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Assessing the role of hydrogen in Europe towards 2050 through models and scenarios

Full study available at: https://www.hydrogen4eu.com

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54° Séance du Séminaire de Recherches en Economie de l’Energie. Mines PSL, Paris – 12/10/2021

Reaching net-zero emissions in the EU by 2050 is a formidable challenge

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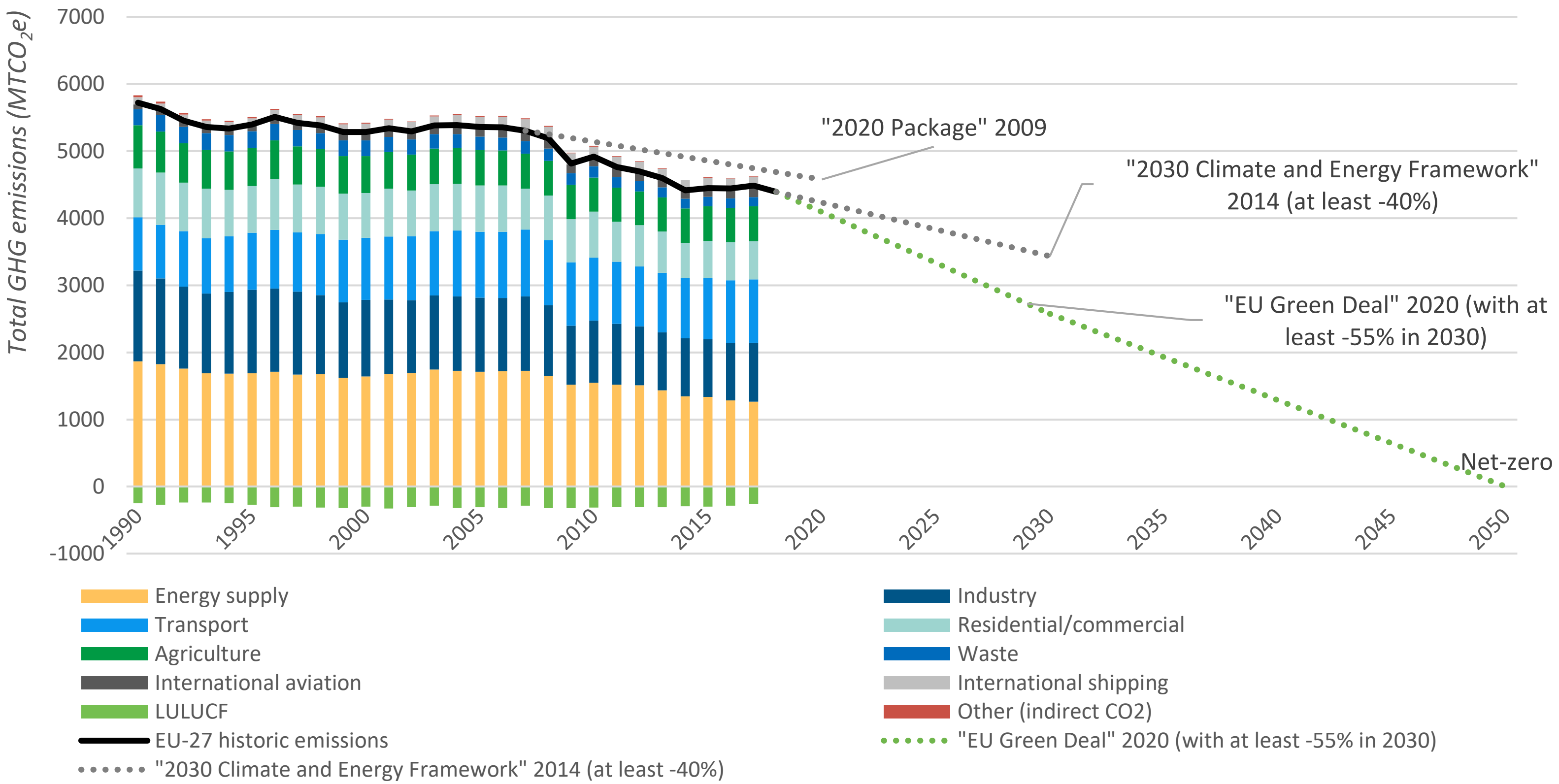
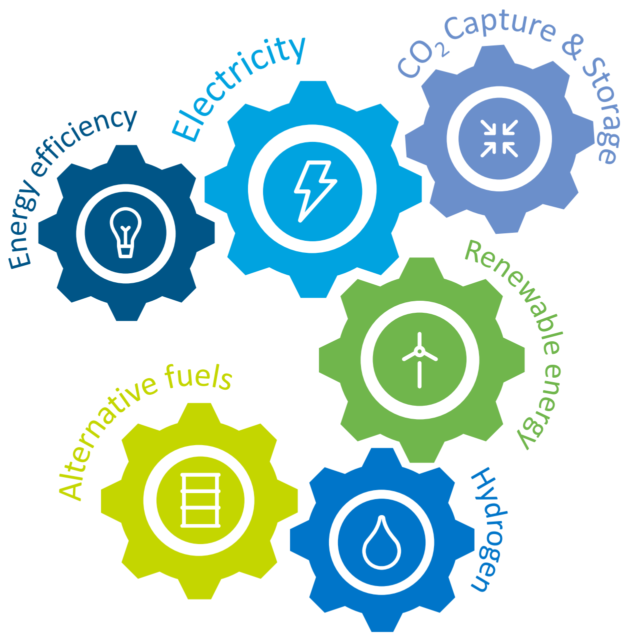
The European Union has reduced its carbon emissions during the last decade but the path towards net-zero requires a step change in efforts





Own elaboration based in European Environmental Agency (EEA) data.

Note: The figure includes emissions from international aviation, and net removals from land use, land use change and forestry sector (LULUCF). Completed with linear trajectories to comply with enacted legislations.

Is hydrogen the missing piece in the transition puzzle?

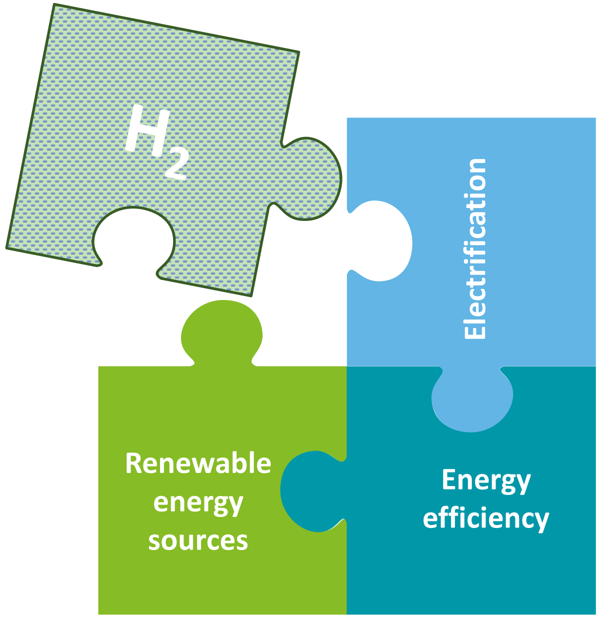
Opportunities

Hydrogen allows a cost-effective transition:

- Mitigate costs and challenges linked with deep electrification
- Avoid stranding gas assets
- Allow diversification and exploiting synergies between energy sectors.

Support emission reductions in "hard-to-decarbonize" sectors such as energy intensive industries, freight transport, aviation etc.

Manage seasonality of renewables in the power grid



Challenges, barriers and uncertainties

Technology uncertainties:

- **Supply-side**: readiness and competitivity of hydrogen production technologies
- **Demand-side**: high potential for fuel shifting end-uses (e.g., FCV, fuel-cells, etc.) but adoption remains uncertain.

Regulatory uncertainties: Limiting view of opposing complementary sources in current policies (blue vs. green).

Transport infrastructure: lack of clarity with respect to blending rates and interoperability issues in the gas network, and timeline for building-up a European hydrogen backbone.

The design of the Hydrogen for Europe study in a nutshell

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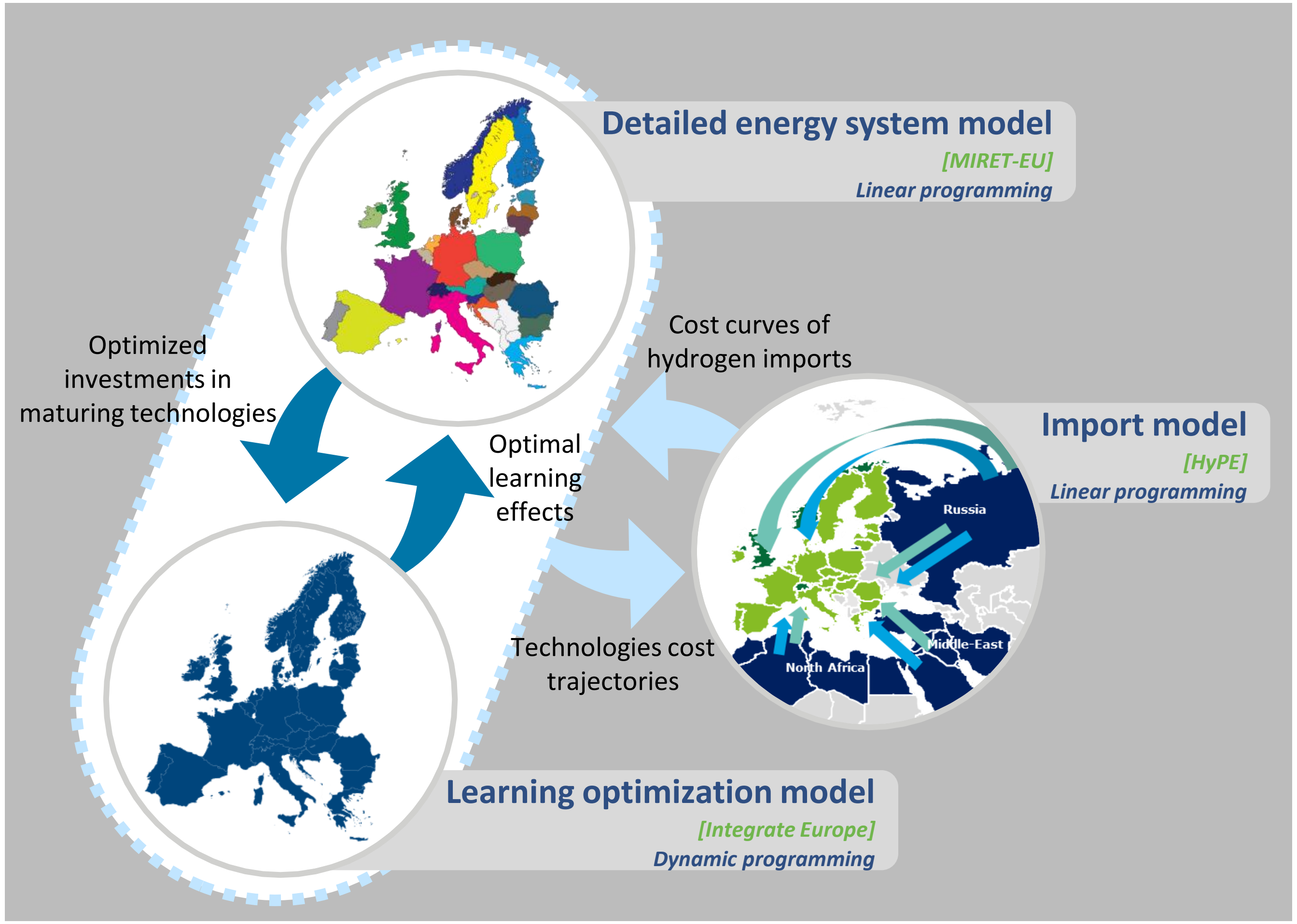
The study rests on a quantitative analysis, relying on three models and their interaction: MIRET EU (IFPEN), Integrate Europe (SINTEF) and HyPE (Deloitte).

Methodology and tools



Scenarios and results

Technology Diversification pathway

→ Illustrates how an inclusive approach helps minimize the cost of the transition

Renewable Push pathway

→ Shows the implications of a deliberate focus on renewables in policymaking

Both pathway are aligned with key EU policy goals:

- 55% reduction in GHG by 2030,
- Net-zero by 2050

Representation of the European energy system

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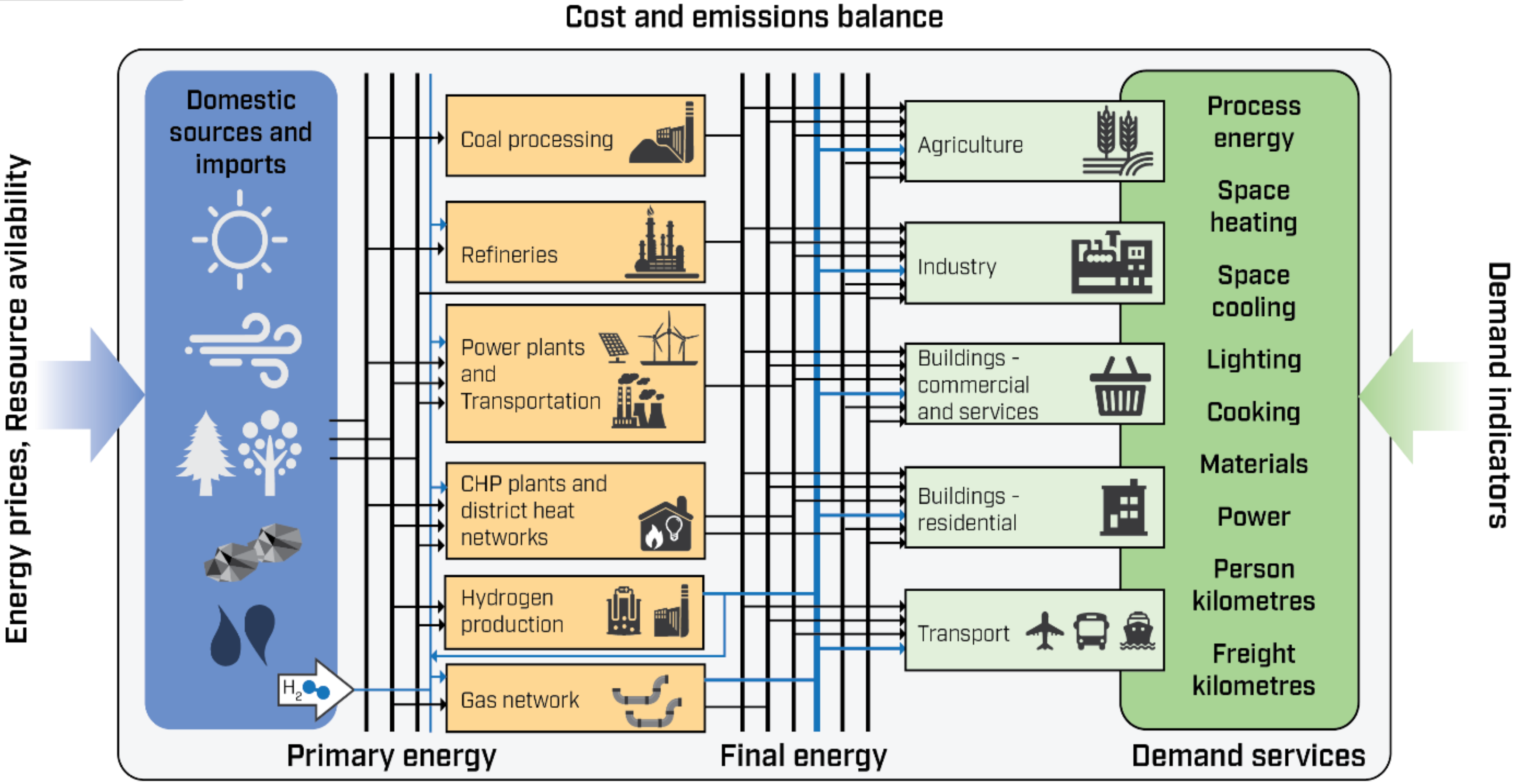
The *Hydrogen for Europe* study relies on energy system modelling that integrates a wide range of existing and future hydrogen technologies with the most up to date knowledge and data

