D3.1 – Hydrogen Policy Assessment Report

WP3 – Test line upgrade & Long Term business strategy

Document Detail

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The objective of this document is to address the analysis of the current hydrogen strategies and actions implemented at national (some) and international levels, generating a database of hydrogen policies by geographical area, development stage and sector.

It will help to identify the targets and instruments for the innovation in the field of hydrogen processes and technologies.

1 First analysis: international H_2 market according to IEA

As a starting point, the first step is the analysis of the projection of the H_2 market at the global (international) level, referring to the most relevant international energy-analysis institute, the International Energy Agency (IEA).

These projections will determine the context in which we can analyse the main targets and instruments for the innovation in the field of hydrogen processes and technologies.

1.1 Global H_2 demand and share by World Region

Current hydrogen demand is 95 million tons in 2022, with China holding the largest share [International Energy Agency, "Global Hydrogen Review 2023," 2023. [Online]. Available: www.iea.org].

IEA		
Hydrogen use by World Region in 2022 https://www.iea.org/reports/global-hydrogen-review-2023		
	Share	**Quantity [Mt]**
China	29%	27.55
North America	17%	16.15
Middle East	13%	12.35
India	9%	8.55
Europe	8%	7.60
Rest of the world	24%	22.80

Table 1. *Hydrogen use by World Region in 2022 according to IEA [1].*

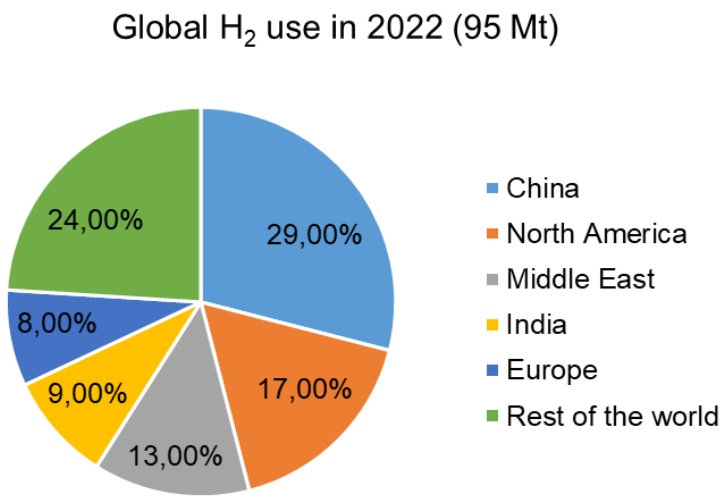


Figure 1. *Hydrogen use by World Region in 2022 according to IEA*

1.1.1 H_2 end uses

The division of the hydrogen demand by sector in the last few years is the following [International Energy Agency, "Global Hydrogen Review 2023," 2023. [Online]. Available: www.iea.org]:

IEA						
Global demand for hydrogen [Mt], 2019-2022						
https://www.iea.org/data-and-statistics/charts/global-hydrogen-demand-by-sector-in-the-net-zero-scenario-2019-2030						
	Refining	**Ammonia**	**Methanol**	**Iron and steel**	**Other**	**Total**
2019	39.6	32.4	13.8	4.5	0.9	91.2
2020	37.9	32.9	13.3	4.5	0.9	89.5
2021	39.8	33.8	14.6	5.2	0.9	94.3
2022	41.9	32.9	14.9	5.1	0.2	95.0

Table 2 Global hydrogen demand by sector in 2022 according to IEA [2].

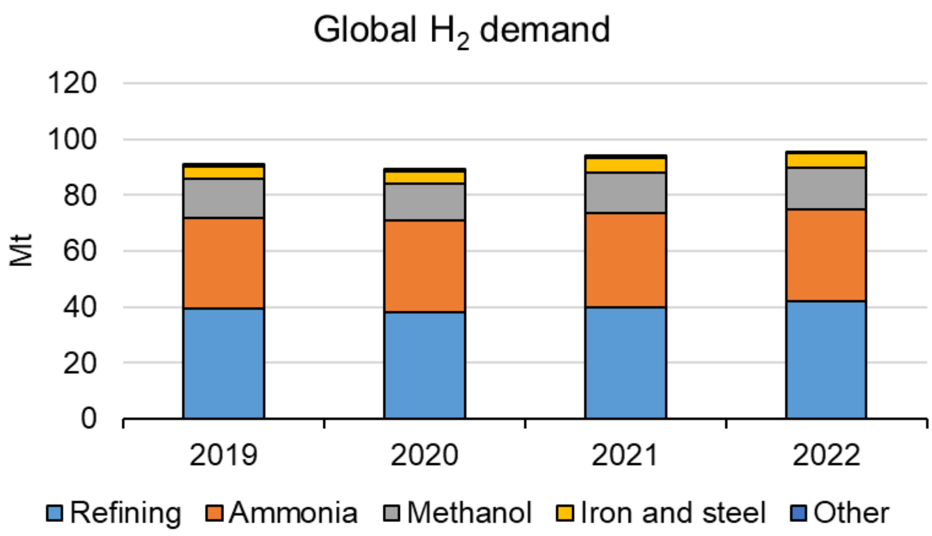


Figure 2 Global hydrogen demand by sector in 2022 according to IEA

The two main sectors that currently and historically constitute the main source of hydrogen demand are refining and ammonia [International Energy Agency, "Global Hydrogen Review 2023," 2023. [Online]. Available: www.iea.org]:

IEA		
Global H_2 demand for refining and ammonia, in [Mt]		
https://www.iea.org/data-and-statistics/charts/global-demand-for-pure-hydrogen-1975-2018		
	Refining	**Ammonia**
1975	6.20	10.88
1980	6.83	16.17
1985	8.56	20.00
1990	12.03	21.41
1995	15.83	21.96

2000	21.45	28.57
2005	25.26	26.14
2010	30.97	28.35
2015	35.97	31.92
2018	38.24	31.46
2019	39.60	32.40
2020	37.90	32.90
2021	39.80	33.80
2022	41.90	32.90

Table 3 Historical trend of global hydrogen demand by refining and ammonia according to IEA [3]

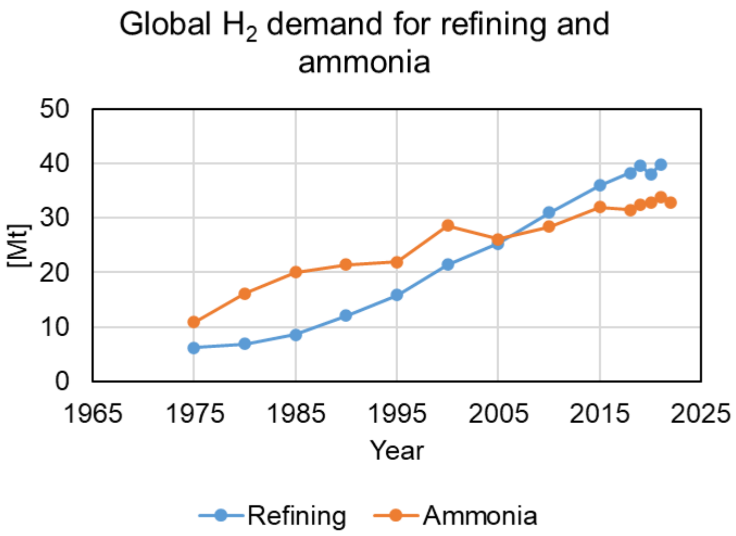


Figure 3 Historical trend of global hydrogen demand by refining and ammonia according to IEA

1.1.2 H_2 production routes

IEA				
Global hydrogen production by technology, in [Mt] https://www.iea.org/data-and-statistics/charts/global-hydrogen-production-by-technology-in-the-net-zero-scenario-2019-2030				
	Fossil fuels without CCUS	**By-product**	**Fossil fuels with CCUS**	**Electricity**
2019	75.8	14.3	0.4	0.0
2020	74.4	14.2	0.4	0.0
2021	77.4	14.4	0.4	0.1
2022	79.6	14.8	0.5	0.1

Table 4 Recent historical trend of global hydrogen production according to IEA [4].

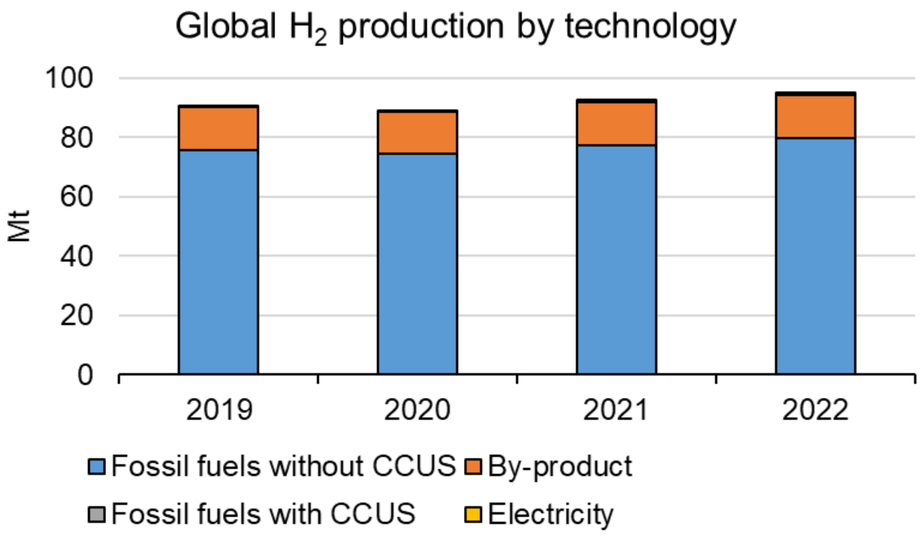


Figure 4 Recent historical trend of global hydrogen production according to IEA

1.1.3 Current low-carbon H_2 projects

IEA					
Low-emission hydrogen production projects https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map					
WILIAM regions		**Operational production capacity [kt H_2/yr]**			**Installed electrolysis capacity [MW]**
		Electrolysis	**Fossil fuels with CCUS**	**Other**	
European Union	EU27	140	34	0	210
United Kingdom	UK	1	0	0	9
China	China	117	0	0	615
East Asia and Oceania	EASOC	6	0	0	41
India	India	3	0	0	19
Latin America	LATAM	4	0	0	30
Russia	Russia	1	0	0	20
United States, Mexico and Canada	USMCA	10	418	0	71
Rest of the world	LROW	6	0	0	39
Total		288	452	0	1054

Table 5 Low-emission hydrogen production by World Region in 2022 according to IEA [5].

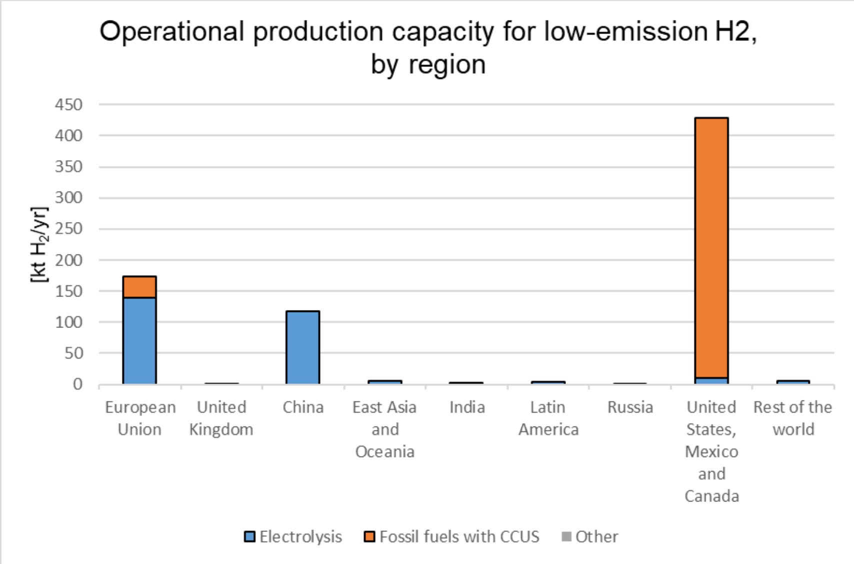


Figure 5 Low-emission hydrogen production by World Region in 2022 according to IEA

1.1.4 Future H_2 production and demand

IEA states that, in 2030, announced projects correspond to low-emission hydrogen production of 20 Mt, and 38 Mt when early-stage projects are included, but only 4% have reached final investment decision or are under construction.

Electrolyser projects dominate among the announced hydrogen production projects: more than 70% of low-emission hydrogen production in 2030 could come from electrolysis [International Energy Agency, "Global Hydrogen Review 2023," 2023. [Online]. Available: www.iea.org]:

IEA		
Low-emission hydrogen production by technology route, maturity and region based on announced projects and in the "Net Zero Emissions by 2050 Scenario", 2030, in [Mt] https://www.iea.org/reports/global-hydrogen-review-2023		
	Electrolysis	**Fossil fuels with CCUS**
Europe	8	4
Australia and New Zealand	6	1
Latin America	6	0
India	2	0
United States	2	4
China	1	0
Canada	0	1
Middle East	1	0
RoW	2	0
Total	28	10

Table 6 Low-emission hydrogen production by process in World Region announced in 2022 according to IEA [1].

IEA					
Low-emission hydrogen production projects https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map					
WILIAM regions		**Operational production capacity [kt H_2/yr]**			**Installed electrolysis capacity [MW]**
		Electrolysis	**Fossil fuels with CCUS**	**Other**	
European Union	EU27	25839	2477	102	127452
United Kingdom	UK	1051	6217	0	5905
China	China	3696	55	0	10824
East Asia and Oceania	EASOC	18911	1330	12	89268
India	India	6594	62	0	38842
Latin America	LATAM	14196	0	198	82820
Russia	Russia	1	0	0	20
United States, Mexico and Canada	USMCA	4726	7354	85	26467
Rest of the world	LROW	9707	935	0	17507
Total		97728	18909	759	443692

Table 7 Low-emission hydrogen production by World Region projected in 2030 according to IEA [5].

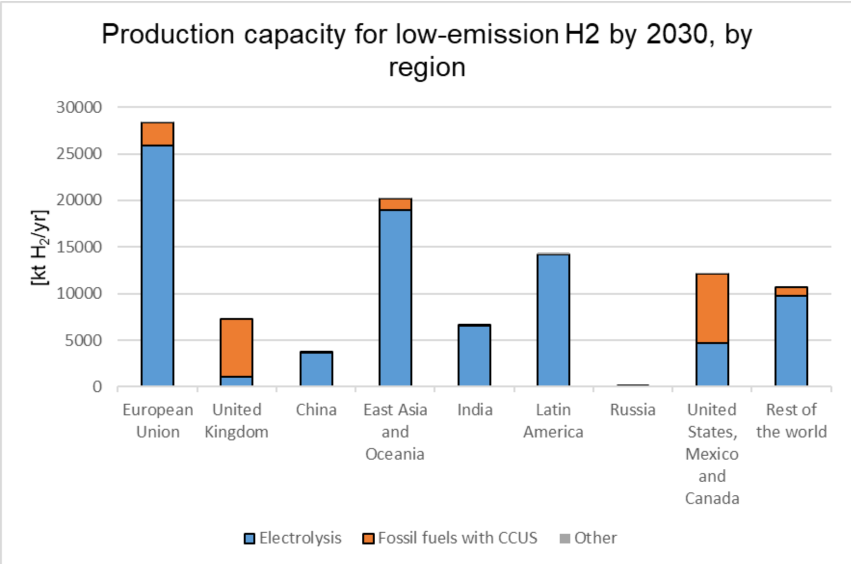


Figure 6 Low-emission hydrogen production by World Region projected in 2030 according to IEA

IEA					
Global hydrogen production by technology in the NZE scenario 2019-2030 [Mt] https://www.iea.org/data-and-statistics/charts/global-hydrogen-production-by-technology-in-the-net-zero-scenario-2019-2030					
	Fossil fuels without CCUS	**By-product**	**Fossil fuels with CCUS**	**Electricity**	**Bioenergy**
2030	68	13.3	22.4	50.8	0.2

Table 8 Global hydrogen production by technology projected in 2030 according to IEA [4].

