


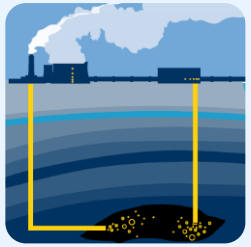



Cost of Hydrogen for Domestic Heating in the EU – final report

Global Witness

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Objectives

Hydrogen infrastructure in the EU cost calculation

- Supply: Generation and Storage
  - Methodology overview
  - Reference data and archetyping
- Networks: Conversion, Transmission and Distribution
  - Methodology overview
  - Reference data and scaling
- Final results and commentary
- Appendix and supporting information

Supply: Generation and Storage – methodology overview

Introduction

- The Consumer Costs of Decarbonised Heat study, produced by Element Energy for the European consumer organisation BEUC, analysed the implications for transitions to decarbonised heating for consumers in 4 European countries: Poland, Spain, Czech Republic and Italy. The outputs concerning generation and storage of hydrogen are used in this study for each of these selected countries.
- The generation and storage costs were then applied across Europe based on the renewable resources and storage type available. As a result, different costs for the production and storage of hydrogen were used to reflect the high, low and expected costs of green hydrogen supply. Only domestic production is considered.

Base data

- Models designed for the Sustainable Energy Authority in Ireland (SEAI), National Grid (NG) and BEUC were used to determine ranges of generation and storage costs for hydrogen.
- The generation of hydrogen assumes 100% green hydrogen produced from collocated renewable energy and electrolysers. Hydrogen storage relies on geological storage or pressurised tanks. Both generation and storage of green hydrogen are highly dependent on the natural resources available, representing a wide range of prices available even within a single country.

Archetyping and generating EU-wide results

- The 4 selected countries for deeper analysis represent a variety of different generation and storage resources available throughout the EU. These costs, determined as € / kWh, are then applied to each country based on the renewables available in each country (reference: European Climate's Towards Fossil-Free Energy in 2050) and the technical potential for hydrogen storage in salt caverns (reference: Underground storage of Hydrogen in Salt Caverns and *Technical potential of salt caverns for hydrogen storage in Europe* by D. G. Caglayan et al. (https://doi.org/10.1016/j.ijhydene.2019.12.161).

