Hydrogen4EU

CHARTING PATHWAYS TO ENABLE NET ZERO

Hydrogen for Europe study

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Executive summary

1. The European Green Deal, published in December 2019 by the European Commission, strengthened the previously announced objectives in terms of sustainability, renewable energy deployment and reduction of greenhouse gas emissions. It sets unprecedented objectives for the decarbonization of the European Union, with a target of net-zero emissions by 2050 and an intermediary 55% reduction of emissions in 2030, compared to 1990.

2. Achieving net-zero emissions in the next thirty years represents a formidable challenge for the entire continent, and especially for its energy sector, which accounts for around three quarters of European greenhouse gas emissions today[1]. Under these climate ambitions, even the hardest-to-abate sectors are now confronted with the challenge of reducing their emissions to near net-zero. The transition towards a decarbonized European energy system needs to mobilize a wide range of solutions to ensure that energy supply remains secure and affordable for all European consumers. While renewables, electrification and energy efficiency are obvious and well-known contributors to a successful decarbonization, it is uncertain whether they are sufficient.

3. Promising technologies are renewable and low-carbon hydrogen; versatile and clean fuels that could be used across the energy supply chain: as energy carrier and as feedstock for other synthetic fuels and industry processes. Renewable hydrogen is produced from biomass or via electrolysis (powered by electricity from renewable sources), while low-carbon hydrogen is based on fossil fuels with low-emissions technologies like carbon capture and permanent storage (reformers with CCS) or pyrolysis. The potential and adaptability of renewable and low-carbon hydrogen have gained the interest of policy-makers and industrials. Not only can hydrogen help decarbonize the energy uses but it can also – together with electrification and renewables – foster energy system integration.

4. Few studies have addressed the potential of hydrogen in decarbonizing the European energy system in a holistic and detailed manner. The *Hydrogen for Europe* research project fills this gap. It is a scientific study based on a joint modelling effort from research centers IFPEN and SINTEF, led by Deloitte. The study delivers a comprehensive analysis regarding the dynamics of the European energy transition and the contribution of renewable and low-carbon hydrogen to the European climate objectives. It seeks to inform industrial players and policy-makers in fostering an optimal pathway to energy transition, that leverages the full potential of low-carbon and renewable technologies and allows to achieve net-zero emissions by 2050 at the least cost.

5. The study relies on a detailed model-based analysis with a full representation of the European energy system and its transition from 2020 to 2050. The modelling architecture combines *MIRET-EU* and *Integrate Europe*, two state-of-the-art partial-equilibrium models, enhanced specifically to tackle the objectives of this study. Both models are research-oriented tools, built on sound mathematical formulations, that have transparent modelling frameworks and deliver robust results. The *HyPE* model developed by Deloitte for this project is used to explicitly assess the potential of imports from neighboring regions, thus going further than what is usually represented in European hydrogen studies and reflecting the recent expectations on the role of imports.

6. This joint modelling effort is among the first to consider explicitly the latest European targets (e.g. the 55% CO_2 emissions reduction by 2030 and climate neutrality by 2050). It allows for an analysis of hydrogen's potential with a detailed technological, sectoral and geographic scope, including 27 European countries and considering the potential of hydrogen imports from North Africa, the Middle East, Russia and Ukraine. It considers the techno-economic parameters and drivers behind each main technology option. The modelling framework accounts for how investments lead to cost reductions through technology learning; an innovative approach typically not included in large-scale modelling of energy systems. Its energy system perspective also allows to represent, in detail, the interdependencies between the different sectors, assessing how to leverage the potential of energy system integration. Moreover, comprehensive data research has been carried out, not only relying on the existing literature, but also discussing with numerous experts and a wide range of hydrogen industry stakeholders to enhance data quality.

