AURORA ENERGY RESEARCH

European Hydrogen Market Service

October 2022

Aurora provides market leading forecasts & data-driven intelligence for the global energy transition

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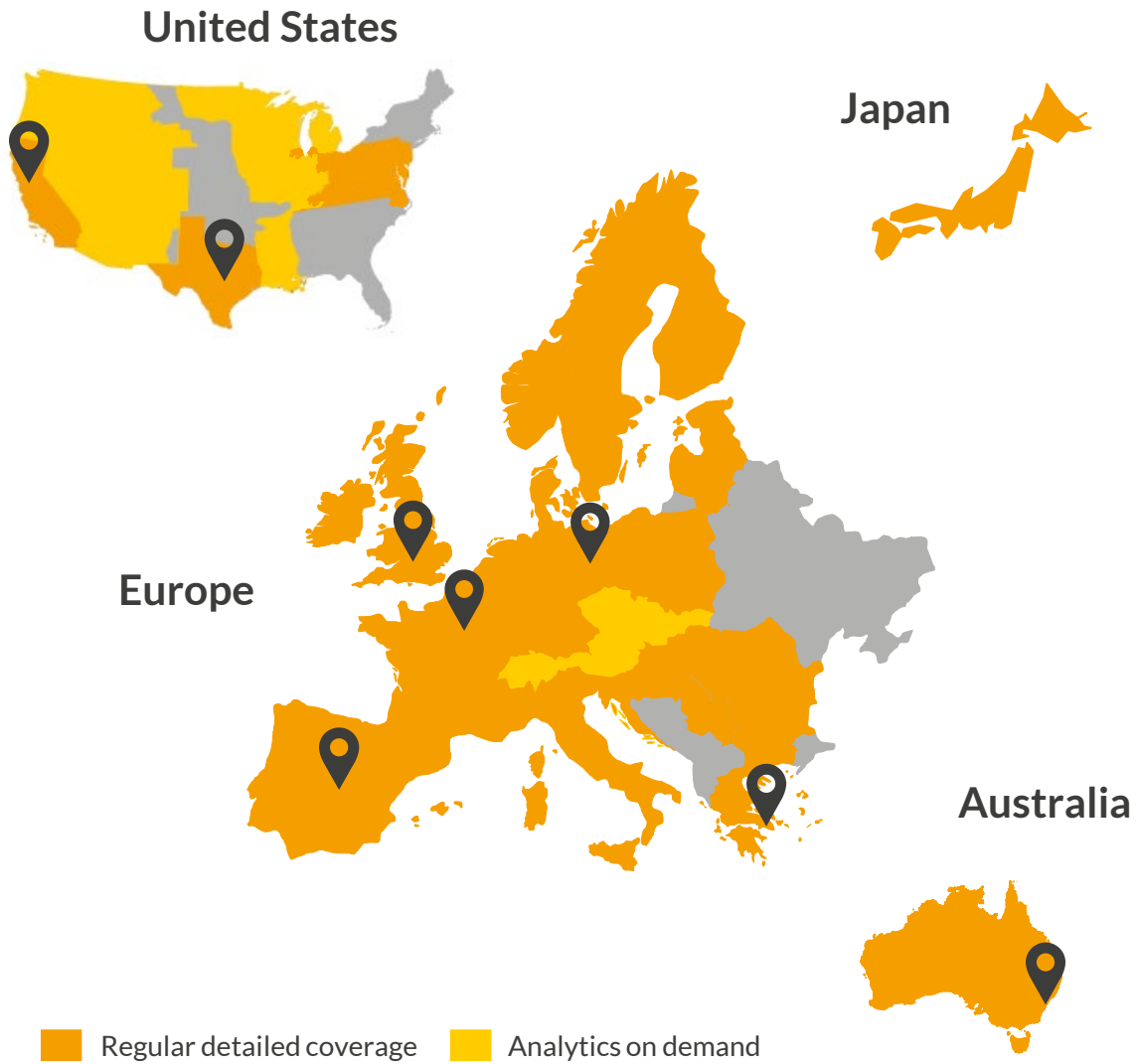
- Power markets
- Renewables
- Storage
- Electric vehicles
- Hydrogen H_2
- Carbon CO_2
- Natural gas



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Source: Aurora Energy Research

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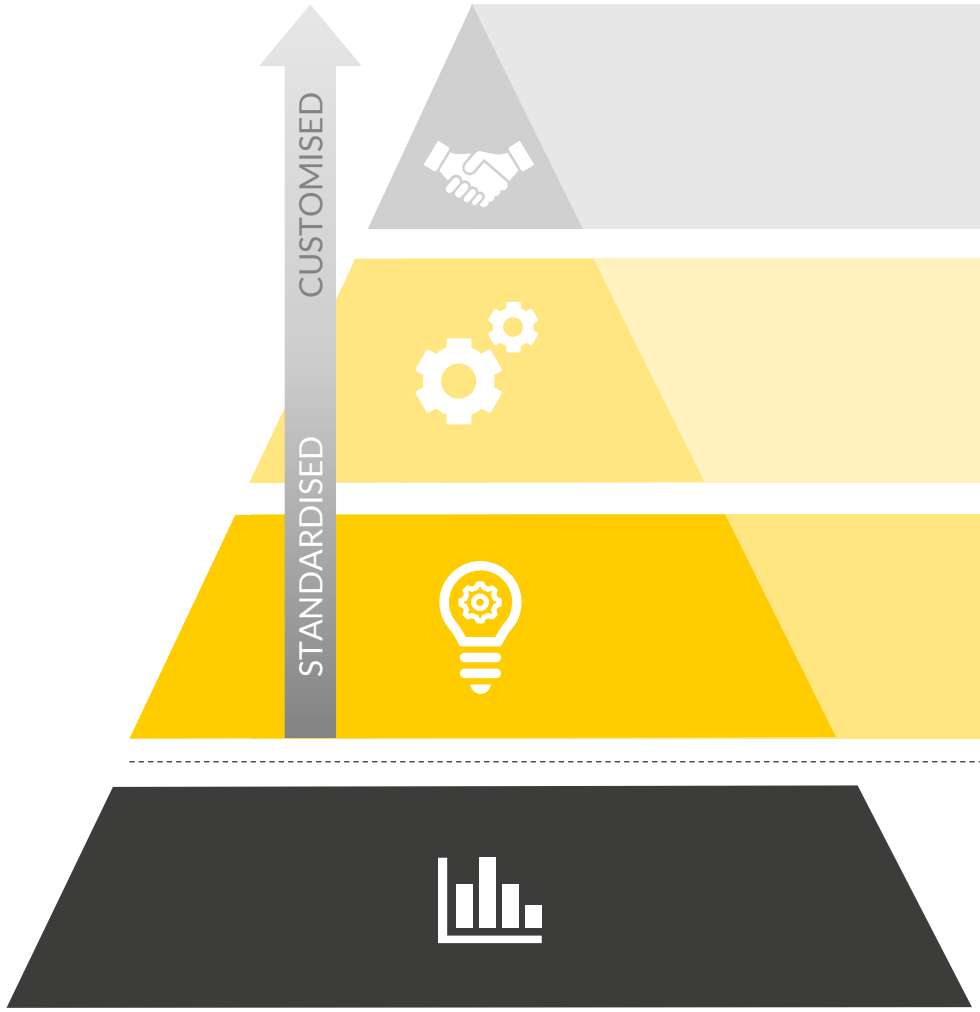

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Proprietary and continuously updated cutting-edge models populated with highest quality curated datasets

Developed over 10 years, 40+ dedicated modellers

Source: Aurora Energy Research

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This is an extract from the latest Hydrogen Market Attractiveness Report (HyMAR).