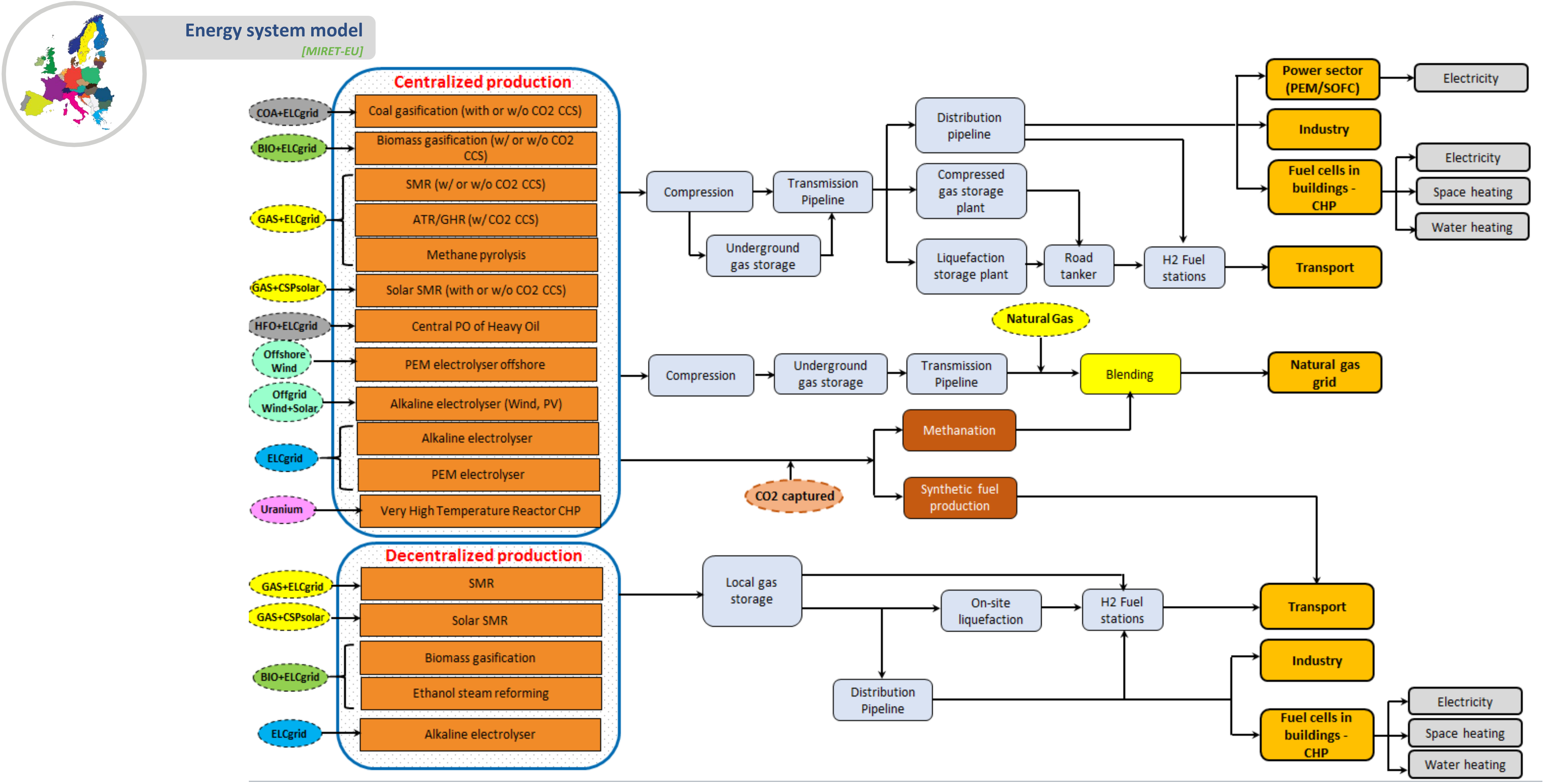
Energy system model
[MIRET-EU]



Based on Remme and Mäkela, 2001

A focus on the hydrogen value chain in MIRET EU

Each European country has the potential to develop hydrogen value chains



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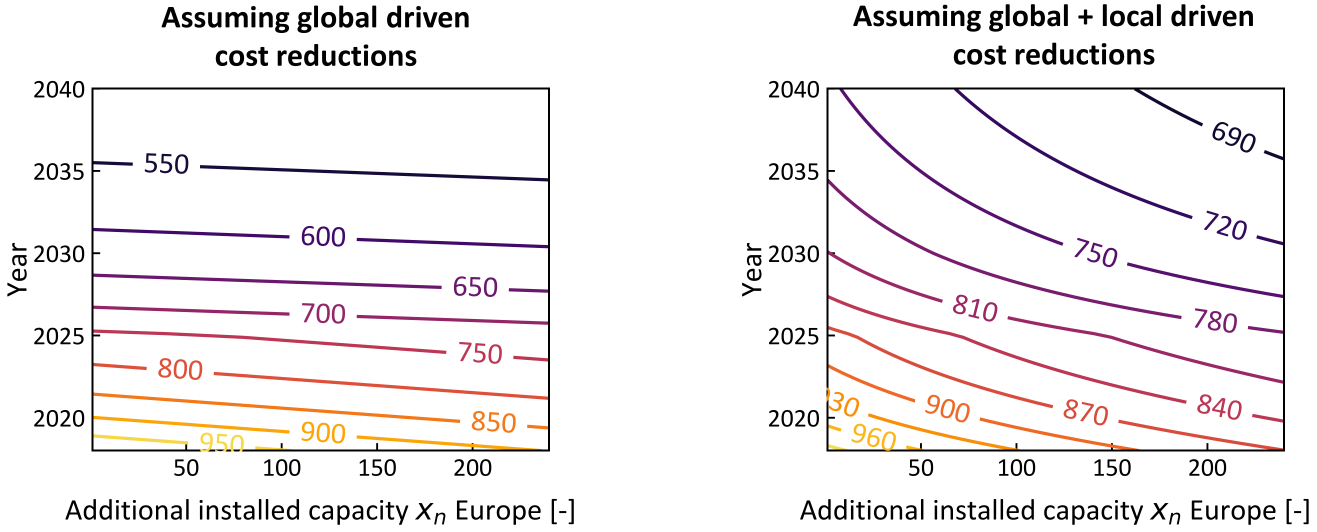
Learning-by-doing

Global learning – time dependency

Global expansion data for PV based on IEA WEO 2019 SDS



H2 4EU study (2021)

- Certain factors are <u>only</u> affected by local learning (e.g. installation costs and balance of system costs)
- Inclusion of these factors is important for proper cost estimation (RHS figure):

$$C_n = C_0 \left[\alpha \left(\frac{x_{n,row} + x_{n,eur}}{x_{0,\mathrm{row}} + x_{0,eur}} \right)^{b_{\mathrm{lbd,global}}} + (1-\alpha) \left(\frac{x_{n,eur}}{x_{0,eur}} \right)^{b_{\mathrm{lbd,eur}}} \right]$$

Learning-by-doing

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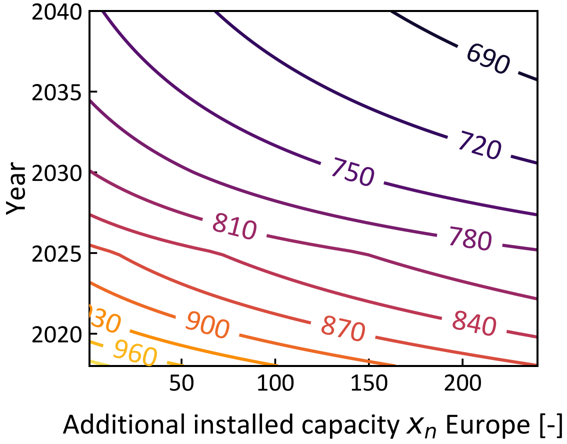
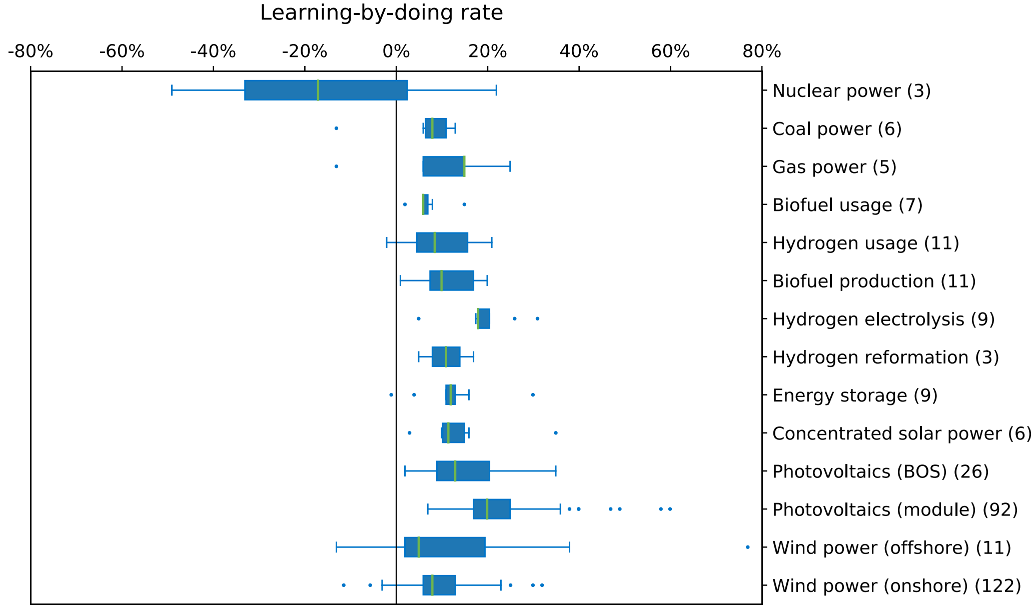
Global learning – time dependency and investment packages

Learning model
[Integrate Europe]

Assuming global + local driven cost reductions

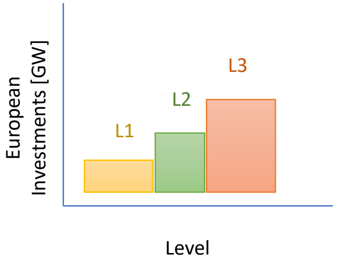


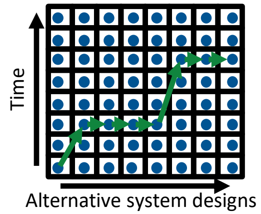


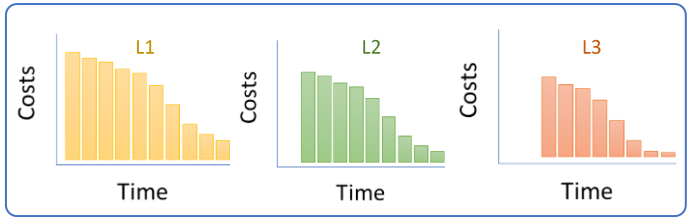
H2 4EU study (2021) and Ouassou et al. (2021)

The **Integrate Europe model** bring capacity expansion planning of the EU energy system with endogeneous learning:

Discretization of investments in packages







Widening the scope by including hydrogen import potential

Hydrogen Pathways Exploration [HyPE]: value chain optimization for hydrogen trade

H2 Import model
[HyPE]

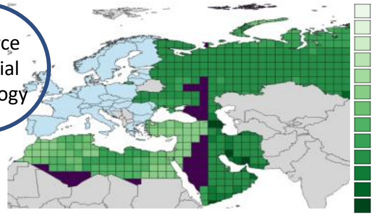
Hydrogen production (*onsite*) → LCOH (*onsite*) [EUR/kgH_2] → **Conversion 1** (*onsite*) → Domestic transport → **Conversion 2** (Exporting point) → FOB** LCOH[EUR/kgH_2] → International transport → *Importing point in the EU* → **Reconversion** (Importing point) → CIF LCOH [EUR17/kgH_2]

Domestic inland transport and logistics | *International transport and logistics*

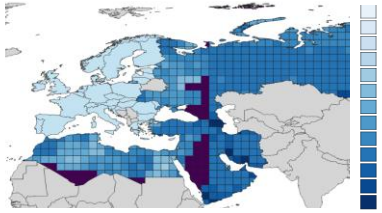
1. LCOH exploration

QGIS

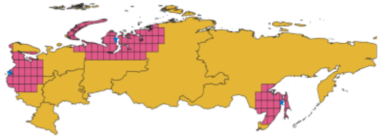
Resource potential & topology



Solar onsite LCOH distribution in 2050



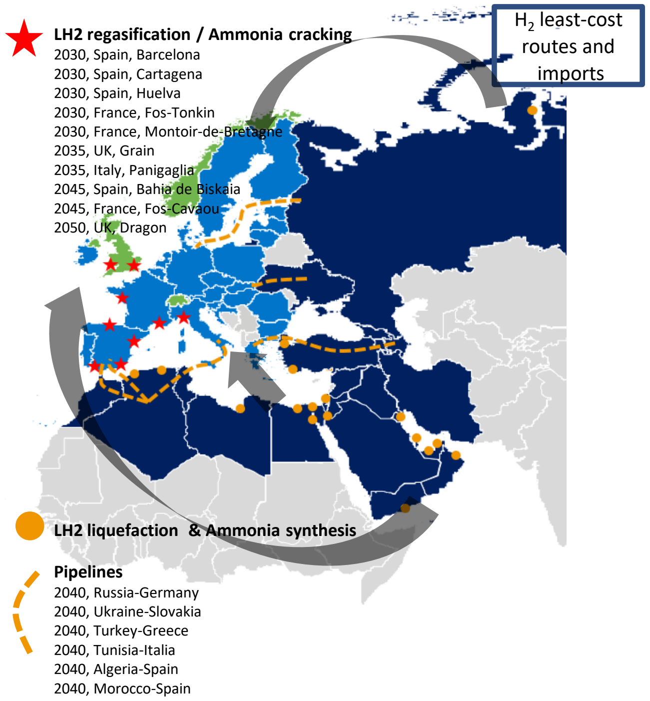
Wind onsite LCOH distribution in 2050



Biomass gasification in russian federal districts

2. Route optimisation

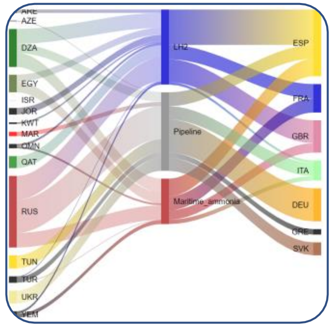
GAMS IBM CPLEX



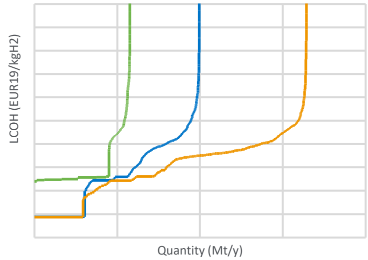
Note: Existing gas terminals are also entry point for hydrogen shipping

3. Point-to-point H2 imports

Hydrogen point-to-point flow analysis



Hydrogen point-to-point cost curves



The model linking strategy

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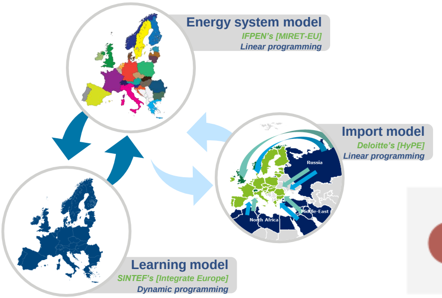
Avoiding overlapping, fostering synergies and adding value



1 **Model alignment**
Scenario definition and translation into technical assumptions

+

2 **Model alignment**
Data collection, common database on energy consumption, technology costs, regulatory measures

MIRET-EU adopts a disaggregated representation of sectors and focuses on optimal paths for each EU country

3 Detailed representation of technologies, sectors and countries in MIRET-EU:

- Detailed description of technologies and energy chains (electricity, gas, hydrogen…), centralized vs. decentralized.
- Individual representation of demand and supply in all sectors (residential, services, agriculture, transport, industry)

6 Complete and disaggregated optimization modeling at a country level:

- Hydrogen imports from the HyPE model
- Least-cost technology pathways and disaggregated investment trajectories according to each scenario under any policy constraint.
- Policy implementation

Provides a disaggregated view of the future of hydrogen on each EU country

Data aggregation →

← ***Investment profiles and costs***

Integrate Europe captures the dynamic issues and path dependencies of the energy transition at the European level

4 Aggregated model of the European energy system. A detailed modelling of energy supply chains is possible for multiple energy carriers.