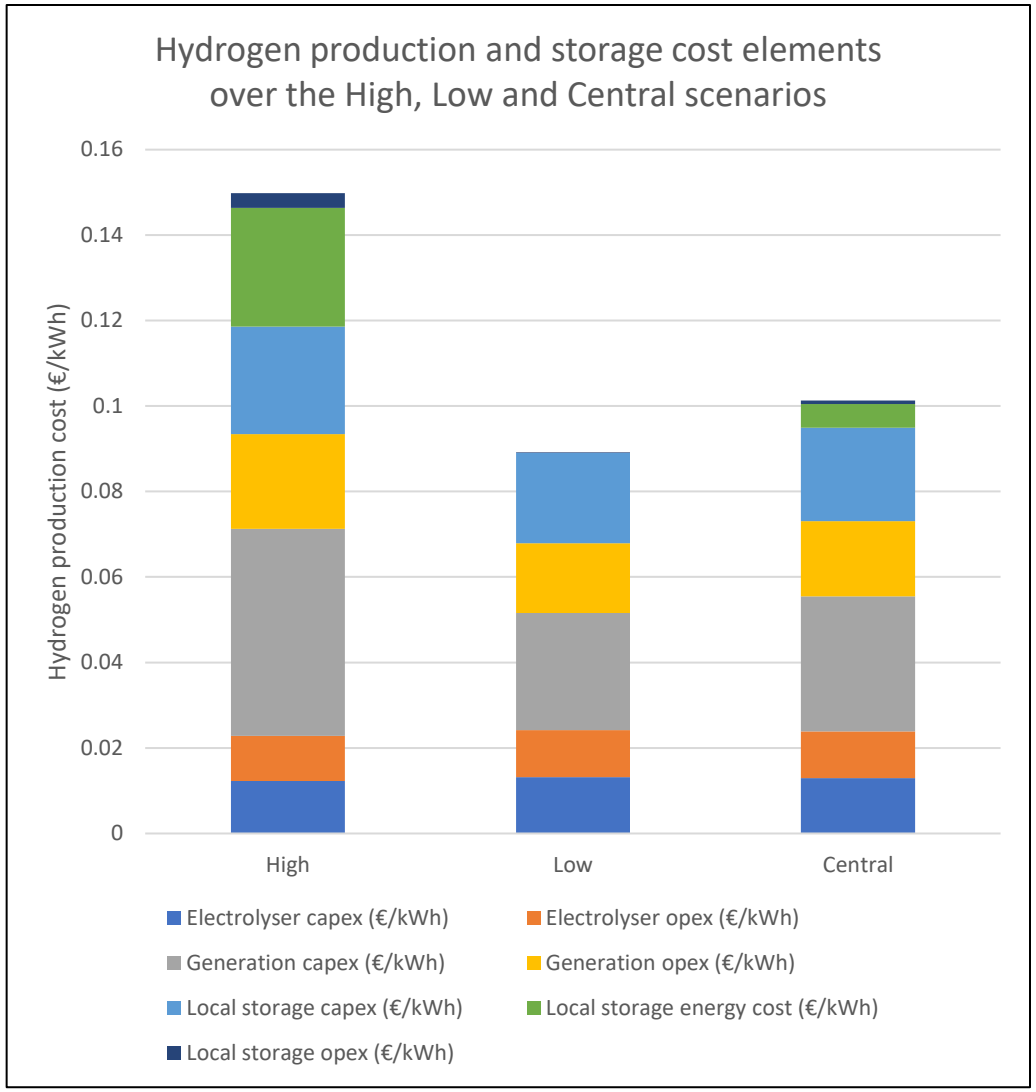
Supply: Generation and Storage – methodology overview

Production

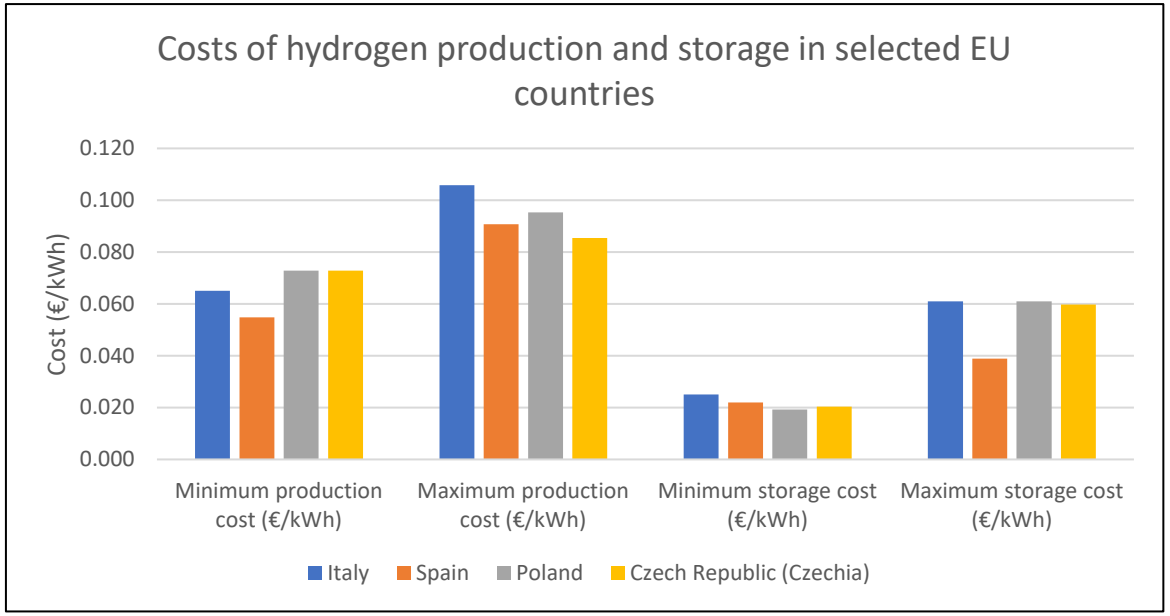
- In each country, the cost of hydrogen production was estimated for the three primary new renewable projects: onshore wind, offshore wind, and solar. Each of these technologies gave a hydrogen production price in €/kWh, with production prices ranging from 0.129 €/kWh to 0.228 €/kWh.
- The production components were split between electrolyser costs and generation costs, summing annualized capital costs and operational costs.
- The study assumes the use of green hydrogen, and makes a simplifying assumption that all green hydrogen is produced through collocation of electrolysers with renewables, which are expected to be the lowest cost form of green hydrogen.