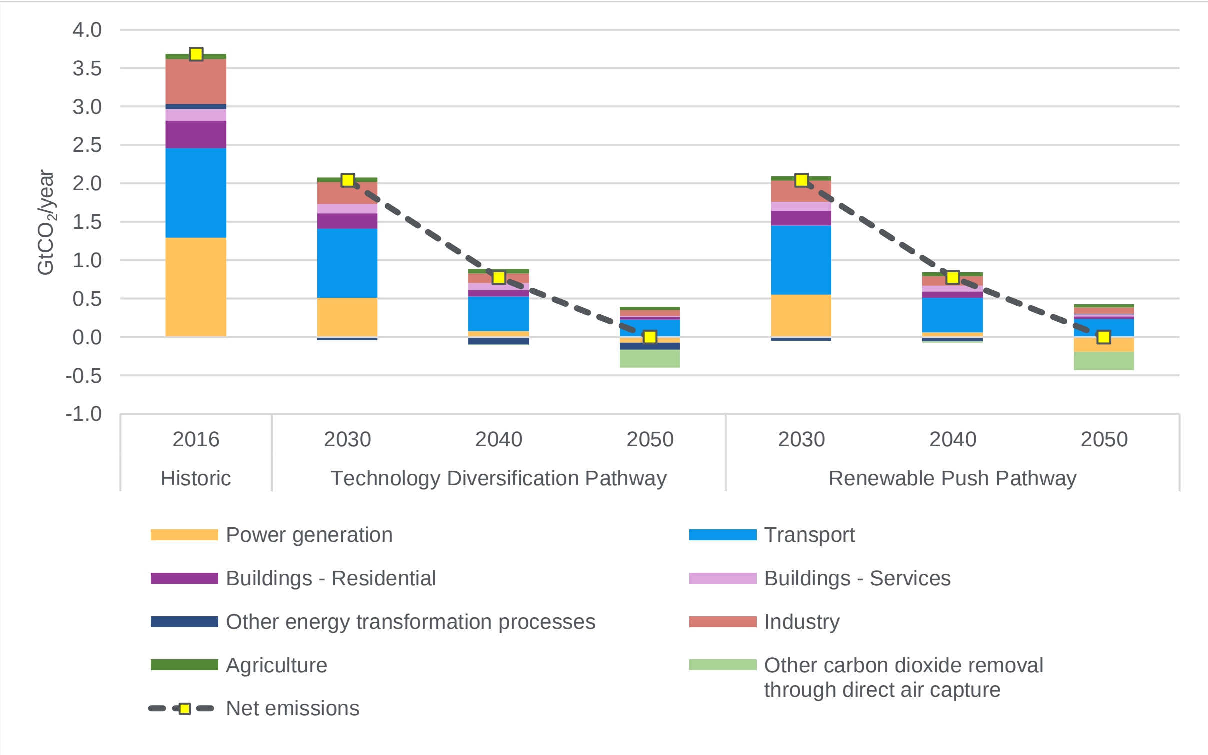
[1] European Environmental Agency, 2018.

7. The *Hydrogen for Europe* research project explores two pathways that lead to carbon neutrality. The "Technology Diversification" pathway provides insights into how an inclusive approach, that harnesses a wide-range of decarbonisation technologies, can help minimize the cost of the energy transition. The "Renewable Push" pathway examines the possible impact of a deliberate focus on renewable technologies; a prominent feature of the current policy debate. It differs from the other pathway by a series of targets on the share of renewables in gross final energy consumption, which is more ambitious for 2030 compared to today's policy (40% versus 32% in the Technology Diversification pathway) and includes binding targets for 2040 (at 60%) and 2050 (at 80%). Both pathways otherwise assume a level playing field between technologies.

8. Each of the two pathways presented in this outlook depicts an alternative future, a trajectory along which the European energy system could travel if its underlying economic, technological and regulatory assumptions unfold in a certain way, based on a least-cost optimization approach. They should neither be misinterpreted as forecasts nor misunderstood as the only viable pathways. The objective of our pathways is to stimulate debate and illuminate strategic decision-making, not to predict the future correctly or prescribe a certain evolution.

9. The two pathways follow a progressive trajectory towards deep decarbonization and achieve climate neutrality by 2050 (figure 1). By 2030, CO_2 emissions at European level are reduced by 55% compared to 1990 levels. This reduction is led by fuel switching in the power and industry sectors. CO_2 emissions then continue to decrease precipitously to reach net-zero emissions in 2050. The results suggest that the development of a fully operational CCUS value chain (including carbon capture and storage from fossil fuels and biomass and direct air capture) is indispensable for the success of the energy transition. Negative emissions from biomass and direct air capture with CCS serve to offset the residual emissions from the hard-to-abate sectors.