5 Optimizes and evaluates investment pathways for Europe considering:

- Emission-free energy needs, and other policy choices
- Technology learning (learning-by-doing)
- Hydrogen imports from the HyPE model

Assesses the impact early investment decisions and corresponding policies have on the learning effects, cost and deployment pace of hydrogen technologies.

The transformation of energy supply

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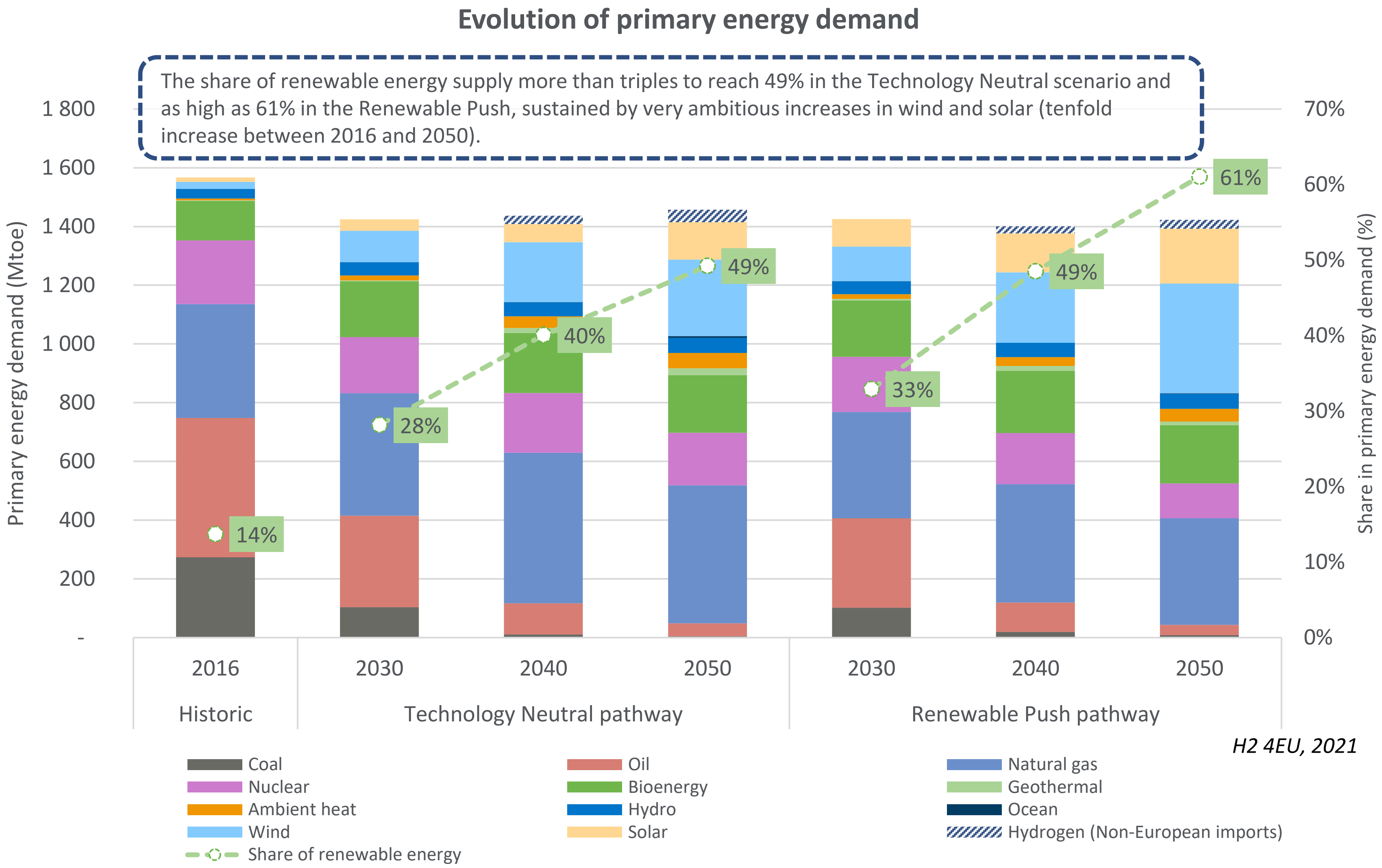
The share of renewable energy sources in primary supply more than triples



- **x3.5** in **30 years**
- Meets almost **half** of primary energy by 2050

- **32% share by 2050**
- Resilient during the transition

- Dwindling role of coal and oil
- **3%** share by 2050

Energy transition and final uses

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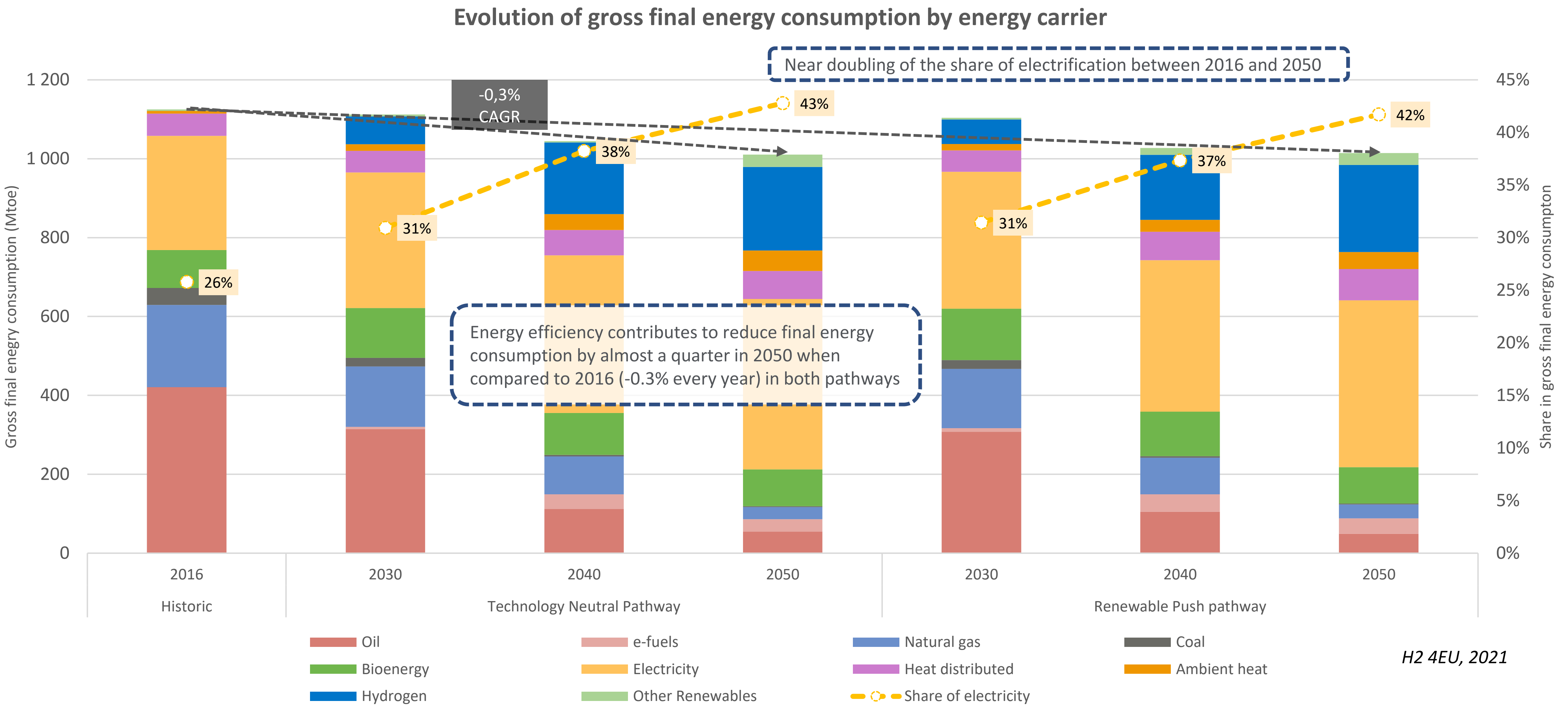
Electrification and energy efficiency play their expected role in the transition…



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Energy transition and final uses

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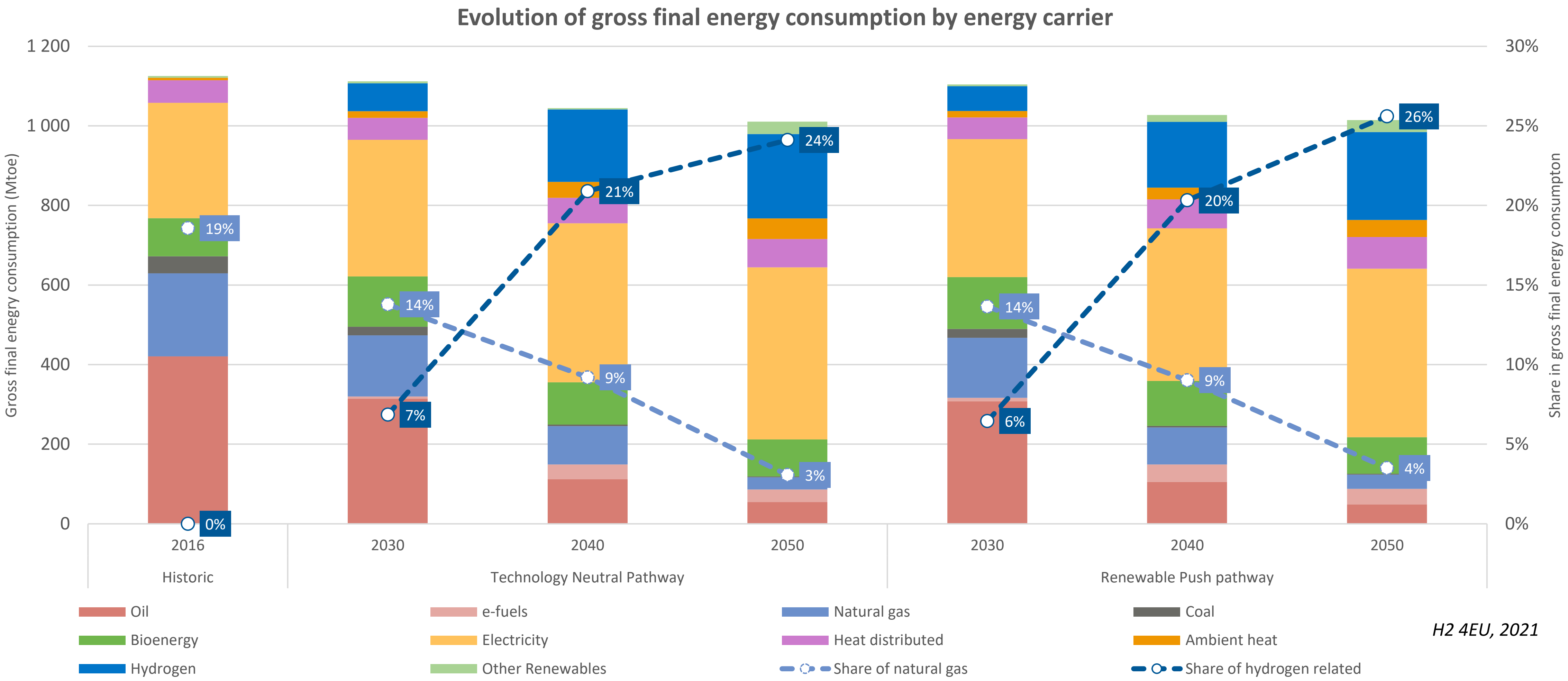
As the share of hydrogen in final energy use grows, the share of natural gas falls, underscoring the ability of hydrogen to replace natural gas where CO_2 capture is difficult



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Hydrogen demand

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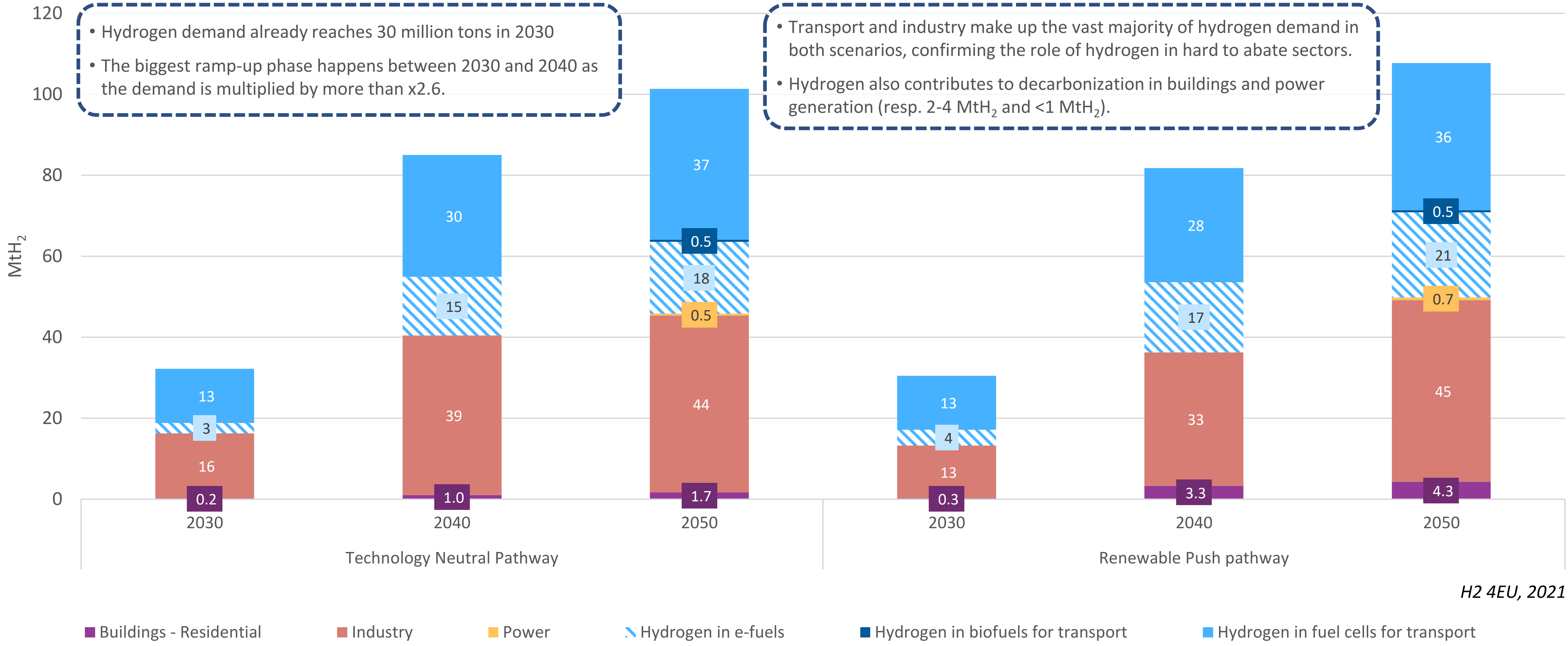
Hydrogen plays a similar role in the two scenarios as it proves a robust solution for hard-to-abate sectors, which hydrogen consumption is very similar between the two scenarios