To access the full HyMAR report and find out more about the European Hydrogen Market Service, contact Opeoluwa Adenmolu, (*opeoluwa.adenmolu@auroraer.com*)

Executive Summary

The European Hydrogen Market Attractiveness Report (HyMAR) assesses which markets in Europe are most attractive to invest in for low-carbon hydrogen. Germany, The Netherlands and the UK remain on the podium.

Since our previous HyMAR report in April 2022 several changes have occurred in the hydrogen market in Europe, which we examine in this report. We have included updated data and analysis from our global electrolyser database, as well as updated our view on European hydrogen demand.

Policy and market updates

1

Germany, the Netherlands and the UK remain the most attractive countries for hydrogen investments in Europe. Further down the ranking, Norway displaced France and Spain due to its doubled electrolyser manufacturing capacity by NEL

Electrolyser database and electrolyser manufacturers

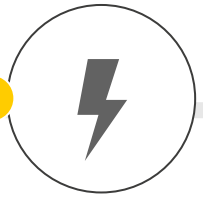
2

Aurora's global electrolyser pipeline is at 957 GW. Excluding the 500 GW Spirit of Scotia project, the pipeline has grown by 92 GW or 25% to 457 GW.

Electrolyser manufacturers have increased their ambitions, and electrolyser manufacturing capacity. The cumulative capacity of manufactured electrolysers by 2030 is more than enough to supply European electrolyser projects

Hydrogen supply

3



The current gas crisis increases the cost of blue and grey hydrogen production. On a lifetime basis, Aurora now estimates a blue hydrogen production cost of 3 EUR/kg for a project starting in 2025 (+10% compared to pre-war). This makes green hydrogen more competitive vs blue in a few countries such as Ireland, Denmark and Belgium

Hydrogen demand

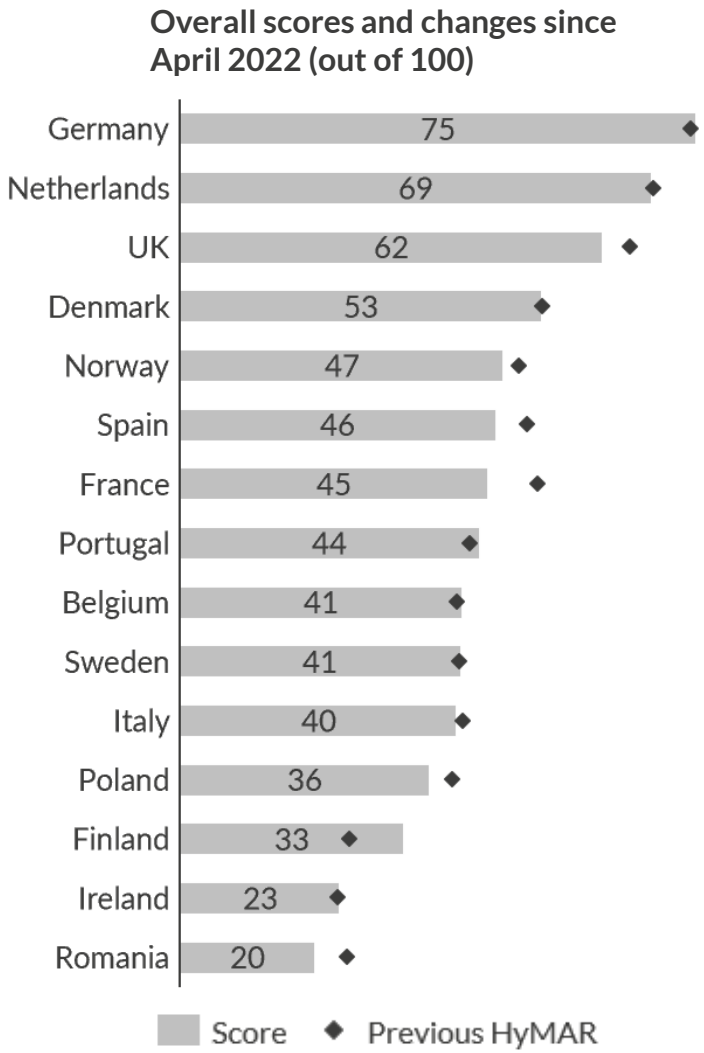
4

Our updated demand projections indicate ~1000 TWh of hydrogen and derivatives by 2050 for Aurora's Central scenario; this value increases to ~1800 TWh if Net Zero ambitions are realised. This increase represents 3 to 6 times the current demand levels (<300 TWh). The uptake of hydrogen derivatives will mostly be driven by the maritime and aviation sectors

Find out more about the European Hydrogen Market Service, contact Opeoluwa Adenmolu, Commercial Associate

The most attractive countries are Germany, The Netherlands and the UK; Norway, Belgium and Ireland have recently improved their scores

Country	Latest Rank (Oct-22)		Previous Rank (Apr-22)	Highlights
Germany	1	=	1	
Netherlands	2	=	2	
UK	3	=	3	
Denmark	4	=	4	
Norway	5	▲	7	Nel doubling its electrolyser manufacturing capacity
Spain	6	=	6	
France	7	▼	5	Displaced by Norway and Spain
Portugal	8	=	8	
Belgium	9	▲	11	
Sweden	9	=	9	
Italy	11	▼	9	
Poland	12	▼	11	
Finland	13	=	13	New hydrogen targets in the National Climate and Energy Strategy
Ireland	14	▲	15	New electrolyser manufacturing plant, 25x H_2 production increase
Romania	15	▼	14	



Source: Aurora Energy Research

A number of major policy announcements are investigated in detail in our HyMAR report for October

