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European Hydrogen Market Report (HyMaR)
Redacted

April 2025

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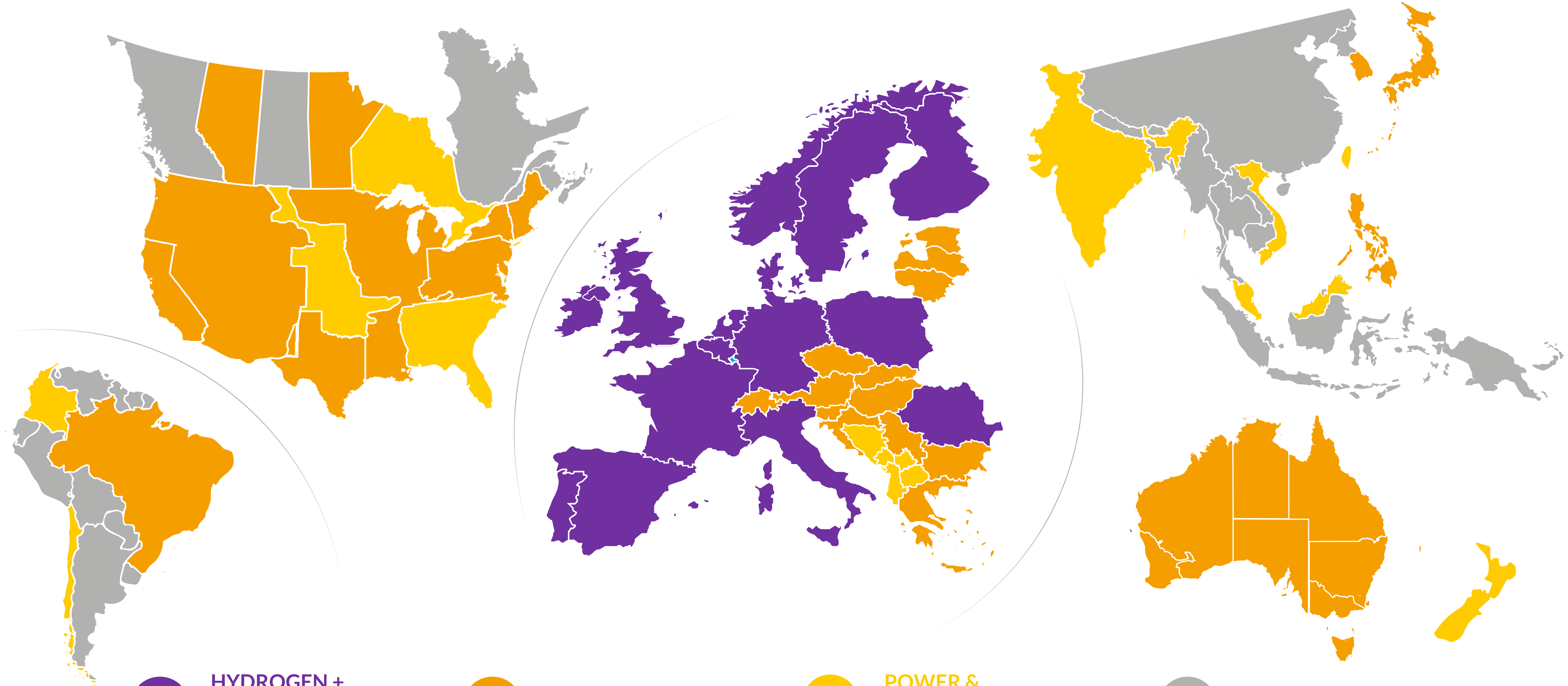