Figure 1. Evolution of CO_2 emissions by sector in the Technology Diversification and Renewable Push pathways, 2016 to 2050



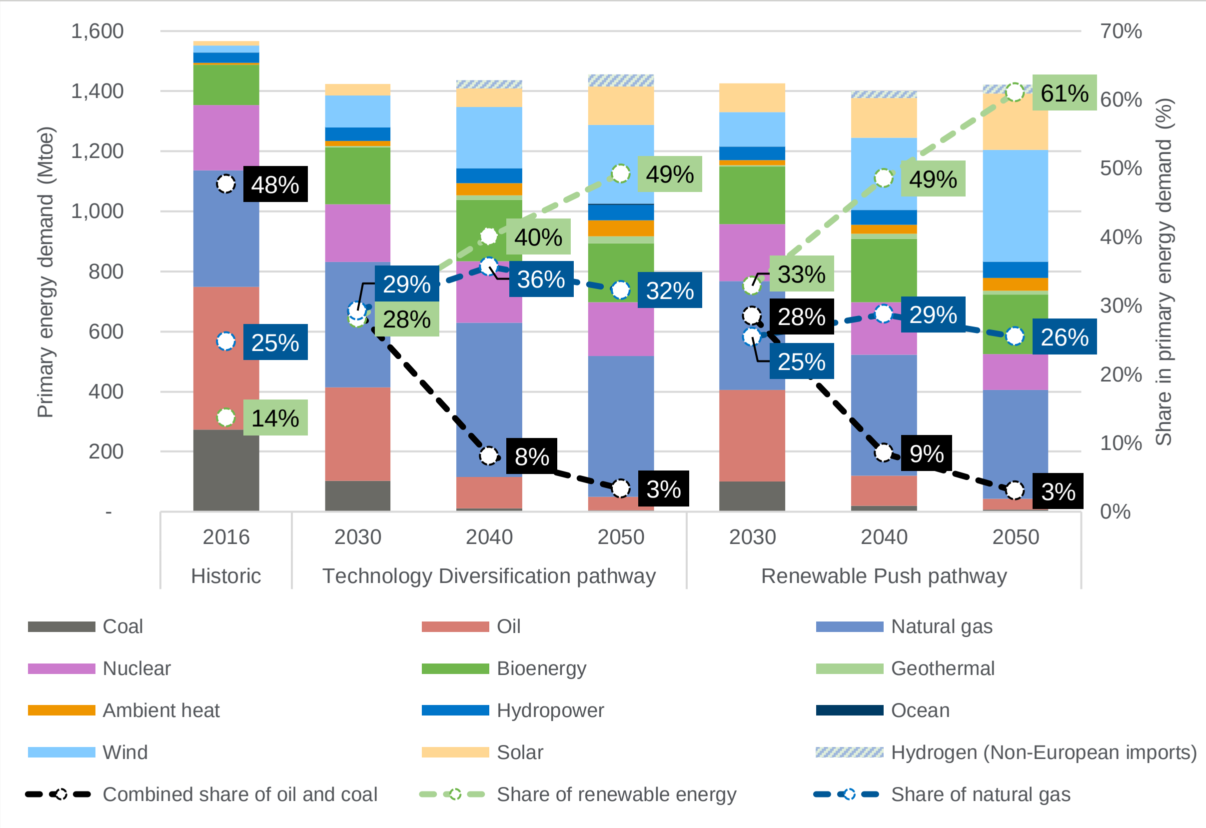
Other energy transformation processes include hydrogen production and refining.

Source : *Hydrogen for Europe* study

10. In achieving net-zero emissions, the primary energy mix is fundamentally reshaped in the two pathways (figure 2). Primary energy demand sees a pronounced shift to renewable energy. The share of renewable energy in primary energy demand reaches between 50% and 60% in 2050, sustained mostly by significant investments in wind and solar. This uptake is mirrored by a declining role of oil and coal, whose combined share in primary

energy demand drops to 3% in 2050. Natural gas is an element of continuity in the energy mix: use of natural gas remains resilient also in the Renewable Push pathway, where it provides important flexibility as a complement to renewables. Natural gas offers greatest benefits when coupled with CCUS. Much of its use is thus displaced from final energy consumption to transformation processes, e.g. for hydrogen production, where low-carbon hydrogen helps foster the growth of the hydrogen economy, or in power generation, where natural gas provides flexible power for load following and back-up generation.