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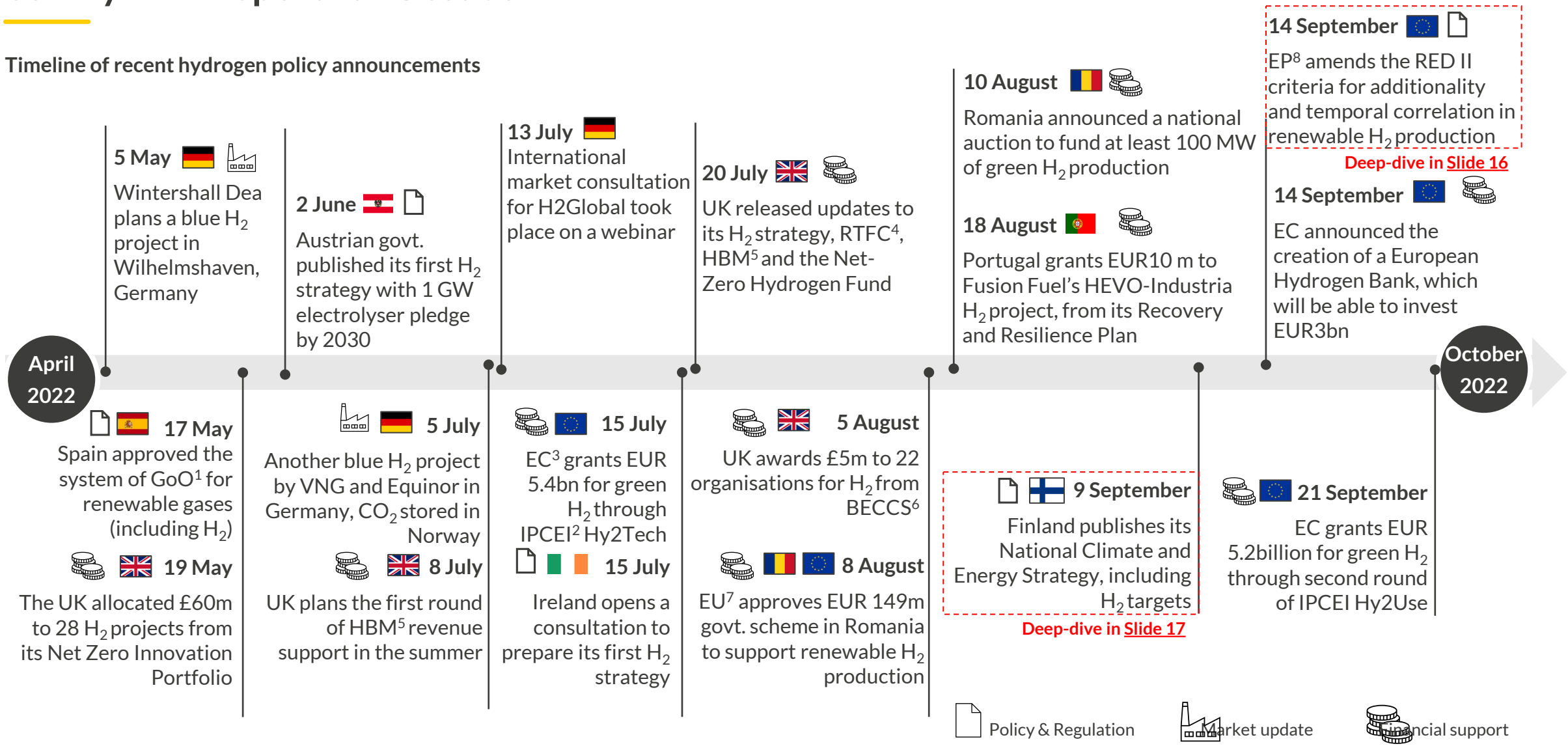
Timeline of recent hydrogen policy announcements



1) Guarantee of Origin 2) Important Project of Common European Interest 3) European Commission 4) RTFC: Renewable Transport Fuel Certificate 5) HBM: Hydrogen Business Model 6) Bioenergy with carbon capture and storage 7) European Union 8) European Parliament

Source: Aurora Energy Research

Aurora expects hydrogen demand to exceed 1800 TWh across Europe to reach Net Zero emissions

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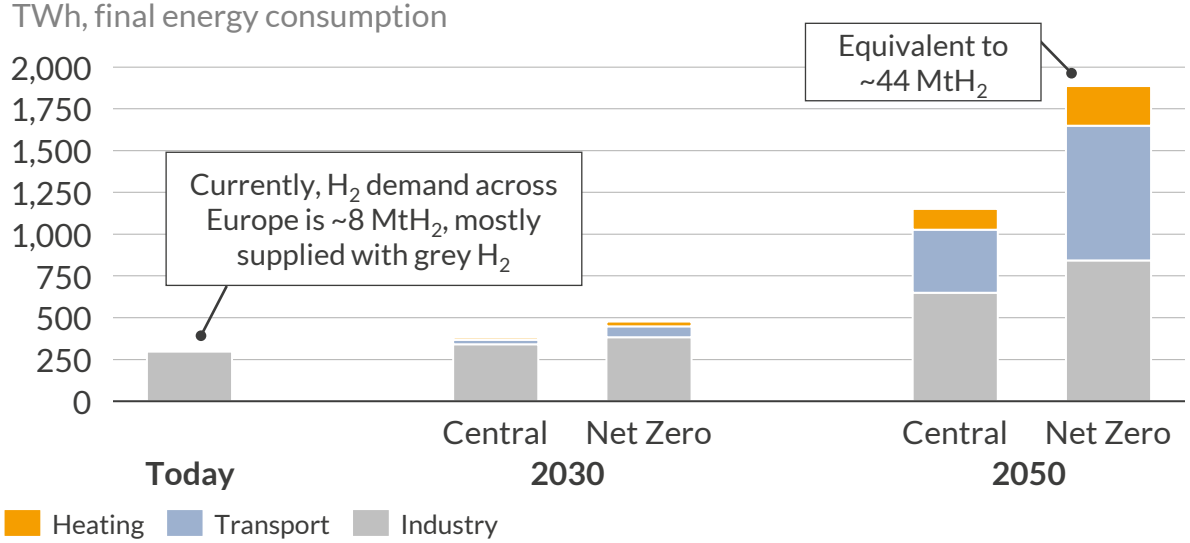
Hydrogen demand in Europe

We consider two scenarios given the high degree of uncertainty around technological and financial feasibility of hydrogen applications:

Aurora's Net Zero scenario is aligned with Europe's plan to reach net zero emissions economy-wide by 2050

Aurora's Central scenario represents a more conservative view on the evolution of the energy transition, where hydrogen penetration is more limited to the most economically viable applications and does not meet government targets. This scenario is aligned with meeting Net Zero across Europe only after 2050

European[1] H_2 demand by sector, including H_2 derivatives and imports[2]
TWh, final energy consumption



Industry

- Until 2030, we expect uptake of green H_2 mostly from ammonia and refinery industries, without much increase in total H_2 demand
- Beyond that, we expect increasing uptake in high-grade process heat, especially at temperatures that are difficult to electrify
- We also expect increasing demand for hydrogen in the steel industry from the mid-2030s