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Upstream gas & networks

REPSOL, Shell, equinor, Naturgy, OGE, nationalgrid, Thyssengas, Vitol, fluxys

Source: Aurora Energy Research

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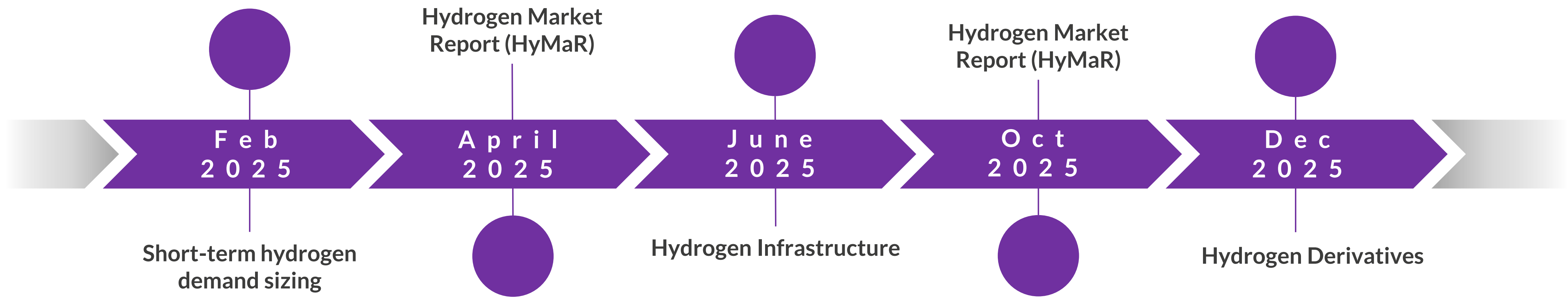
- Designing for value: innovative power procurement strategies and upsides for electrolyser business models
- Closing the gap: offtakers’ willingness to pay for low-carbon hydrogen
- Hype to HPA: crafting offtake strategies and purchase agreements
- Seas of opportunity: economics of hydrogen from offshore co-location
- A traded hydrogen market in Europe: what will prices and market structures look like?
- The economics of hydrogen imports: Better to stay local?
- Financing electrolysers: Overview of market trends in Europe

Country deep-dives

- The “13k mechanism” in Germany – price formation and its impact on hydrogen production
- Hydrogen in the NLD: From natural gas to green hydrogen hub
- The role of green hydrogen in the I-SEM
- Policies, regulation, and economics of green hydrogen in France
- The role of green hydrogen in Iberia
- Hydrogen for a Net Zero Great Britain
- Low carbon hydrogen in the Nordics
- Net Zero and the role of hydrogen for the Italian power system

Major deliverables of European Hydrogen Service in 2025



1) Existing reports are available in our EOS platform under the European Hydrogen Product

Source: Aurora Energy Research

Contents of the report

October 2024 (Biannual update)

April 2025 (Biannual update)

October 2025 (Biannual update)

This document presents Aurora Energy Research's biannual European Hydrogen Market Forecast for April 2025. This biannual report provides Aurora's analysis of the latest hydrogen market developments and forecasted costs. The document is presented with the following sections:

I. **Executive summary:** Provides an overview and key takeaways of Aurora's European hydrogen market forecast.

II. **Current hydrogen market:** Looks at the current structure of the European hydrogen market, including key news highlights from the past six months.

III. **Policy ecosystem:** Provides an overview of the current regional and state-level policies, covering regulations, frameworks, and support mechanisms.

IV. **Aurora's global electrolyser database:** Provides an overview of the global and European electrolyser project pipeline by country in terms of electrolyser capacity, power source, end user, etc.

V. **Key assumptions:** Provides an overview of Aurora's assumptions around electrolysers, demand, and power market fundamentals.

VI. **Levelised cost of hydrogen:** Evaluates the levelised cost of hydrogen (LCOH) for grid-connected and PPA-based electrolyser business models across the 15 European HyMaR countries. This includes bespoke cases like co-location, battery integration, single-technology PPAs, baseload PPAs, and PPA oversizing setups in select countries aimed at producing cost-effective renewable or low-carbon hydrogen.

VII. **Hydrogen market overview:** Explores different scenarios for short- and long-term market development, shaped by factors like sector-specific floor willingness to pay (for ammonia, steel, refineries, and industrial process heat), the long-term supply-demand balance, and the potential emergence of a liquid H_2 market.

Source: Aurora Energy Research

The current report provides an analysis of the H_2 market across 15 European countries, examining it across regional and country-specific perspectives

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Country coverage of the report

To note prior to reading this report

- This report covers 15 European countries: Belgium, Denmark, Finland, France, Germany, Great Britain, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Spain, and Sweden.
- All currency is reported in € unless otherwise stated. Key foreign exchange rates used in this report include:
  - € : £ - 1.16959 : 1
- Weighted average cost of capital (WACC) is assumed to be 10.5% unless otherwise stated.
- Higher heating value of 39.4kWh/kgH_2 is used when referring to the energy content of H_2.
- In the levelised cost of H_2 production, only H_2 produced by electrolysis is considered.
- Electricity prices used for electrolyser business models are based on Aurora's power market forecasts.
- Electrolyser CAPEX and efficiency assumptions are provided under the 'Key assumptions' section.
- Levelised cost of H_2 analysis and price benchmarking is for directional or strategic use only. Asset-specific forecasts can be completed separately in bespoke analysis.