Storage

- The hydrogen storage types for each country were partially dictated by geological conditions. Storage in the form of (NH_3) or Liquid Organic Hydrogen Carriers (LOHC) was possible in all countries. Lower-cost forms of storage in geological formations such as salt caverns were selected for countries where this was possible.
- The analysis assumes that **Spain** and **Poland** were selected as archetypal countries capable of storing hydrogen in salt caverns.



Supply: Generation and Storage – reference data and archetyping



Base data and archetyping methodology

- The minimum and maximum costs for the 4 selected EU countries are shown in the table above. These cost ranges are determined using in-house models developed for the National Grid, Sustainable Energy Authority of Ireland (SEAI), and European Climate Foundation (ECF).
- The costs are applied to the appropriate country based on the renewable and storage archetype. As such, costs are applied to all EU27 countries to determine an EU-wide average. The EU average cost is the weighted average of the cost in each country scaled based on each country's share of the total EU gas consumption. The fuel consumption in a typical household is then used to calculate the final cost per household.

Country	Renewable archetype	Storage available
Germany	Windy	Geological
France	Windy	Geological
Italy	**Sunny**	**Pressurised**
Spain	**Sunny**	**Geological**
Poland	**Windy**	**Geological**
Romania	Sunny	Geological
Netherlands	Windy	Geological
Belgium	Windy	Pressurised
Czech Republic (Czechia)	**Windy**	**Pressurised**
Greece	Sunny	Pressurised
Portugal	Sunny	Geological
Sweden	Windy	Pressurised
Hungary	Sunny	Pressurised
Austria	Windy	Pressurised
Bulgaria	Sunny	Pressurised
Denmark	Windy	Geological
Finland	Windy	Pressurised
Slovakia	Sunny	Pressurised
Ireland	Windy	Pressurised
Croatia	Windy	Pressurised
Lithuania	Sunny	Pressurised
Slovenia	Windy	Pressurised
Latvia	Sunny	Pressurised
Estonia	Windy	Pressurised
Cyprus	Sunny	Pressurised
Luxembourg	Sunny	Pressurised
Malta	Sunny	Pressurised

Networks: Conversion, Transmission and Distribution – methodology overview

Introduction

- Hydrogen distribution for domestic heating relies on the conversion (a single conversion of the whole network) of the existing natural gas transmission and distribution systems to transport hydrogen.
- Element Energy has completed multiple studies analysing this question, and findings from the UK are combined with work covering various specific EU countries to produce an overall picture for the EU gas grid's conversion and operational costs.