Transport

- Hydrogen road transport will have a more important role for coaches and heavy-duty vehicles, particularly for vehicles of intensive use (e.g. long-distance travel)
- Additionally, maritime and aviation sectors will significantly increase the use of hydrogen and its derivatives, mostly after mid-2030s

Heating

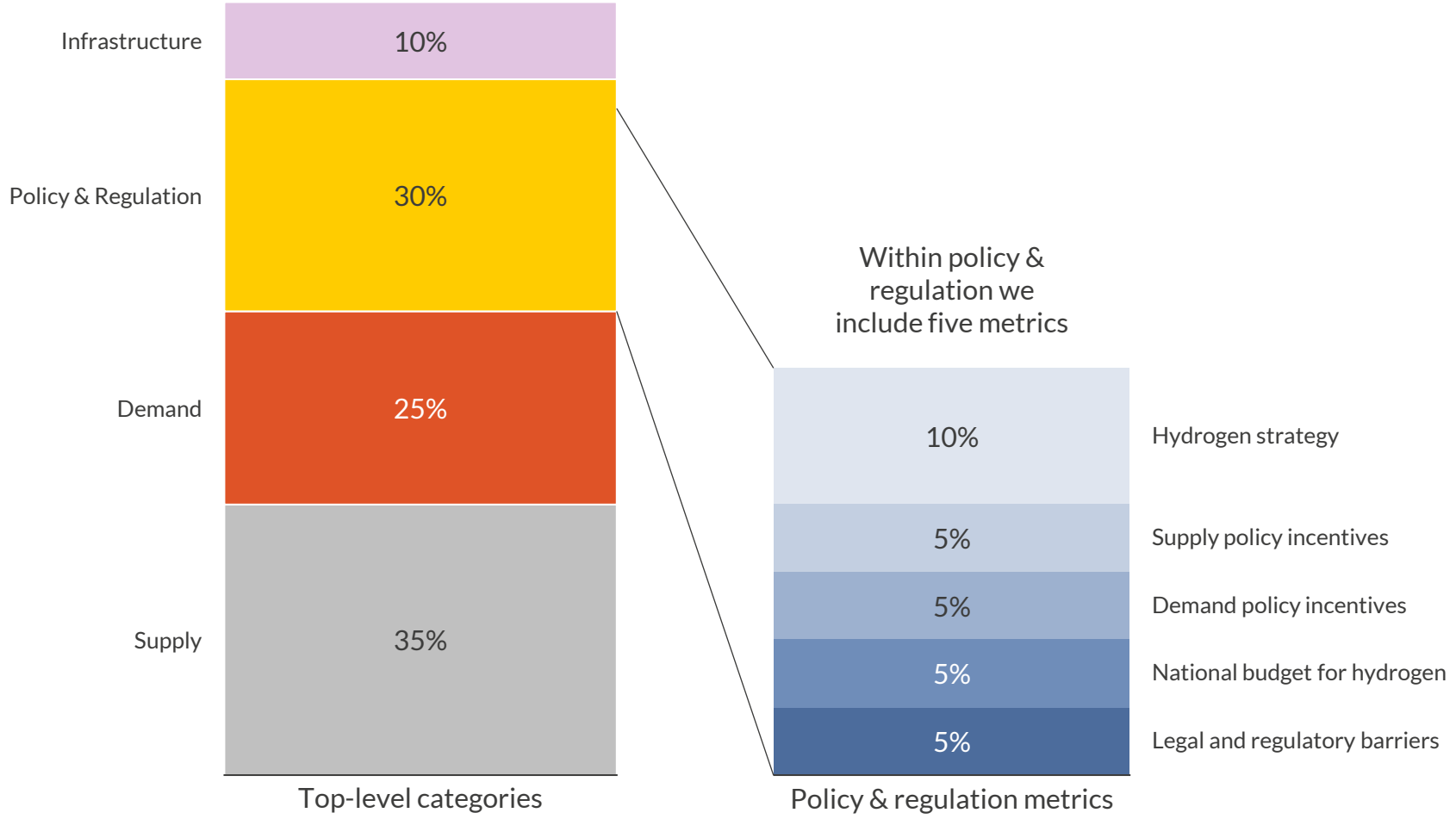
- The role of hydrogen for space heating is limited as only few countries are pursuing hydrogen for heating
- We expect uptake driven by the injection of hydrogen in gas networks, which can be used without major equipment changes

1) European countries include HyMAR countries analysed in this report. These countries include BEL, DNK, DEU, ESP, FIN, FRA, GBR, IRL, ITA, NLD, NOR, POL, PRT, ROU, and SWE. 2) Includes hydrogen required to produce derivatives such as ammonia or synthetic fuels. The hydrogen demand shown accounts for the total domestic consumption, including any potential imported hydrogen or hydrogen derivatives.

Source: Aurora Energy Research

Aurora's Hydrogen Market Attractiveness Rating (HyMAR) combines indicators to derive an overall attractiveness score

How we score countries



1) The metrics and weighting factors are shown in the appendix. 2) Variable renewable energy i.e. from Solar PV, onshore wind and offshore wind. 3) HRS: Hydrogen Refuelling Station

Source: Aurora Energy Research

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We use 22 metrics for the assessment

- These metrics are structured around four top-level categories: Supply, Demand, Policy & Regulation and Infrastructure
- Data on these metrics can be found in the data book accompanying this report
- Compared to the previous HyMAR report, we have implemented some changes in order to keep our metrics up-to-date, as well as to better assess the status of policy and regulation across countries[1]
- The weighting of grid blending is decreased from 8% to 3% as there are few projects target grid blending according to our project database. The weighting factor is distributed over VRE penetration[2], grid carbon intensity and HRS[3]