Source: Aurora Energy Research

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Executive Summary

The European Hydrogen Market Report (HyMaR) offers an in-depth analysis of the hydrogen market across 15 countries, covering market structure, policy, regulation, levelised costs, and prices for renewable and low-carbon hydrogen. It also includes updates from the Aurora Global Electrolyser Database, with key developments and findings.

Policy and regulation:

- Between October and April, significant progress has been made at the EU level on regulations and mandates. ReFuelEU and FuelEU Maritime have provided greater regulatory clarity, while more member states are advancing in transposing the RED III directive into national legislation, with Finland and the Netherlands making the most progress.

Global electrolyser database:

- The global electrolyser database continues to stand at ~1.3TW, with 26 new projects added and 5 cancellations.
- Of the 1.3 TW total, 114 GW is in development, with 32% set for commissioning by end-2026.
- Over the past two years, a total of 6.2GW has reached FID globally, while 7.3GW has been cancelled—signalling a re-shaping of the market.

Levelised cost of hydrogen (LCOH) for electrolysers:

- By 2030, at least ten bidding zones—including regions in Italy and Scandinavia—are expected to meet the 90% renewable electricity threshold required to produce renewable hydrogen directly from the grid.
- In this edition of HyMaR, we've refined our electrolyser business models to reflect current market trends. PPAs are emerging as the preferred procurement strategy, with variations such as hybrid setups, single-technology agreements, oversizing, and battery integration to lower production costs.
- Hybrid PPAs, with LCOHs ranging from 5.4 to 10.6 €/kg, are often preferred for their pricing stability and broader availability across markets. The Nordics and Iberia continue to lead in low-cost renewable hydrogen production, thanks to their abundant, low-cost renewable electricity ideal for electrolysis.

Hydrogen market overview:

- Willingness to pay for industrial process heat has been added to our market outlook, alongside refineries, ammonia, and steel. Without policy support (e.g. quotas or certificates), the floor willingness to pay ranges from 2.4-5.2 €/kg.
- The current market is driven by bilateral agreements, but its future depends on several long-term factors. It could either remain dominated by bilateral deals or gradually evolve into a semi-liquid or fully liquid market.

Source: Aurora Energy Research

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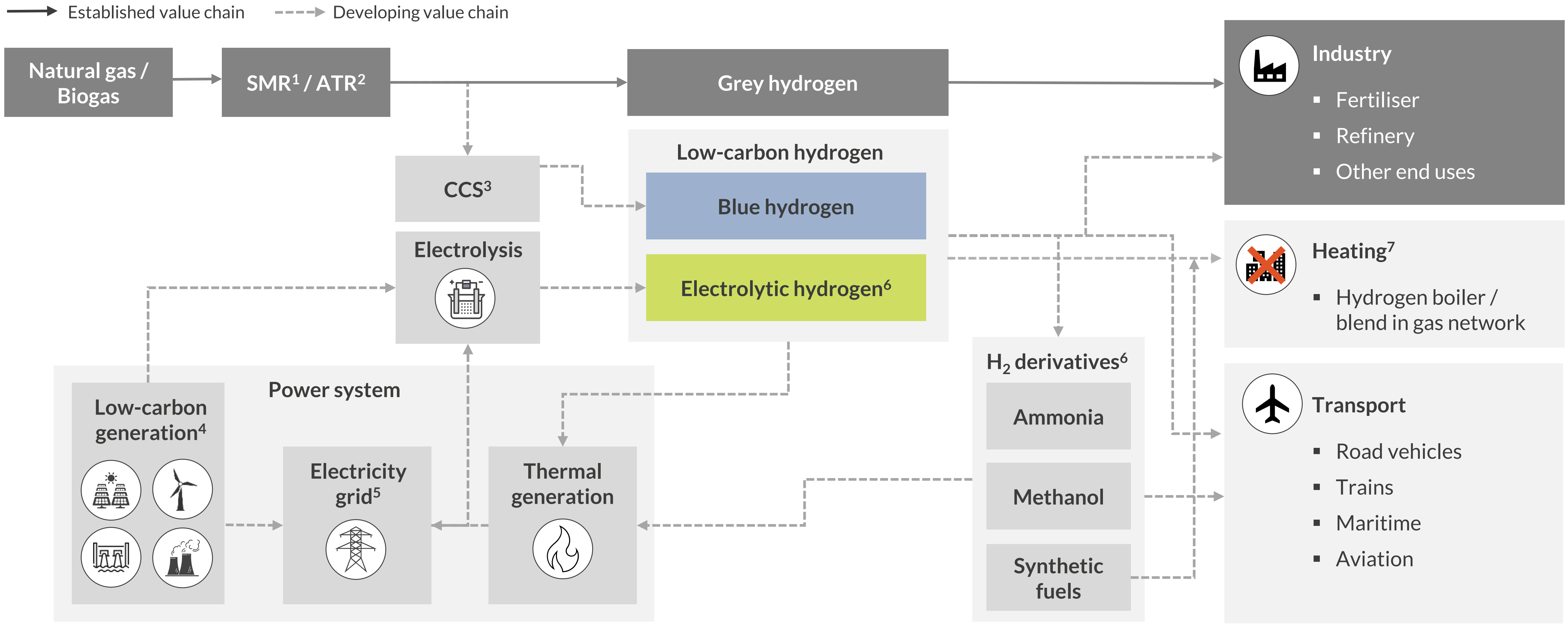
Hydrogen is used in many sectors, with low-carbon hydrogen driving new uses in industry and transport, adding complexity to the value chain