Figure 2. Evolution of total primary energy demand in the Technology Diversification and Renewable Push pathways, 2016 to 2050



Source : Hydrogen for Europe study

11. At final consumption level, energy efficiency and electrification play their expected role in the transition to net-zero emissions. Final energy consumption is reduced by nearly a quarter in 2050 when compared to 2005, achieving along the way, the binding target of 32.5% reduction by 2030 (compared to a business-as-usual scenario) for the EU member states. Electricity's share in gross final energy consumption increases by almost 50% between today and 2050, with step changes observed in industry, transport and buildings. While this confirms the high expectations put on electrification, it also highlights the complementary roles played by molecules and other energy carriers to decarbonize end-use; also in the Renewable Push pathway that sees an acceleration of renewable deployment. As such, more than half of total gross final energy consumption is supplied by non-electrified technologies in 2050 in the two pathways.

12. Hydrogen plays a major role in the decarbonization of the energy sector. In light of the ambitious decarbonisation objectives, European hydrogen demand in our pathways exceeds 30 Mt by 2030, which is triple the current policy objective described in the EU hydrogen strategy. Demand for hydrogen ramps up substantially over the 2030s and 2040s and exceeds 100 million tons (Mt) by 2050 in both pathways. This is equivalent to more than 3,300 TWh or around 300 Mtoe (in lower heating value). The Renewable Push pathway, which shows a stronger deployment of renewable energy, demonstrates hydrogen's complementarity with renewable energies, helping to absorb, store and transport the bulk of the additional energy from renewable sources.

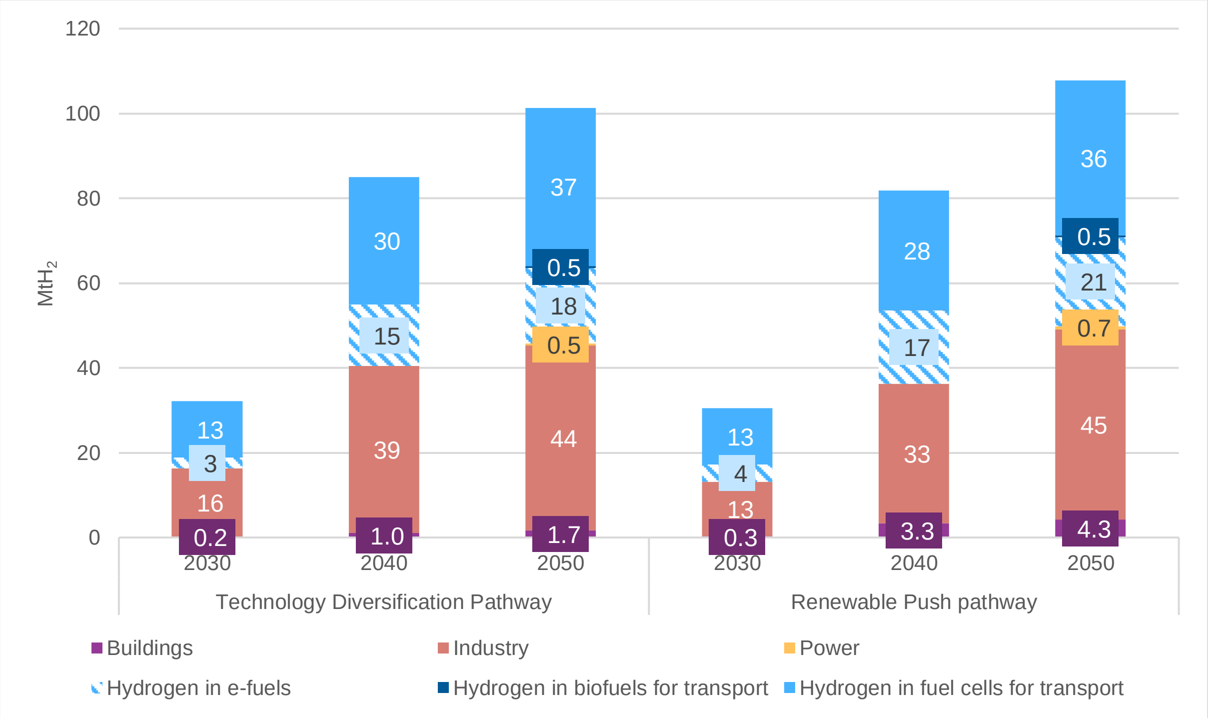
13. The sectoral breakdown of hydrogen demand confirms the versatility of hydrogen in decarbonizing the energy system (figure 3). Hydrogen can provide an answer to the challenges of deep electrification and the limits of energy efficiency improvements. It proves to be a cost-efficient solution for certain hard-to-abate energy uses in transport and industry.