Evolution of hydrogen demand by sector



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Hydrogen demand

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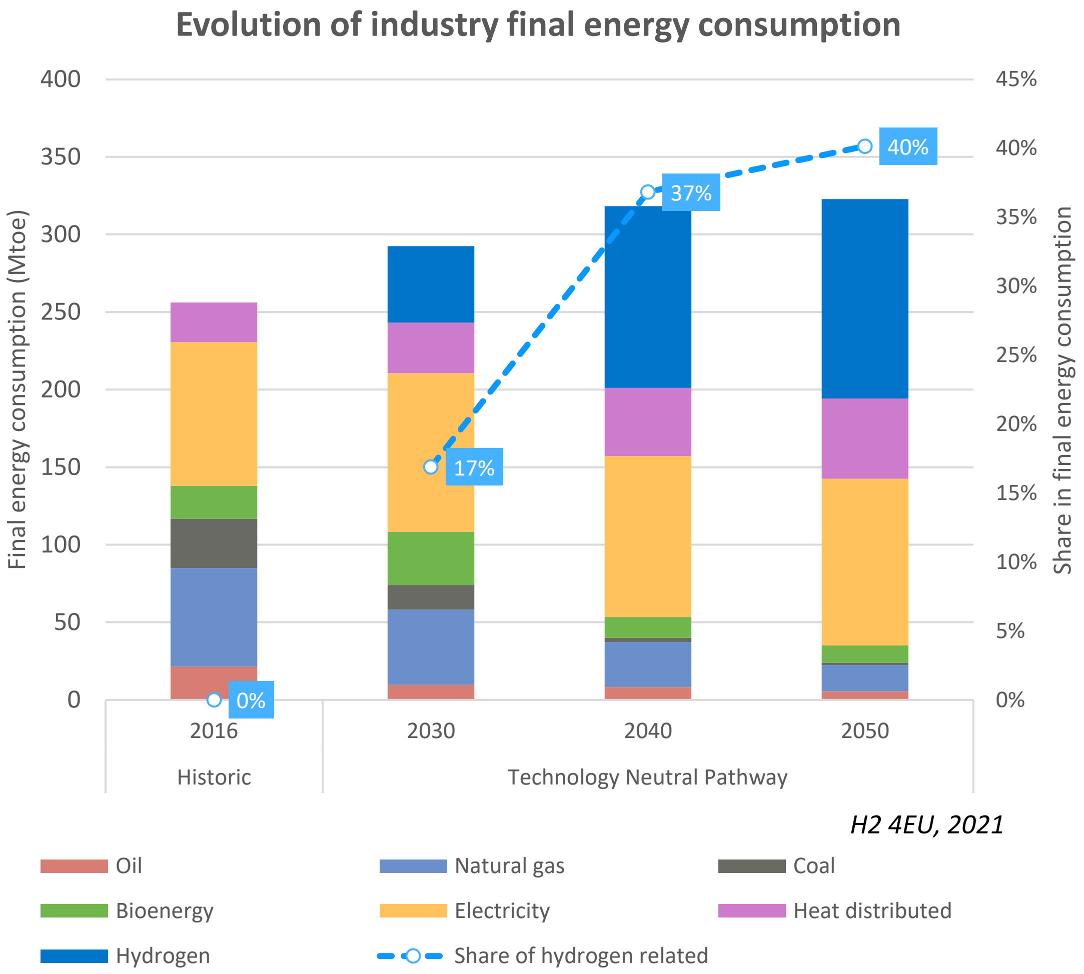
Focus on **Technology Neutral** pathway: by 2050, hydrogen is mostly consumed in **industry** and transport



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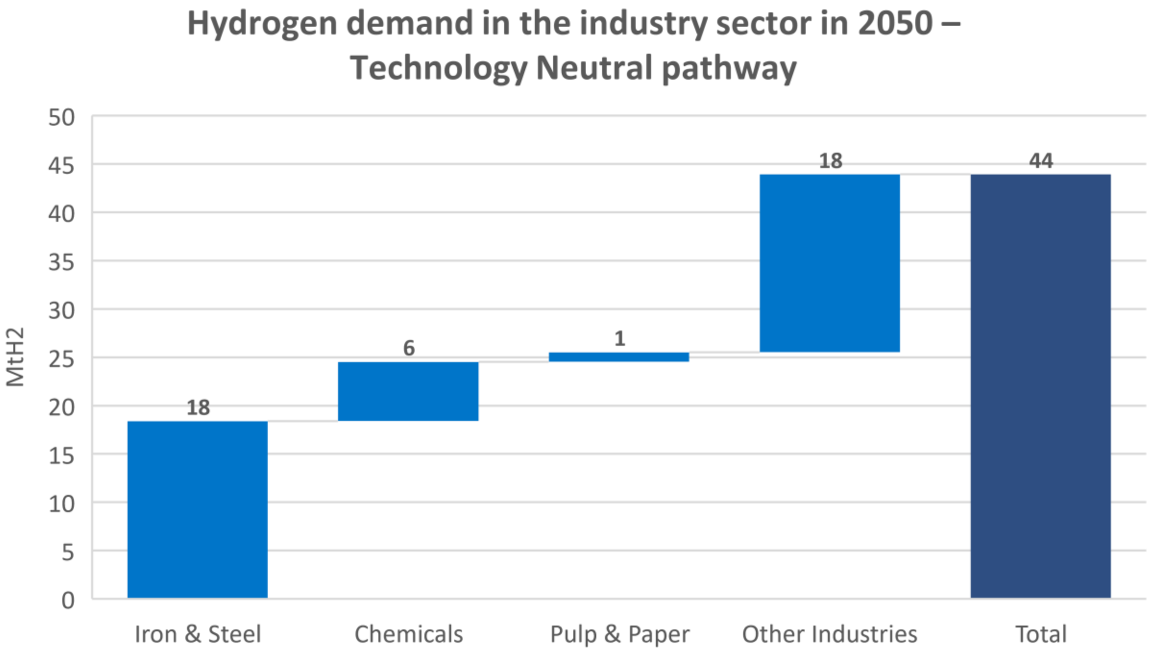

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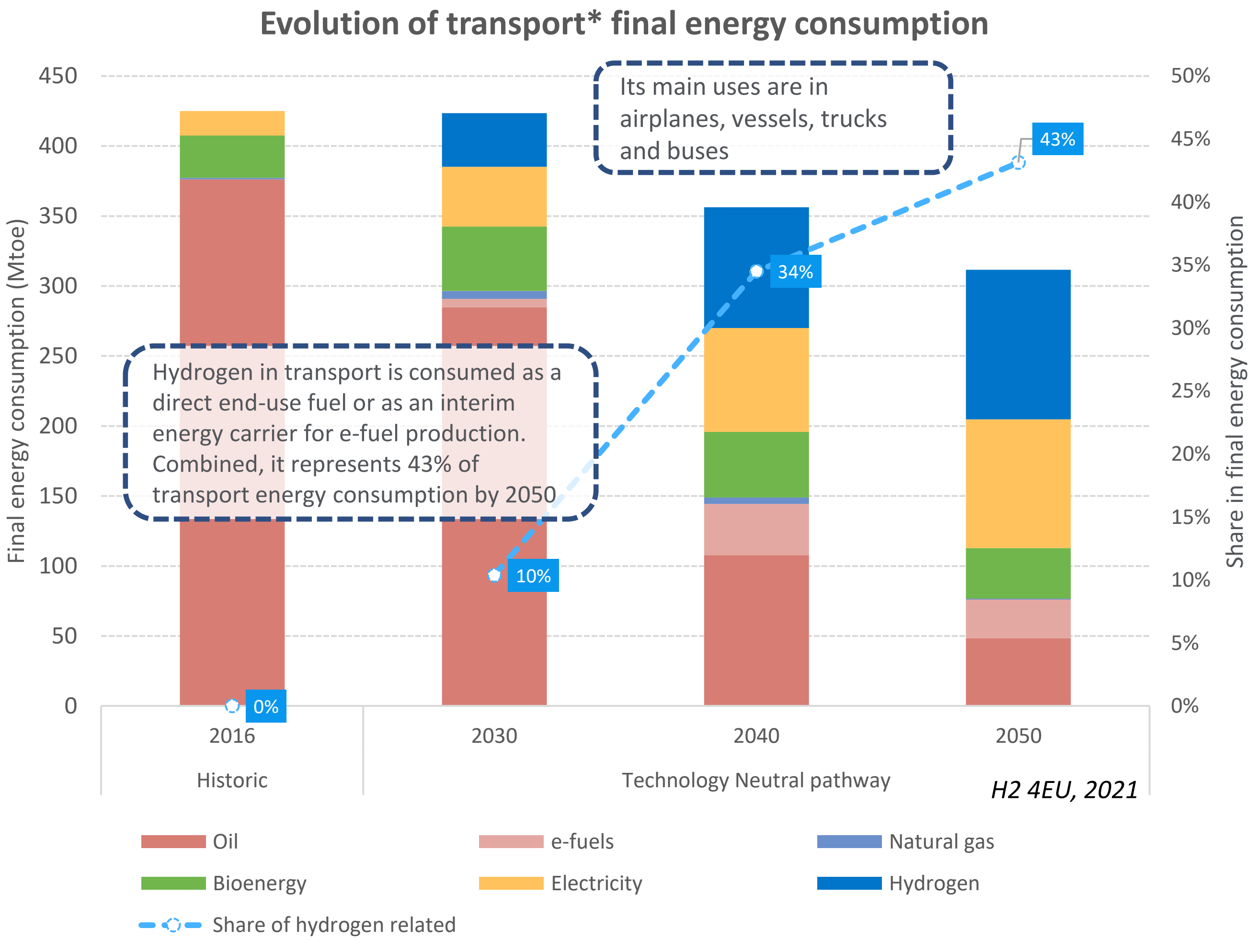
Note: only included energy-related hydrogen uses in the industry. Feedstock uses of hydrogen are also expected to be key for decarbonizing chemical and petrochemical products.

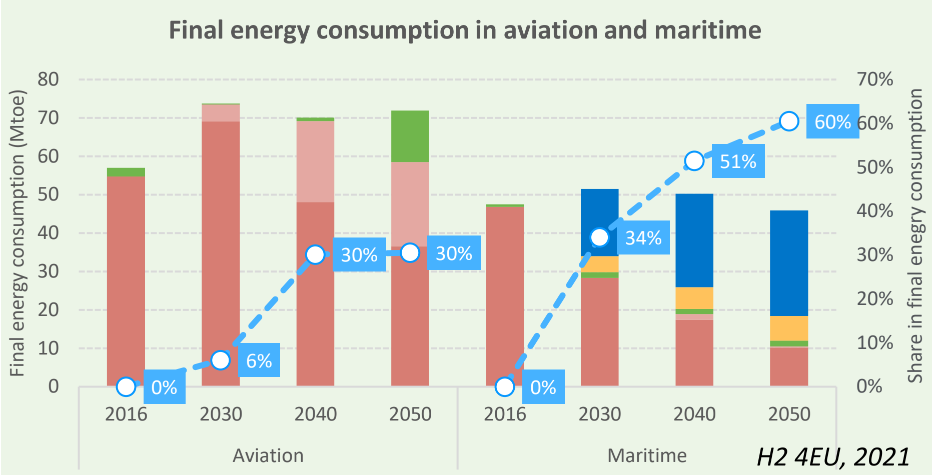
- Industrial hydrogen demand, primarily for energy, reaches some 44 Mt by 2050.
- Hydrogen is consumed in a diverse set of industry sectors mainly to provide process heat and steam.
- Its potential is particularly strong in the steel sector and in the chemical industry.

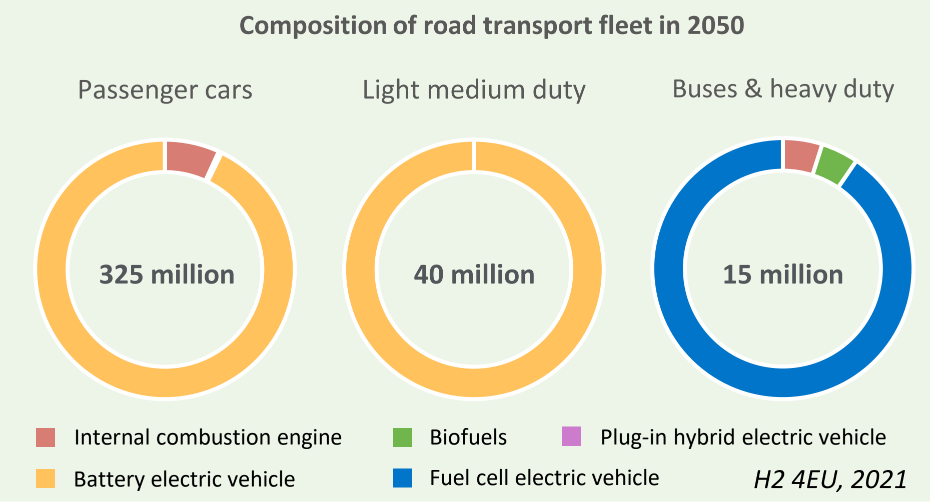
Hydrogen demand

Focus on **Technology Neutral** pathway: in 2050, hydrogen is mostly consumed in industry and **transport**



*Aviation and maritime included





Note: hydrogen also includes related hydrogen used for ammonia production for energy-use in the maritime sector

Hydrogen key for decarbonizing hard-to-abate sectors

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~ 100 million tonnes

of H_2 consumed by 2050

Diversity and complementarity between hydrogen supply options

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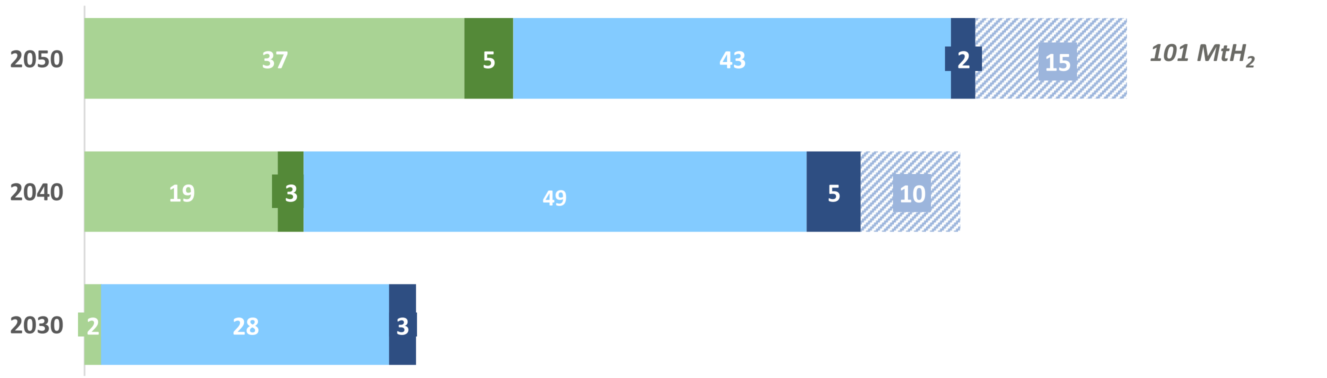
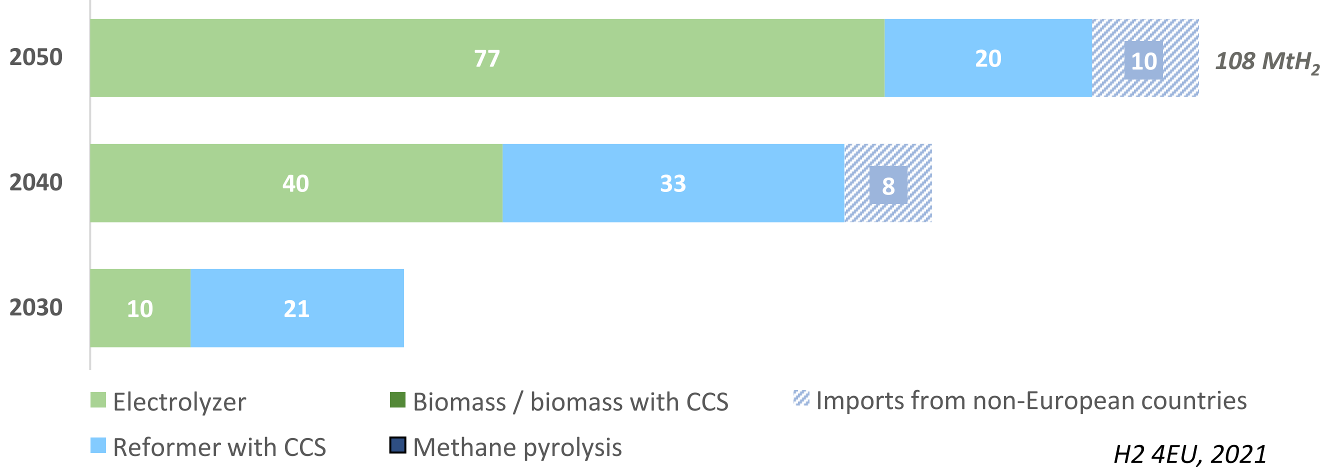
Technology Diversification pathway
Supply in MtH_2