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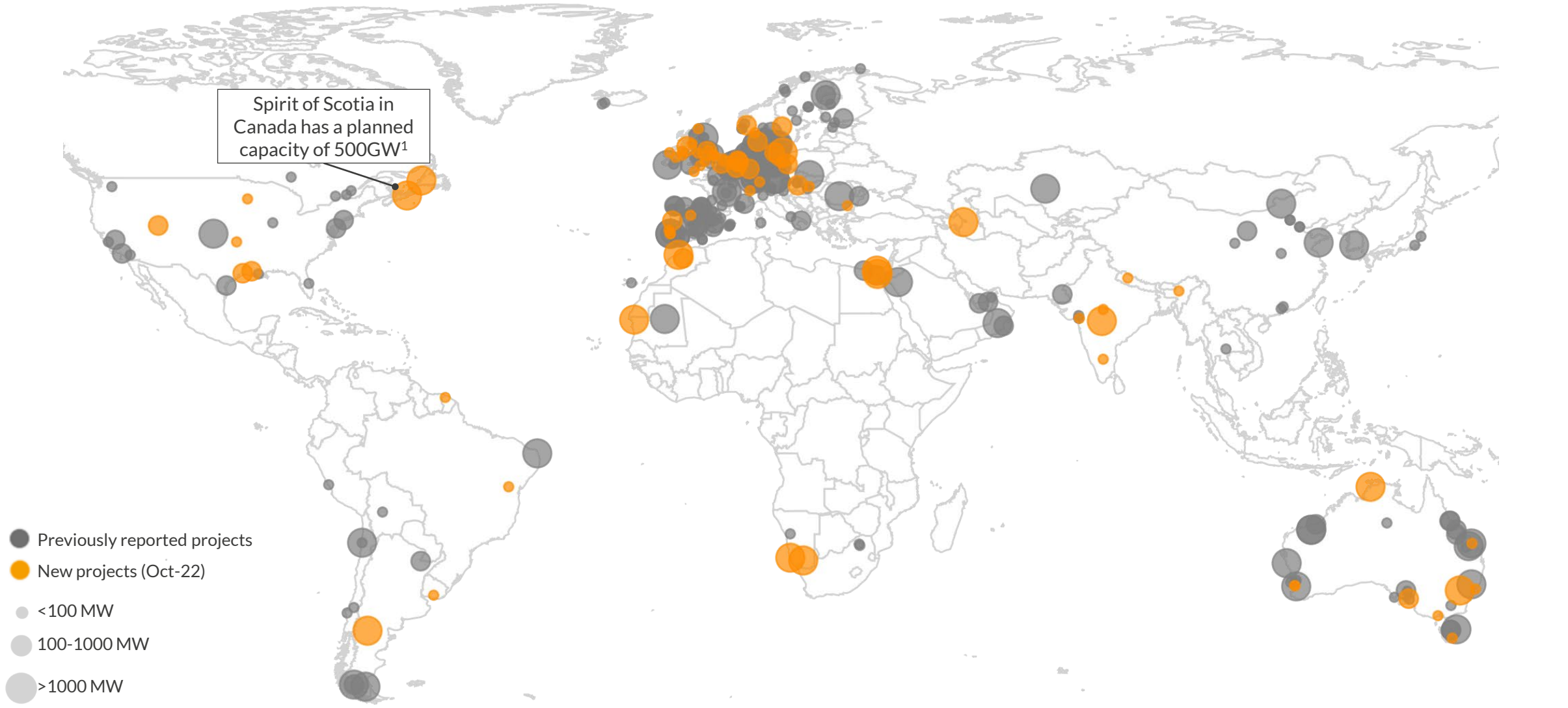
Global electrolyser pipeline has swelled from 365GW to 957GW, but 500GW of this growth is from one project



1) No commissioning date has been announced yet.

Source: Aurora Energy Research

Europe electrolyser project pipeline seems healthy; yet only half of the RePowerEU target is at advanced project stage

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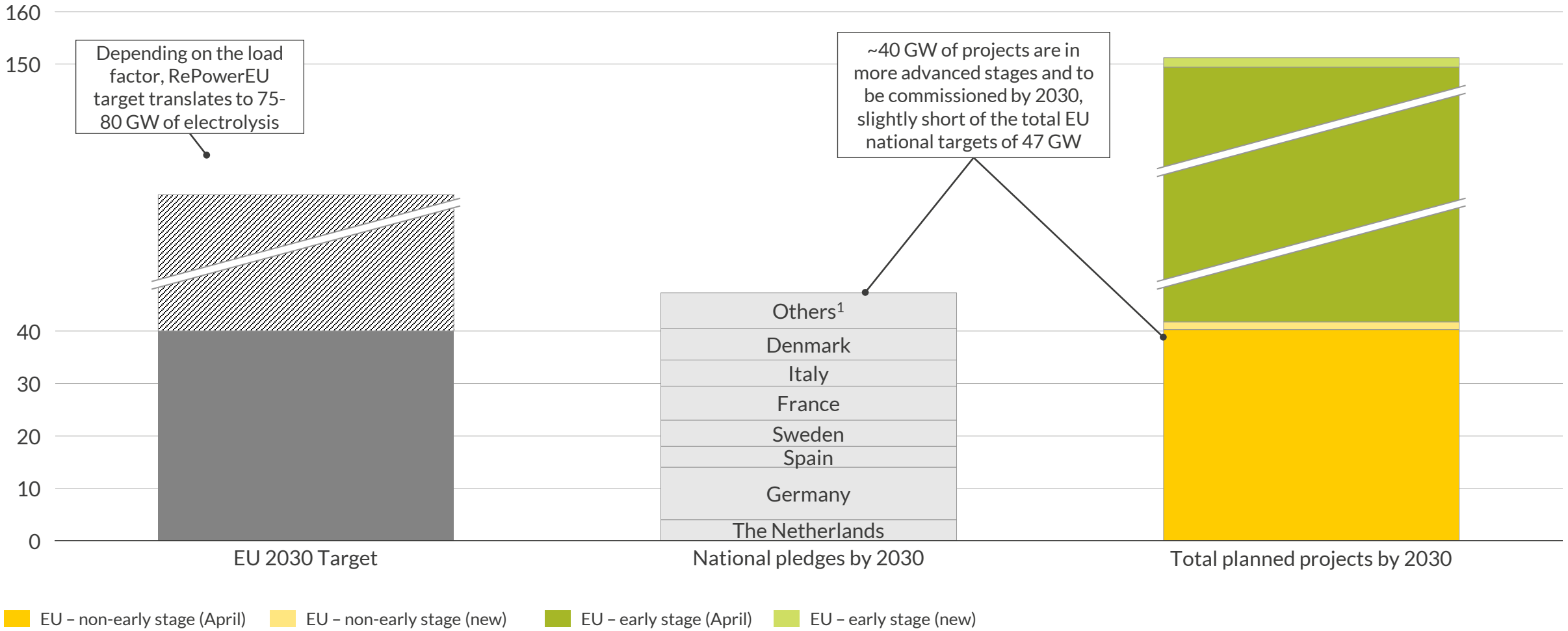
Current H_2 electrolyser capacity pledges and actual planned construction by 2030, GW



1) Other countries include: Portugal (2.5GW), Poland (2GW), Finland (1GW), Austria (1GW), Hungary (240 MW) and Serbia (100 MW)

Sources: Aurora Energy Research, LBST International Hydrogen Strategies, National Hydrogen Strategies

With ~10 GW of new electrolyser manufacturing plants announced in Europe, project pipeline demand by 2030 can be met