Base data

- The capital cost of gas grid conversion has been developed for Great Britain in detail in the Hydrogen supply chain evidence base (2018). Element Energy followed a bottom-up approach to determine the total cost of gas grid conversion for this region to be £22.2 billion. This data is combined with the Committee on Climate Change's (CCC) 6th Carbon budget to determine a cost incurred by the domestic consumer for their share of the conversion of the gas grid, per kWh of hydrogen in the system. The fuel consumption in an average household in the UK is also based on the CCC 6CB. Conversion to an EU household assumes that UK households consume 16% more natural gas than the EU27 average from a special feature on European Energy Efficiency trends.
- Hydrogen transmission and distribution operational costs for a converted gas network is used from the European Climate's Towards Fossil-Free Energy in 2050, which determined costs for 6 specific EU countries. These are obtained based on annual gas consumption and distribution gas grid fees as reported by the EU COM in the report. Gas demand per household for each country was gathered from the Eurostat database.

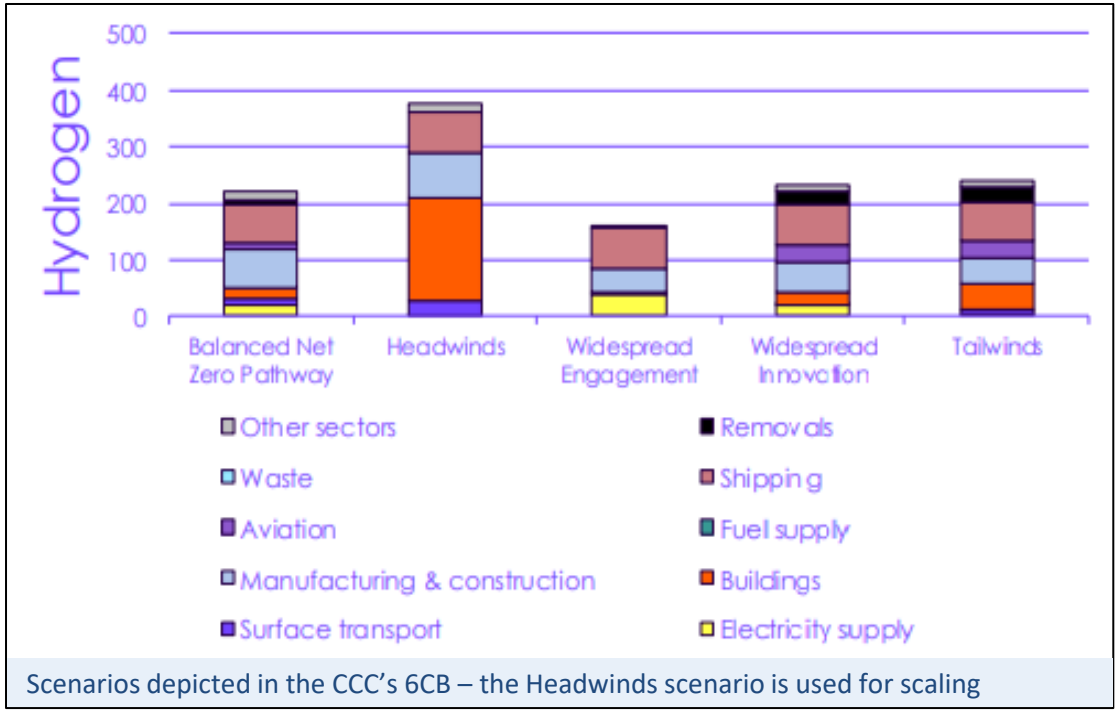
Scaling and generating EU-wide results

- Network conversion capital cost is calculated on a per household basis after contributions from non-domestic users of hydrogen based on the predicted share of hydrogen usage. Since we assume maximum roll-out of hydrogen to determine final hydrogen demand, we are relying on the CCC's **Headwinds scenario** which assumes a high roll-out of hydrogen. The cost per GB household is then scaled to the average EU household to determine a cost per household.
- Instead of archetyping by country type, these results either produce a per household cost or an EU-specific per kWh cost which can be directly applied across the EU.