Nowadays, most hydrogen is produced from fossil fuel sources and used in chemical and other heavy industries. However, as low-carbon hydrogen starts playing a role in aiding decarbonisation of power and hard-to-abate sectors, the hydrogen value chain will become increasingly more complex.



1) SMR: Steam Methane Reforming; 2) ATR: Autothermal Reforming; 3) CCS: Carbon Capture and Storage; 4) According to the EC's Delegated Regulation (EU) 2023/1184, renewable H_2 producers may only directly connect with renewable energy sources; 5) (EU)2023/1184 applies restrictions on grid connection in renewable H_2 production; 6) May be categorised as RFNBO (Renewable fuel of non-biological origin) if compliant with EU standards; 7) No longer expect heating to be a significant end-use case;
Sources: Aurora Energy Research, European Commission

Current hydrogen supply is dominated by grey hydrogen, with low-carbon hydrogen remaining marginal

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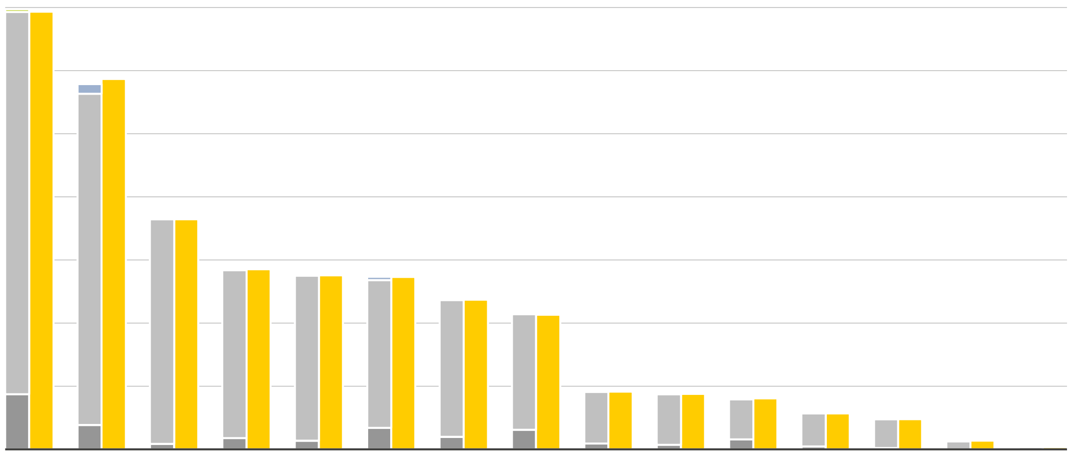