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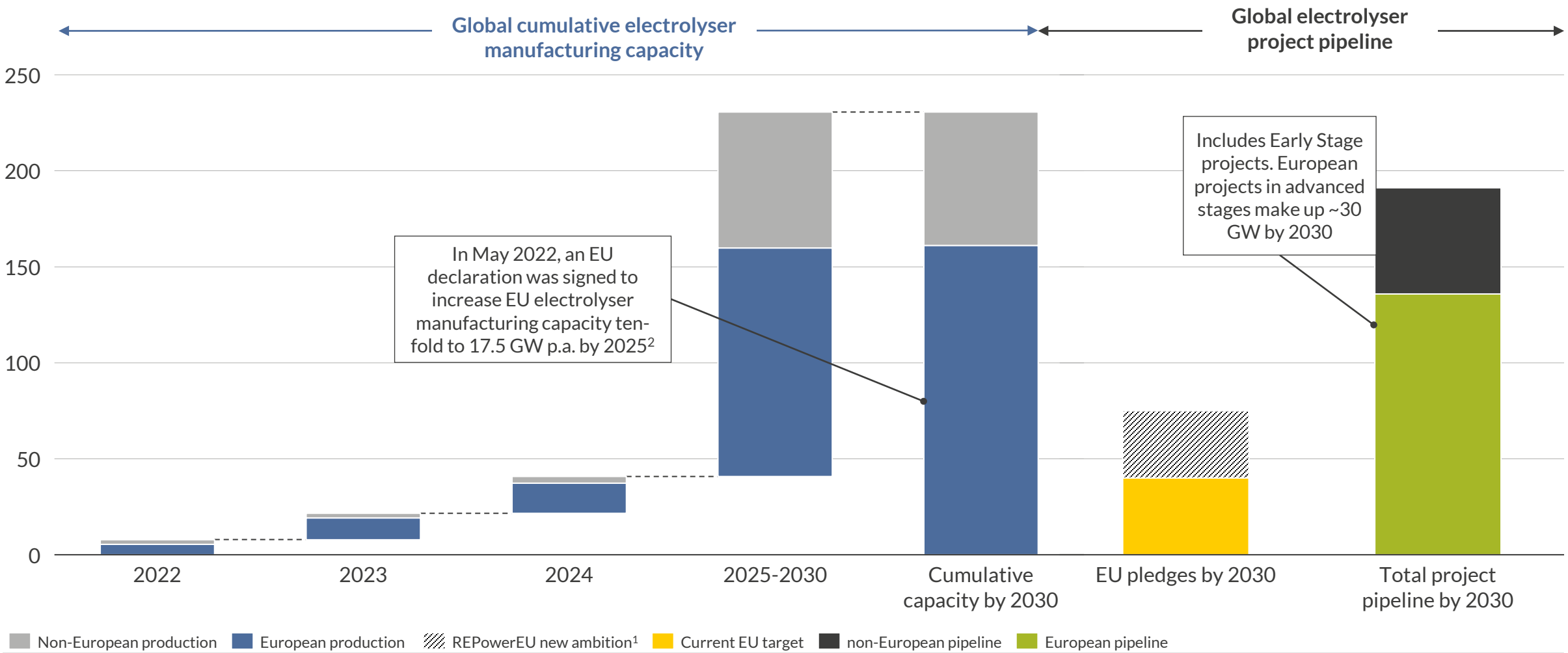
Global cumulative electrolyser manufacturing capacity vs project pipeline, GW



1) Aurora's estimate based on the REPowerEU strategy renewable hydrogen supply goals 2) It was signed by the European Commission, Hydrogen Europe and 20 industrial players

Sources: Aurora Energy Research, World Hydrogen Leaders, Renewables Now

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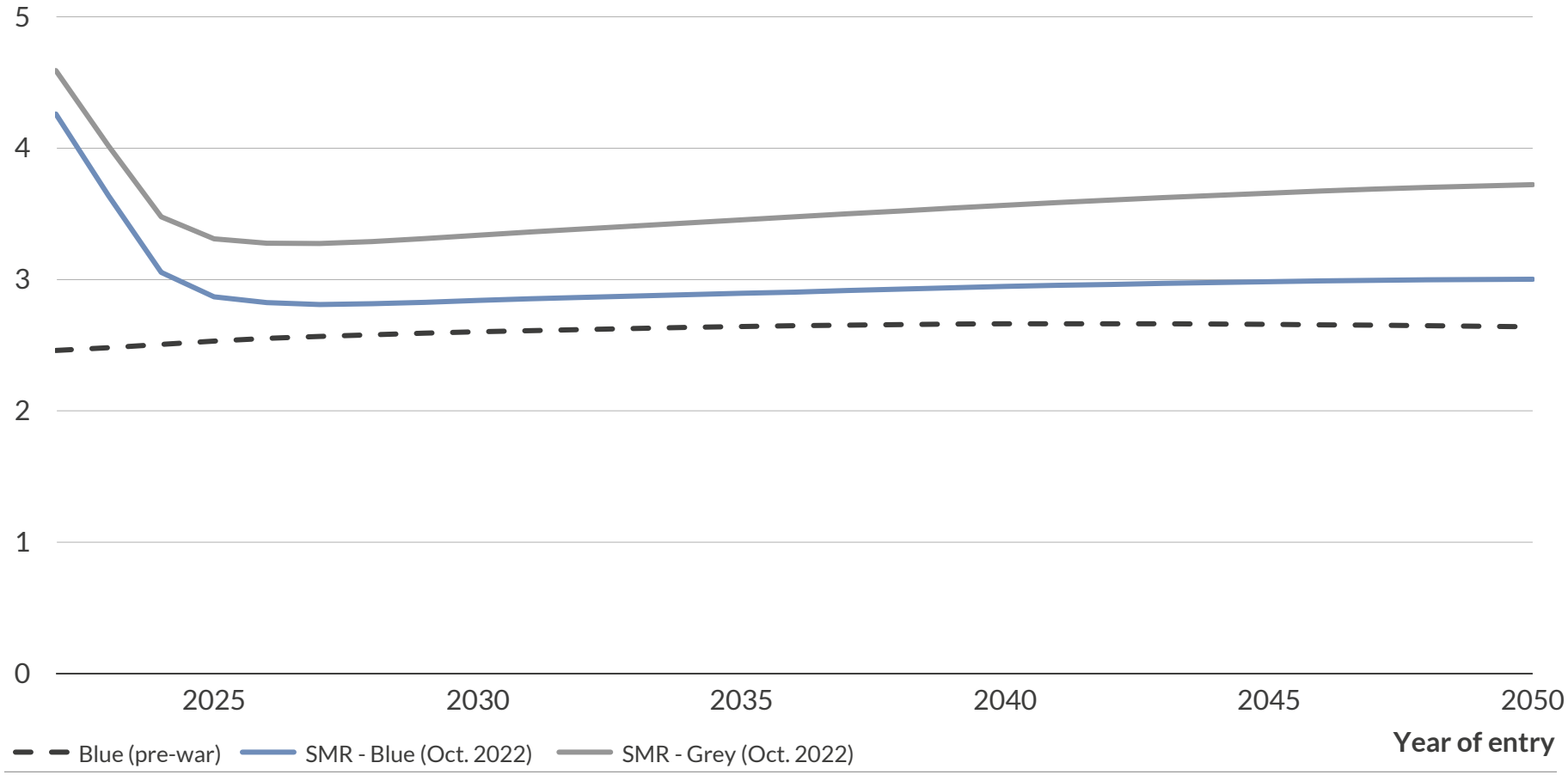
Aurora expects blue H_2 cost to settle around 3 EUR/kg after mid-2020s; this means ~10% increase compared to before the gas crisis

