAPEX and OPEX values according to the network cost estimations by 2040 (in billion €). Source: own elaboration based on Wang et al. (2020), Jens et al. (2021), and Van Rossum et al. (2022).

Year of the EHB report	CAPEX	OPEX <sup>64</sup>
2020	27-64	1.6-3.5
2021	43-81	1.7-3.8
2022	80-143	1.6-3.2

The investment costs and the levelised cost of transmission (LCOT), as estimated in the EHB reports, largely reflect the cost assessments carried out in the first chapter of this work, concerning both new and repurposed H<sub>2</sub> pipelines. If we consider first the unit capital cost figures (in million € per km of pipeline length), we can indeed see that the cost estimations outlined in Table 3 (Chapter 1) correspond to the data reported by the EHB. The EHB estimates

<sup>64</sup> A load factor of 5000 hours per year is assumed.

a CAPEX of around 2.8 M€/km for new pipelines, and 0.3-0.6 M€/km for repurposed pipes (Van Rossum et al. 2022), while the economic analysis in Chapter 1 included costs of 2.48 M€/km for new pipelines, and around 0.37 M€/km for repurposed lines. This category of costs mostly depends on variables such as the electricity price and the compressor size. The levelised cost of hydrogen transmission is also like that hypothesised in the first chapter, as it is estimated at around 3.3-6.3 €/MWh in the EHB report, and it is around 3.7-4.6 €/MWh in the first chapter of this thesis.

## Conclusions

The analysis presented in this chapter has shown the extent to which the EU's approach, and that of the European Commission in particular, has been influenced by its own experience in the previous efforts to liberalise natural gas markets. This includes not only the discussion regarding the new Hydrogen and Decarbonised Gas Markets Package, thus linking the role of hydrogen and biomethane with the need to replace fossil-based molecules, but it also regards the critical issue of the network structure (unbundling issues, market access and infrastructure planning). After examining the key proposals made by the Commission and negotiated by the EU legislative institutions, a question arises as to whether these regulatory measures will allow enough flexibility and time for the still emerging hydrogen market and infrastructure to reach maturity. Scenarios developed by the EU institutions and research bodies, as well as those drawn up by private entities and energy sector associations must consider the possibility that the H<sub>2</sub> market will develop at a slower or even faster pace in the next decades, and thus the proposals may bolster or slow down the establishment of a mature market.

The importance of timely investments has been stressed also because there is the possibility to repurpose and retrofit part of the existing infrastructure for hydrogen. This perspective is currently characterised by a so-called «chicken or egg problem», whereby H<sub>2</sub> producers, consumers, infrastructure operators and regulatory actors are all waiting for the other one to take the first step. Several top-down funding mechanisms have been put in place to create a favourable environment for private investments, but the most critical element that must be considered is the identification of potential hydrogen off-takers, who can drive demand in different sectors. Industry and long-haul or public transport applications can serve as frontrunners in the uptake of hydrogen, as various projects around the EU currently demonstrate, also thanks to the nascent hydrogen valleys.

This situation partly reflects the status of the emerging hydrogen economy in Italy, which will indeed be the subject of the next chapters, together with the examination of how to ensure that enough renewable and low-carbon hydrogen is imported in Europe, through a fit-for-purpose infrastructure, a part of which will be located on Italy's territory. Finally, the need to integrate the electricity and gas sector to unlock the potential of a clean energy system, as was analysed in this chapter, is one of the main items that we will attempt to deepen, with respect to the Italian power and gas systems, which are among the largest in the EU.