Networks: Conversion, Transmission and Distribution – reference data and scaling

Gas network conversion

- GB-wide figures were first used to determine a cost per GB household to convert the gas network. All values in £ are converted to € using a conversion factor of £1 : €1.18
  - Residential-level conversion to hydrogen consists of the installation of gas meters and detectors, giving a total installation cost of £12.55 b. **This is entirely associated with the Buildings sector (including households). We assume that residential properties incur this entire cost.**
  - Aspects of gas grid conversion upstream of the meter, such as replacing gas pipelines, make up £9.65 b. **This is shared between all other sectors such as shipping, manufacturing & construction and surface transport**.
  - Internal household pipes must be replaced at an average cost of €585 per household.
  - These costs are annualized over a 40-year lifetime with a 5% discount rate to give a total cost of €0.0098/kWh and the additional pipe-replacement annualized cost of €34/y per household, amounting to €0.0125/kWh.



Scenarios depicted in the CCC's 6CB – the Headwinds scenario is used for scaling

Transmission and distribution operational costs

- The final transmission network operational cost is calculated from combining the costs of hydrogen onshore and electrolyser pipelines to give a total figure of €0.0067/kWh.
- The final distribution network operational cost is determined to be €0.0044/kWh, based on a study in Ireland commissioned for the SEAI.

Final results and commentary

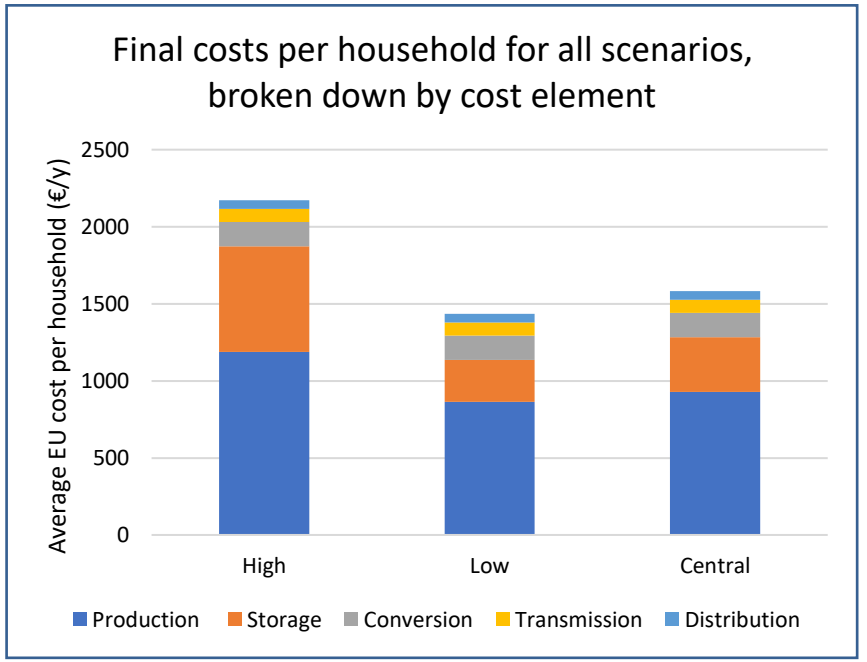
Cost scenario	Production	Storage	Conversion	Transmission	Distribution	Total final cost per household
Unit	€/household/y					
High	1,190	685	158	85	56	2,170
Low	864	272	158	85	56	1,440
Central	929	355	158	85	56	1,580

Final results

- By combining all elements of the cost of hydrogen for an average home with a consumption of 12,700 kWh/year, the final total figures for the Low, High and Central scenarios for heating by hydrogen give a cost of €2170, €1440 and €1580 per household respectively.