a. More than half of hydrogen demand (above 50 Mt) comes from the transport sector, either for consumption in fuel cells, as intermediary feedstock for the production of synthetic fuels, or for use in biorefineries. By 2050, demand for hydrogen for e-fuels reaches around 20 Mt, with the majority being used in the transport sector and especially aviation. Hydrogen, e-fuels and other hydrogen-based solutions provide energy-dense fuels and gases to heavy and long-distance road transport, aviation and shipping, and thus address some of the limitations electric mobility faces in terms of energy density, weight, range and refueling.

b. Industrial hydrogen demand, primarily for energy, reaches some 45 Mt by 2050. Hydrogen is consumed in a diverse set of industrial sectors mainly to provide process heat and steam. Its potential is particularly high in the steel sector and in the chemical industry[2].

c. Hydrogen also contributes to emission reduction in buildings and power generation (with slightly greater use in those sectors in the Renewable Push pathway). Combined, buildings and power generation represent up to 5 Mt of hydrogen demand in 2050 in the Renewable Push pathway. This moderate uptake is notably due to trade-offs between a wide range of available options to decarbonize those sectors such as biogas, direct renewables, heat pumps and continued use of natural gas[3].

Figure 3. Evolution of hydrogen energy-related demand by sector in the Technology Diversification and Renewable Push pathways, 2030 to 2050