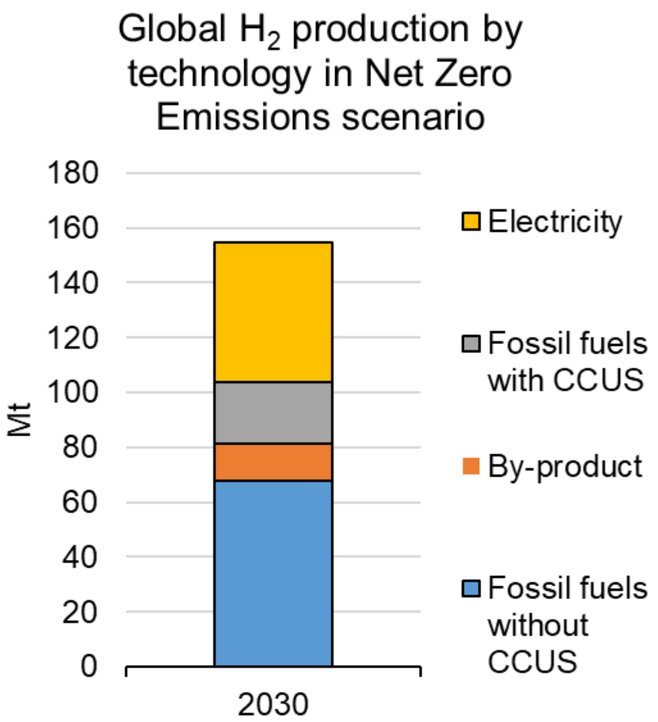


Figure 7 Global hydrogen production by technology projected in 2030 according to IEA

IEA				
Global hydrogen demand by sector in the Net Zero Scenario, in [Mt] https://www.iea.org/data-and-statistics/charts/global-hydrogen-demand-in-the-net-zero-scenario-2022-2050				
		2030	**2040**	**2050**
Oil refining	**Low-emission hydrogen**	6	7	6
	From unabated fossil fuel	29	11	4
Chemical (existing)	**Low-emission hydrogen**	7	26	47
	From unabated fossil fuel	45	30	9
Iron and steel (existing)	**Low-emission hydrogen**	1	4	7
	From unabated fossil fuel	6	4	1
Chemical (new)	**Low-emission hydrogen**	2	9	14
	From unabated fossil fuel	0	0	0
Iron and steel (new)	**Low-emission hydrogen**	6	28	41
	From unabated fossil fuel	0	0	0
Other industry	**Low-emission hydrogen**	4	13	21
	From unabated fossil fuel	0	0	0

Aviation and marine fuel	**Low-emission hydrogen**	11	60	116
	From unabated fossil fuel	0	0	0
Power generation	**Low-emission hydrogen**	22	68	75
	From unabated fossil fuel	0	0	0
Road transport	**Low-emission hydrogen**	4	22	61
	From unabated fossil fuel	0	0	0
Total		143	282	402

Table 9 Global hydrogen demand by sector projected in 2030-2040-2050 according to IEA [6].

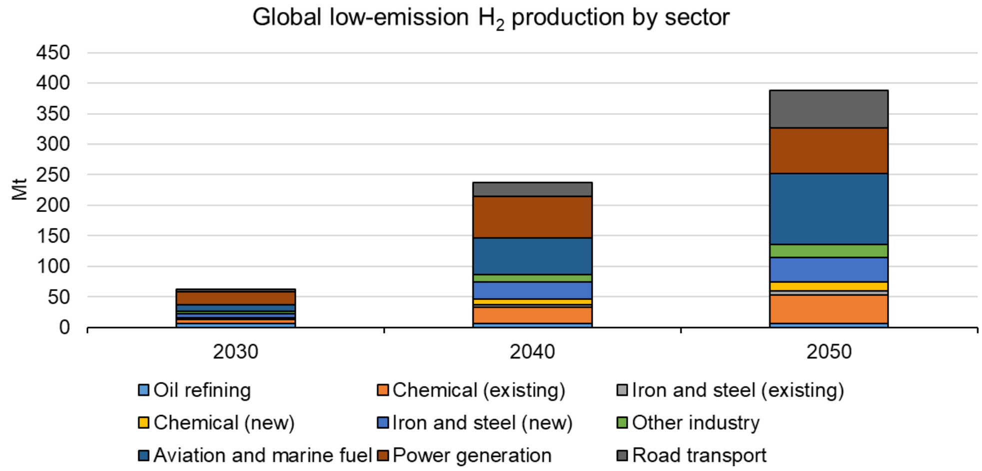


Figure 8 Global hydrogen demand by sector projected in 2030-2040-2050 according to IEA

It is to consider that the IEA projected various scenarios, each with a different trajectory towards emission reduction goals, depending on the level of effort that the different nations will dedicate in decarbonization.

The demand for low-carbon hydrogen in the coming decades by sector is expected to be as follows, based on the Sustainable Development scenario:

IEA							
Global hydrogen demand by sector in the Sustainable Development Scenario, 2019-2070, in [Mt] https://www.iea.org/data-and-statistics/charts/global-hydrogen-demand-by-sector-in-the-sustainable-development-scenario-2019-2070							
	Refining	**Power**	**Transport**	**Buildings**	**Industry**	**Synfuels production**	**Ammonia production**
2019	38.4	0	0	0	32.6	0	0
2030	32.9	4.7	1.6	2	39.1	6.9	1.1
2040	25.1	6.4	19.6	13.2	49.5	15.5	7.2
2050	16.9	55	66.5	26.6	62.9	40.8	18.3
2060	10.5	70.7	117.6	29.6	72.0	81.5	33.3
2070	7.8	72.9	158.2	27.4	77.7	121.5	53.6

Table 10 Global hydrogen demand by sector projected in 2030-2040-2050-2060-2070 according to IEA in the Sustainable Development scenario [7].

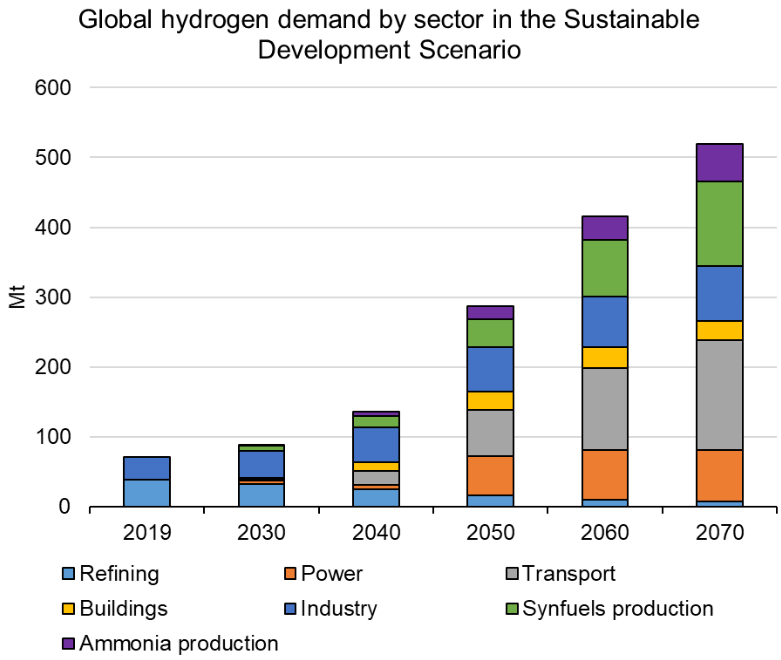


Figure 9 Global hydrogen demand by sector projected in 2030-2040-2050-2060-2070 according to IEA in the Sustainable Development scenario

These are the projections in which we will develop the decisions inside the H_2SHIFT project.

2 Second analysis: policy measures on H_2

2.1 International context

2.1.1 Global Hydrogen Review 2023 (IEA)

A total of 41 governments, accounting for nearly 80% of global energy-related CO_2 emissions, have now adopted hydrogen strategies.

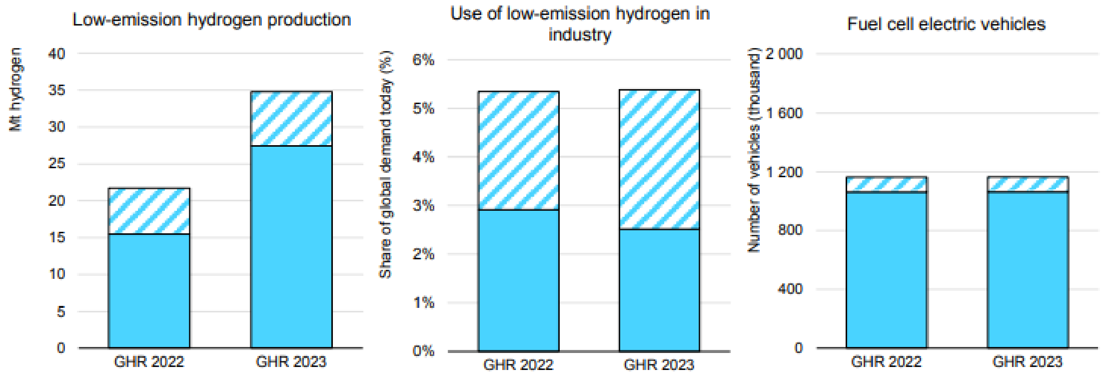


Figure 10 Global targets for low-emission hydrogen production, use in industry and fuel cell electric vehicles by 2030, according to IEA

Hydrogen is becoming a more common topic in general co-operation agreements. Some multilateral co-operations like G7, G20 or COP27 have strengthened their work on hydrogen.

The establishment of a global hydrogen market could be greatly aided by collaboration and co-operation among governments to foster a certain level of interoperability among regulatory frameworks. Beyond environmental attributes, the creation of hydrogen value chains requires the development of a comprehensive portfolio of international standards dealing with safety, technology compatibility and operational issues. The European Clean Hydrogen Alliance published in March 2023 a roadmap on hydrogen standardisation. Regarding safety standards, the European Hydrogen Safety Panel (EHSP) has updated its guidance on Safety Planning and Management in EU hydrogen and fuel cell projects.

The ISO aims to publish a Technical Specification for Hydrogen by the end of 2023 and subsequently a draft International Standard by the end of 2024.

A key area in which there has been no notable progress is in the development of hydrogen leakage measurement, reporting and verification protocols, and the development of methods and standards to detect and repair hydrogen leakage.

Governments have also adopted regulations unrelated to the environmental attributes of hydrogen, in areas such as infrastructure or permitting.

2.1.2 Hydrogen Standardisation Roadmap (ECH2A)

Objectives:

- Make a comprehensive analysis of ongoing hydrogen related standardisation activities.
- Establish a comprehensive overview of standardisation gaps/priorities and needs along the whole value chain.
- Increase information exchange about and improve the awareness of, future and ongoing standardisation activities.
- Streamline standardisation ideas emanating from different initiatives.
- Schedule topics in a timeline.

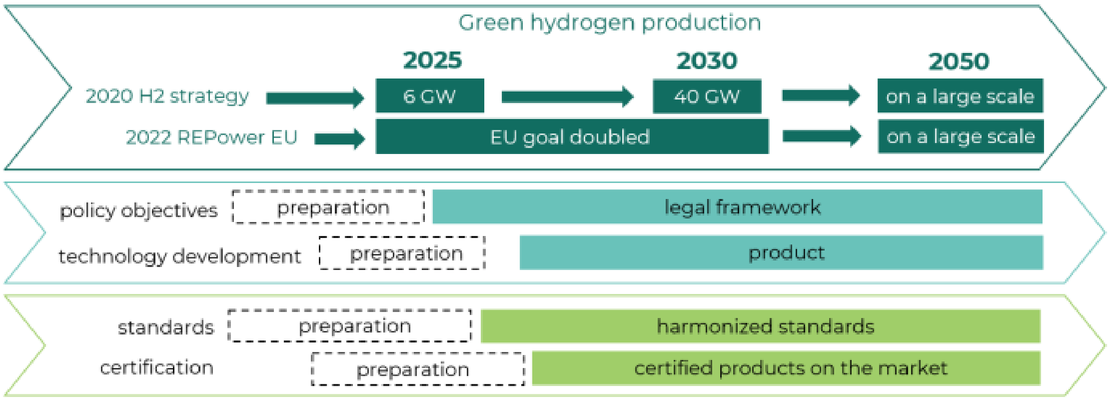


Figure 11 Policy framework in relation to development of hydrogen technologies

2.1.3 Global Hydrogen Review 2023

The number of announced projects for low-emission hydrogen production is rapidly expanding. Annual production of low-emission hydrogen could reach **38 Mt in 2030**, if all announced projects are realised, although 17 Mt come from projects at early stages of development.

Large amounts of government funding are being made available through schemes such as the US Hydrogen Production Tax Credit, the EU Important Projects of Common European Interest and the UK Low Carbon Hydrogen Business Model.

Manufacturers have announced plans for further expansion, aiming to reach 155 GW/year of manufacturing capacity by 2030, but only 8% of this capacity has at least reached FID (Final Investment Decision).

Global hydrogen use reached 95 Mt in 2022, a nearly 3% increase year-on-year. Demand remains concentrated in industry and refining, with less than 0.1% coming from new applications in heavy industry, transport or power generation. Low-emission hydrogen is being taken up very slowly in existing applications, accounting for just 0.7% of total hydrogen demand, implying that hydrogen production and use in 2022 was linked to more than 900 Mt of CO_2 emissions.

Developed under the Clean Energy Ministerial framework, the **Hydrogen Initiative (H2I)** is a voluntary multi-governmental initiative that aims to advance policies, programmes and projects that accelerate the commercialisation and deployment of hydrogen and fuel cell technologies across all areas of the economy.

- Breakthrough Agenda
- Hydrogen Council
- International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)
- International Renewable Energy Agency (IRENA)
- Mission Innovation Clean Hydrogen Mission
- World Economic Forum
- United Nations Industrial Development Organization (UNIDO)
- IEA Advanced Fuel Cells and Hydrogen Technology Collaboration Programmes (TCPs)

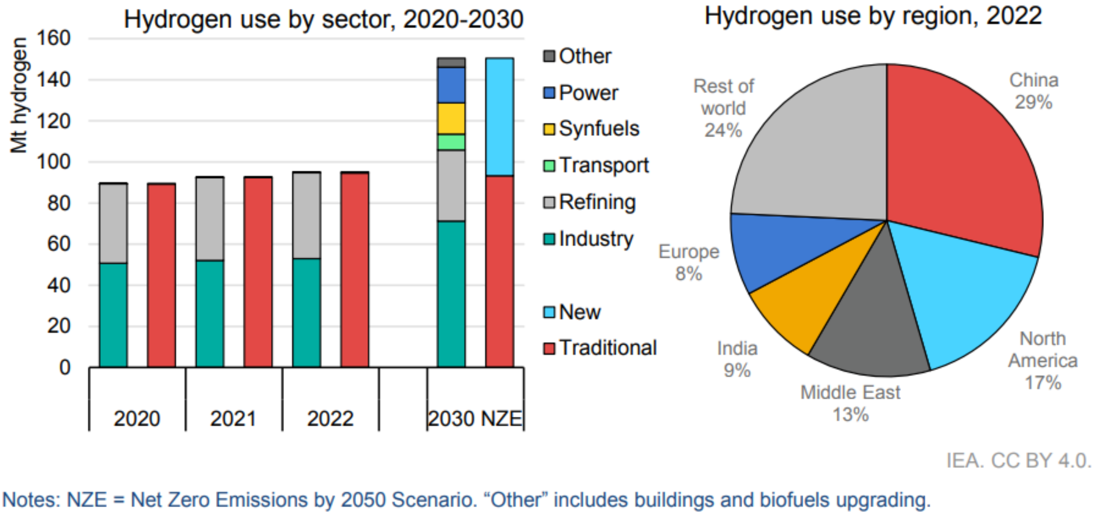


Figure 12 Hydrogen use by sector and by region, historical and in the Net Zero Emissions by 2050 Scenario, 2020-2030

In the NZE Scenario, hydrogen use in industry grows to 70 Mt by 2030. Meeting this need would require a 4% annual increase in production, compared to just 2% over the past 4 years. Furthermore, to meet emission reduction objectives, about one-third of industrial hydrogen production capacity needs to be low-emission by 2030, which would require most of the new capacity to be low-emission, as well as retrofits to some existing stock.

Significant efforts have been undertaken to develop programmes to support low emission hydrogen production (such as the Important Projects of Common European Interest [IPCEI] in the European Union, the Low Carbon Hydrogen Business Model in the United Kingdom or the Clean Hydrogen Production Tax Credit in the United States) and regulations.