Blue hydrogen

LCOH of blue and grey hydrogen in Great Britain[1]
EUR/kg H_2



1) Both blue and grey hydrogen calculations are conducted for an SMR with 90% carbon capture rate and 95% load factor

Source: Aurora Energy Research

- By using our October 2022 central scenarios, we have updated our LCOH forecasts for blue and grey hydrogen. Our forecasts curve reflects the increasing gas prices due to Russian invasion of Ukraine.
- The gas market rebalances in mid-2020s with new LNG liquefaction and regasification infrastructure; hence, we expect a price dip in our hydrogen production costs around 2025.
- Compared to last year's forecasts, our gas prices; hence the cost of hydrogen have increased by ~10%. For a large-scale blue hydrogen producer benefiting from economies of scale, the cost will be around 2.6 GBP/kg.

In selected locations in Europe, hydrogen produced via renewables can beat blue production costs by 2030

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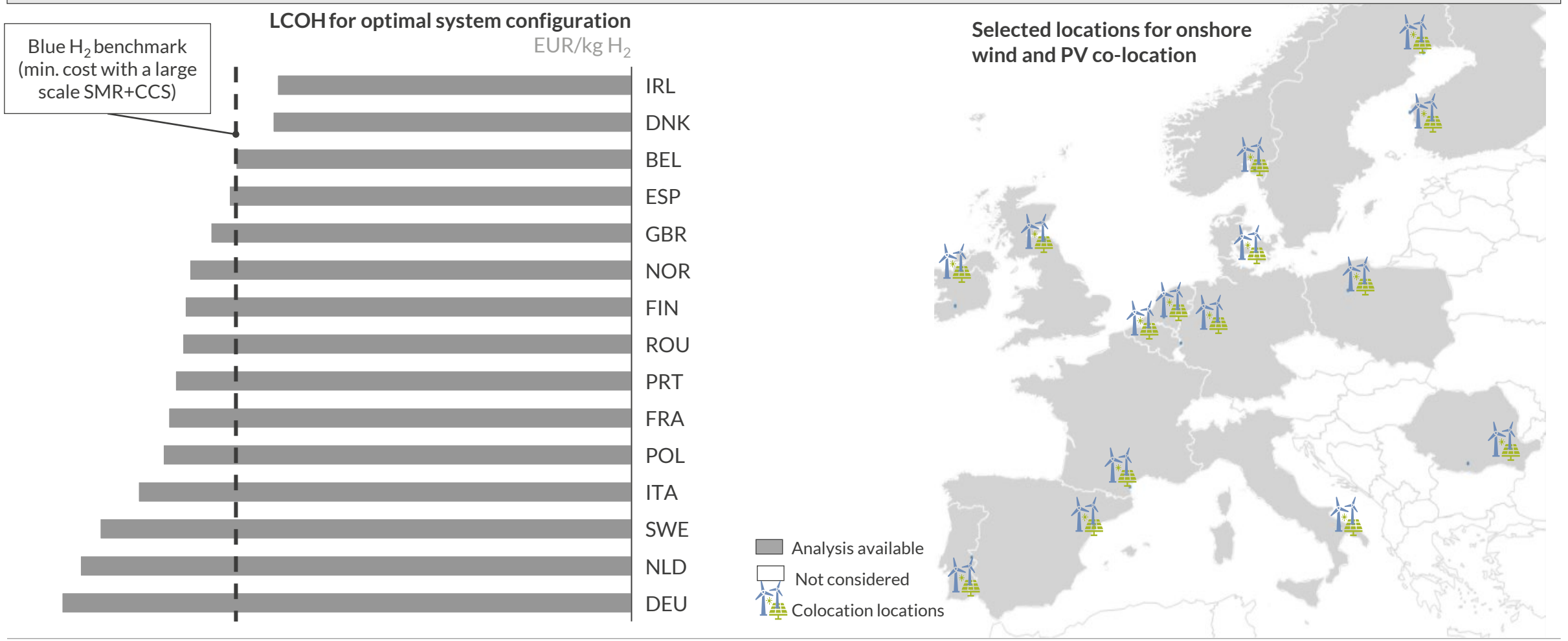
Green hydrogen

Results shown below are calculated for a PEM electrolyser co-located with renewables, the system is commissioned in 2030



Source: Aurora Energy Research

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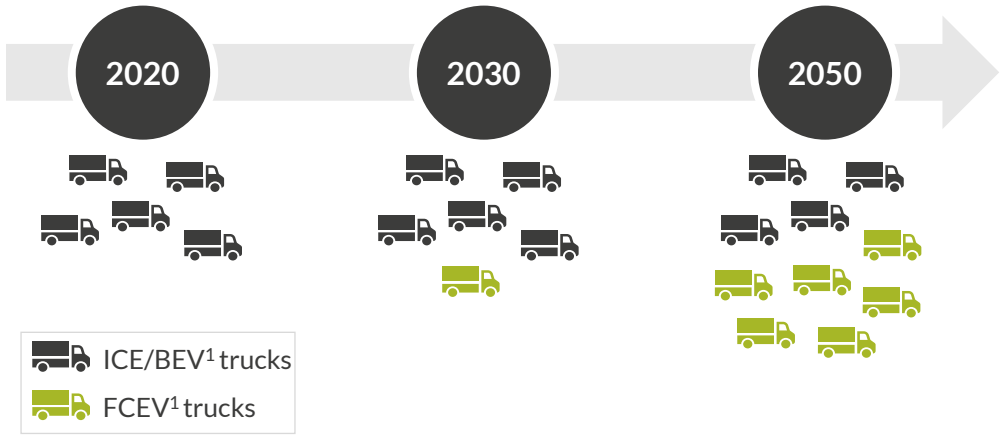
Hydrogen demand increases 3-7 fold by 2050; we estimate bottom up based on sector size, hydrogen penetration, and consumption rates

To describe the methodology, we illustrate a hypothetical hydrogen demand in heavy-duty vehicles for 2020, 2030 and 2050