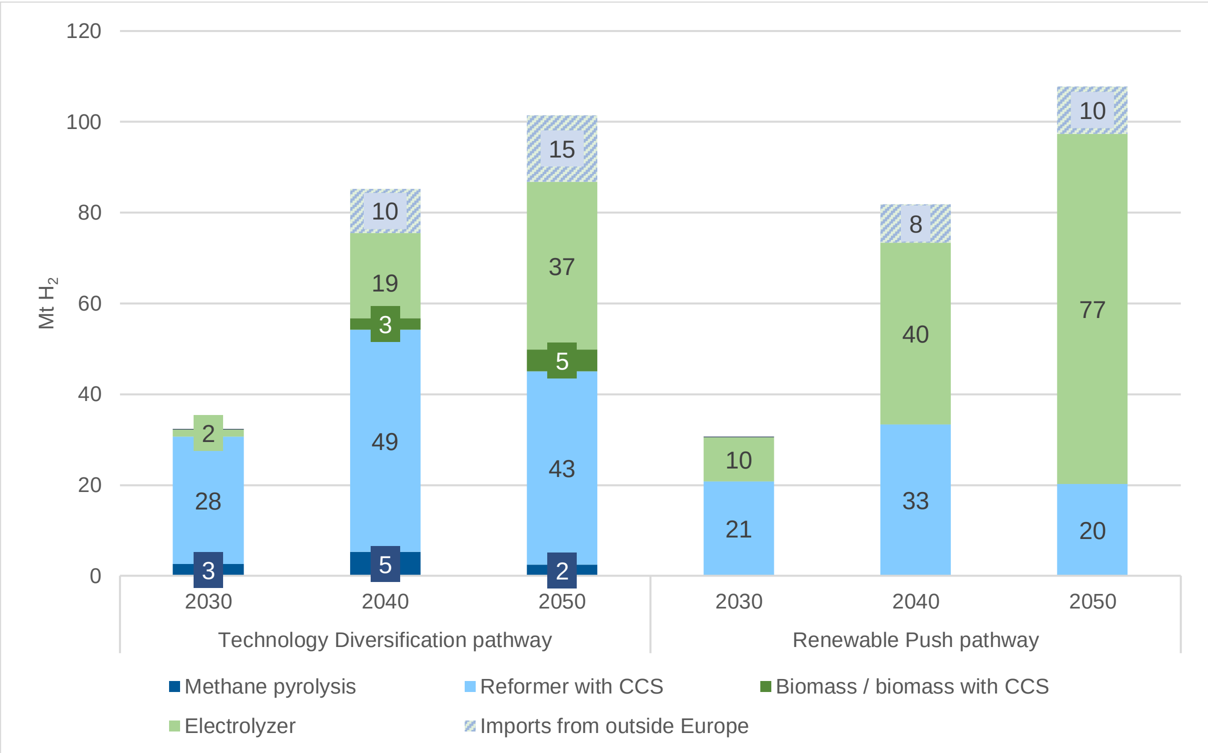
Source : *Hydrogen for Europe* study

[2] Note that consumption in refineries is attached to the transport sector and not to the industry sector.
The energy-related potential of hydrogen in industry should be supplemented by further assessment of the future hydrogen demand as a feedstock in chemical processes, which is out of the study's scope. This could mean that the potential of hydrogen for industry (both as a feedstock and as an energy fuel) in Europe is higher than what the Hydrogen for Europe's findings suggest.
[3] It should be noted that the inclusion of hydrogen turbine technologies in the energy system modelling scope could lead to higher hydrogen uptake in the power sector and is a subject for further studies. Likewise, constraints in the supply of renewable electricity and the conversion to heat pumps, efforts to protect the value of existing distribution grids and wider economic considerations, such as the creation of regional hydrogen ecosystems, could locally confer a more important role to hydrogen in buildings.

14. In the two *Hydrogen for Europe* pathways, European hydrogen production rises steeply over the next three decades, relying on a diverse production mix, comprising renewable and low-carbon technologies (figure 4). Hydrogen output in Europe soars to nearly 90 Mt in 2050 in the Technology Diversification pathway. Output increases markedly between 2030 and 2040, going from just over 30 Mt in 2030 to around 75 Mt in 2040, reflecting the accelerating uptake of the hydrogen economy after 2030. The pathways highlight the importance of keeping the momentum that is currently seen in Europe behind hydrogen production projects. Early investments are needed to increase the volumes of hydrogen production as soon as the next decade and create the necessary scale.

15. The pathways show the diversity of hydrogen production technologies and the complementarity between renewable and low-carbon routes. While low-carbon hydrogen plays a critical role in establishing a hydrogen economy in the first half of the outlook period, renewable hydrogen develops mainly in the second half of the outlook period and meets the bulk of the additional demand growth. In the Technology Diversification pathway, the production mix is balanced in 2050 with renewable and low-carbon sources both providing about half of the European output. In the Renewable Push pathway, underpinned by higher policy targets for renewable energy deployment, renewable hydrogen takes over during the late 2030s and becomes the biggest hydrogen production source by 2040. As in the other pathway, low-carbon hydrogen plays an important role to establish the hydrogen economy: it serves most of the demand in the first half of the outlook period.

Figure 4. Evolution of European hydrogen supply in the Technology Diversification and Renewable Push pathways, 2030 to 2050



Source : *Hydrogen for Europe* study

16. The development of low-carbon hydrogen and of other technologies such as biomass with CCS is highly dependent on the parallel deployment of the CCUS value chain and the ability of CO_2 storage capacities to grow rapidly over the next thirty years. The Technology Diversification pathway reaches an injection capacity limit of 1.4 Gt/year in 2050. This injection capacity has been derived as a reasonable estimate from a survey of existing literature and expert knowledge. However, the modelling also shows that higher levels of CO_2 injection capacities would allow for a bigger role for low-carbon hydrogen.

17. Achieving high levels of renewable hydrogen and renewable energy in the system, in the latter half of the period to 2050, requires significant investments, underpinned by accelerated deployment of renewable and electrolyzer supply chains and the optimal utilization of renewable energy potential in Europe. In the Renewable Push pathway, more than 1,800 GW of dedicated solar and wind capacities and more than 1,600 GW of electrolyzers need to be installed by 2050 to sustain the renewable hydrogen trajectory and get to over 75 Mt of output by 2050. The availability of bioenergy is another parameter that could shape the future European energy system and the prospects for renewable hydrogen. The modelling shows that a greater potential would lead to a more important role of biomass with CCS, contributing to hydrogen and power production and displacing direct air capture for negative emissions.