Renewable Push pathway
Supply in MtH_2



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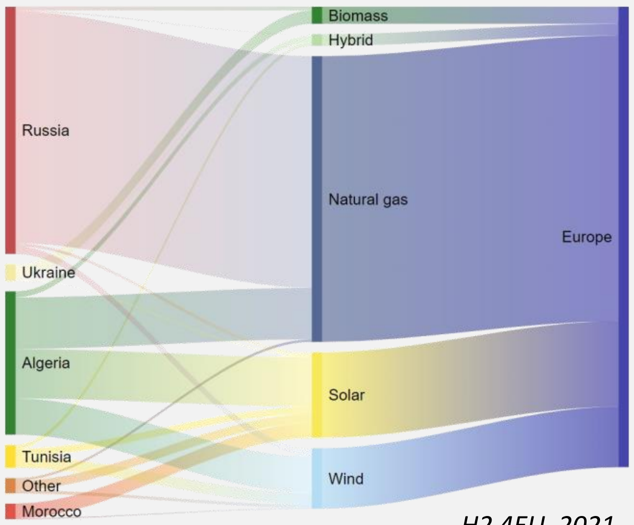
Imports from non-European countries



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European hydrogen production

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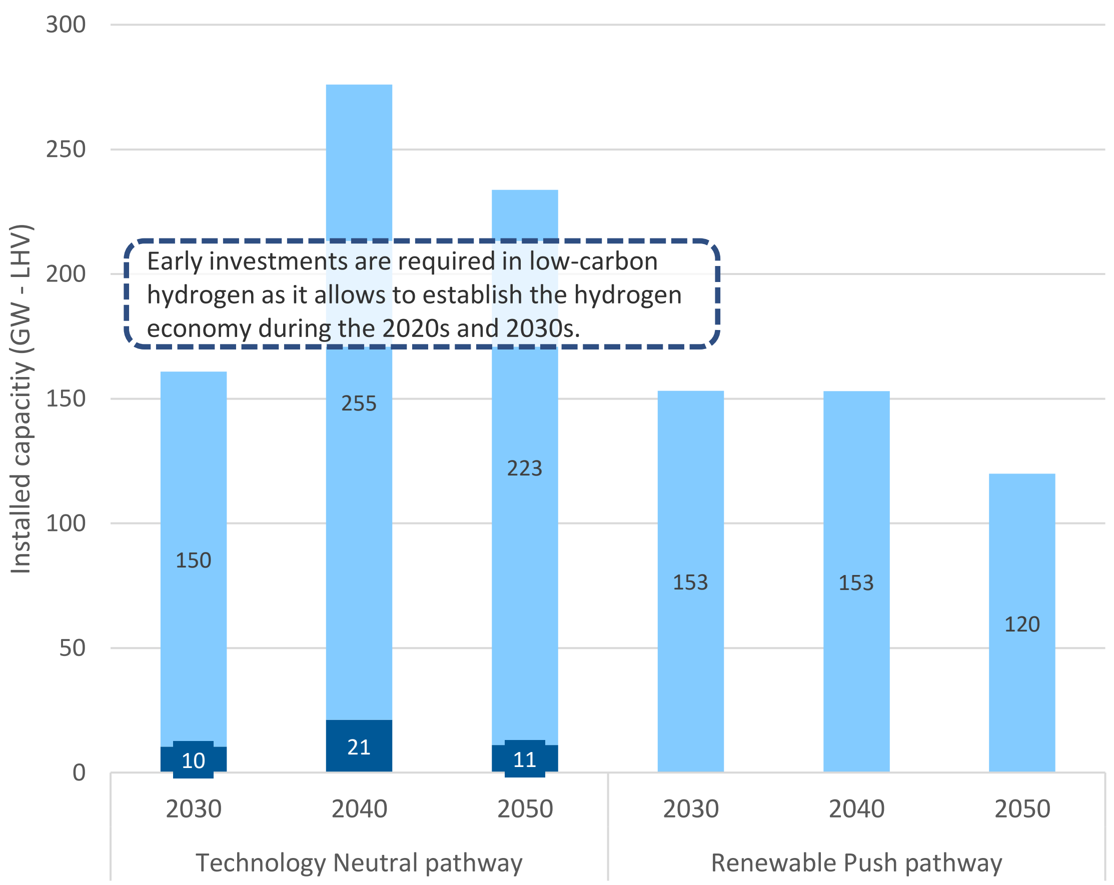
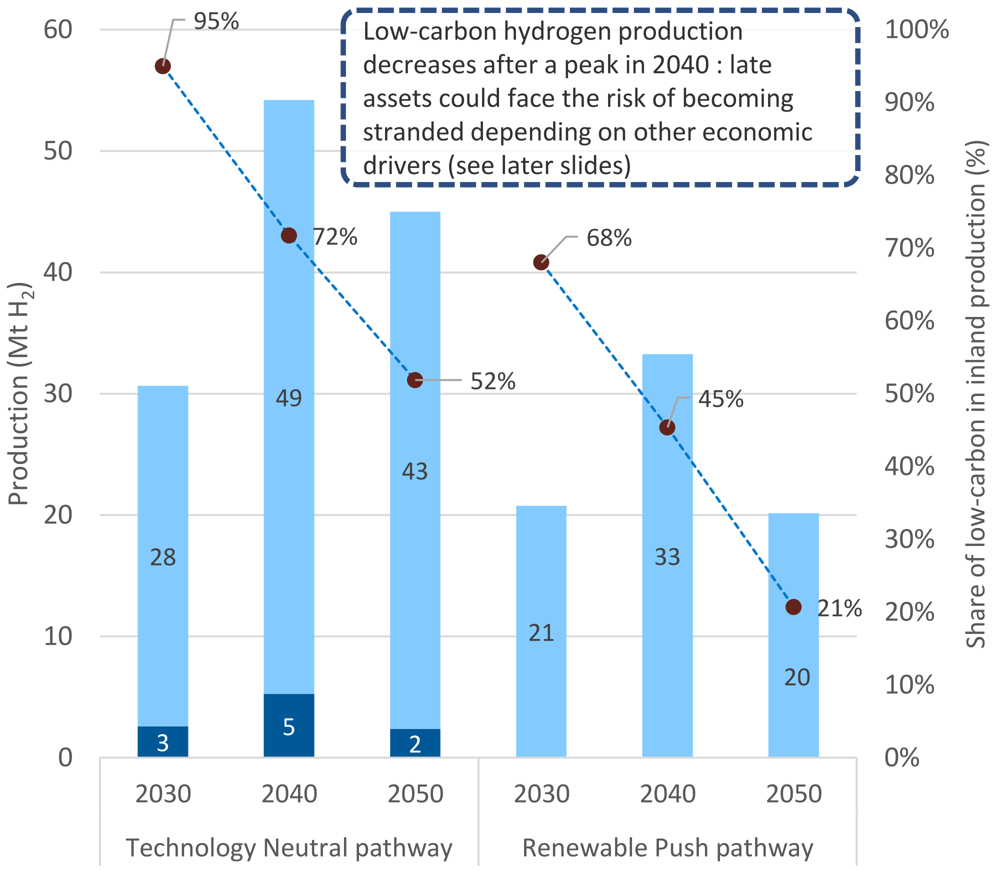
Low-carbon* hydrogen plays an essential role in the transition

Low-carbon hydrogen installed capacity



Low-carbon hydrogen production



**Not including hydrogen from ongrid electrolysis, that is considered "renewable" (up to 5 MtH_2 – 5% of total in 2050)*

Reformer with CCS | Methane pyrolysis | Share of low-carbon H2 % inland production

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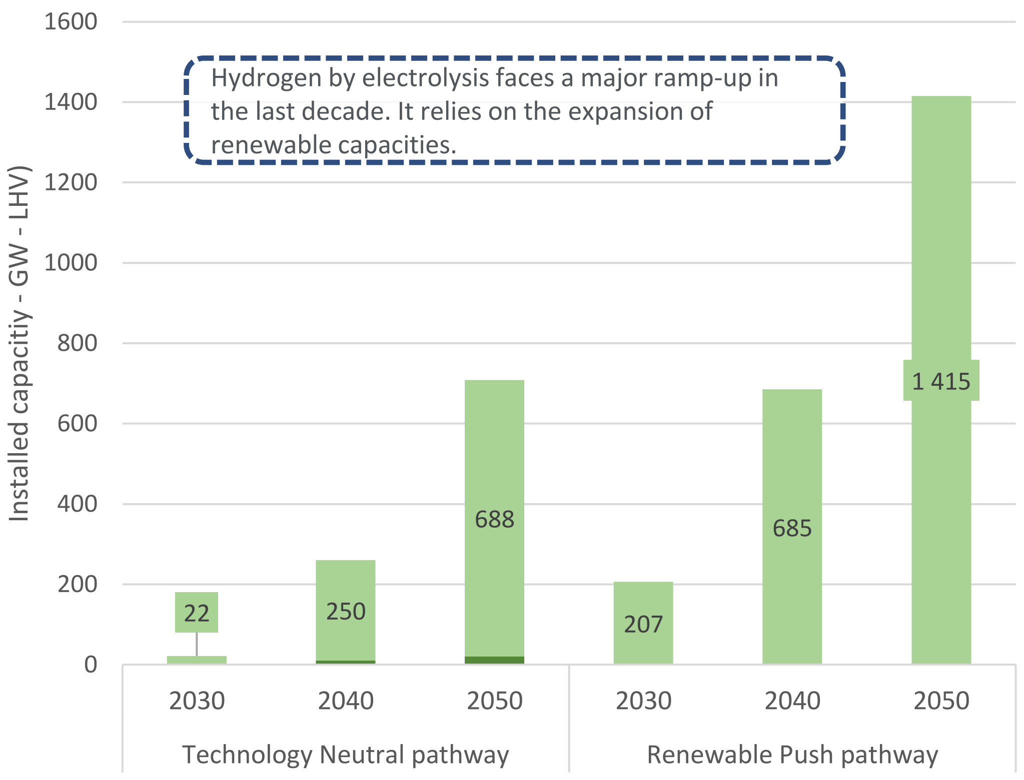
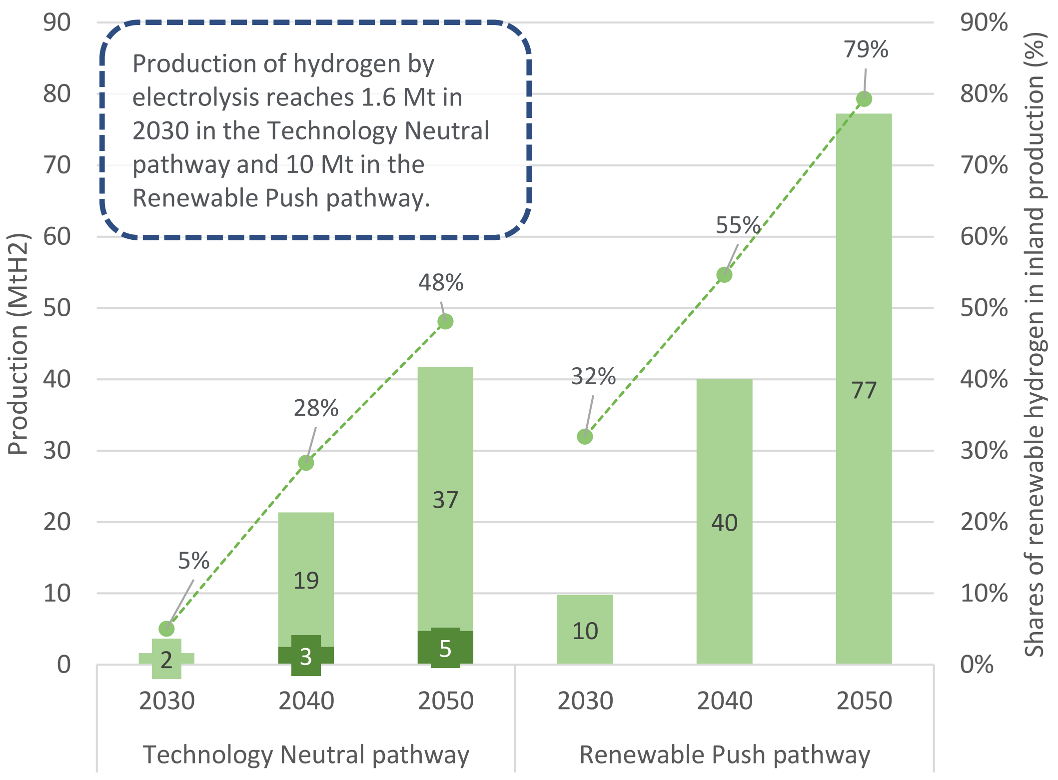
European hydrogen production

Renewable hydrogen uptake relies on electrolysis powered by wind and solar





**Including hydrogen from ongrid electrolysis, that is considered "renewable" (up to 5 MtH_2 – 5% of total in 2050)*

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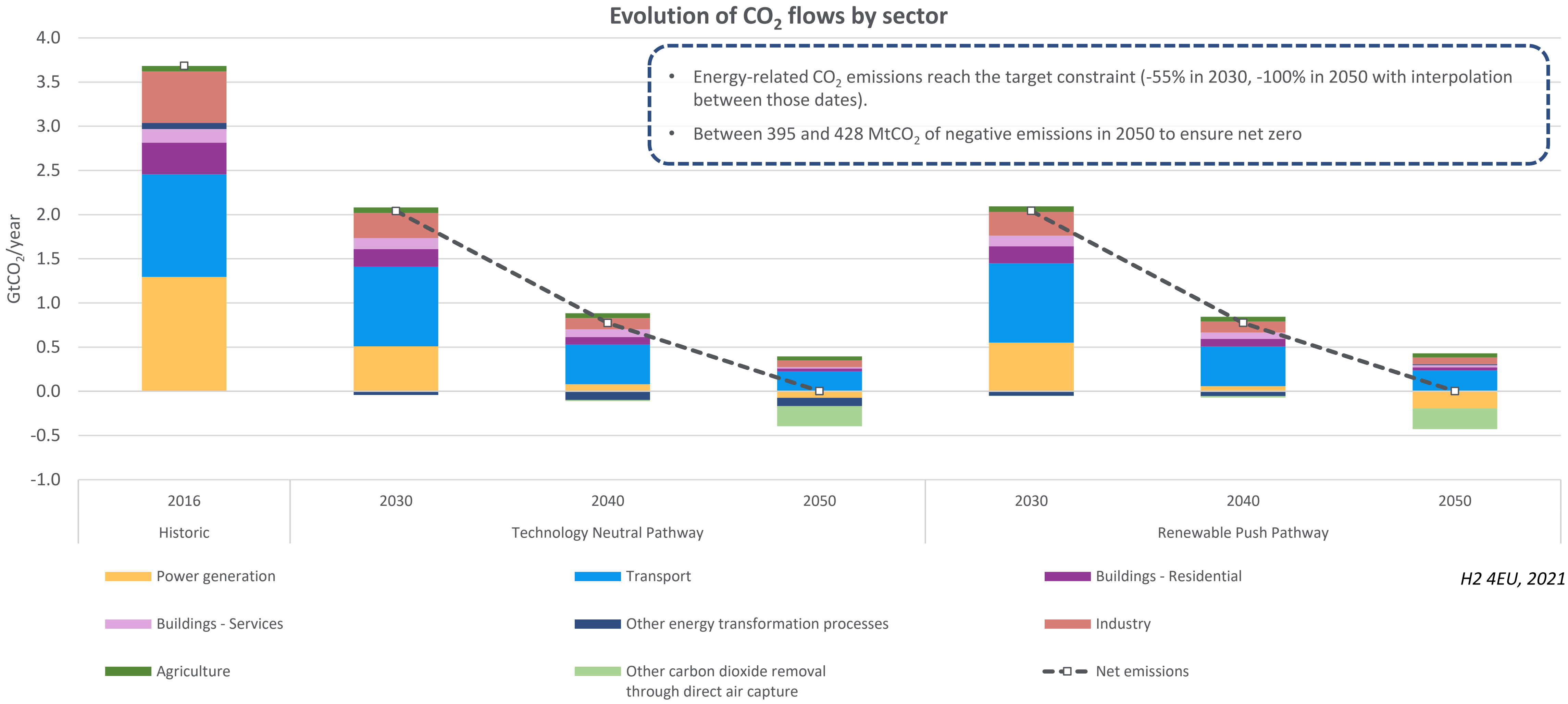
Biomass / biomass with CCS | Electrolyzer | Share of renewable H2* % inland production