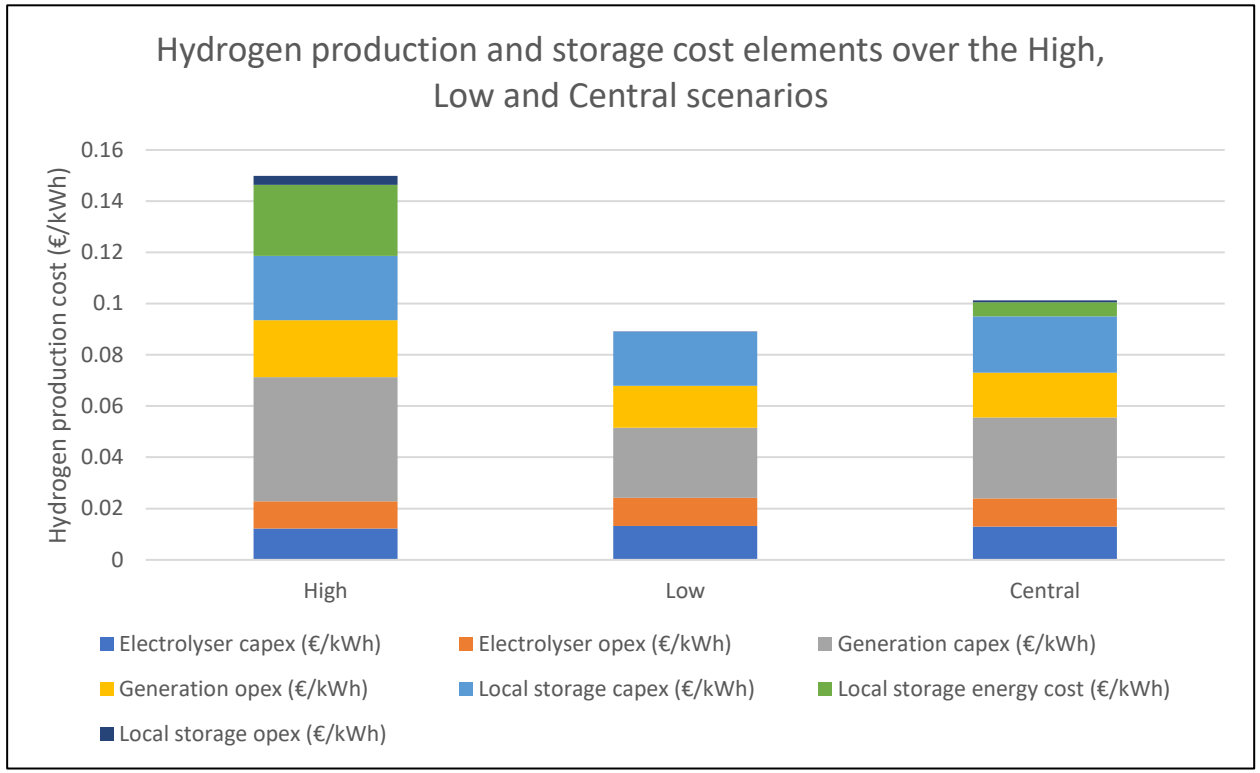
Limitations and commentary

- This represents an average across all EU households and all countries. In practice, this is likely to differ substantially between different regions and property characteristics such as type and size.
- The assumption in our analysis of widespread use of hydrogen across Europe means that the costs derived represent a 'best case' scenario from the context of the economy of scale in hydrogen rollout, and allocation of the conversion costs across a large customer base. Under scenarios with more limited use of hydrogen, the per household costs are likely to be higher. We have not quantified the potential costs under a lower rollout scenario, which is beyond the scope of this work.