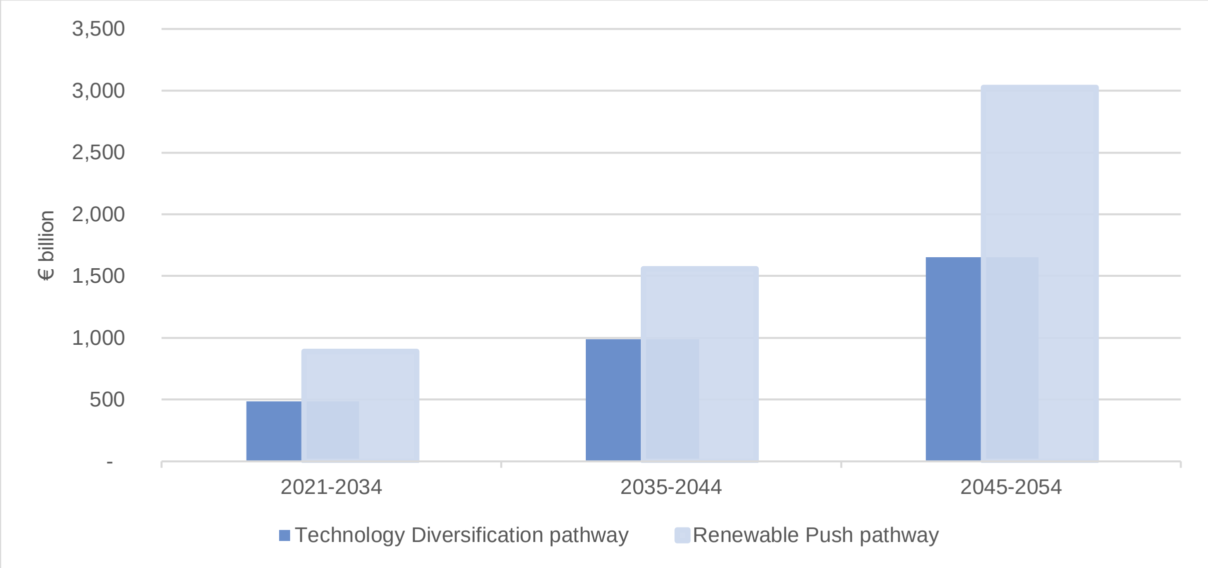
18. Part of the hydrogen needed in the transition to net-zero emissions is imported from outside Europe. The results show that imports of renewable and low-carbon hydrogen burgeon in the 2030s, including from North Africa, Russia, Ukraine and the Middle East. Imports play an important role in complementing European production of hydrogen and serving countries that have limited options for cost-efficient domestic hydrogen production. In the Technology Diversification pathway, up to 15 Mt of imports are able to compete on cost terms with domestic production, thus contributing nearly 15% to total hydrogen supply in Europe.

19. Trade between countries is needed to transport the hydrogen molecules from where they are produced to where they are consumed. Infrastructure, both cross-border and national, are developed progressively in the system to link demand to supply. The results underline the importance of repurposing existing natural gas infrastructure, protecting the value of the existing infrastructure and unlocking a lower cost option for hydrogen transportation. The pathways also show some potential for blending hydrogen with natural gas; with blending rates up to 15% in certain periods and in some countries. Blending with natural gas helps, in particular, to reduce emissions in the buildings sector and in industry.

20. Considering the hydrogen value chain as a whole, the results show that trillions of euros in investment are needed to leverage the full potential of hydrogen in the energy transition[4] (figure 5). These investments need to start in a timely manner to ensure demand and supply grow in lockstep, avoid technology lock-outs and mitigate risk of stranded assets. Investors need to start investing from the early 2020s in low-carbon hydrogen to take most advantage of their window of opportunity and avoid risk of becoming stranded as other sources become prominent or access to CO_2 storage becomes scarce. The difference of more than €2 trillion in capital spending between the two pathways demonstrates the higher capital intensity of a pathway focusing on renewable assets and electrolyzers. As such, one of the main challenges of the Renewable Push pathway is the ability to mobilize almost twice as much capital over the next thirty years to accomplish the hydrogen uptake.

[4] The time-steps in the planning period are: 2020 (today's system; no new investments), 2030, 2040 and 2050. Each period represents 10 years, e.g. 2045 – 2054 for 2050. The first day after the planning horizon is thus 2055.

Figure 5. Investments in the hydrogen value chain (including offgrid renewables) per period supply in the Technology Diversification and Renewable Push pathways, 2021 to 2054



Source : *Hydrogen for Europe* study

21. The Technology Diversification pathway underscores the value of adopting an agnostic approach with a level playing field between technologies and supply options and provides for a least-cost pathway to net-zero emissions. Compared to a pathway that focuses on acceleration of renewable energy deployment, it allows de-risking investments, relieving some of the financing and technological bottlenecks and enabling a more competitive and efficient energy system. In terms of total energy system costs, this approach would help save more than a trillion euros over the next thirty years, representing more than €70 billion of savings per year on average.