Total demand if everything was converted into hydrogen now

Annual market size × Fuel consumption × Sectoral growth × H_2 penetration

Total demand if everything was converted into hydrogen in future

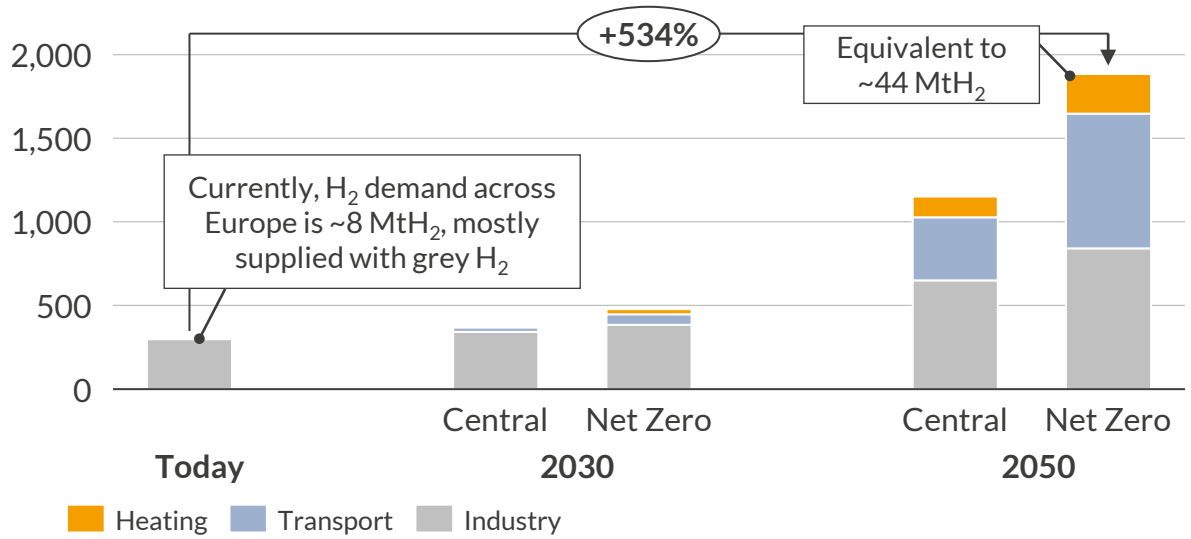
We consider two scenarios given the high degree of uncertainty around technological and financial feasibility of hydrogen applications:

Aurora's Net Zero scenario is aligned with Europe's plan to reach net zero emissions economy-wide by 2050

Aurora's Central scenario represents a more conservative view on the evolution of the energy transition, where hydrogen penetration is more limited to the most economically viable applications and does not meet government targets. This scenario is aligned with meeting Net Zero across Europe only after 2050

Aurora's hydrogen demand forecast for HyMAR countries[2]

TWh/y, final energy consumption



1) ICE: Internal combustion engine; BEV: Battery electric vehicle; FCEV: Fuel cell electric vehicle 2) These countries include BEL, DNK, DEU, ESP, FIN, FRA, GBR, IRL, ITA, NLD, NOR, POL, PRT, ROU, and SWE

Source: Aurora Energy Research

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Forecasts Reports & Data

Hydrogen Market Attractiveness Report (HyMAR)

- Summary of policy developments and incentives across Europe
- Global electrolyser project database
- Hydrogen market sizing: demand scenarios by country and sector
- Analysis of demand and supply drivers

Investment case analysis

- Hydrogen production economics based on Aurora's in-house power, gas and carbon price forecasts
- Granular electrolyser business cases, including optimised grid-connected and renewables co-located models
- For use in strategy formulation, transactions and JV negotiations

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Explore scenarios through EOS, our dynamic online platform featuring a full library of reports and datasets.

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Strategic Insight Reports

- Regular insight reports on topical issues in the evolving European hydrogen market covering country, policy and technology deep dives

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- Thought leadership on required policies and incentives to grow hydrogen sector

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- Presentation of Market Attractiveness reports and Strategic Insight reports
- Networking opportunity with developers, investors and Governments – the 'go-to' roundtable to discuss hydrogen developments in Europe

Analyst Support

Bi-annual workshops and support from our bank of analysts, including native speakers and on-the-ground experts

Contact Opeoluwa Adenmolu, (*opeoluwa.adenmolu@auroraer.com*), Commercial Associate to find out more

What's coming up in the European Hydrogen Market Service?

Timeline of Strategic Insight reports and policy updates

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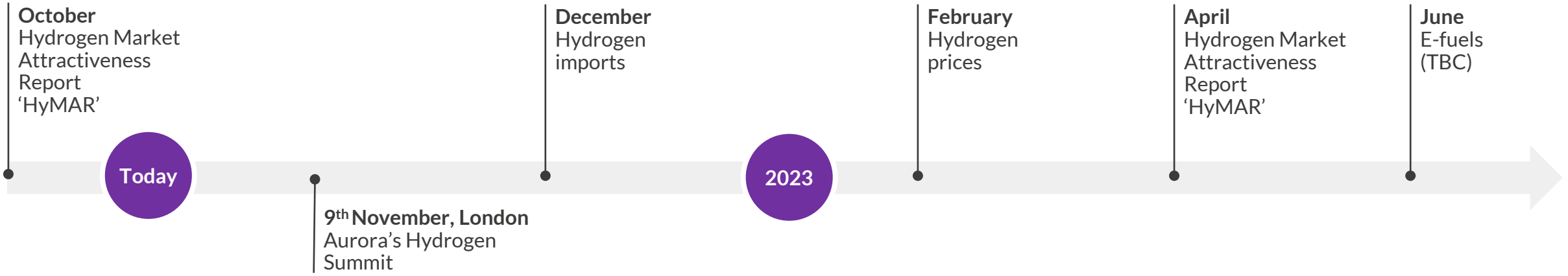
Upcoming reports for the European Hydrogen Market Service



Existing reports[1]

Policy Notes

- RePowerEU Plan: May 22
- UK hydrogen policy updates
- Poland H_2 strategy policy note
- Scotland H_2 strategy policy note
- Canada H_2 strategy policy note
- Preliminary Italian National Hydrogen Strategy

Country deep-dives

- Green hydrogen in Germany- Could co-location become a new business model for renewables?
- The role of green hydrogen in Iberia
- Hydrogen for a Net Zero Great Britain
- Low carbon hydrogen in the Nordics
- Italian Net Zero Strategy and Aurora's Net Zero modelling for hydrogen
- Hydrogen in France

Strategic Insights

- Hydrogen in mobility: understanding the economics and incentives
- Shades of green (hydrogen) – part 2: in pursuit of 2 EUR/kg
- Shades of green (hydrogen): optimising electrolyser business models
- From near and far: the economics of hydrogen imports
- Financing electrolysers: Overview of market trends in Europe

1) All reports are available to subscribers of Aurora's European Hydrogen Service

Source: Aurora Energy Research

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Source: Aurora Energy Research

Details and disclaimer

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