A pathway to carbon neutrality

CO_2 removal solutions are key to achieve net-zero in both scenarios



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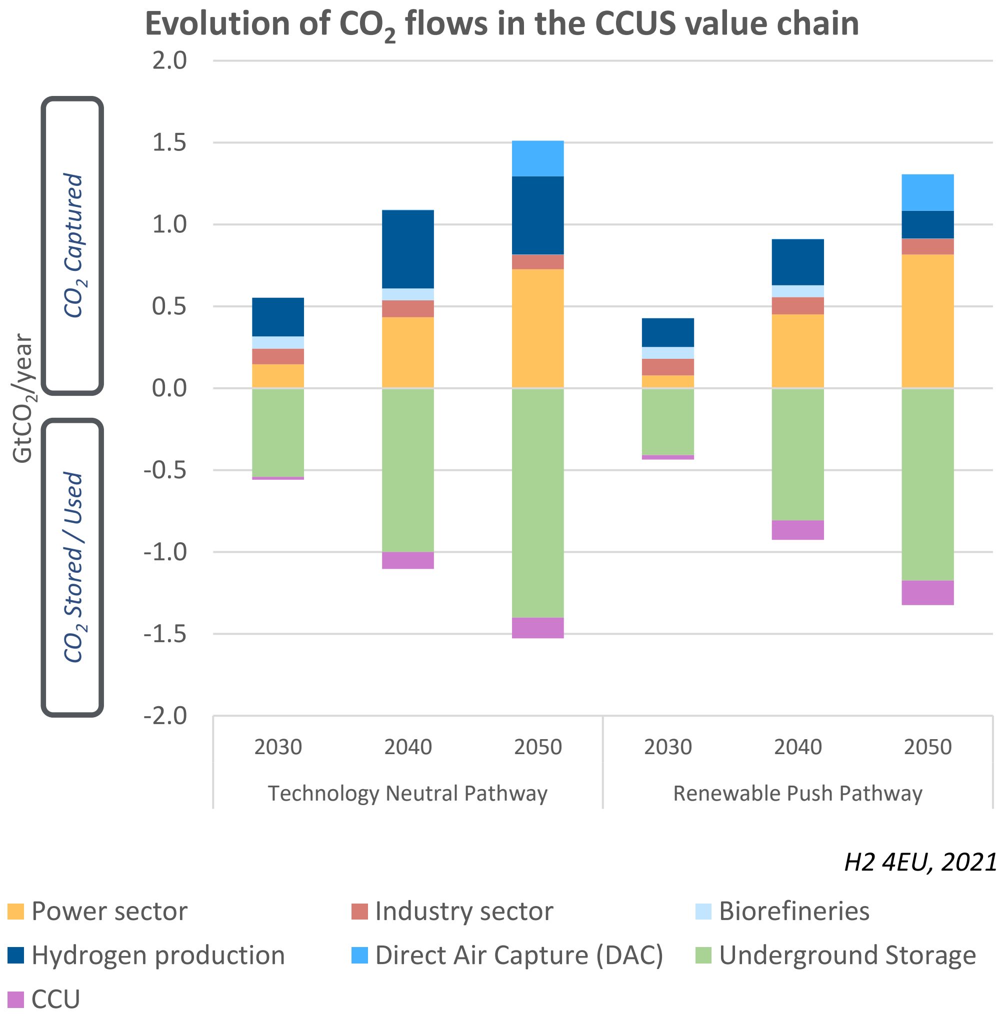
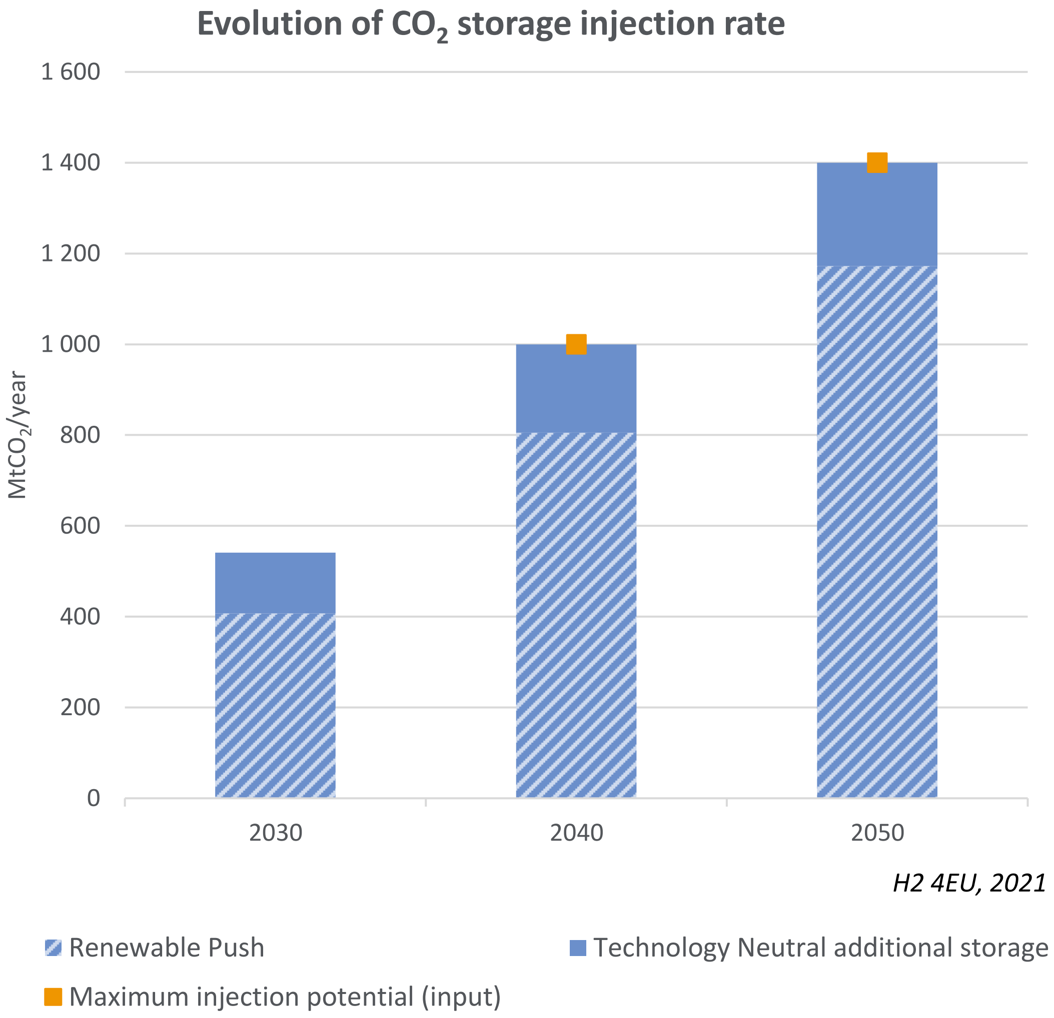
A pathway to carbon neutrality

CO_2 storage and re-use as an enabler of low-carbon technologies' full potential





Learning in the Technology Neutral pathway

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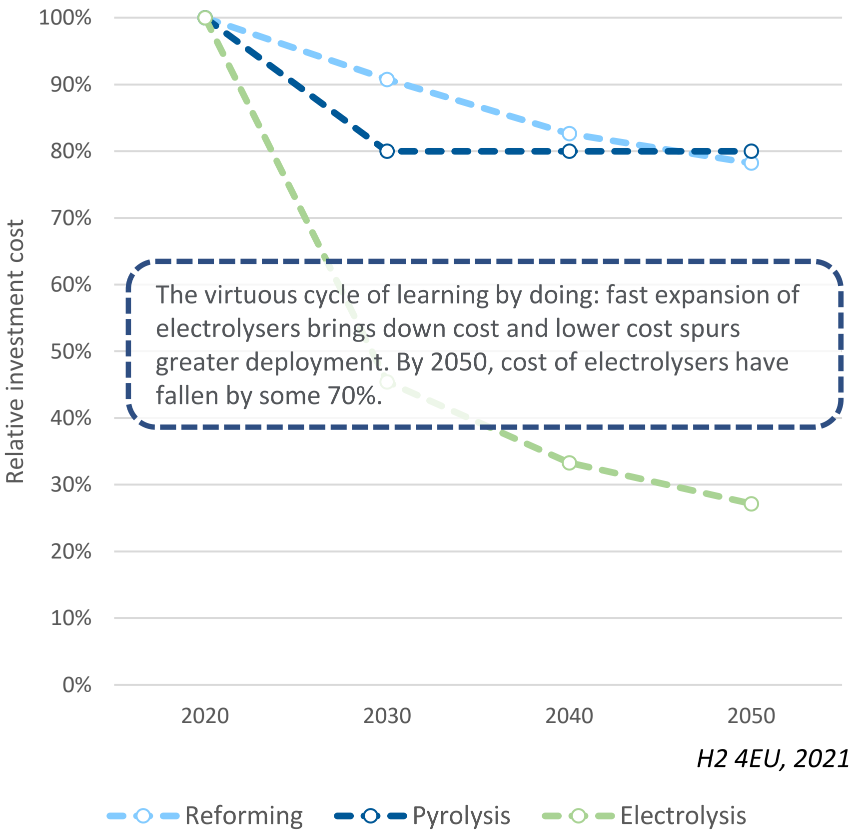
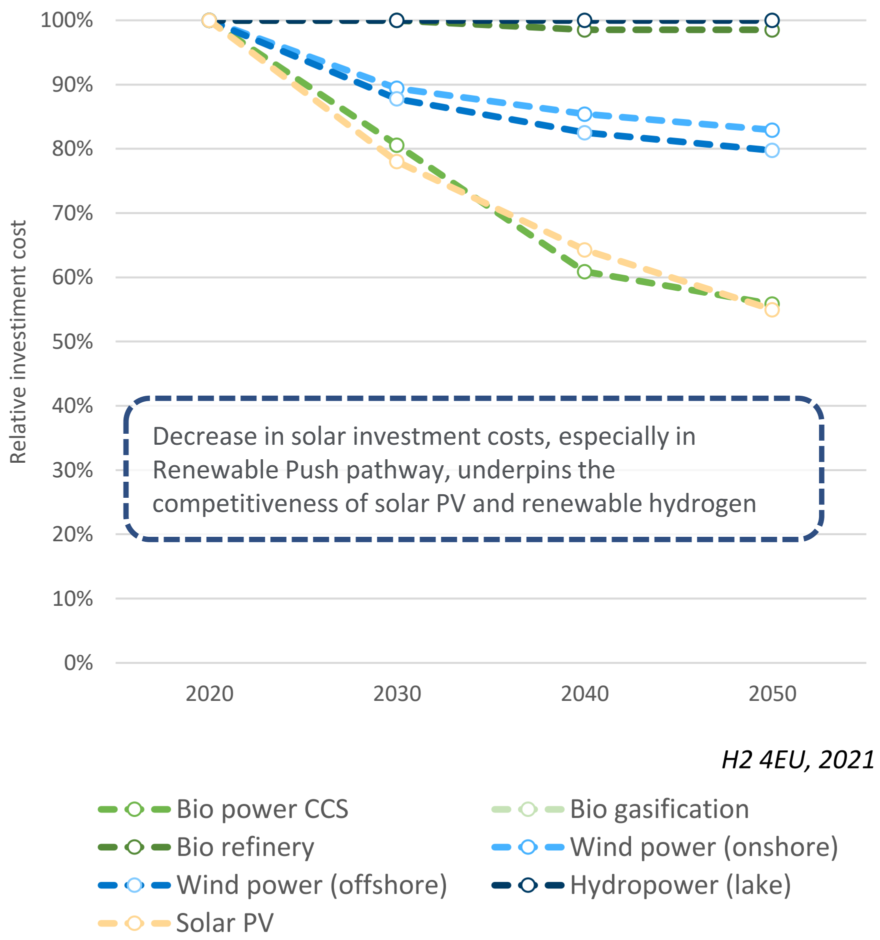
Learning by doing drives drown the cost of key technologies

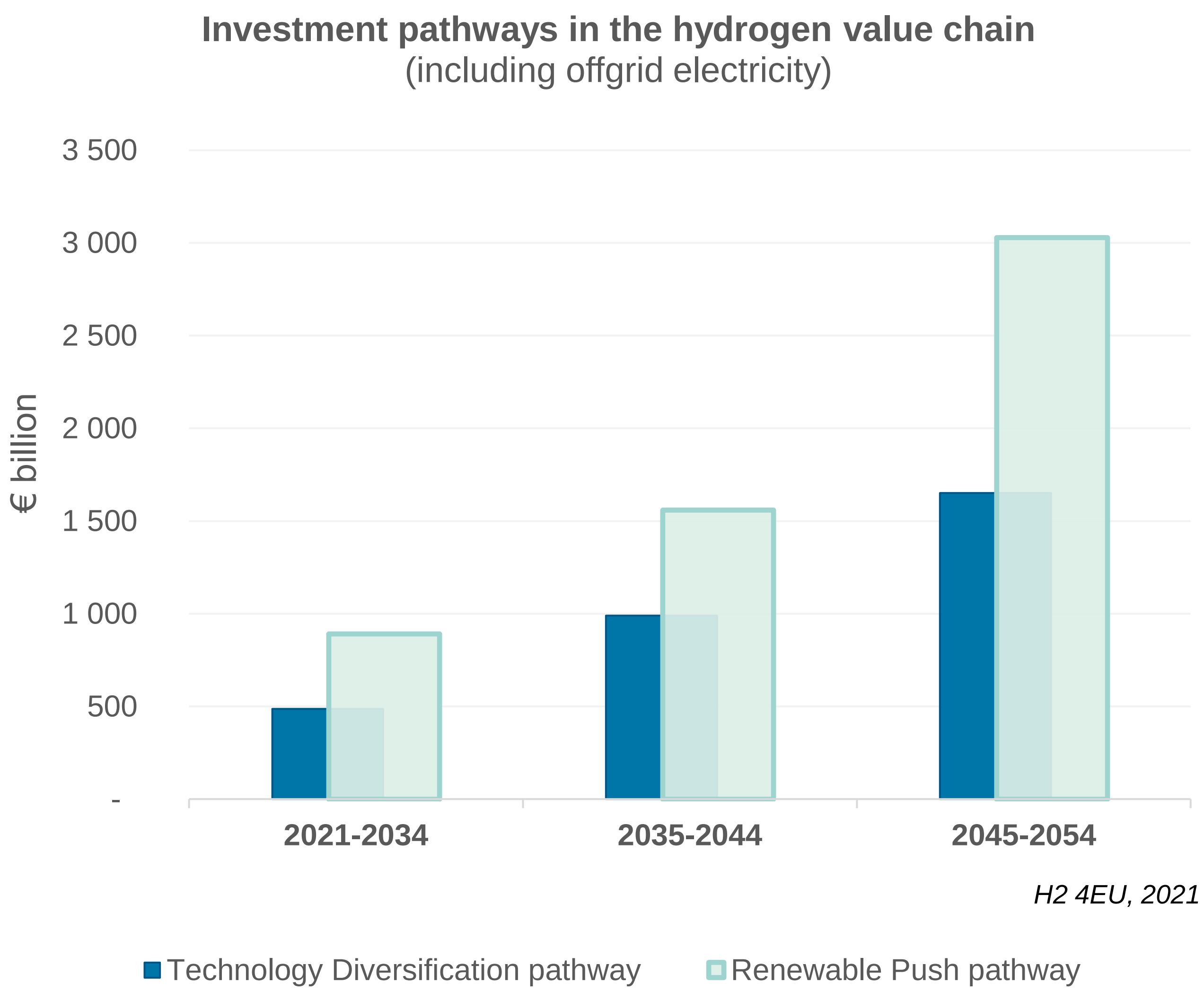
Learning by doing for hydrogen-producing technologies



Learning by doing for other low-carbon technologies



Investment, investment, investment…



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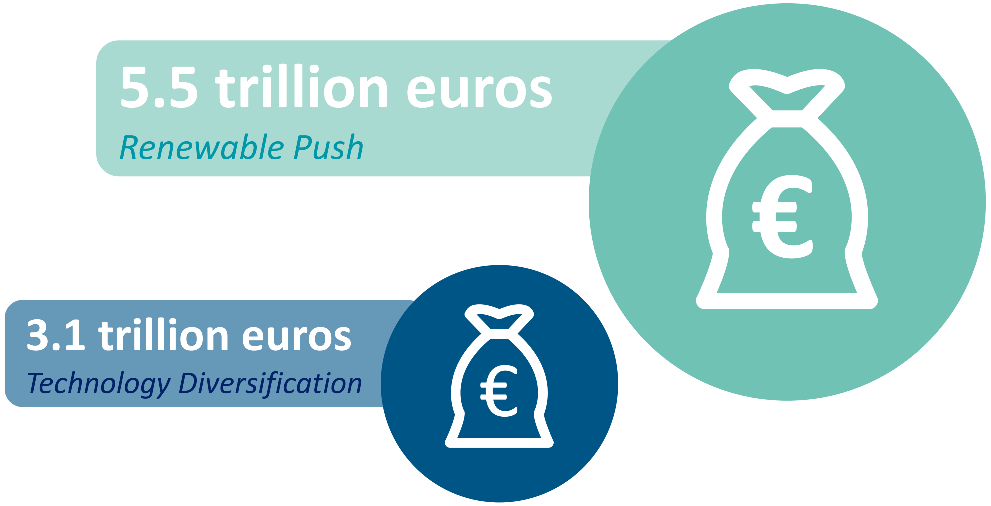
Trillions of euros are needed in both scenarios to finance the hydrogen value chain.