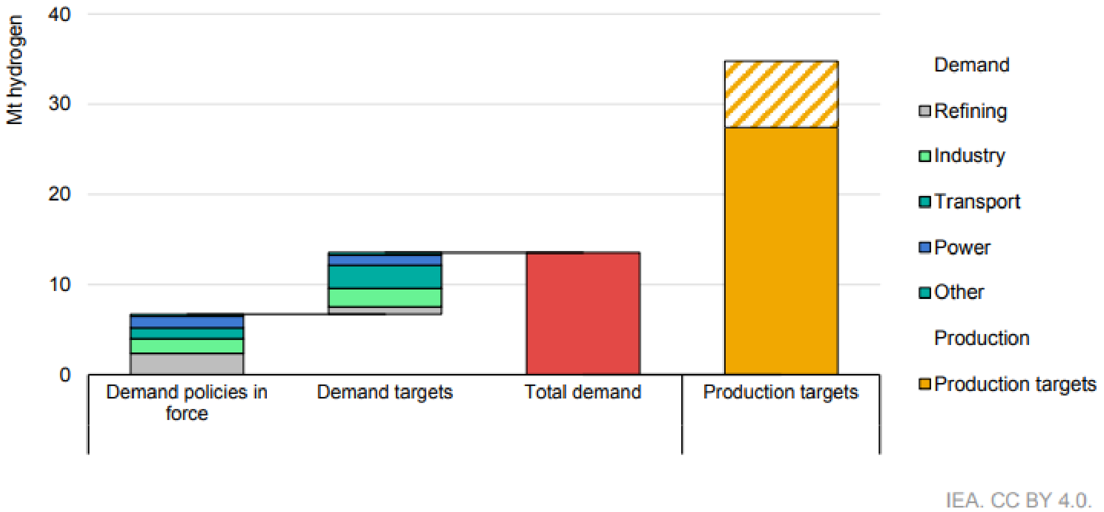
Infrastructure development has only come into the policy debate very recently, with most efforts taking place in Europe, where European transmission system operators have started to plan the development of hydrogen infrastructure through the European Hydrogen Backbone initiative. Activity intensified after Russia's invasion of Ukraine, when European countries started developing new gas infrastructure to diversify supply away from Russian gas. This drew attention to the need to carefully consider how any new gas-related infrastructure could potentially support the future development of hydrogen in the context of climate ambitions.

The priority is to switch the existing demand for hydrogen in industry and refining from using unabated fossil-based hydrogen to low-emission hydrogen. This substitution is hindered by the higher cost of low-emission hydrogen, especially given that most of the supply from unabated fossil fuels is from existing plants operating on a marginal cost basis.

One option would be to apply a sustained, elevated carbon price that raises costs for all hydrogen users, but by a lower amount for users of low-emission hydrogen. Another option is to offer payments to producers of low-emission hydrogen so that they can compete on price with other hydrogen supplies, or payments to consumers to encourage them to use low-emission hydrogen by partially or totally compensating for the additional cost.

To close the cost gap, governments can also facilitate the creation of demand for low-emission hydrogen by adopting regulatory measures such as quotas or mandates that enforce the use of low-emission hydrogen in existing applications.

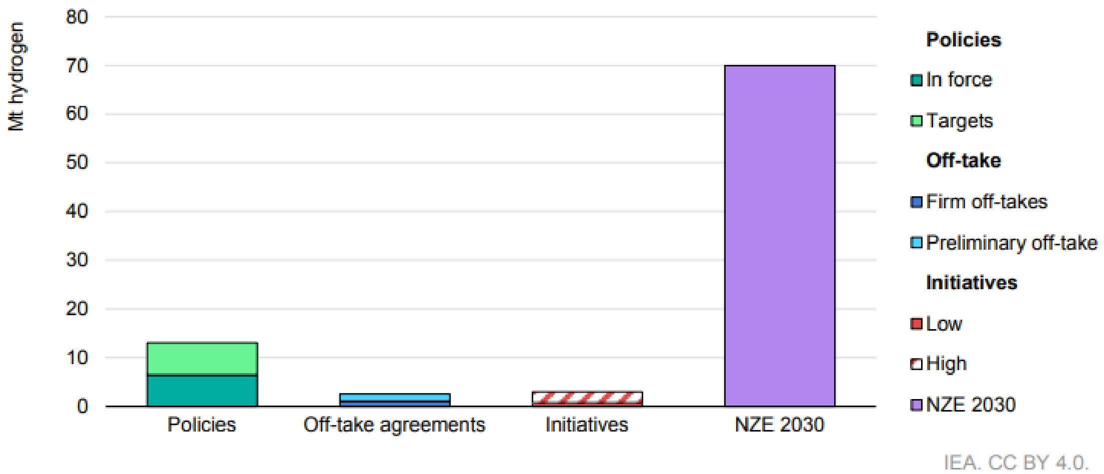
The European Union targets meeting 42% of industrial hydrogen demand with renewable fuels of non-biological origin (RFNBOs) by 2030. While these targets can signal intent to producers and consumers, in the absence of other measures, they are insufficient to encourage market players to fully commit to scaling up the use of low-emission hydrogen, given the associated higher costs. Robust policies and regulations – and not just targets – are required to create the right investment environment, combining both support for incentivising project developers and penalties for non-compliance.



Notes: In Production targets, the dashed area represents policy targets' ranges. For countries that do not have a production target, the low-emission hydrogen production is estimated from the capacity targets assuming a capacity factor of 57% and an energy efficiency of 69% for electrolysers and 90% for fossil-based technologies.

Figure 13 Potential demand for low-emission hydrogen created by implemented policies and government targets, and production targeted by governments, 2030

- The European Commission provides grants through the Innovation Fund and approved EUR 5.2 billion (USD 5.5 billion) for the Hy2Use (IPCEI) to fund projects aiming to use renewable hydrogen in industrial applications.
- The European Council and Parliament reached a political agreement on the ReFuelEU aviation initiative, which includes a minimum share of 1.2% of synthetic fuels in aviation to be implemented from 2030, and the FuelEU Maritime initiative, which includes a subtarget of 2% of RFNBO in maritime fuel from 2034, if these fuels have not reached 1% by 2031.
- The EU Parliament and Council adopted an amended regulation to strengthen CO_2 emission standards for new passenger cars and light commercial vehicles.



Notes: NZE = Net Zero Emissions by 2050 Scenario. In "Initiatives", the dashed area corresponds to the range between the most conservative (low) and boldest (high) estimates of the demand that can be generated by international initiatives.

Figure 14 Potential demand for low-emission hydrogen from announced policies and targets, private off-take agreements, commitments of international cooperation initiatives and the Net Zero Emissions by 2050 Scenario, 2030

A one-size-fits-all approach will not work for stimulating demand in all sectors. In some areas, where hydrogen end-use technologies are not yet commercially available, incentives combined with innovation and demonstration efforts may be more appropriate. In other sectors where technologies are readily available, more coercive measures like mandates and ambitious emissions standards can drive faster adoption.

The scale-up in installed electrolyser capacity is also accompanied by a trend towards larger projects being announced. While the average size of electrolyser plants is about 12 MW today, it could grow to several hundreds of MW in few years and to 1 GW by 2030, with GW-scale projects representing more than 75% of announced capacity for 2030.

The levelised cost of hydrogen production from unabated fossil-based sources was in the range of USD 1.0-3.0/kg H_2 in 2021, the cheapest option to produce hydrogen, compared with the use of fossil fuels with CCUS (USD 1.5-3.6/kg H_2) or the use of electrolysis with low-emission electricity (USD 3.4-12/kg H_2).

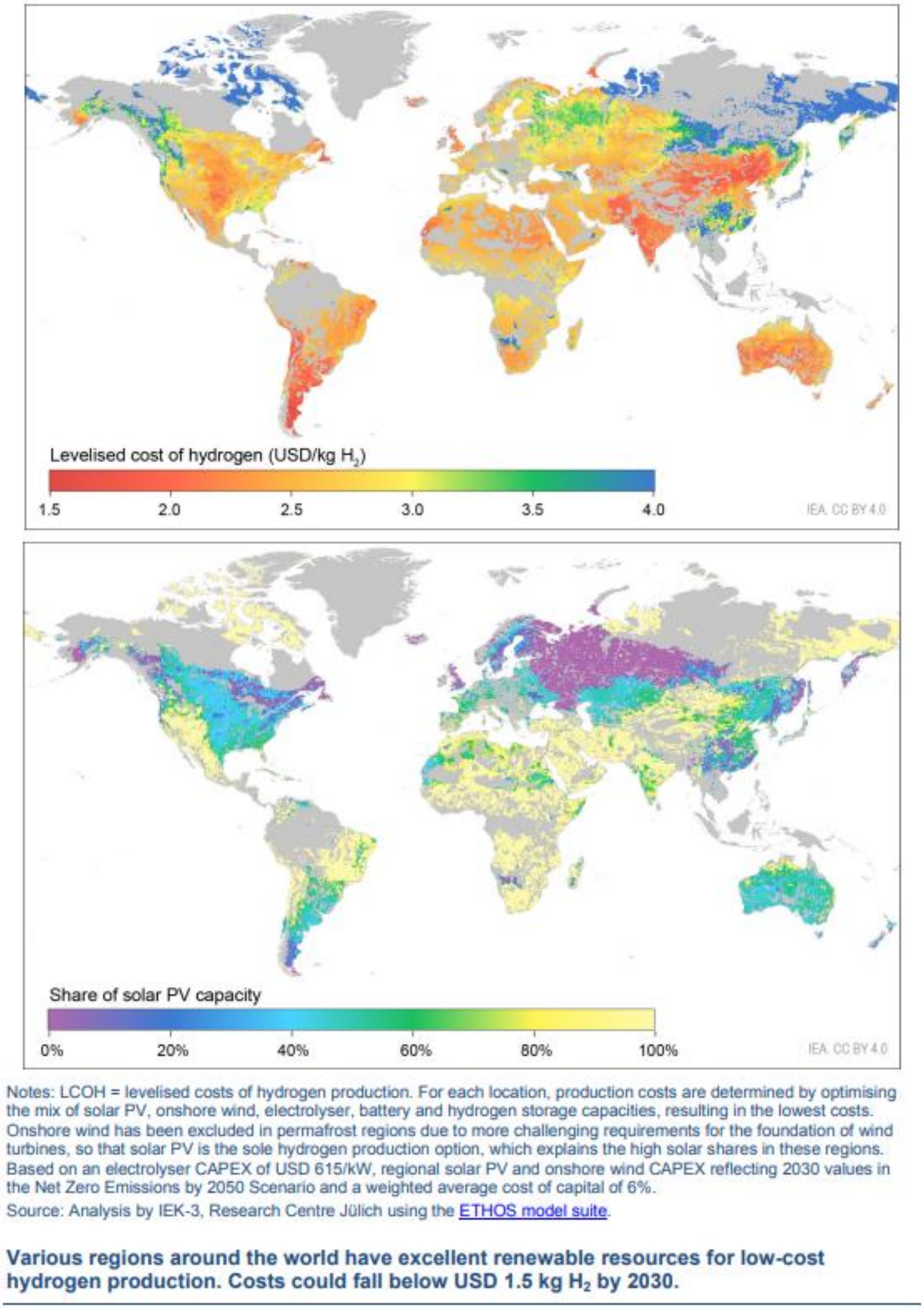


Figure 15 Hydrogen production costs and share of solar PV from hybrid solar PV and onshore wind systems, 2030

Other low-emission hydrogen production routes have gained some attention lately, particularly biomass-based routes, natural hydrogen and methane decomposition.

- Waste processing
- Biomass gasification
- Biomass pyrolysis
- Methane decomposition
- Extracting natural hydrogen

Hydrogen-based fuels and feedstocks, including ammonia, methanol and synthetic hydrocarbons (synthetic methane and Fischer-Tropsch products such as diesel and kerosene), are easier to store and transport than pure hydrogen, and can often make use of existing infrastructure such as natural gas pipelines and end-use technology such as aeroplanes. Despite the advantages with regards to storage and transport, producing hydrogen-based fuels entails additional costs, energy and feedstocks to convert hydrogen into these fuels.

The majority of hydrogen trade announced projects – accounting for 80% of potential production – prioritise ammonia for the transport of hydrogen, in many cases aiming for a final use that does not require reconversion back to hydrogen (Figure 20). This includes use as feedstock in the fertiliser industry, or as a fuel for co-firing in power generation. Reconversion back to hydrogen requires energy and adds significant cost, potentially altering the economic competitiveness of the supply chain.

The REPowerEU plan sets a target of 10 Mt of renewable hydrogen imports into the European Union by 2030, of which 40% should be in the form of ammonia or other derivatives.

In the NZE Scenario, 14 Mt of hydrogen equivalent are traded inter-regionally by 2030, corresponding to about 25% of low-emission merchant hydrogen production. The volume of the announced trade projects is comparable with the trade volume in the NZE Scenario. Those projects with a defined destination represent only half of the trade in the NZE Scenario in 2030 and those with a potential off-taker only one-third. Almost two-thirds of the trade in the NZE Scenario is in the form of ammonia, while around half of the hydrogen traded in its pure form is transported via pipeline.

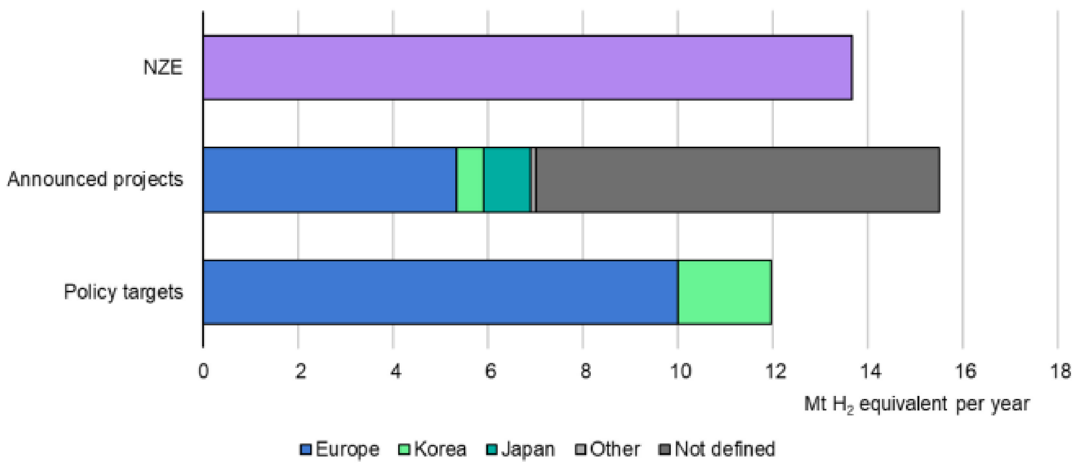


Figure 16 Low-emission hydrogen trade by importing region based on announced projects, policy targets and in the Net Zero Emissions by 2050 Scenario, 2030

As hydrogen supply expands, underground geological facilities could be needed for storage to balance supply fluctuations caused by variable renewable electricity used in electrolysers and from seasonal changes in demand, as well as to bolster energy security.

In addition to salt caverns, hydrogen might also be stored underground in porous media formations such as depleted oil and gas reservoirs or saline aquifers, although they have not yet been proved for pure hydrogen storage. Hydrogen reactivity has been observed in porous reservoirs when town gas was injected, sometimes resulting in very high consumption of stored hydrogen. However, it remains to be assessed whether these findings would also apply to pure hydrogen storage.

Electrolysers' cost inflation increases exacerbate an existing tension in the sector caused by a disconnect between policy targets, cost expectations and the status of manufacturing today, especially in Europe and North America. In many cases, prospective buyers of electrolysers ask for prices that reflect the anticipated costs of an established, mass-manufactured electrolyser sector. Such prices are often needed to meet investors' required rates of returns, given the magnitude of public incentives available.