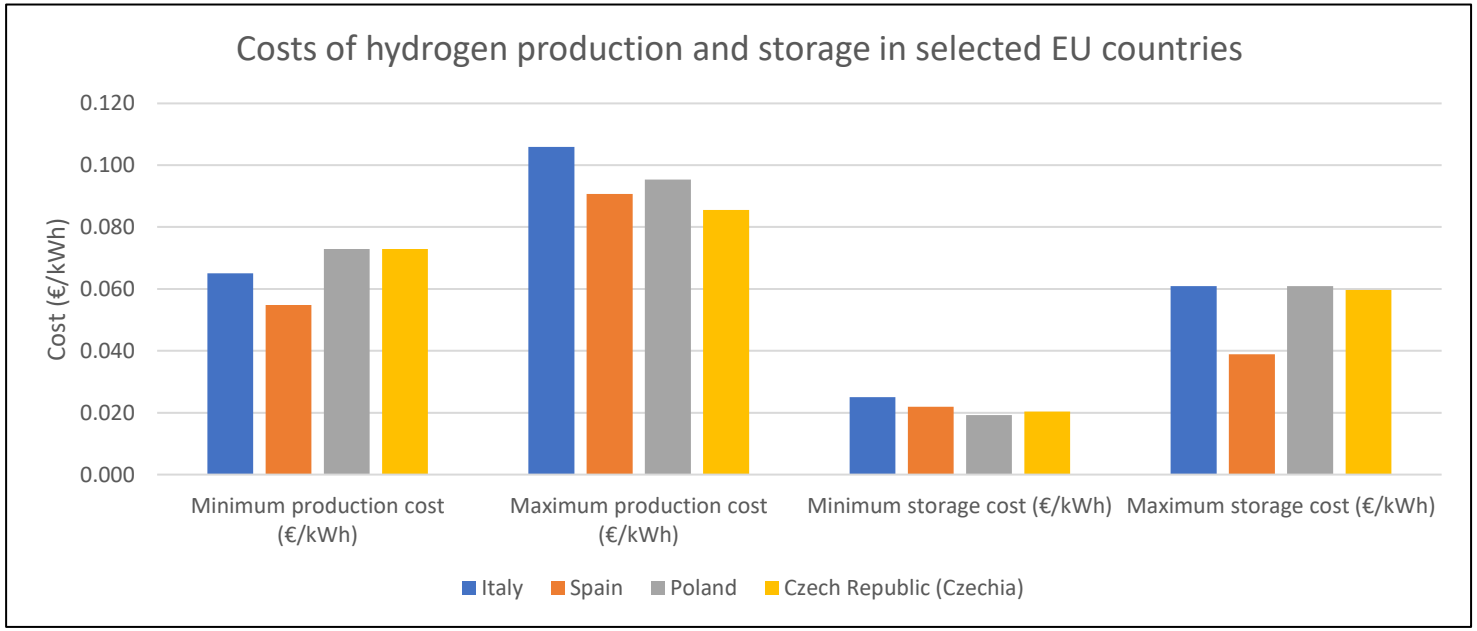
Appendix

Data for the “Hydrogen production and storage cost elements over the High, Low and Central scenarios” on slide 4



	Electrolyser capex (€/kWh)	Electrolyser opex (€/kWh)	Generation capex (€/kWh)	Generation opex (€/kWh)	Local storage capex (€/kWh)	Local storage energy cost (€/kWh)	Local storage opex (€/kWh)
High	0.01226	0.01057	0.04841	0.02223	0.02515	0.02772	0.00345
Low	0.01314	0.01102	0.02738	0.01638	0.02111	0.00000	0.00011
Central	0.01296	0.01093	0.03159	0.01755	0.02192	0.00554	0.00078

Data for the “Costs of hydrogen production and storage in selected EU countries” on slide 5



Country	Production archetype	Minimum production cost (€/kWh)	Maximum production cost (€/kWh)	Storage availability	Minimum storage cost (€/kWh)	Maximum storage cost (€/kWh)
Italy	(Sunny)	0.065	0.106	Pressurised	0.025	0.061
Spain	(Sunny)	0.055	0.091	Geological	0.022	0.039
Poland	(Windy)	0.073	0.095	Geological	0.019	0.061
Czech Republic (Czechia)	(Windy)	0.073	0.086	Pressurised	0.020	0.060