Temporality and level of necessary investment differ between the scenarios: more money needs to be mobilized earlier in the Renewable Push pathway



Key insights from the modelling for energy policy-making

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The Technology Diversification pathway offers to European society several advantages that policy-makers should trade-off against other criteria

Achieving the net-zero emissions goal at a lower cost

- De-risking achievement of the energy transition
- Relieving the financing bottleneck
- A more competitive and efficient energy system

Five main guidelines to inform the design of next policy packages and measures

- Internalising CO_2 emissions and changing the economics in favour of clean technologies
- Accounting for CO_2 content of energy use
- Fostering innovation and R&D and bringing new technologies to commercial viability
- Enabling low-cost financing and bankability of investments in low-carbon and renewable solutions
- Ensure system integration and coordinate supply and demand uptake

Key findings and conclusions

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1. **Hydrogen is the missing link in the energy transition**

- Hydrogen is resilient to any pathway.
- Hydrogen's versatility, and its ability for storage and transport makes the molecule ideally suited to decarbonize hard to abate sectors.
- Hydrogen is used to integrate renewable energy in the system.

2. **Hydrogen demand could top 100 million tons in 2050**

- Hydrogen plays a key role for cleaning up hard to abate sectors such as transport and industry, where it is also used as an energy carrier for more suited molecules (e-fuels, ammonia).
- It also contributes to decarbonizing buildings and power.
- Hydrogen as a feedstock has promising potential but it will be the subject of future research.

3. **Hydrogen's optimal role in the transition is enabled by a diverse set of technologies and supply options**

- Low-carbon hydrogen (including reformers with CCS and pyrolysis) plays a critical role in establishing a hydrogen economy in the first half of the outlook period
- Renewable hydrogen from electrolysis with renewable electricity, and biomass catches up in the second half of the outlook period and meets the bulk of the additional demand growth. In the Renewable Push pathway, it becomes the biggest hydrogen production source by 2040.
- There is a substantial role for hydrogen imports from 2040 onwards. Imports reach 10-15 Mt in 2050 mainly from countries with interconnectors (i.e. Russia and Algeria) but not only.

4. **Timeliness of investments is critical**

- Timely investments are a required to ensure demand and supply grow are balanced, avoid technology lock-ins, and mitigate risk of stranded assets.
- The synchronicity of infrastructure development is another key driver.

5. **The least cost pathway underscores the value of adopting an agnostic approach to hydrogen**

Technology diversification leads to lower total cost of the energy transition (first-best). The Renewable Push pathway requires on average some € 70 billion extra cost, every year.

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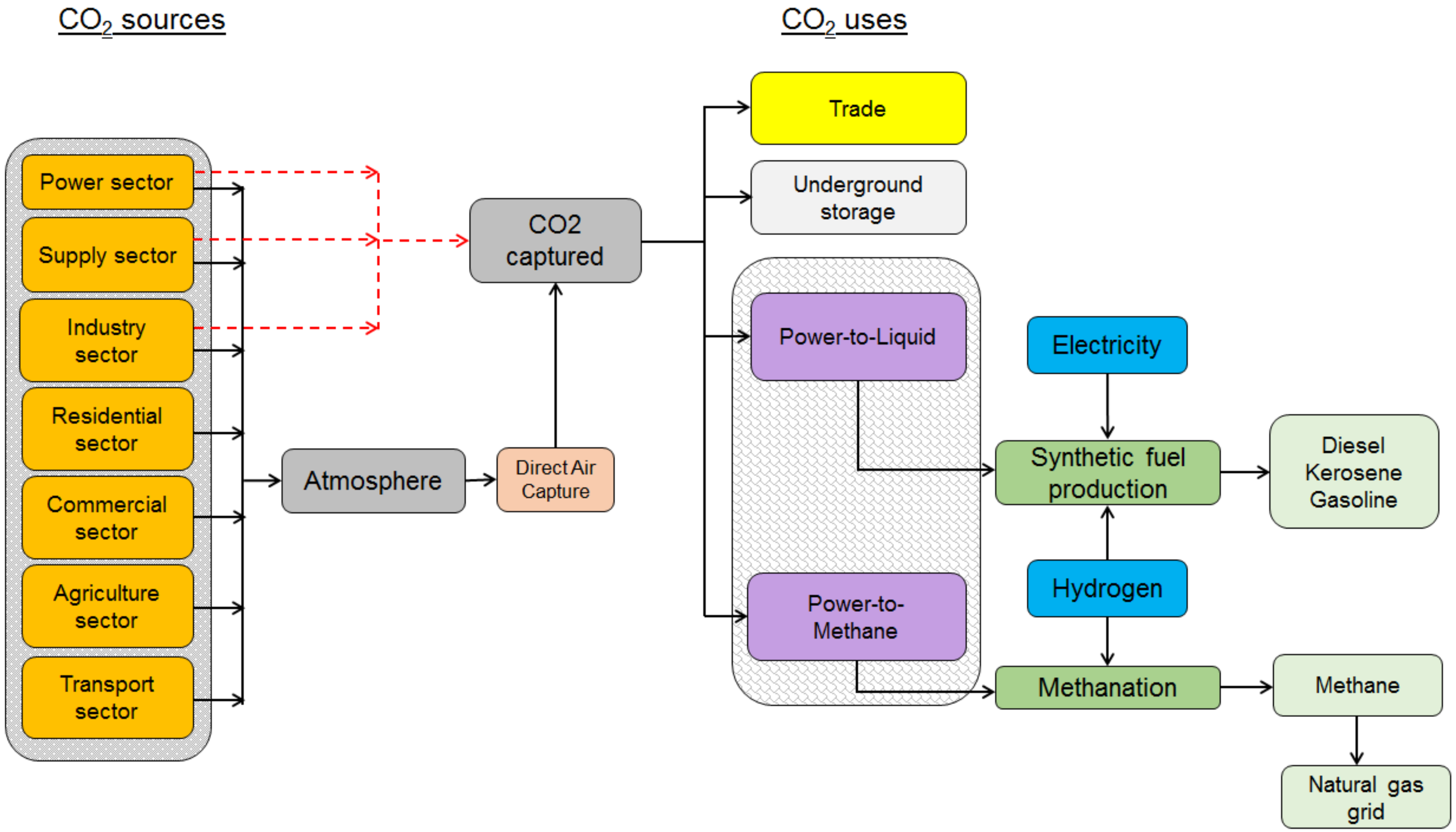
Thanks for your attention

Appendix

A focus on CCUS technologies considered

In each country there are CO_2 flows represented by sources and uses

Energy system model
[MIRET-EU]



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Energy accounting fundamentals

Understanding the key concepts

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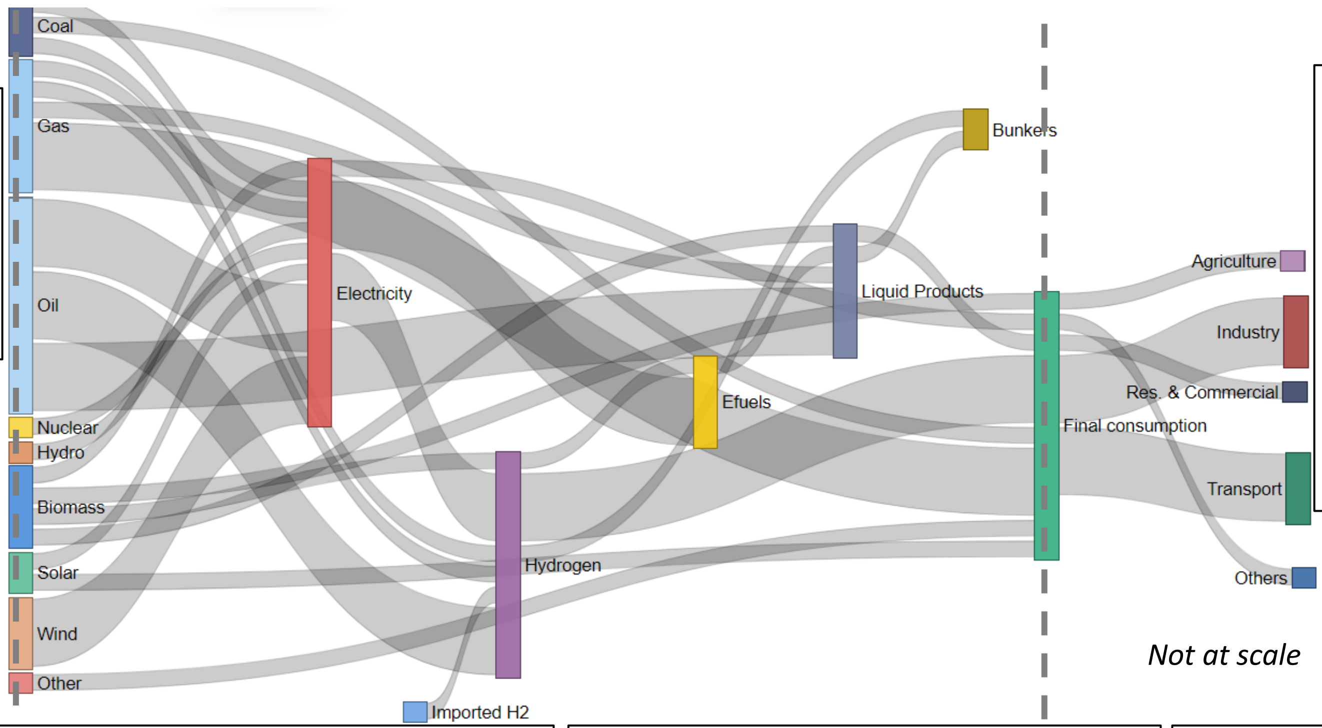
Primary Energy

Final Energy

<u>Primary energy</u> includes Gross inland consumption excluding final non-energy consumption



<u>Final Energy consumption</u> includes the final energy consumed by end-use sectors (industry, transport and other) and ambient heat from heat pumps. Excludes international aviation and maritime bunkers

<u>Gross inland consumption</u> = consumption by the energy sector itself + distribution and transformation losses + final energy consumption by end users (includes now ambient heat for heat pumps but excludes international maritime bunkers)

<u>Gross Final Energy consumption</u> = Final energy consumption + international aviation + Losses in electricity and heat distribution and transmission.

<u>Share of Renewables</u>: Percentage of Renewables in Gross final energy consumption

Energy transition and final uses

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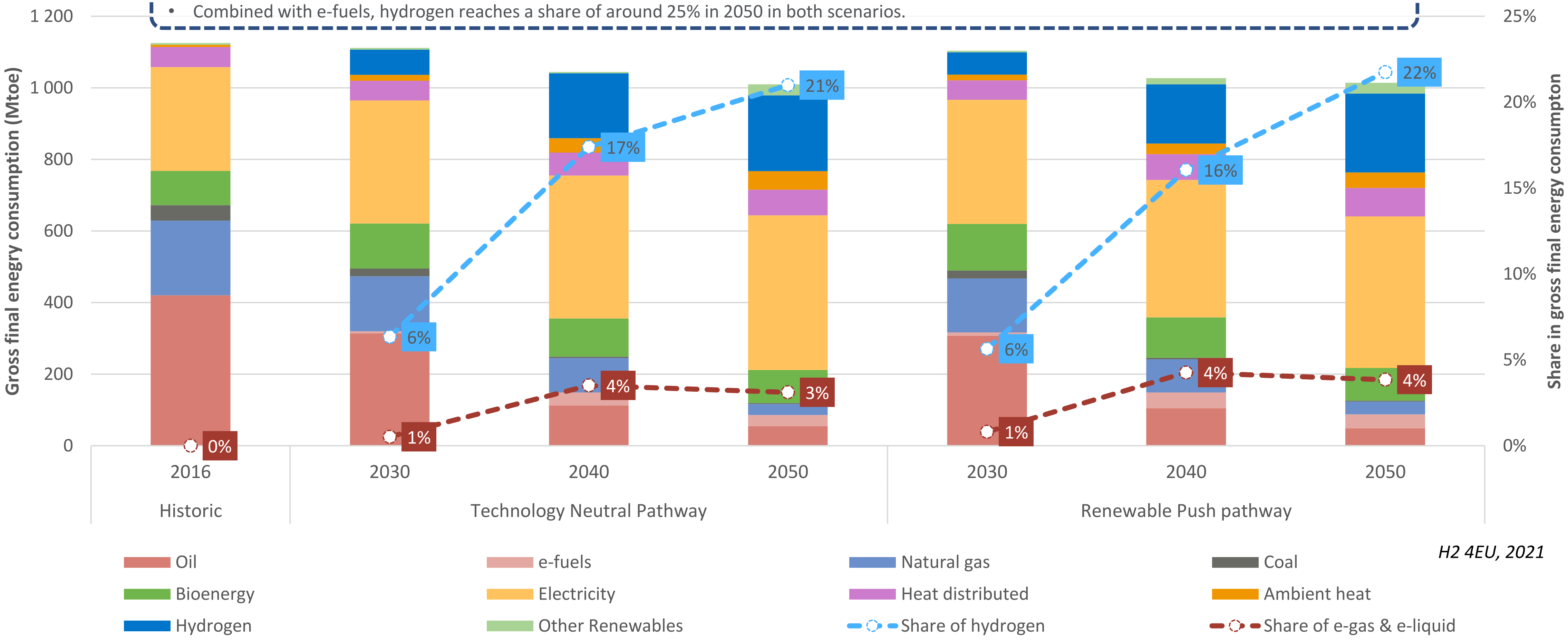
... but hydrogen and other synthetic/biofuels hold the keys to net zero

Evolution of gross final energy consumption by energy carrier

- Hydrogen plays a dual role: as a gas for final energy consumption, and as an energy carrier for the production of e-fuels and other molecules.
- Combined with e-fuels, hydrogen reaches a share of around 25% in 2050 in both scenarios.