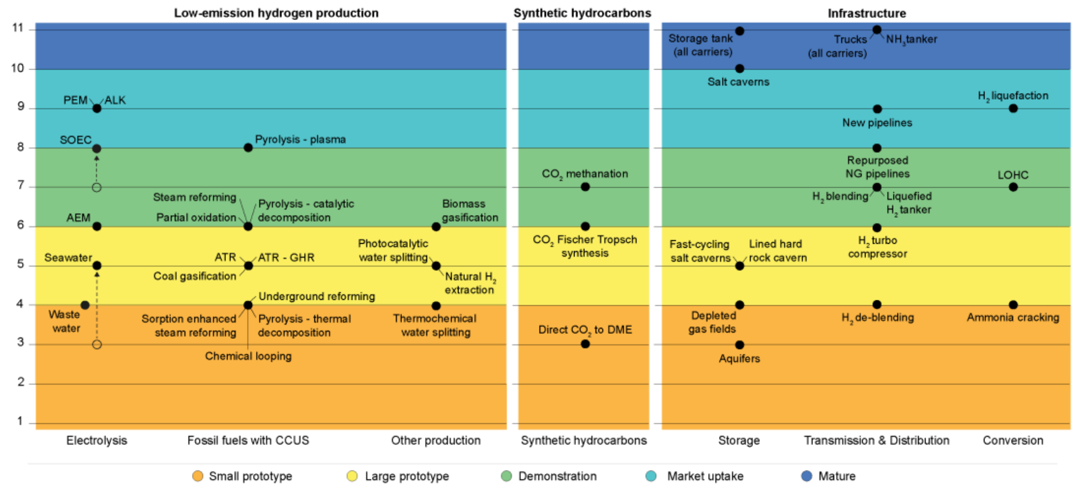


Figure 17 Technology readiness levels of production of low-emission hydrogen and synthetic fuels, and infrastructure

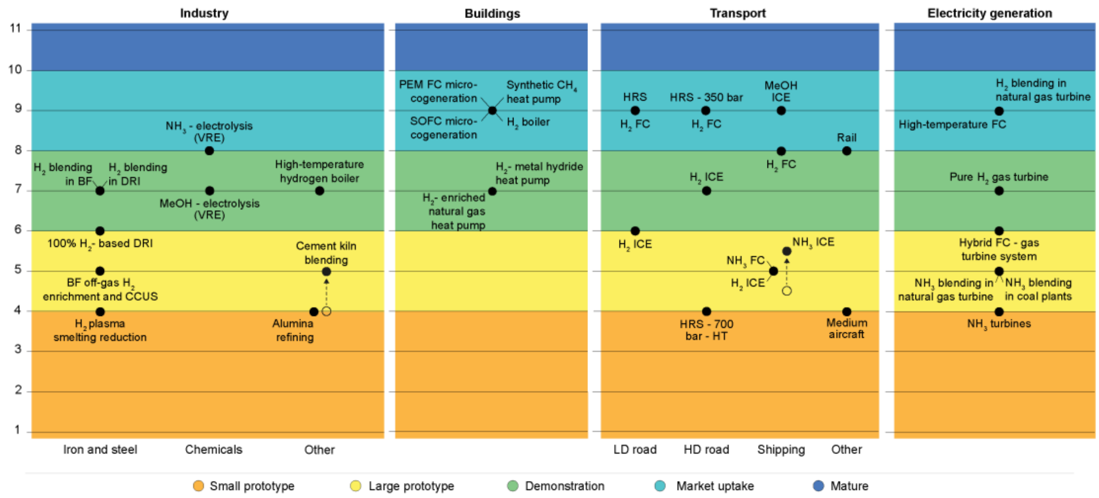


Figure 18 Technology readiness levels of hydrogen end use by sector

2.1.4 Net Zero by 2050

The prospect for a net-zero future is deeply intertwined with current and future investment and commitment of sustainable hydrogen technologies. This report states key figures and milestones to reach this target: the milestones start in 2030 (2030: 150 Mt low-carbon hydrogen; 850 GW electrolysers), have a step in 2035 (2035: Capacity fitted with CCUS or co-firing hydrogen-based fuels reaches 6% of total generation), a further step in 2040 (2040: Electrolyser capacity reaches 2400 GW) and a final milestone in 2050 (2050: 520 Mt low-carbon hydrogen).

Every month from 2030 onwards, ten heavy industrial plants are equipped with CCUS, three new hydrogen-based industrial plants are built, and 2 GW of electrolyser capacity are added at industrial sites

Annual investment in CO_2 pipelines and hydrogen-enabling infrastructure increases from USD 1 billion today to around USD 40 billion in 2030.

Hydrogen and hydrogen-based fuels play a larger role in the APC than in the STEPS, reaching almost 15 exajoules (EJ) in 2050, though they still account for only 3% of total final consumption worldwide in 2050. Transport accounts for more than two-thirds of all hydrogen consumption in 2050. In parallel, on-site hydrogen production in the industry and refining sectors gradually shifts towards low-carbon technologies.

Hydrogen and ammonia start to emerge as fuel inputs to electricity generation by around 2030, used largely in combination with natural gas in gas turbines and with coal in coal-fired power plants.

This report describes a comprehensive and detailed pathway to achieve **net-zero energy-related and industrial process CO_2 emissions globally by 2050**. It assesses the costs of achieving this goal, the likely impacts on employment and the economy, and the wider implications for the world. It also highlights the key milestones for technologies, infrastructure, investment and policy that are needed along the road to 2050.

The **Net-Zero Emissions by 2050 Scenario (NZE)** shows what is needed across the main sectors by various actors, and by when, for the world to achieve net-zero energy-related and industrial process CO_2 emissions by 2050. It also aims to minimise methane emissions from the energy sector. Alongside corresponding reductions in GHG emissions from outside the energy sector, this is consistent with limiting the global temperature rise to 1.5°C without a temperature overshoot (with a 50% probability). Achieving this would require all governments to increase ambitions from current Nationally Determined Contributions and net zero pledges. In addition, the NZE incorporates concrete action on the energy-related United Nations Sustainable Development Goals related to achieving universal energy access by 2030 and delivering a major reduction in air pollution. The projections in the NZE were generated by a hybrid model that combines components of the IEA's World Energy Model (WEM), which is used to produce the projections in the annual World Energy Outlook, and the Energy Technology Perspectives (ETP) model.

The Net-Zero Emissions by 2050 Scenario is built on the following principles:

- The uptake of all the available technologies and emissions reduction options is dictated by costs, technology maturity, policy preferences, and market and country conditions.
- All countries co-operate towards achieving net-zero emissions worldwide. This involves all countries participating in efforts to meet the net zero goal, working together in an effective and mutually beneficial way, and recognising the different stages of economic development of countries and regions, and the importance of ensuring a just transition.
- An orderly transition across the energy sector. This includes always ensuring the security of fuel and electricity supplies, minimising stranded assets where possible and aiming to avoid volatility in energy markets.

By 2050, nearly 90% of all electricity generation is from renewables, as is around 25% of non-electric energy use in industry and buildings. There is also a major role for emerging fuels and technologies, notably hydrogen and hydrogen-based fuels, bioenergy and CCUS, especially in sectors where emissions are often most challenging to reduce.

In 2050, around 925 bcm of natural gas is converted to hydrogen with CCUS.

The supply of low-emissions gases, such as hydrogen, synthetic methane, biogas and biomethane rises from 2 EJ in 2020 to 17 EJ in 2030 and 50 EJ in 2050. The increase in gaseous hydrogen production between 2020 and 2030 in the NZE is twice as fast as the fastest ten-year increase in shale gas production in the United States.

The direct use of renewables in buildings and industry together with low-emissions fuels such as bioenergy and hydrogen-based fuels provide a further 28% of final energy consumption in 2050.

The demand for merchant hydrogen in industry increases from less than 1 Mt today to around 40 Mt in 2050.

Hydrogen and hydrogen-based fuels will be used mainly in shipping, with a smaller role in long-haul heavy-duty trucks and aviation. By 2050, these fuels account for nearly 30% of consumption (almost zero in 2020).

In buildings, low-emissions district heating and hydrogen provide only 7% of energy use, but play a significant role in some regions.

The IPCC scenarios have a median of 18 EJ hydrogen in total final consumption in 2050, compared with 33 EJ in the NZE (includes the total energy content of hydrogen and hydrogen-based fuels consumed in final energy consumption).

Alongside the growth in the direct use of electricity in end-use sectors, there is also a huge increase in the use of electricity for hydrogen production. Merchant hydrogen produced using electrolysis requires around 12 000 TWh in 2050 in the NZE, which is greater than current total annual electricity demand of China and the United States combined.

The initial focus for hydrogen use in the NZE is the conversion of existing uses of fossil energy to low-carbon hydrogen in ways that do not immediately require new transmission and distribution infrastructure. This includes hydrogen use in industry and in refineries and power plants, and the blending of hydrogen into natural gas for distribution to end-users.

Global hydrogen use expands from less than 90 Mt in 2020 to more than 200 Mt in 2030; the proportion of low-carbon hydrogen rises from 10% in 2020 to 70% in 2030. Around half of low-carbon hydrogen produced globally in 2030 comes from electrolysis and the remainder from coal and natural gas with CCUS, although this ratio varies substantially between regions. Hydrogen is also blended with natural gas in gas networks: the global average blend in 2030 includes 15% of hydrogen in volumetric terms, reducing CO_2 emissions from gas consumption by around 6%.

During the 2020s, there is also a large increase in the installation of end-use equipment for hydrogen, including more than **15 million hydrogen fuel cell vehicles on the road by 2030**.

After 2030, low-carbon hydrogen use expands rapidly in all sectors in the NZE. In the electricity sector, hydrogen and hydrogen-based fuels provide an important low-carbon source of electricity system flexibility. In transport, hydrogen provides **around one-third of fuel use in trucks in 2050 in the NZE**: this is contingent on policy makers taking decisions that enable the development of the necessary infrastructure by 2030. By 2050, **hydrogen-based fuels also provide more than 60% of total fuel consumption in shipping**.

Of the 530 Mt of hydrogen produced in 2050, around 25% is produced within industrial facilities (including refineries), and the remainder is merchant hydrogen (hydrogen produced by one company to sell to others). Almost 30% of the low-carbon hydrogen used in 2050 takes the form of hydrogen-based fuels, which include ammonia and synthetic liquids and gases. An increasing share of hydrogen production comes from electrolysers, which account for 60% of total production in 2050. Electrolysers are powered by grid electricity, dedicated renewables in regions with excellent renewable resources and other low-carbon sources such as nuclear power. Rolling out electrolysers at the pace required in the NZE is a key challenge given the lack of manufacturing capacity today, as is ensuring the availability of sufficient electricity generation capacity. Global trade in hydrogen develops over time in the NZE, with large volumes exported from gas and renewables-rich areas in the Middle East, Central and South America and Australia to demand centres in Asia and Europe.

Sector	2020	2030	2050
Total production hydrogen-based fuels (Mt)	**87**	**212**	**528**
Low-carbon hydrogen production	9	150	520
share of fossil-based with CCUS	*95%*	*46%*	*38%*
share of electrolysis-based	*5%*	*54%*	*62%*
Merchant production	15	127	414
Onsite production	73	85	114
Total consumption hydrogen-based fuels (Mt)	**87**	**212**	**528**
Electricity	0	52	102
of which hydrogen	0	43	88
of which ammonia	0	8	13
Refineries	36	25	8
Buildings and agriculture	0	17	23
Transport	0	25	207
of which hydrogen	0	11	106
of which ammonia	0	8	44
of which synthetic fuels	0	5	56
Industry	51	93	187

Note: Hydrogen-based fuels are reported in million tonnes of hydrogen required to produce them.

Table 11 Key development milestones for hydrogen and hydrogen-based fuels

The share of fossil fuel supply in total energy sector investment drops from its 25% level in recent years to just 7% by 2050: this is partly offset by the rise in spending on low-emissions fuel supply, such as hydrogen, hydrogen-based fuels and bioenergy. Annual investment in these fuels increases to nearly USD 140 billion in 2050.

In addition to investment in electrification, there is a moderate increase in investment in hydrogen to 2030 as production facilities are scaled up, and larger increases after as hydrogen use in transport expands: annual investment in hydrogen, including production facilities, refuelling stations and end-user equipment, reaches USD 165 billion in 2030 and over USD 470 billion in 2050.

Not all steps of the low-carbon hydrogen value chain are available on the market today. Most demand technologies, such as hydrogen-based steel production, are only at the demonstration or prototype stage. These deliver more than 75% of the cumulative emissions reductions in the NZE related to hydrogen.

Hydrogen-based fuels meet a further 28% of transport energy needs by 2050. Low-carbon gases (biomethane, synthetic methane and hydrogen) meet 35% of global demand for gas supplied through networks in 2050, up from almost zero today. The combined share of low-carbon hydrogen and hydrogen-based fuels in total final energy use worldwide reaches 13% in 2050. Hydrogen and ammonia also provide important low-emissions sources of power system flexibility and contribute 2% of overall electricity generation in 2050, which is enough to make the electricity sector an important driver of hydrogen demand.

Hydrogen use in the energy sector today is largely confined to oil refining and the production of ammonia and methanol in the chemicals industry. Global hydrogen demand was around 90 million tonnes (Mt) in 2020, mainly produced from fossil fuels (mostly natural gas) and emitting close to 900 Mt CO_2. Both the amount needed, and the production route of hydrogen change radically in the NZE. Demand increases almost sixfold to **530 Mt in 2050**, of which **half is used in heavy industry** (mainly steel and chemicals production) and in the transport sector; **30% is converted into other hydrogen-based fuels**, mainly ammonia for shipping and electricity generation, synthetic kerosene for aviation and synthetic methane blended into gas networks; and **17% is used in gas-fired power plants** to balance increasing electricity generation from solar PV and wind and to provide seasonal storage. Overall, hydrogen-based fuels account for **13% of global final energy demand in 2050**.

- Ammonia accounts for around 45% of global energy demand for shipping in 2050.
- Synthetic kerosene meets around one-third of global aviation fuel demand in 2050.

By 2050, hydrogen production in the NZE is almost entirely based on low-carbon technologies: water electrolysis accounts for more than 60% of global production, and natural gas in combination with CCUS for almost 40%. Global electrolyser capacity reaches 850 gigawatts (GW) by 2030 and 3600 GW by 2050, up from around 0.3 GW today. Electrolysis absorbs close to 15 000 terawatt-hours (TWh), or 20% of global electricity supply in 2050, largely from renewable resources (95%), but also from nuclear power (3%) and fossil fuels with CCUS (2%). Natural gas use for hydrogen production with CCUS is 925 bcm in 2050, or around 50% of global natural gas demand, with 1.8 Gt CO_2 being captured.

For natural gas with CCUS, production costs in the NZE are around USD 1-2 per kilogram (kg) of hydrogen in 2050, with gas costs typically accounting for 15-55% of total production costs. For water electrolysis, learning effects and economies of scale result in CAPEX cost reductions of 60% in the NZE by 2030 compared to 2020. Production cost reductions hinge on lowering the cost of low-carbon electricity, as electricity accounts for 50-85% of total production costs, depending on the electricity source and region. The average cost of producing hydrogen from renewables drops in the NZE from USD 3.5-7.5/kg today to around USD 1.5-3.5/kg in 2030 and USD 1-2.5/kg in 2050 – essentially about the same as the cost of producing with natural gas with CCUS.

Sector	2020	2030	2050
Bioenergy			
Share of modern biofuels in modern bioenergy (excluding conversion losses)	20%	45%	48%
Advanced liquid biofuels (mboe/d)	0.1	2.7	6.2
Share of biomethane in total gas networks	<1%	2%	20%
CO_2 captured and stored from biofuels production (Mt CO_2)	1	150	625
Hydrogen			
Production (Mt H_2)	87	212	528
of which: low-carbon (Mt H_2)	9	150	520
Electrolyser capacity (GW)	<1	850	3 585
Electricity demand for hydrogen-related production (TWh)	1	3 850	14 500
CO_2 captured from hydrogen production (Mt CO_2)	135	680	1 800
Number of export terminals at ports for hydrogen and ammonia trade	0	60	150

Note: mboe/d = million barrels of oil equivalent per day; Mt = million tonnes; H_2 = hydrogen.

Table 12 Key milestones in transforming low-emissions fuels

Financial support instruments, such as contracts for differences, could help to reduce the current cost gap of low-carbon hydrogen production compared to existing unabated production from fossil fuels.

Pairing battery storage systems with solar PV and wind to improve power system flexibility and maintain electricity security becomes commonplace in the late 2020s, complemented by demand response for short duration flexibility and hydropower or hydrogen for flexibility across days or even seasons.