Data tables included as supplementary information following the draft report

Scenario	Electrolyser capex (€/a)	Electrolyser opex (€/a)	Generation capex (€/a)	Generation opex (€/a)	Local storage capex (€/a)	Local storage energy cost (€/a)	Local storage opex (€/a)
High	156	134	615	283	320	352	44
Low	167	140	348	208	268	0	1
Central	165	139	402	223	279	70	10

Scenario	Electrolyser capex (€/a)	Generation capex (€/a)	Local storage capex (€/a)	Grid conversion capex (€/a)	Internal pipework capex (€/a)	Total capex (€/a)
High	156	615	320	124	34	1249
Low	167	348	268	124	34	942
Central	165	402	279	124	34	1004

Hydrogen infrastructure conversion costs detailed analysis

- The hydrogen conversion costs are calculated from the BEIS H2 supply chain evidence base report.
- We have split all conversion costs in 2 categories: 1. domestic-only, highlighted in red, and 2. applicable to all hydrogen users.
- All costs are then annualised using a 40 year lifetime of infrastructure and a 5% discount rate. 9.65 b£ total = 0.56 b£/y
- The infrastructure costs that could be passed to non-H2 gas domestic users are the costs not highlighted in red in the table to the right, as those would be incurred across the whole gas network.
- Using the CCC high H2 scenario (Headwinds), we used the estimated 210 TWh of hydrogen consumption in 2050 across all consumers using the network (domestic + commercial, excluding shipping and manufacturing) to find the conversion cost per kWh of consumption. We use the 2050 figure as this assumes consumers still on gas in 2040 who would take hydrogen by 2050 would be including in paying for the H2 network.
- The final cost obtained is: 0.56 * 1.18 (£->€ conversion) * 0.56/210 = 0.0032 €/kWh
- Using a typical 12,700 kWh consumption per year, we find that number is equivalent to 40 €/year

Domestic-only costs

Repurposing Category	Total CAPEX	%	Cost Rank
Replacing Domestic Gas Meters - excluding installation	£3,519,494,101	15.9%	1
Labour and Fittings for Installation of Domestic Gas Meters	£3,486,179,700	15.7%	2
Replacing Gas Detectors - excluding installation	£3,176,745,981	14.3%	3
Replacing Low Pressure Steel Pipelines	£3,109,431,439	14.0%	4
Additional 7 bar Pipeline Required due to Reduction in Linepack Energy	£2,450,921,086	11.0%	5
Labour and fittings for installation of detectors	£2,349,256,700	10.6%	6
Replacing Low Pressure Iron Pipelines	£1,072,444,558	4.8%	7
Replacing Medium Pressure Steel Pipelines	£798,362,558	3.6%	8
Replacing Non-Domestic Gas Meters - excluding installation	£622,699,078	2.8%	9
Reinforcing Low Pressure Pipelines	£444,934,981	2.0%	10
Installing Isolations	£361,856,721	1.6%	11
Replacing Medium Pressure Iron Pipelines	£275,355,671	1.2%	12
Replacing District Governors	£133,480,494	0.6%	13
Replacing Intermediate Pressure Steel Pipelines	£103,171,634	0.5%	14
Gate Metering Station with Odourisation	£70,000,000	0.3%	15
Labour and Fittings for Installation of Non-Domestic Gas Meters	£62,842,250	0.3%	16
Reinforcing Medium Pressure Pipelines	£47,343,413	0.2%	17
Conducting Network Survey	£44,493,498	0.2%	18
Replacing Intermediate Pressure Iron Pipelines	£35,583,952	0.2%	19
Selective Pressure Testing	£14,468,898	0.1%	20
Replacing Low Integrity Components	£2,402,649	0.0%	21
Replacing Domestic Iron and Steel pipe	£0	0.0%	22
Reinforcing Intermediate Pressure Pipelines	£0	0.0%	22
Total	**£22,181,469,362**	**100.0%**	

BEIS H2 supply chain evidence base report