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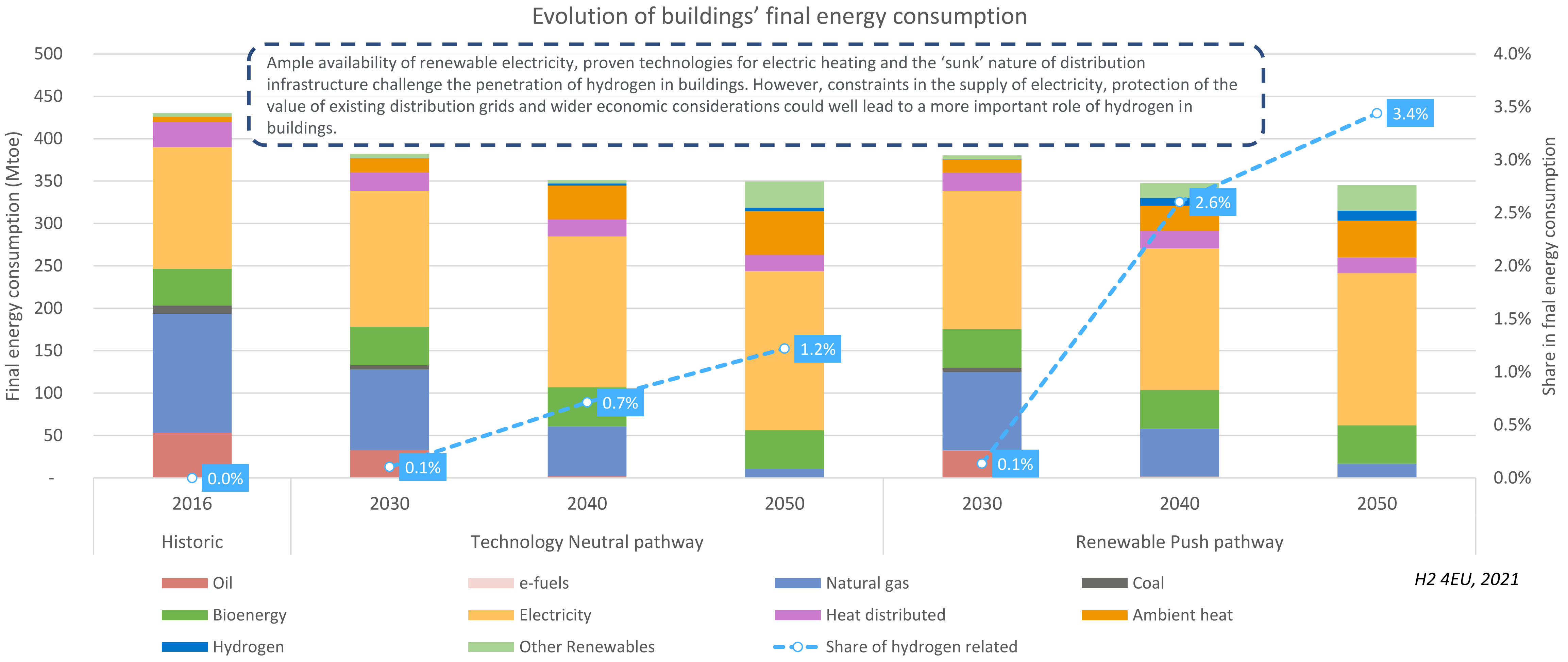
Note: hydrogen also includes related hydrogen used for ammonia production for energy-use in the maritime sector

Hydrogen demand

Hydrogen also makes inroads to the buildings/residential sector



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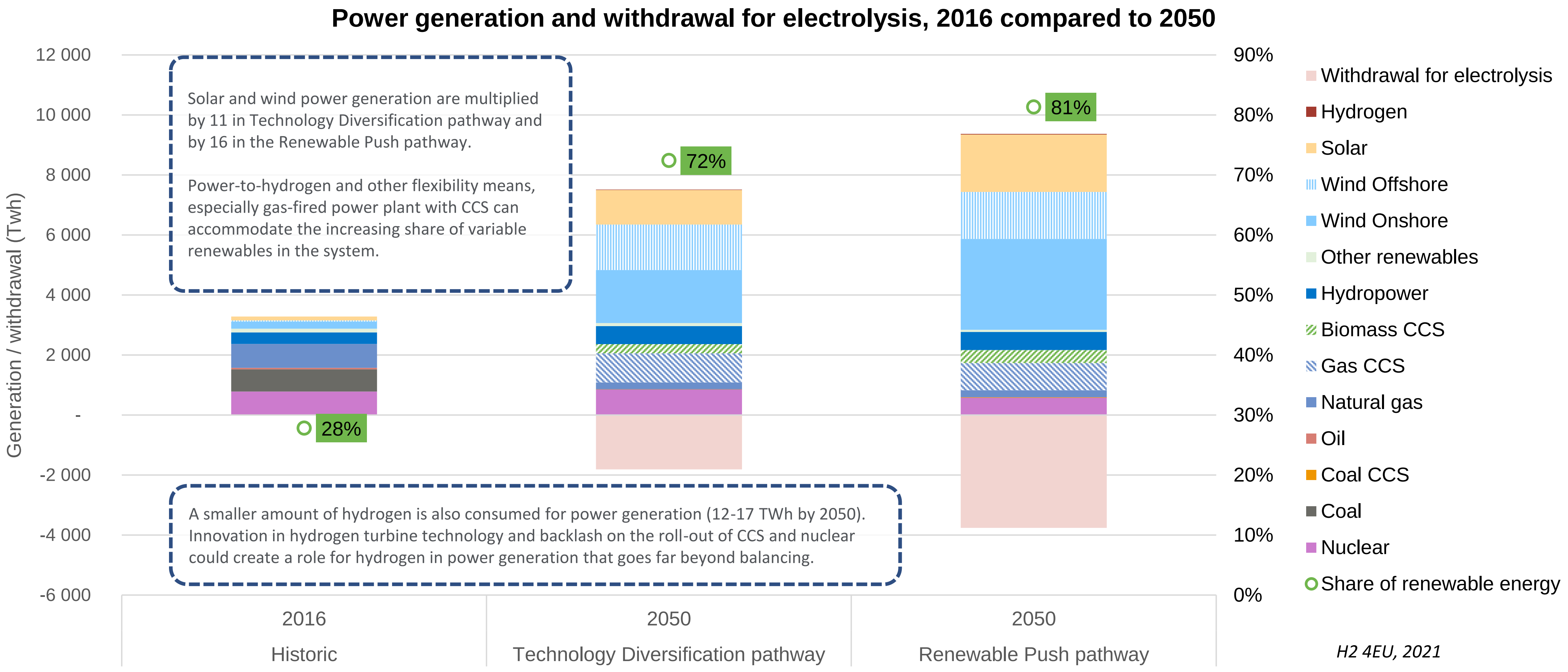
Hydrogen and electricity

Expansion of renewables increases the need for flexibility



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Investment pathways

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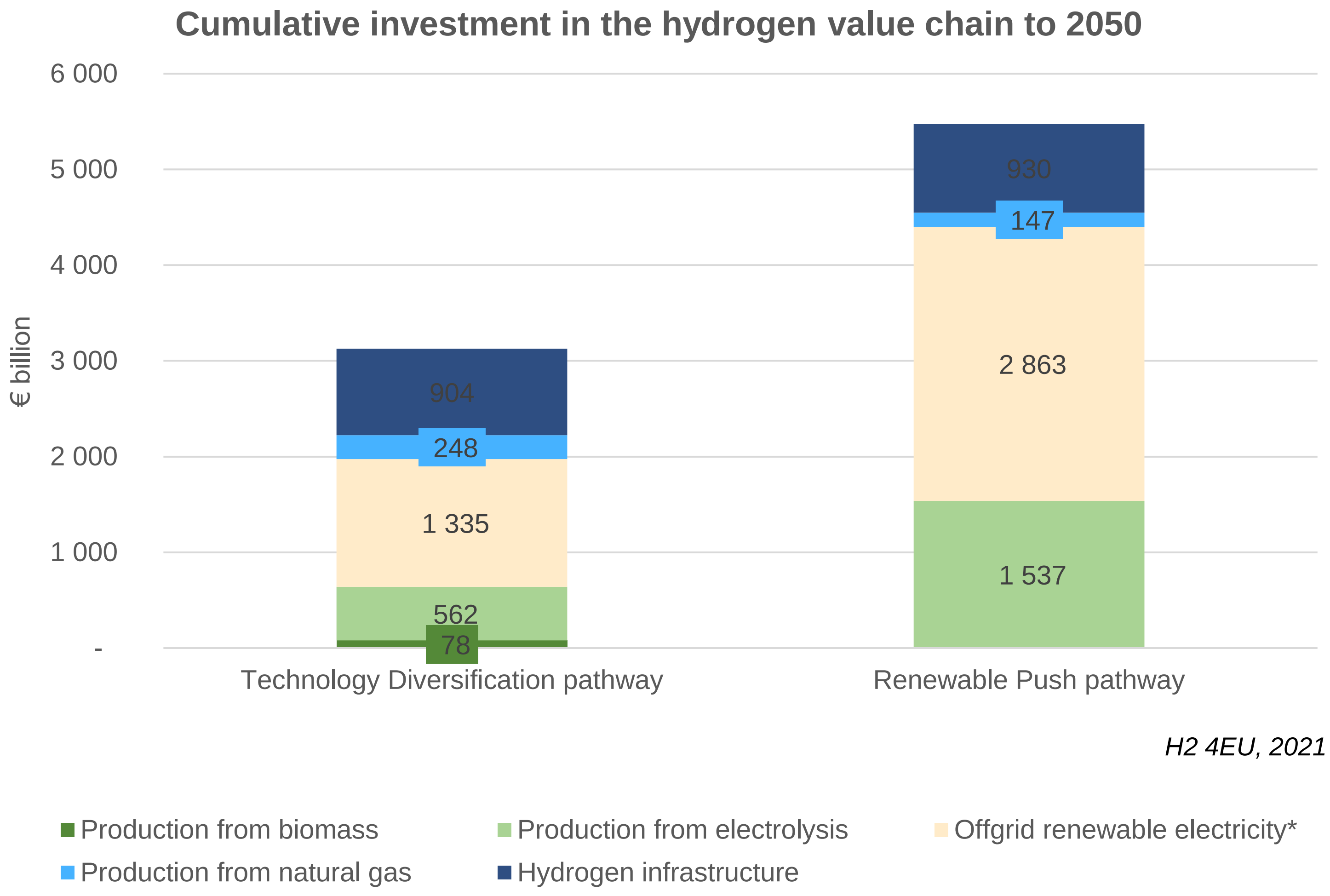
Three to five trillion euros of dedicated investments in the hydrogen value chain



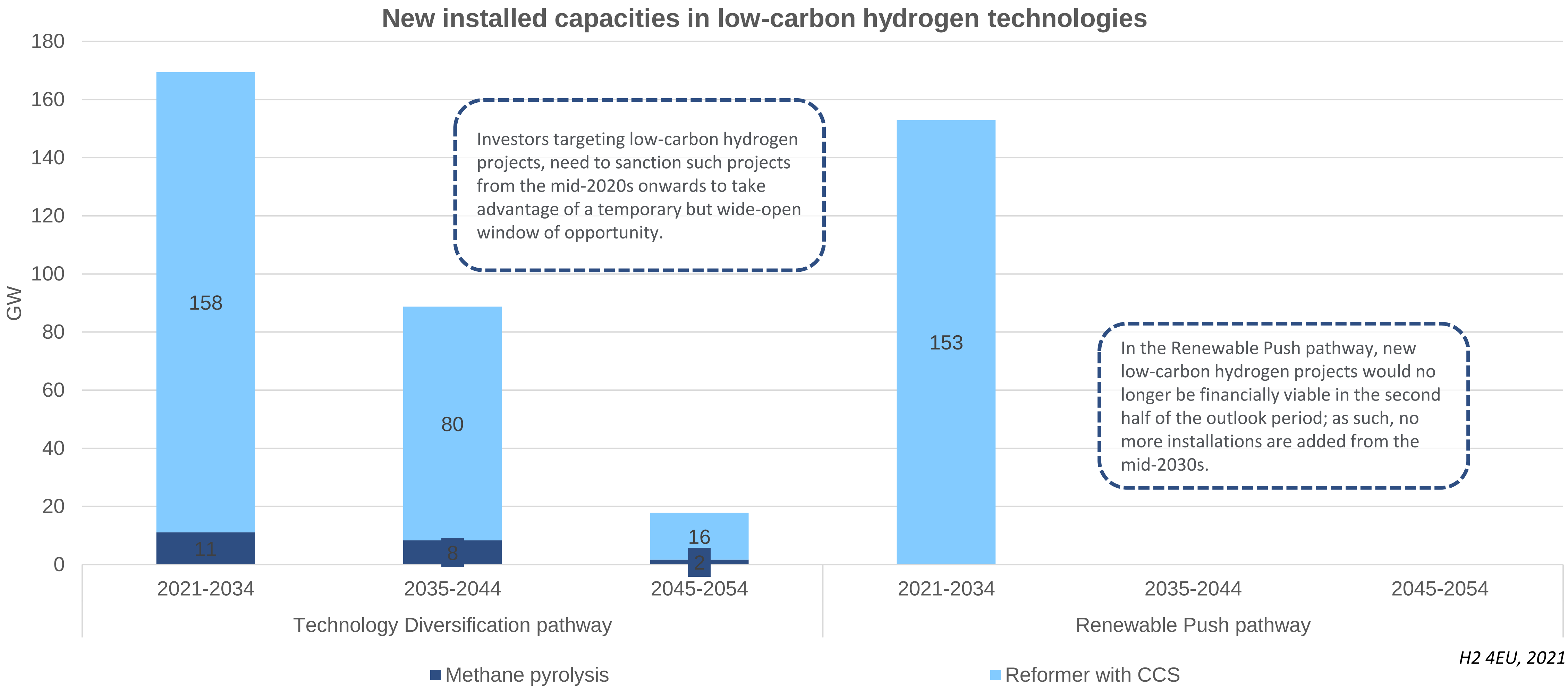
Cumulative investments in the hydrogen value chain, including investments in renewables for offgrid electrolysis, amount to several trillion euros over the outlook period.

The difference of more than two trillion in capital spending between the two scenarios demonstrates the higher capital intensity of a pathway focusing primarily 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.

**Fixed investment costs for the hydrogen value chain (CAPEX + O&M fixed costs)*
Post treatment of results was carried out to retrieve CAPEX from offgrid renewables

Investment pathways

Timeliness of investments in low-carbon hydrogen production is critical



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**Not including hydrogen from ongrid electrolysis, that is considered "renewable" (up to 5 MtH_2 – 5% of total in 2050)*

Investment pathways

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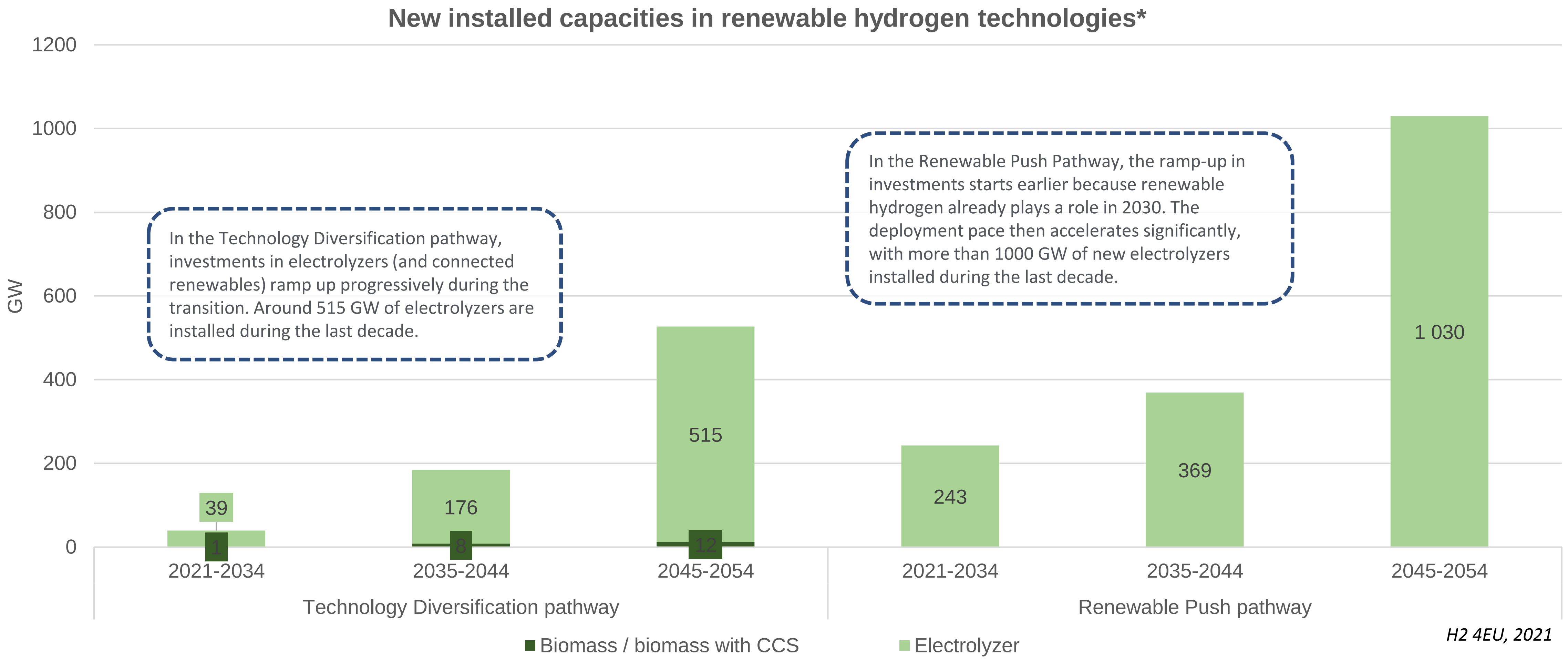
Renewable hydrogen can take the pole position if the industry manages to expand electrolysis, wind and PV at a high and steady rate



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Including hydrogen from ongrid electrolysis, that is considered "renewable" (up to 5 MtH_2 – 5% of total in 2050)