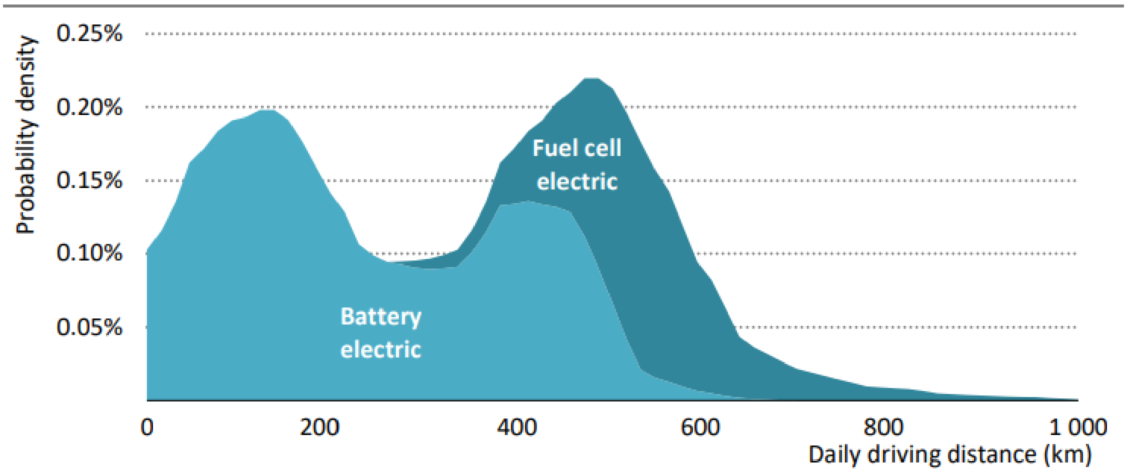
In the NZE, hydrogen-based fuels generate 900 TWh of electricity in 2030 and 1700 TWh in 2050 in this way (about 2.5% of global generation in both years). A large-scale (1 GW) demonstration project to co-fire with 20% ammonia is underway in 2021, with aims to move towards ammonia-only combustion. Manufacturers have signalled that future gas turbine designs will be capable of co-firing high shares of hydrogen. While the investment needed to co-fire hydrogen-based fuels looks to be modest, relatively high fuel costs point to targeted applications to support power system stability and flexibility rather than bulk power.

Hydrogen and CCUS technologies together contribute around 50% of the emissions reductions in heavy industry in 2050 in the NZE. These technologies enable the provision of large amounts of high-temperature heat, which in many cases cannot be easily provided by electricity with current technologies and help to reduce process emissions from the chemical reactions inherent in some industrial production. Bioenergy also contributes to a wide array of industrial applications.

In 2050, 15% of the electricity generated is used to produce hydrogen.

Each month from 2030 to 2050, the NZE implies an additional 10 industrial plants equipped with CCUS, three additional fully hydrogen-based industrial plants and 2 GW of extra electrolyser capacity at industrial sites.

Hydrogen-based fuels account for a **28% of transport energy demand by 2050**.



Driving distance is the key factor affecting powertrain choice for trucks

Figure 19 Heavy trucks distribution by daily driving distance, 2050

By 2050, biojet kerosene meets 45% of total fuel consumption in aviation and synthetic hydrogen-based fuels meet about 30%.

Ammonia and hydrogen are the main low-carbon fuels for shipping adopted over the next three decades in the NZE, their combined share of total energy consumption in shipping reaching around 60% in 2050.

Oil use, which accounted for 55% of total energy consumption in the rail sector in 2020, falls to almost zero in 2050: it is replaced by electricity, which provides over 90% of rail energy needs and by hydrogen which provides another 5%.

By 2025 in the NZE, any gas boilers that are sold are capable of burning 100% hydrogen and therefore are zero-carbon-ready. The share of low-carbon gases (hydrogen, biomethane, synthetic methane) in gas distributed to buildings rises from almost zero to 10% by 2030 to above 75% by 2050.

Governments need to establish policies for coal and oil boilers and furnaces for space and water heating, which in the NZE are no longer available for sale from 2025. They also need to take action to ensure that new gas boilers can operate with low-carbon gases (hydrogen ready) in decarbonised gas networks.

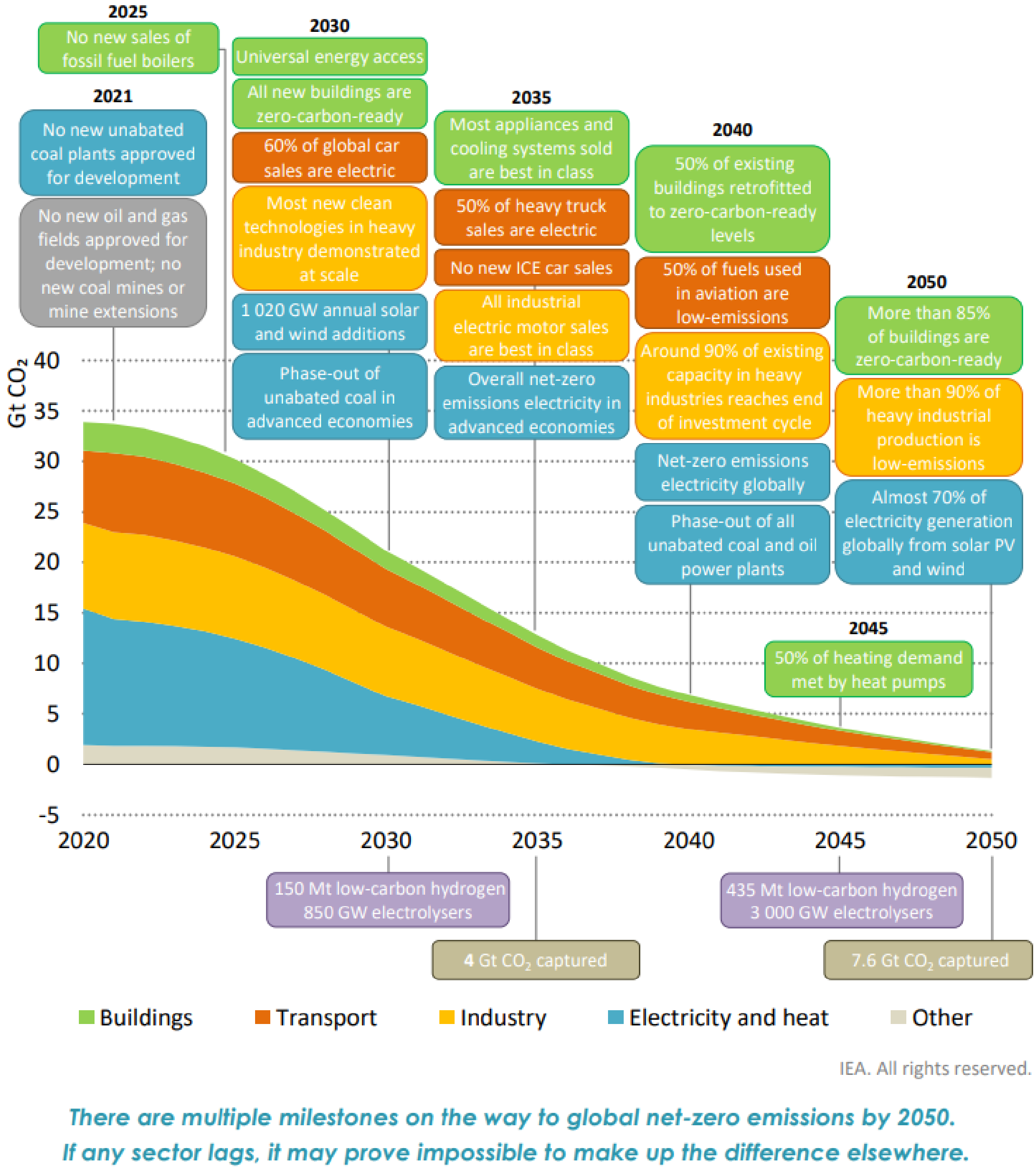


Figure 20 Selected global milestones for policies, infrastructure and technology deployment in the NZE

Low-emissions hydrogen and hydrogen-based fuels. Oil and gas companies could contribute to developing and deploying low-emissions hydrogen in several ways (IEA, 2019a). Nearly 40% of hydrogen production in 2050 in the NZE is from natural gas in facilities equipped with CCUS, providing an important opportunity for companies and countries to utilise their natural gas resources in a way that is consistent with net-zero emissions. Of the total output of 530 Mt of hydrogen in 2050, about 30% is processed into ammonia and synthetic fuels (equivalent to around 7.5 mboe/d). The transformation processes involved have many potential synergies with the skills and equipment used in oil and gas processing and refining. Oil and gas companies also have long experience of transporting liquids and gases by pipeline and ships.

Taxing natural gas used in industry would improve the competitiveness of less carbon-intensive fuels and technologies such as hydrogen but would run the risk of undermining the international competitiveness of energy-intensive sectors and carbon leakage in the absence of coordinated global action or border carbon-tax adjustments.

2.1.5 IPCEIs on hydrogen

In December 2020, 22 EU countries and Norway signed a manifesto paving the way for a clean hydrogen value chain and committing to launch 'Important Projects of Common European Interest' (IPCEIs) in the hydrogen sector.

The joint projects shall include sectors along the whole hydrogen value chain, notably (i) the safe and sustainable low-carbon production of hydrogen, where emphasis should be given to hydrogen from renewable sources, and its derivatives, (ii) equipment manufacturing (incl. electrolysers and equipment for heavy-duty mobility, such as light commercial vehicles, buses, trucks, hard-to-electrify railways, shipping or aviation), (iii) solutions for hydrogen storage, transmission and distribution (incl. refueling stations along roads, rails and ports), and (iv) industrial applications of hydrogen (incl. the decarbonisation of industrial facilities). Projects should encompass research, development, innovation activities, first industrial deployment and the large-scale roll-out and broad implementation of related installations, factories and networks, based on a clustered approach where possible, in order to achieve an initial range of significant hydrogen-based GHG-emission reductions, thereby being of great importance for the environment, energy, and transport strategy goals of the Union.

IPCEI Hy2Use

The objective of this project is to support research and innovation, first industrial deployment and construction of relevant infrastructure in the hydrogen value chain.

The Member States will provide up to €5.2 billion in public funding, which is expected to unlock additional €7 billion in private investments

IPCEI Hy2Use will cover a wide part of the hydrogen value chain by supporting (i) the construction of hydrogen-related infrastructure, notably large-scale electrolysers and transport infrastructure, for the production, storage and transport of renewable and low-carbon hydrogen; and (ii) the development of innovative and more sustainable technologies for the integration of hydrogen into the industrial processes of multiple sectors, especially those that are more challenging to decarbonise, such as steel, cement and glass. The IPCEI is expected to boost the supply of renewable and low-carbon hydrogen, thereby reducing dependency on the supply of natural gas.

2.1.6 IEA CCUS Handbook

IEA CCUS Handbook is a resource to develop and update legal and regulatory frameworks for CCUS. It identifies 25 priority issues that frameworks should address for CCUS deployment and presents global case studies on how different jurisdictions have approached these issues.

Role of CCUS in reaching net zero ambitions:

- Tackling emissions from existing energy assets
- Reducing emissions in hard-to-abate sectors
- Providing a platform for low-carbon hydrogen production
- Removing carbon from the atmosphere

2.1.7 Hydrogen for Development Partnership (H4D)

H4D will help catalyze significant financing for hydrogen investments in the next few years, both from public and private sources. The partnership will foster capacity building and regulatory solutions, business models, and technologies toward the roll out of low-carbon hydrogen in developing countries. Through H4D, developing countries will gain further access to concessional financing and technical assistance to scale up hydrogen projects.

The main activities of the H4D partnership, to be hosted in the Energy Sector Management Assistance Program (ESMAP) of the World Bank, will include:

- Convening international cooperation to increase the knowledge base in low-carbon hydrogen technologies for developing countries.
- Building capacities by following a global public goods approach.

- Understanding requirements from emerging markets and the private sector for the deployment of low-carbon hydrogen and its derivatives.
- Creating opportunities to inform innovation and for new technologies to gain visibility.
- Generating policy dialogue on enabling the deployment of low-carbon hydrogen across countries.
- Fostering collaboration with private sector partners for clean hydrogen projects.

2.1.8 H2GLASS

Glass and aluminium manufacturers are searching for sustainable alternatives. Carbon emissions related to the production of glass mainly stem from the combustion of natural gas. In this context, the EU-funded H2GLASS project will bring together 23 partners from around Europe to create a new technology stack that glass and aluminium manufacturers can use to achieve complete hydrogen combustion. Specifically, the project will address the challenges related to emissions of nitrogen oxides and high flame propagation speed, process efficiency and supply of hydrogen for on-site demonstrations. Digital twin techniques will be used to assess risk-based predictive maintenance. Another project feature is the demonstrator in the aluminium industry to prove the transferability of underlying models to similar energy-intensive industries.

H2GLASS aims to create the technology stack that glass manufacturers need to (a) realize 100% H_2 combustion in their production facilities, (b) ensure the required product quality, and (c) manage this safely. H2GLASS will address the challenges related to NOx emissions and high flame propagation speed, process efficiency, and supply of H_2 for on-site demonstrations.

2.1.9 International Hydrogen Trade Forum

Emphasizing the importance of establishing international hydrogen supply chains, also known as "trade corridors," the governments aim at transporting substantial volumes of clean energy from regions with abundant renewable resources and geological CO_2 storage potential to areas with limited access. To meet the increasing global demand, they highlight the necessity of accelerating investments across the entire hydrogen value chain.

The joint declaration underscores the significance of non-discriminatory market access and participation for international hydrogen trade in the emerging hydrogen market. Global cooperation and coordination are identified as critical elements to share valuable knowledge, experiences, best practices, and promote research, innovation, and demonstration. It is also crucial that any measures taken in the realm of international hydrogen trade conform to the rules of the World Trade Organization (WTO).

In pursuit of these objectives, the governments express their collective determination to establish the International Hydrogen Trade Forum as an inter-governmental forum, facilitating collaboration between potential future hydrogen importing and exporting countries, as well as synchronising priority actions of decision-makers and industrial leaders through public-private action plans. The Forum therefore aims to accelerate international hydrogen trade, reduce barriers, and foster productive market conditions.

2.1.10 Hydrogen Public Funding Compass

The hydrogen public funding compass is an online guide for stakeholders to identify public funding sources for hydrogen projects. It is designed as a single-entry point for stakeholders to access information on the most important public funding programmes and funds for renewable and low carbon hydrogen.

The funding compass provides orientation to members of the European Clean Hydrogen Alliance in terms of funding opportunities for projects featuring in the pipeline of viable investment projects for the large-scale deployment of renewable and low-carbon hydrogen, that the alliance is building up along the emerging European hydrogen value chain in line with the EU hydrogen strategy and the industrial policy strategies.

2.1.11 Safety Planning and Management in Hydrogen Projects

The project safety plan aim is to develop technical and organisational activities to:

- Ensure that project outputs in a form of device, system, process and/or infrastructure provide an adequate level of safety and follow or even improve the state-of-the-art

- Identify and address essential for the project success knowledge gaps and technological bottlenecks if relevant
- Formulate activities providing a high level of technical and organisational safety activities in the project delivery.

This aim can be achieved through the delivery of the following key objectives that should be reported in relevant project deliverables:

- Review the state-of-the-art in safety provisions of systems and processes related to the project
- Identify system or process vulnerabilities, select incident scenarios, including low frequency high consequences scenarios
- Apply available hydrogen safety engineering models and tools to assess hazards and associated risks for selected scenarios. In case of absence of models and tools, develop and validate new models to perform hydrogen safety engineering for a system, infrastructure or process under the project scope
- Continuously update the initial safety plan during the project to include new knowledge and information, appoint safety professionals to thoroughly monitor the plan's implementation by all partners and the project as a whole, and report results on safety findings in the deliverables, reports, databases, through publications, etc.

2.2 European Context

2.2.1 EU Hydrogen Strategy (EC)

Large-scale deployment of clean hydrogen at a fast pace is key for the EU to achieve a higher climate ambition, reducing greenhouse gas emissions by minimum 50% and towards 55% by 2030, in a cost-effective way.