22. The trajectory drawn by the Technology Diversification pathway is founded on two principal paradigms: technology neutrality, assuming a comprehensive approach to decarbonization that includes the potential of all technologies, and reliability, transparency and effectiveness of the policy framework. It assumes that all barriers and uncertainties are addressed along the road by policy-makers and industrial leaders. In reality, despite some indisputable advances on the European policy and industrial fronts, much of the work is still lying ahead and the enablers identified in the *Hydrogen for Europe* study are not there yet to allow for an optimal contribution of hydrogen to the energy transition. The current regulatory and policy framework still lacks the tools and measures needed to stimulate hydrogen's upscaling, and more generally, to allow clean technologies to compete on a level playing field with existing CO_2-emitting solutions and to break even in the long term. The policy announcements and publications of the last year also put clear emphasis on certain technologies like renewable hydrogen, at the risk of creating a two-speed system and limiting the choice of available solutions.

23. The momentum built over the last few years thus needs to be followed by concrete actions to implement the building blocks of the European energy transition and of the hydrogen policy framework. The announced 'Fit for 55' policy package brings an opportunity to fundamentally reshape European energy policy. It is also the occasion to foster an optimal pathway to hydrogen deployment and emission reduction that complements the least-cost principle with other key policy considerations like energy security and social acceptance. The results of the *Hydrogen for Europe* study and their underlying assumptions can help inform the design of next policy packages and measures. The results can be used to better understand the gap between the current framework and the enablers of a least-cost pathway. In order to achieve the overarching policy objective of net-zero emissions by 2050, five main guidelines are proposed:

    1. Include externalities of CO_2 emissions in the economics of the energy system and incentivize CO_2 abatement technologies and uses: CO_2 pricing is today limited in scope and effect, which prevents renewable and low-carbon technologies from competing on a level playing field with emitting technologies. The reform of the EU-ETS and the reflections around a carbon border adjustment mechanism are

opportunities to address obstacles to coordinated and efficient CO_2 pricing and reflect the reinforced objectives of climate neutrality. There is possibly a need to complement them with other regulatory tools such as direct support, mandates or binding targets.

2. Design accounting rules for CO_2 content of energy: a common understanding on how to determine the CO_2 content of different forms of energy is crucial to compare their merits in achieving the transition. This is an important step in establishing a level playing field between technologies. European policy-makers have opportunities coming up to progress on CO_2 accounting e.g. the revision of the Renewable Energy Directive with regard to a EU-wide scheme of guarantees of origin, and the finalization of the EU Taxonomy, that should define a common CO_2 threshold applicable to low-carbon and renewable solutions.

3. Foster innovation and R&D to bring clean technologies to commercial viability: policy-makers need to create the right conditions for innovation to take place and give new clean technologies (e.g. renewables, CCS, electrolysis or pyrolysis) a hand so they can enter the market while keeping the virtuous learning-by-doing process for mature technologies going. The Horizon Europe program and the ETS-financed Innovation Fund are particularly well-suited for hydrogen technologies. National support schemes and State aid can also be used to support the uptake of less mature technologies and encourage learning-by-doing and cost decrease. Finally, the IPCEI (important project of common European interest) could be a powerful instrument to accelerate the roll-out of large-scale value chains and infrastructure.

4. Enable financing of investments: optimal timing of investments in the hydrogen value chain implies that all components need to anticipate demand growth and the establishment of a hydrogen market. Policy-makers can help mitigating the financing risks and open the door to low-cost financing. The upcoming ‘Fit for 55’ legislative package is important in alleviating uncertainty. Many public schemes and regulatory tools are, or could be, available to finance the European Green Deal and support innovation and competitiveness for low-carbon and renewable technologies, starting with the European and national Covid-19 recovery plans and the Just Transition Fund.

5. Ensure system integration and create a market: the upcoming framework for competitive decarbonized gas markets is expected to establish the foundation of the future internal market for hydrogen, which would enable trade of hydrogen within Europe. It should progressively establish an organized and liquid market for hydrogen that could be integrated within the existing gas market. It should also introduce a phased reform of gas infrastructure regulation, accommodating a full-fledged regulatory framework for hydrogen infrastructure. Taking a holistic perspective on the energy transition, the future hydrogen policy framework could be embedded in the European Commission’s efforts towards energy system integration.