Cumulative investments in renewable hydrogen in Europe could be up to EUR 180-470 billion by 2050, and in the range of €3-18 billion for low-carbon fossil-based hydrogen. Combined with EU's leadership in renewables technologies, the emergence of a hydrogen value chain serving a multitude of industrial sectors and other end uses could employ up to 1 million people, directly or indirectly. Analysts estimate that clean **hydrogen could meet 24% of energy world demand by 2050**, with annual sales in the range of €630 billion.

EU industry is rising to the challenge and has developed an ambitious plan to **reach 2x40 GW of electrolysers by 2030** (40 GW in Europe and 40 GW in Europe's neighborhood with export to the EU).

This Communication sets out a vision of how the EU can turn clean hydrogen into a viable solution to decarbonise different sectors over time, **installing at least 6 GW of renewable hydrogen electrolysers in the EU by 2024** and **40 GW of renewable hydrogen electrolysers by 2030**.

The document adds definitions of the different types of hydrogen according to the ways to produce it, their greenhouse gas emissions and their relative competitiveness.

In the first phase, **from 2020 up to 2024**, the strategic objective is to install at least **6 GW** of renewable hydrogen electrolysers in the EU and the **production of up to 1 million tonnes of renewable hydrogen**, to decarbonise existing hydrogen production, and facilitating take up of hydrogen consumption in new end-use applications such as other industrial processes and possibly in heavy-duty transport.

In a second phase, **from 2025 to 2030**, hydrogen needs to become an intrinsic part of an integrated energy system with a strategic objective to install at least **40 GW** of renewable hydrogen electrolysers by 2030 and the production of **up to 10 million tonnes of renewable hydrogen in the EU**.

2.2.2 REPowerEU Plan

REPowerEU is about rapidly reducing our dependence on Russian fossil fuels by fast forwarding the clean transition and joining forces to achieve a more resilient energy system and a true Energy Union.

REPowerEU builds on the full implementation of the **Fit for 55 proposals** tabled last year without modifying the ambition of achieving at least -55 % net GHG emissions by 2030 and climate neutrality by 2050 in line with the **European Green Deal**

The Commission therefore proposes to increase to 13% the binding target in the Energy Efficiency Directive.

The European Commission has launched, in cooperation with the International Energy Agency (IEA), a nine-point plan "Playing my part" for reducing energy use in the EU. Based on input from stakeholders, the IEA estimates that these types of short-term energy saving measures could achieve a 5% reduction in the demand for gas (around 13 bcm) and in that for oil (around 16 mtoe).

Renewable hydrogen will be key to replace natural gas, coal and oil in hard-to-decarbonise industries and transport. REPowerEU sets a target of **10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of renewable hydrogen imports by 2030**. The Commission:

- calls upon the European Parliament and the Council to align the sub-targets for renewable fuels of non-biological origin under the Renewable Energy Directive for industry and transport with the REPowerEU ambition (75% for industry and 5% for transport) and to rapidly conclude the revision of the Hydrogen and Gas Market package;
- will top-up Horizon Europe investments on the Hydrogen Joint Undertaking (EUR 200 million) to double the number of Hydrogen Valleys;
- publishes for public feedback two Delegated Acts on the definition and production of renewable hydrogen;
- intends to complete the assessment of the first Important Projects of Common European Interest on hydrogen by the summer;

- calls on industry to accelerate the work on missing hydrogen standards, in particular for hydrogen production, infrastructure and end-use appliances;
- will regularly report, in close cooperation with the Member States, starting in 2025, on hydrogen uptake, and the use of renewable hydrogen in hard-to-abate appliances in industry and transport.

Accelerated efforts are needed to deploy hydrogen infrastructure for **producing, importing and transporting 20 million tonnes of hydrogen by 2030**. Cross-border hydrogen infrastructure is still in its infancy, but the basis for planning and development has already been set by the inclusion of hydrogen infrastructure in the revised trans-European networks for energy. Total investment needs for key hydrogen infrastructure categories are estimated to be in the range of EUR 28 – 38 billion for EU-internal pipelines and 6 - 11 billion for storage.

To facilitate the import of up to 10 million tonnes of renewable hydrogen, the Commission will support the development of three major hydrogen import corridors via the Mediterranean, the North Sea area and, as soon as conditions allow, with Ukraine. Green Hydrogen Partnerships will facilitate the imports of green hydrogen while supporting the decarbonisation in the partner countries. Other forms of fossil-free hydrogen, notably nuclear-based, also play a role in substituting natural gas (see map).

To help achieve these targets, the Commission will:

- map preliminary hydrogen infrastructure needs by March 2023, based on the TEN-E Regulation, in a process involving Member States, national regulatory authorities, ACER, ENTSOG, project promoters and other stakeholders;
- mobilise EU funding under CEF, Cohesion Policy and RRF;
- set up a dedicated work stream on joint renewable hydrogen purchasing under the EU Energy Platform.

To support hydrogen uptake and electrification in industrial sectors, the Commission:

- will roll out carbon contracts for difference and dedicated REPowerEU windows under the Innovation Fund to support a full switch of the existing hydrogen production in industrial processes from natural gas to renewables and the transition to hydrogen-based production processes in new industrial sectors, such as steel production. the Commission expects that around **30% of EU primary steel production will be decarbonized with renewable hydrogen by 2030**, [requiring 1.4 million tonnes of renewable hydrogen and investments of EUR [18-20] bn to replace blast furnaces with direct reduced iron (DRI) processes fuelled by renewable hydrogen.];
- publishes guidance to Member States on renewable energy and power purchase agreements (PPAs);
- will, in cooperation with the EIB, develop a technical advisory facility under the InvestEU Advisory Hub to support PPA-financed renewable energy projects. To unlock industrial investment, the Commission will double the funding available for the 2022 Large Scale Call of the Innovation Fund this autumn to around EUR 3 billion. A specific REPowerEU window will support (1) innovative electrification and hydrogen applications in industry, (2) innovative clean tech manufacturing (such as electrolysers and fuel cells, innovative renewable equipment, energy storage or heat pumps for industrial uses), and (3) mid-sized pilot projects for validating, testing and optimising highly innovative solutions.

In transport, electrification can be combined with of the use of fossil-free hydrogen to replace fossil fuels. To enhance energy savings and efficiencies in the transport sector and accelerate the transition towards zero-emission vehicles, the Commission:

- will consider a legislative initiative to increase the share of zero emission vehicles in public and corporate car fleets above a certain size;
- calls on the co-legislators to swiftly adopt the pending proposals on alternative fuels and other transport related files supporting green mobility;
- will adopt in 2023 a legislative package on greening freight transport;

To address the skills shortages, the Commission will support skills through ERASMUS + and the Joint Undertaking on Clean Hydrogen, with the launch of a large project to develop skills for the hydrogen economy.

Figure 21 Indication of potential hydrogen corridors across EU, according to REPowerEU Plan

2.2.3 Alternative fuels infrastructure (25/07/2023)

More recharging and refuelling stations for alternative fuels will be deployed in the coming years across Europe enabling the transport sector to significantly reduce its carbon footprint following today's adoption on the alternative fuel infrastructure regulation (AFIR).

The alternative fuels infrastructure regulation (AFIR) is part of the *Fit for 55 package*. Presented by the European Commission on 14 July 2021, the package aims to enable the EU to reduce its net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and to achieve climate neutrality in 2050.

The text of the regulation provides for specific deployment targets that will have to be met in 2025 or 2030, in particular:

- Hydrogen refuelling stations serving both cars and lorries must be deployed from 2030 onwards in all urban nodes and every 200 km along the EU's main transport corridors, the so-called 'trans-European transport (TEN-T) network'.
- All hydrogen refuelling stations to be deployed along the TEN-T road network should be located on the TEN-T road network or within 10 km driving distance from the nearest exit of a TEN-T road.
- To ensure that publicly accessible destination refuelling is possible at least in the main urban areas, such hydrogen refuelling stations should be provided for in all urban nodes as defined in Regulation (EU) No 1315/2013.
- To ensure interoperability, all publicly accessible hydrogen stations should at least serve gaseous hydrogen at 700 bar.

- Users of electric or hydrogen-fuelled vehicles must be able to pay easily at recharging or refuelling points with payment cards or contactless devices and without a need for a subscription and in full price transparency.
- Operators of recharging or refuelling points must provide consumers full information through electronic means on the availability, waiting time or price at different stations.

Member States shall ensure that by 31 December 2030 publicly accessible hydrogen refuelling stations designed for a minimum cumulative capacity of 1 tonne per day and equipped with at least a 700 bar dispenser are deployed with a maximum distance of 200 km between them along the TEN-T core network. At least one publicly accessible hydrogen refuelling station deployed in each urban node.

2.2.4 ReFuelEU (23/04/2023)

The Council and the European Parliament reached a provisional political agreement on a proposal aiming to decarbonise the aviation sector and create a level playing field for a sustainable air transport (ReFuelEU aviation initiative). The proposal aims to increase both demand for and supply of sustainable aviation fuels (SAF).

The ReFuelEU Aviation initiative is part of the 'Fit for 55' package. Presented by the European Commission on 14 July 2021, the package aims to enable the EU to reduce its net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and to achieve climate neutrality in 2050.

At least 5% of aviation fuels are SAFs by 2030 and 63% by 2050.

The yearly quantity of aviation fuel uplifted by a given aircraft operator at a given Union airport shall be at least 90% of the yearly aviation fuel required.

Annex I (volume shares)

(a) From 1 January 2025, a minimum share of 2% of SAF;

(b) From 1 January 2030, a minimum share of 5% of SAF, of which a minimum share of 0.7% of synthetic aviation fuels;

(c) From 1 January 2035, a minimum share of 20% of SAF, of which a minimum share of 5% of synthetic aviation fuels;

(d) From 1 January 2040, a minimum share of 32% of SAF, of which a minimum share of 8% of synthetic aviation fuels;

(e) From 1 January 2045, a minimum volume share of 38% of SAF, of which a minimum share of 11% of synthetic aviation fuels.

(f) From 1 January 2050, a minimum volume share of 63% of SAF, of which a minimum share of 28% of synthetic aviation fuels

Annex II – Template for aircraft operator reporting

Union airport	ICAO code of Union airport	Yearly aviation fuel required (tonnes)	Actual aviation fuel uplifted (tonnes)	Yearly non-tanked quantity (tonnes)	**Total** yearly non-tanked quantity (tonnes)

Figure 22 Volume share of SAF in aviation fuels, according to ReFuel EU

2.2.5 Fit for 55 package

The Fit for 55 package is a set of proposals to revise and update EU legislation and to put in place new initiatives with the aim of ensuring that EU policies are into line with the climate goals agreed by the Council and the European Parliament.

The package of proposals aims at providing a coherent and balanced framework for reaching the EU's climate objectives, which:

- ensures a just and socially fair transition

- maintains and strengthens innovation and competitiveness of EU industry while ensuring a level playing field vis-à-vis third country economic operators
- underpins the EU's position as leading the way in the global fight against climate change

EU hydrogen goals for 2030:

- 40 gigawatts of renewable hydrogen electrolyser capacity
- 10 million tonnes of renewable hydrogen

Carbon Border Adjustment Mechanism

The carbon border adjustment mechanism (CBAM) is expected to be a tool to counter carbon leakage – a situation when industries with high greenhouse gas emissions shift production outside of the EU to jurisdictions with lower climate policy standards than those of the EU. It will help to reduce emissions globally while providing level playing field for businesses.

For production outside of the EU, EU importers will have to buy CBAM certificates to cover price difference coming from ETS allowances that producers in the EU have to use to cover their CO_2 emissions.

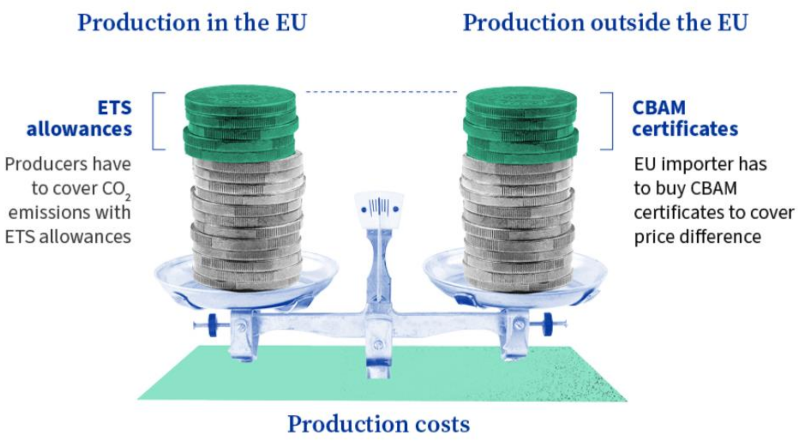


Figure 23 Some rules for H2 production inside and outside EU according to FitFor55 Package

Hydrogen production will be covered by CBAM.

Hydrogen in industry:

42% should come from renewable fuels of non-biological origin by 2030

60% should come from renewable fuels of non-biological origin by 2035

Hydrogen in transport:

5.5% share of advanced biofuels and renewable fuels of non-biological origin combined, with at least 1% of renewable fuels of non-biological origin (mostly hydrogen)

2.2.6 European Hydrogen Bank

The EHB will help address the initial financial challenges in order to create an emerging renewable hydrogen market. It will also have an international dimension to facilitate renewable hydrogen imports to the EU.

The Communication sets out the four pillars of the EHB, which should be operational by the end of 2023. Two of them are financing mechanisms - for creating the EU domestic market, and for international imports into the EU. The third pillar is linked to transparency and coordination – assessing demand, infrastructure needs, hydrogen flows, and cost data. The final element is streamlining existing financial instrument - coordinating and blending these with new public and private funding, both in the EU and internationally.

To achieve the 10 mt of domestic renewable hydrogen production foreseen in the REPowerEU plan, total investment needs are estimated at €335-471 billion including €200-300 billion needed for additional renewable energy production.

2.2.7 European Hydrogen Backbone

The European Hydrogen Backbone (EHB) initiative consists of a group of thirty-three energy infrastructure operators, united through a shared vision of a climate-neutral Europe enabled by a thriving renewable and low-carbon hydrogen market.

The EHB initiative aims to accelerate Europe's decarbonisation journey by defining the critical role of hydrogen infrastructure – based on existing and new pipelines – in enabling the development of a competitive, liquid, pan-European renewable and low-carbon hydrogen market.

The initiative seeks to foster market competition, security of supply, security of demand, and cross-border collaboration between European countries and their neighbours.

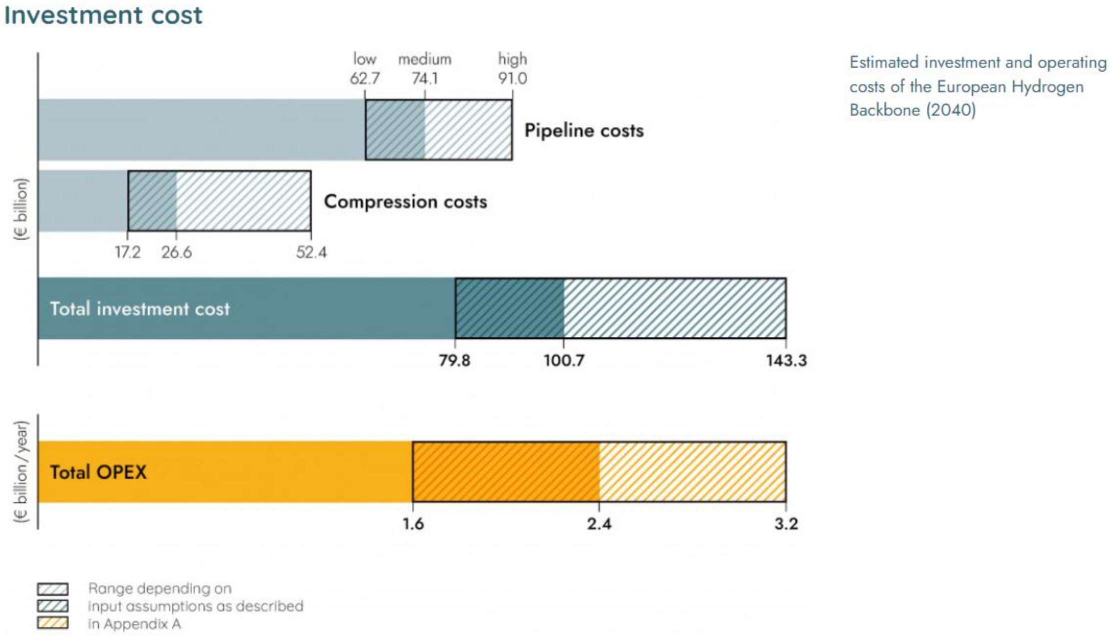


Figure 24 Estimated investment and operating costs associated to the European Hydrogen Backbone 2040

The accelerated EHB vision shows that by 2030 an initial 28,000 km pipeline network could emerge, connecting industrial clusters, ports, and hydrogen valleys – and laying the foundation for future large-scale hydrogen supply corridors. The hydrogen infrastructure can then grow to become a pan-European network, with a length of 53,000 km by 2040.

2.2.8 TEN-E Regulation

The Hydrogen Strategy set a strategic goal to increase installed electrolyser capacity to 40 Gigawatts (GW) by 2030 to scale up the production of renewable hydrogen and facilitate the decarbonisation of fossil-fuel dependent sectors, such as industry or transport. Therefore, the trans-European energy networks policy should include new and repurposed hydrogen transmission infrastructure and storage as well as electrolyser facilities. Hydrogen transmission and storage infrastructure should also be included in the Union-wide ten-year network development plan to allow a comprehensive and consistent assessment of their costs and benefits for the energy system, including their contribution to sector integration and decarbonisation, with the aim of creating a hydrogen backbone for the Union.

2.2.9 Net Zero Industry Act

The Net-Zero Industry Act is part of the Green Deal Industrial Plan's pillar for a predictable and simplified regulatory environment, which aims at promoting investments in the production capacity of products that are key in meeting the EU's climate neutrality goals.

The Regulation encompasses products, components and equipment necessary for manufacturing net-zero technologies. It separates between net-zero technologies and strategic net-zero technologies, the latter of which making a significant contribution to decarbonisation by 2030 and are commercially available or soon to enter the market. Whilst all net-zero technologies benefit from the provisions in this regulation, strategic net-zero technologies enjoy additional benefits, such as benefitting from the resilience criterion in auctions and the possibility to become Net-Zero strategic projects. These projects may be granted priority status so they can benefit from shorter timelines. They are selected based on the three following criteria

1) Technology readiness level
2) Contribution to decarbonisation and competitiveness
3) Resilience of the energy system

The list includes the following technologies:

- Solar photovoltaic and solar thermal technologies
- Onshore and offshore renewable technologies
- Battery/storage technologies
- Heat pumps and geothermal energy technologies
- Electrolysers and fuel cells
- Sustainable Biogas/Biomethane technologies
- Carbon Capture and Storage (CCS) technologies
- Grid technologies

The proposal sets a benchmark for the manufacturing capacity of strategic net-zero technologies to meet at least 40% of the EU's annual deployment needs by 2030.

Global production of electric vehicles will increase 15-fold by 2050, while the deployment of renewables will nearly quadruple. Deployment of heat pumps will increase more than six times by 2050, compared to today and **production of hydrogen from electrolysis or natural gas-based hydrogen with carbon capture and storage will reach 450 Mt in 2050**. This will translate into global cumulative manufacturing investments of USD 1.2 trillion required to bring enough capacity on track with the global 2030 targets. China accounts for 90% of investments in manufacturing facilities.

RePowerEU plan sets inter alia the targets to double solar photovoltaic capacity by 2025 and to install 600 GW of solar photovoltaic capacity by 2030; to double the rate of deployment of heat pumps; to **produce 10 million tonnes of domestic renewable hydrogen by 2030**; and to substantially increase production of biomethane. EU electrolyser manufacturers should further boost their capacity, such that **the overall installed electrolyser capacity being deployed reaches at least 100 GW hydrogen by 2030**.

Hydrogen Valleys with industrial end-use applications play an important role in decarbonising the energy-intensive industries. REPowerEU set the objective of doubling the number of Hydrogen Valleys in the Union. To achieve this objective, Member States should accelerate permitting and consider regulatory sandboxes and prioritise access to funding. To strengthen the net zero resilience, Member States should ensure the interconnection of Hydrogen Valleys across the Union's borders. Industrial installations which produce their own energy, and which can provide a positive contribution to the production of electricity, should be encouraged to contribute to the smart electricity grid as energy producers by simplifying regulatory requirements.

The skill needs for the fuel cell hydrogen sub-sector in manufacturing alone are estimated at **180.000 trained workers, technicians and engineers by the year 2030**, according to the Commission's European Strategic Energy Technology Plan.

2.2.10 Clean Hydrogen Partnership (Clean Hydrogen Join Undertaking)

The Clean Hydrogen Partnership (as per its legal name Clean Hydrogen Joint Undertaking) is a unique public private partnership supporting research and innovation (R&I) activities in hydrogen technologies in Europe.

Its aim is to strengthen and integrate EU scientific capacity, to accelerate the development and improvement of advanced clean hydrogen applications. The three members of the Joint Undertaking are the European Union, represented by the European Commission, the fuel cell and hydrogen industries represented by Hydrogen Europe and the research community represented by Hydrogen Europe Research.

The research and innovation activities of the Clean Hydrogen JU are guided primarily by EU's Hydrogen Strategy and the policy developments in this context, contributing to its implementation. Its focus is on renewable hydrogen production, as well as hydrogen transmission, distribution and storage, alongside selected fuel cell end-use technologies in transport, buildings and industry.

2.2.11 European Hydrogen Regulation

The Council clarified the rules for tariffs and tariff discounts for hydrogen and renewable gases seeking to access the gas grid and gave more flexibility to member states for setting them. It differentiated between tariff discounts for renewable (100%) and low-carbon gases (75%) in the natural gas system.

Regarding the certification of storage system operators, the general approach integrates the provisions of the gas storage regulation adopted in June 2022 into the text. It introduces a 100% discount to capacity-based transmission and distribution tariffs to underground gas storage facilities and LNG facilities.

The general approach allows for the blending of hydrogen into the natural gas system of up to 2% by volume (instead of 5%) to ensure a harmonised quality of gas.

2.2.12 European Clean Hydrogen Alliance (ECH2A)

The European Clean Hydrogen Alliance was set up in July 2020 to support the large-scale deployment of clean hydrogen technologies by 2030. It brings together renewable and low-carbon hydrogen production, demand in industry, mobility and other sectors, and hydrogen transmission and distribution. Its members come from industry, public authorities, civil society, and other stakeholders.

The alliance aims to promote investments and stimulate clean hydrogen production and use. It is part of the EU's efforts to ensure industrial leadership and accelerate the decarbonisation of industry in line with climate change objectives.

The partnership consists of alliance members involved in:

- Manufacturing electrolysers.
- Supplying important components and materials.
- Testing electrolysers.
- Researching and developing new materials.

The alliance has workgroups on different topics:

- Hydrogen production
- Clean hydrogen transmission and distribution
- Clean hydrogen in industrial applications
- Clean hydrogen for mobility
- Clean hydrogen in the energy sector
- Clean hydrogen in buildings
- Hydrogen standards
- Electrolyser partnership

2.2.13 Modernisation Fund

<u>Objectives</u>

The Modernisation Fund supports the modernisation of energy systems and the improvement of energy efficiency in 13 lower-income EU Member States. Established in 2018 for the 2021-2030 period, it aims to help the beneficiary Member States achieve their climate targets and the objectives of the European Green Deal.

The beneficiary Member States are Bulgaria, Czechia, Estonia, Greece, Croatia, Latvia, Lithuania, Hungary, Poland, Portugal, Romania, Slovenia and Slovakia.

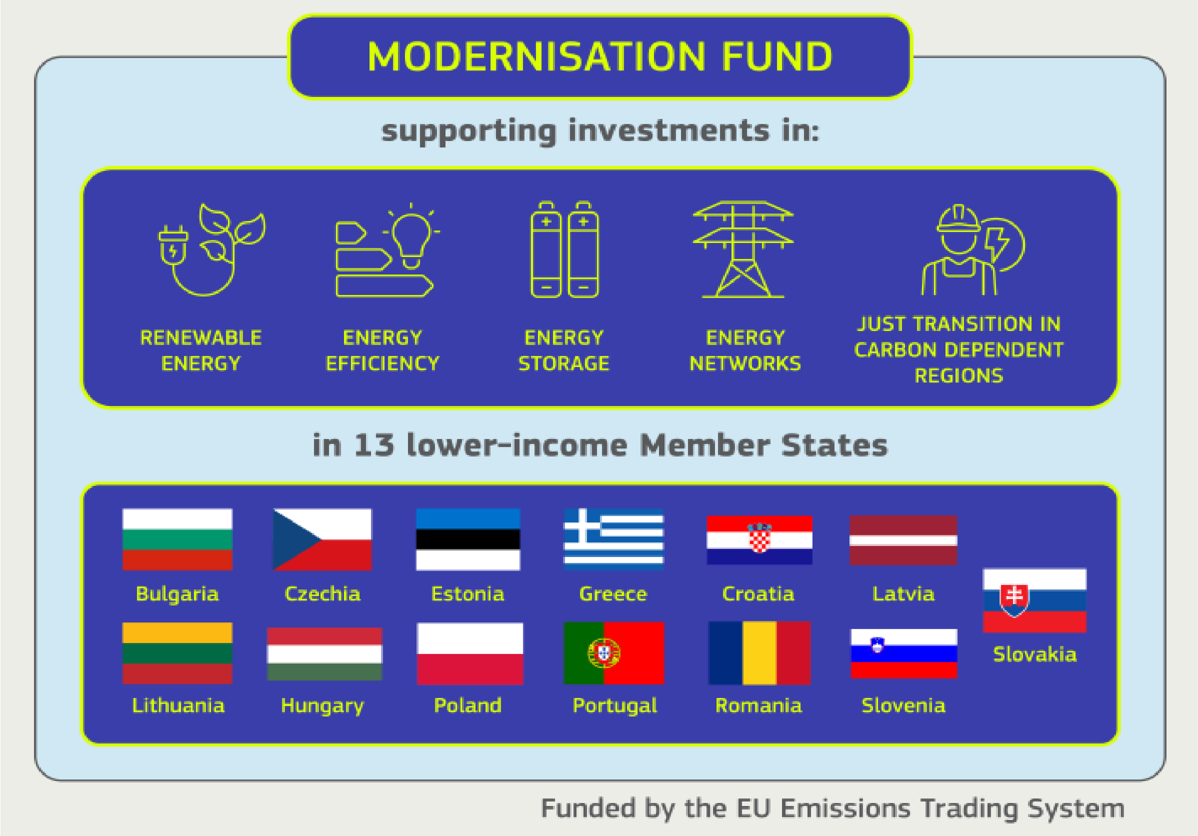


Figure 25 General description of the EU Modernisation Fund

The Modernisation Fund envisages two types of investments:

Priority investments that must fall into at least one priority area as defined by the EU Emission Trading System (EU ETS) Directive, namely:

- generation and use of electricity from renewable sources;
- improvement of energy efficiency (including in transport, buildings, agriculture, waste, and except in energy efficiency related to energy generation using solid fossil fuels);
- energy storage;
- modernisation of energy networks (including district heating pipelines, grids for electricity transmission, increase of interconnections among EU countries);
- support to a just transition in carbon-dependent regions in the beneficiary EU countries (including support to the redeployment, re-skilling and up-skilling of workers, education, job seeking initiatives and start-ups, in dialogue with social partner).

Non-priority investments that do not fall into a priority area but meet the Modernisation Fund objectives and demonstrate reduction of greenhouse emissions.

The majority of the resources of the Modernisation Fund (at least 70%) must be invested in priority areas.

What type of hydrogen related actions can be funded

Looking from the hydrogen sector perspective, the following activities could be funded via the Modernisation Fund as priority investments, among others:

- Generation and use of electricity from renewable sources.
- Production of green hydrogen from renewable electricity.
- Use of hydrogen produced from renewable electricity.
- Zero direct emission mobile assets based on renewables (for instance electric green hydrogen-fuelled trains, trucks or cars).
- Improvement of energy efficiency:
    - High efficiency hydrogen CHP investment if major amount of electricity is cogenerated at high efficiency on an annual basis,

- Energy Efficiency in industrial ETS installations, which do not prolong the use of solid fossil fuel assets.
- Energy storage and modernisation of the energy networks, including district heating pipelines, grids for electricity transmission and the increase of interconnections between EU countries.
- Upgrading electricity grids for e-mobility/deployment of charging stations.
- Energy storage (electricity, heat, cold, etc).
- Natural gas infrastructure projects to facilitate the use of low carbon/renewable hydrogen in existing gas network.

Furthermore, the Modernisation Fund cannot finance investments which involves solid fossil fuels, while gaseous fossil fuels are not excluded, providing that a significant greenhouse gas (GHG) reduction can be achieved.

Financing an investment from the Modernisation Fund

The Modernisation Fund operates under the responsibility of the beneficiary Member States, who work in close cooperation with the European Investment Bank (EIB) and the Commission. Together, they compose the Investment Committee for the Modernisation Fund (Investment Committee). Their roles are defined in the EU ETS Directive.

2.2.14 European Regional Development Fund

Objectives:

The European Regional Development Fund (ERDF) increases cohesion in the European Union by reducing economic, social and territorial disparities between regions and supporting the full integration of less-developed regions with the EU internal market through grants and financial instruments.

It provides funding to public and private bodies in all EU regions to reduce economic, social and territorial disparities. The Fund supports investments through dedicated national or regional programmes.

In 2021-2027, the fund will enable investments to make Europe and its regions:

- **more competitive and smarter**, through innovation and support to small and medium-sized businesses (SMEs), as well as digitisation and digital connectivity
- **greener**, low-carbon and resilient
- **more connected** by enhancing mobility
- **more social**, supporting effective and inclusive employment, education, skills, social inclusion and equal access to healthcare, as well as enhancing the role of culture and sustainable tourism
- **closer to citizens**, supporting locally led development and sustainable urban development across the EU

The ERDF is delivered under shared management. Local authorities call for projects adapted to their specific needs. It is governed by the Common Provisions Regulation.

What type of hydrogen related actions can be funded?

Although hydrogen is not specifically mentioned in the objectives or the key priorities of the fund, ERDF has specific target of 30% to support innovation and entrepreneurship in the transition to a climate neutral economy. This means that EU countries and regions shall spend a minimum amount of their ERDF allocations in these thematic areas.

Therefore, opportunities for funding hydrogen projects will depend on priorities identified in the national and regional programmes. This means that for hydrogen related projects it needs to explore on a case-by-case basis whether they could fit into the priorities of the relevant programmes and the Smart Specialisation Strategies of the EU countries or region where the potential beneficiary is located.

The European Hydrogen Valleys Partnership falls within the context of the Smart Specialisation Thematic Platforms, with the objective to strengthen the value chain for hydrogen and fuel cell (HFC) technologies via interregional cooperation and develop the technological readiness and the commercial availability of HFC applications.

For the new programming period 2021 – 2027, the type of projects being financed by the ERDF are productive investment in enterprises, infrastructure and public policies across a range of topics, including climate economy actions. For instance, hydrogen transmission and distribution projects might be part of the funding envelope. Funding opportunities could eventually be included in innovation and research, small and medium enterprises

(SMEs) and the neutral climate economy actions. The fund also addresses economic, environmental and social problems in urban areas, with a special focus on sustainable urban development (building). In addition, it supports cooperation activities between regions in different EU countries, under the European territorial cooperation goal (Interreg programme) and under the Interregional Innovation Investment Initiative (I3). In this framework, opportunities are open to support portfolios of innovative investment projects in companies, facilitated by smart specialisation ecosystems (S3).

2.2.15 Cohesion Fund

Objectives

The Cohesion Fund provides support to Member States with a gross national income (GNI) per capita below 90% EU-27 average to strengthen the economic, social and territorial cohesion of the EU.

The Cohesion Fund (CF) supports capital-intensive investments in the field of environment and trans-European networks in the area if transport infrastructure (TEN-T), using EU resources predominantly to support investment through grants. CF provides support to EU countries with a gross national income per inhabitant below 90% of the EU average.

For the 2021-2027 period, the Cohesion Fund concerns Bulgaria, Czechia, Estonia, Greece, Croatia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.

37% of the overall financial allocation of the Cohesion Fund are expected to contribute to climate objectives.

The Cohesion Fund finances programmes in shared responsibility between the European Commission and national and regional authorities in Member States. The Member States' administrations choose which projects to finance and take responsibility for day-to-day management.

What type of hydrogen related actions can be funded

Although hydrogen is not specifically mentioned in the objectives or the key priorities of the fund, CF has specific target of 37% to support innovation and entrepreneurship in the transition to a climate neutral economy. This means that EU countries and regions shall spend a minimum amount of their CF allocations in these thematic areas.

Therefore, opportunities for funding hydrogen projects will depend on priorities identified in the national and regional programmes. This means that for hydrogen related projects it needs to explore on a case-by-case basis whether they could fit into the priorities of the relevant programmes and the Smart Specialisation Strategies of the EU countries or region where the potential beneficiary is located.

The European Hydrogen Valleys Partnership falls within the context of the Smart Specialisation Thematic Platforms, with the objective to strengthen the value chain for hydrogen and fuel cell (HFC) technologies via interregional cooperation and develop the technological readiness and the commercial availability of HFC applications.

The CF supports environmental infrastructure and priority EU projects in Trans European Transport Networks (CEF-Transport). Part of the budget of the CF is transferred to the Connecting Europe Facility (€ 11.29 billion out of € 48.03 billion of total envelope). It will also cover projects on use of renewable energy, sustainable mobility and energy efficiency presenting clear environmental benefits.

2.2.16 Connecting Europe Facility – Energy

Objectives

The objective of the Connecting Europe Facility (CEF) is to accelerate investments in Europe’s transport, energy and digital infrastructure networks, so it is a key EU funding instrument for targeted infrastructure investment at European level.

CEF supports the development of high performing, sustainable and efficiently interconnected trans-European networks in the fields of transport, energy and digital services. CEF investments fill the missing links in Europe's energy, transport and digital backbone, and the facility is divided into three distinct instruments. The revised CEF Regulation for the MFF 2021-2027, which underpins this programme, is expected to enter into force in July 2021.

CEF for Energy (CEF-E) is an envelope of CEF that supports the implementation of the Regulation on Trans-European Networks for Energy (TEN-E), a policy framework focused on linking the energy infrastructure of EU countries. To address the energy infrastructure needs at regional and European level, nine priority corridors and three priority thematic areas have been identified in the TEN-E framework. CEF supports the implementation of Projects of Common Interest (PCIs) in these priority corridors and thematic areas. Under the revised CEF Regulation the programme will also support cross-border projects in the field of renewable energy.

Under the revised CEF Regulation, an action that has received a contribution under CEF may also receive a contribution from any other Union funding programme, provided that the contributions do not cover the same costs.

For instance, CEF can benefit from synergies from the EU's Innovation Fund. Now, only actions of electricity storage (except pumped hydro) and CO_2 (Carbon Capture and Storage transportation part) Projects of Common Interest (PCIs) are eligible under both the Innovation Fund (IF) and the CEF. However, new types of projects may be added in the revised TEN-E Revision including hydrogen-related projects (see next section for further details).

The general maximum co-funding rate for CEF is 50% of the project capital expenditure (CAPEX).

What type of hydrogen related actions can be funded

The fund is suited to demonstration projects, studies, and co-financing of development of energy infrastructure. Priority is given to projects with the highest value for all of Europe, particularly those which complete missing cross boarder links, remove bottlenecks or deploy EU-wide systems.

CEF-E can finance Projects of Common Interest (PCIs) as identified under the TEN-E Regulation as well as cross-border projects in the field of renewable energy which shall be included in a cooperation agreement between at least two EU countries or arrangement between at least one EU country and a third country or countries as set out in Articles 6, 7, 9 or 11 of Directive 2009/28/EC. The TEN-E Regulation currently in force does not include hydrogen infrastructure, electrolysers, or smart gas grids as eligible projects, however it does include CO_2 (Carbon Capture and Storage transportation chunk) pipelines as eligible.

TEN-E revision and hydrogen related projects

In December 2020, the Commission presented a legislative proposal to revise the TEN-E Regulation. The Commission's proposal envisages to support the roll-out of cross-border hydrogen infrastructure, certain types of electrolysers, and smart gas grids as new PCI categories. Negotiations with the European Parliament and the Council are currently under way, with a political agreement expect by early to mid-2022.

Turning to electrolysers, under the conditions in the Commission's proposal, only 100 MW electrolysers and above can be eligible, if they have a network related function. Furthermore, hydrogen production must comply with life cycle greenhouse gas emissions savings requirement of 70 % relative to a fossil fuel comparator of 94g CO_2e/MJ as set out in Article 25(2) and Annex V of the Renewable Energy Directive. Additionally, any related equipment for electrolyser equipment would fall under this category.

The Commission's proposal includes cross-border hydrogen infrastructure that match some project archetypes of Transmission & Distribution, notably transmission pipelines for hydrogen, giving access to multiple network users on a transparent and non-discriminatory basis, which mainly contains high-pressure hydrogen pipelines, but excluding pipelines for the local distribution of hydrogen.

The category also includes underground storage facilities connected to the high-pressure hydrogen pipelines. The reception, storage and regasification or decompression facilities for liquefied hydrogen or hydrogen embedded in other chemical substances with the objective of injecting the hydrogen into the grid would also be eligible under the TEN-E revision, as well as any equipment or installation essential for the hydrogen system to operate safely, securely and efficiently or to enable bi-directional capacity, including compressor stations. Importantly, the provision also specifies that any of the above "may be newly constructed assets or assets converted from natural gas dedicated to hydrogen, or a combination of the two."

When it comes to categories of smart gas grids, the TEN-E revision would support equipment or installation aiming at enabling and facilitating the integration of renewable and low-carbon gases (including biomethane or hydrogen) into the network. These would be digital systems and components integrating ICT, control systems and sensor technologies to enable the interactive and intelligent monitoring, metering, quality control and management of gas production, transmission, distribution and consumption within a gas network. Furthermore, such projects may also include equipment to enable reverse flows from the distribution to the transmission level and related necessary upgrades to the existing network.

Financial details

CEF shall contribute 60% of its overall financial envelope to climate objectives.

CEF-E has total budget of €5.84 billion, out of which 15%, subject to market uptake, should be allocated to cross-border renewable energy projects (which may be increased to 20% should that threshold be reached).

CEF is implemented through a mix of grants, procurement and financial instruments.

2.2.17 Connecting Europe Facility – Transport

Objective

The Connecting Europe Facility for Transport (CEF-T) is the funding instrument that is meant to realise the European transport infrastructure in accordance with the objectives of the EU guidelines for the development of the trans-European transport network. The instrument contributes to the implementation of the Trans-European Transport Network (TEN-T) by financing key projects to upgrade infrastructure and remove existing bottlenecks whilst also promoting smart, interoperable, sustainable, inclusive, accessible, safe and secure mobility. These projects cover all EU countries and all transport modes (road, rail, maritime, inland waterways, air).

It aims at supporting investments in building new transport infrastructure in Europe or rehabilitating and upgrading the existing one. CEF-T focuses on cross-border projects, as well as projects aiming at removing bottlenecks or bridging missing links in various sections of the Core Network, and on the Comprehensive Network under the TEN-T. Nine transport corridors and specific horizontal priorities have been established to focus on pan-European integration and development. CEF-T also supports innovation in the transport system to improve the use of infrastructure, reduce the environmental impact of transport, enhance energy efficiency, and increase safety.

In terms of key actions, CEF-T provides funding for actions in support of:

- new technologies and innovation, including automation, enhanced transport services, modal integration, and alternative fuels infrastructure for all modes of transport;
- improving transport infrastructure resilience, to climate change;
- urban nodes, multimodal logistics platforms, maritime ports, inland ports, rail-road terminals, and connections to airports of the core;
- studies for the development of the comprehensive network and actions relating to maritime and inland ports of the comprehensive network;
- re-establishing missing cross-border rail connections on the TEN-T;
- sustainable freight transport services;
- projects of Common Interest (PCIs) to connect the trans-European network with infrastructure networks of neighbouring countries.

Under the revised CEF Regulation, an action that has received a contribution under CEF may also receive a contribution from the RRF and InvestEU, provided that the contributions do not cover the same costs. In terms of funding synergies, some CEF and Horizon 2020/Horizon Europe projects work in the same thematic area, while tackling issues from different perspectives. The results can complement each other and advance the overall technology and related infrastructure. These can also be seen in the area of hydrogen. For instance, the MEHRLIN project in northern Italy, received different funding sources, namely CEF, Horizon 2020, and LIFE. The overall objective of MEHRLIN is to demonstrate a financeable demand-led business model for hydrogen refuelling stations, whilst the LIFE programme is financing the deployment of a fleet of 28 hydrogen fuel-cell cars (Zero Emission LIFE IP). Through theH2020 JIVE project, 27 fuel-cell buses for the same location will also be supported.

The Connecting Europe Facility programme 2021-2027 will address climate change and contribute 60% of its overall financial envelope to co-financing actions supporting climate objectives and moving fast towards zero-emission mobility. CEF will fund alternative fuels infrastructure through blending rolling call for proposals, by continuing the already established approach of combining CEF grants and financing from finance institutions to achieve a higher impact of the investment support.

The facility will be mainly implemented in cooperation with implementing partners, such as the European Investment Bank (EIB) and other national promotional banks which can facilitate access to financing.

What type of hydrogen related actions can be funded

It will support investments for:

- the roll-out of hydrogen refuelling infrastructure on the TEN-T road network, with an additional buffer distance (driving distance) of 10 km;
- the roll-out of hydrogen refuelling infrastructure on sections of the TEN-T rail network for which a derogation from the electrification requirement has been granted in line with Article 12(3) or 39(3) of the TEN-T Regulation, or on sections located in isolated networks as defined in Article 3 (u) of the TEN-T Regulation;
- the roll-out of hydrogen refuelling infrastructure dedicated to public transport in urban nodes and on the TEN-T road network, with an additional buffer distance (driving distance) of 10 km;
- the deployment of hydrogen alternative fuels for TEN-T maritime ports, inland waterways and inland ports.

Costs related to vehicles or vessels will not be eligible, except in the case of inland waterway and short sea shipping, if an initial number of vessels is needed to kick-start the use of the supported hydrogen refuelling infrastructure. In such cases, the eligible cost shall be limited to the difference of cost between a fossil-fuel vessel and the zero-emission vessel(s) proposed. Costs related to the energy storage facilities and/or deployment of electrolysers based on Renewable Energy Sources (RES) for electricity supply and a sustainable use of water resources for the production of green hydrogen for the purpose of transport will be eligible as synergetic elements under the conditions specified in the call text.

The instrument focuses on mobility infrastructure investments, hence there is a certain limitation on the hydrogen-related actions that can be funded under CEF-T.

To illustrate:

Projects on land road and off-road vehicles fleet deployment would fit under CEF-T only for elements of the projects that are linked to transport infrastructure. To illustrate, a case for such a project would be where a hydrogen fuel cell bus roll-out in a city may necessitate special private hydrogen refuelling stations fit for these buses. In that case, only the hydrogen refuelling station element of the project would be eligible for CEF-T funding, not the entirety of the project. However, the entire project could be supported by the financing of the implementing partner or other finance institution, even potentially guaranteed by the InvestEU (blending operation).

Shipping activities (transmission and distribution) need to have a direct link to port infrastructure to benefit from CEF-T, an example of which would be ship bunkering infrastructure.

Another example of this could be for inland distribution (for instance if the distribution is part of a transport project – i.e. needed to supply hydrogen refuelling stations (HRS) and projects relating to onshore power supply for shipping.

2.3 National documents of some EU Countries partners of H_2SHIFT

2.3.1 Denmark

The European Commission has granted approval under EU state aid rules to a EUR 170 million Danish initiative to promote renewable hydrogen production through Power-to-X (PtX) technologies. This program is designed to align with the goals outlined in the European Hydrogen Strategy and the European Green Deal, as well as the objectives of the REPowerEU plan, which aims to reduce dependence on Russian fossil fuels and accelerate the transition to green energy.

Denmark notified the Commission of its intention to introduce an around €170 million scheme (DKK 1.25 billion) to support the upscaling of the production of renewable hydrogen and derivatives, such as renewables-based ammonia, methanol, and e-Kerosene, using PtX technologies. The scheme will support the construction of up to 100-200 MW of electrolysis capacity.

The aid has been awarded through a competitive bidding process in 2023, open to companies constructing new electrolysers in Denmark. It is a direct grant for a ten-year period, contingent on compliance with EU criteria for producing renewable fuels of non-biological origin, including contributing to additional renewable electricity deployment.

The new electrolysers are expected to reduce greenhouse gas emissions by approximately 70,000 tonnes of CO_2 annually across the industrial, mobility and energy sectors. The scheme will contribute to Denmark's efforts to reduce its greenhouse gas emissions by 70% by 2030 compared to the 1990 level and to reach carbon neutrality by 2050.

The scheme is deemed necessary to facilitate renewable hydrogen production, aiding in the decarbonisation of industrial, transport, and energy sectors. It exhibits an "incentive effect," as beneficiaries would not undertake the investments without public support. Denmark has implemented sufficient safeguards to limit its impact on EU competition and trade, including an open, transparent bidding process and minimal aid necessary for projects. Additionally, the scheme's positive environmental effects align with the European Green Deal, outweighing any potential negative competition distortions.

Country targets 2030:

- 4.7 GW of electrolysis capacity for hydrogen production
- 4.5 million tons of CO_2 avoided
- 170 Million € of investments for H_2

2.3.2 Germany

Hydrogen is seen as a versatile chemical feedstock and energy carrier that can be used to secure energy supplies for many sectors, eventually bringing carbon emissions down to zero. Due to the energy intensive nature of green hydrogen production, the strategy emphasizes its use only where electrification is less efficient.

Because hydrogen has a low volumetric energy density, the strategy also considers synthetic fuels derived from electrolysis hydrogen (e-fuels) an important component of the energy mix, especially for transport. Furthermore, due to Germany's relatively low potential for solar and wind power, the strategy envisions partnerships with countries more favourably placed for green hydrogen generation (southern Europe, west Africa). Specifically, exporting technology and investing in production facilities in these countries and then importing the produced hydrogen. Thus, R&D into hydrogen technologies across the value chain are also a major component of the national strategy.

Country targets for 2030:

- GW of electrolysis capacity for hydrogen production
- 3.4 billion € of investments for H_2

2.3.3 Italy

Renewable hydrogen is a key sustainable solution for the decarbonisation of the economy. It is considered as part of the solution to achieve climate neutrality by 2050 and to develop innovative industrial value chains in Italy and the EU, as well as a high value-added green economy.

Renewable hydrogen is set to become a valuable energy vector for end uses where it is the most efficient solution in the process of its decarbonisation, such as hydrogen-intensive industry and high-temperature processes, long-distance heavy transport, maritime transport, rail transport or aviation. In addition, the energy vector quality gives it great potential as an instrument for energy storage and sector coupling.

The creation of hydrogen valleys or clusters will play a very significant role, where production, transformation and consumption are specially concentrated, taking advantage of the application of economies of scale, as well as the development of pilot projects linked, among others, to the transport sector and isolated energy systems.

Country targets for 2030:

- 2% penetration of hydrogen in final energy demand
- 5 GW of electrolysis capacity for hydrogen production
- million tons of CO_2 avoided
- 10 billion € of investments for H_2 (RES investments to be added), of which half from ad hoc resources and funds
- 27 billion € of additional GDP
- Creation of over 200k temporary jobs and up to 10k permanent jobs

2.3.4 Spain

Renewable hydrogen is a key sustainable solution for the decarbonisation of the economy. It is considered as part of the solution to achieve climate neutrality by 2050 and to develop innovative industrial value chains in Spain and the EU, as well as a high value-added green economy.

Renewable hydrogen is set to become a valuable energy vector for end uses where it is the most efficient solution in the process of its decarbonisation, such as hydrogen-intensive industry and high-temperature processes, long-distance heavy transport, maritime transport, rail transport or aviation. In addition, the energy vector quality gives it great potential as an instrument for energy storage and sector coupling.

The creation of hydrogen valleys or clusters will play a very significant role, where production, transformation and consumption are specially concentrated, taking advantage of the application of economies of scale, as well as the development of pilot projects linked, among others, to the transport sector and isolated energy systems.

Country targets for 2030:

- Installed capacity of 4 GW electrolysers
- 25% of hydrogen in industry produced through electrolysis
- 8.9 billion € invested in hydrogen production
- 4.5 million tons of CO_2 avoided

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