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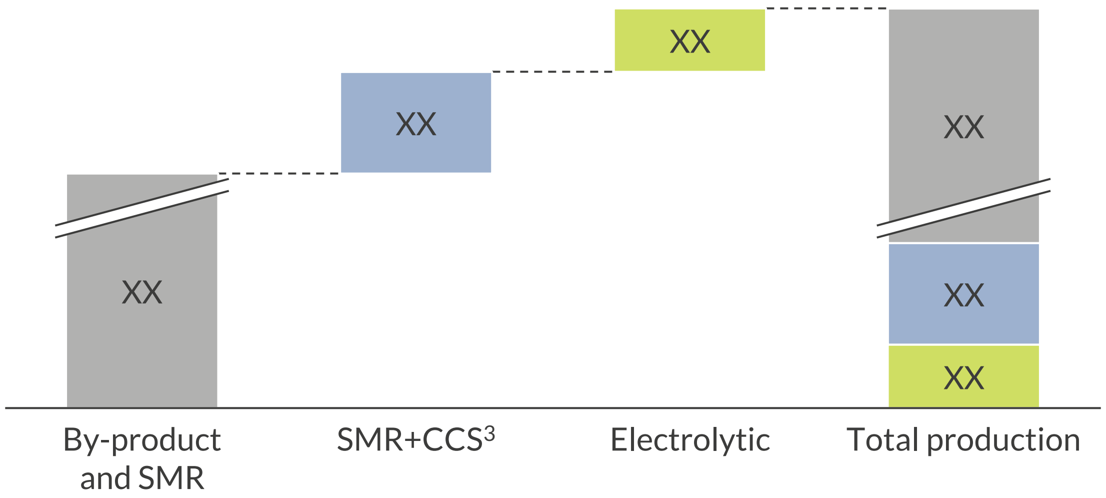

- Around 99% of hydrogen in Europe is produced from the steam methane reforming (SMR) process or derived as a by-product of chemical industries, usually referred to as grey hydrogen.
- SMR facilities are usually located in proximity to refining and fertiliser plants, the major offtakers of hydrogen.
- By-product hydrogen is produced via the chlor-alkali process or the production of ethylene or styrene in the petrochemical industry.

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By-product SMR SMR+CCS Electrolytic Demand

1) Only covers 15 HyMaR countries (DEU, NLD, POL, ESP, ITA, GBR, FRA, BEL, FIN, SWE, NOR, ROU, PRT, DNK, and IRL); 2) Latest available historic data from European Hydrogen Observatory; 3) CCS: Carbon capture storage;

Sources: Aurora Energy Research, European Hydrogen Observatory

While current H_2 demand is met by grey H_2, growing production, demand in new sectors, and infrastructure will eventually drive the renewable H_2 market

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Widespread evolution of the hydrogen market from today's fossil-heavy to future low-carbon will occur from multiple fronts

	Short-term (2025-2027)	Medium-term (2028-2035)	Long-term (2036-2060)
Supply	Fossil-based hydrogen continues to remain the dominant source of supply.	Electrolytic hydrogen[1] gradually scales up while grey hydrogen production is reduced.	Domestically produced electrolytic hydrogen and later imports become the dominant source of supply.
Demand	Total European hydrogen demand of 7Mt H_2 is mostly coming from industry.	Low-carbon hydrogen demand starts to increase in certain sectors such as ammonia, refineries, steel, aviation, and maritime.	Increased hydrogen demand in industry, transportation, and power generation.
Infrastructure	Limited infrastructure to utilise, transport, or store hydrogen due to volumes uncertainty.	Ramp up of hydrogen import facilities for derivatives, and more pipelines for pure H_2.	Better connected regions via pipelines, including regions from outside Europe.
Policy and market	High-level targets are set, but policy and regulatory frameworks are still being built.	Developed policy and regulatory frameworks, but projects require subsidies to varying extents to be viable.	Electrolytic hydrogen production costs are competitive with blue and grey hydrogen in many regions.
Financing and pricing	Electrolyser projects are typically heavily subsidised, generally on-site, and small-scale.	HPAs[2] with firm offtakers become increasingly important for securing financing, while subsidies remain crucial.	Liquid trading in the 2040s may allow for the financing of merchant projects.

1) Renewable/RFNBO hydrogen or low-carbon hydrogen; 2) HPA: Hydrogen purchase agreement;

Source: Aurora Energy Research

In the near-term, sustainable[1] hydrogen growth hinges on closing the cost gap with existing technology or alternatives

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Addressing the "missing money" problem for sustainable[1] hydrogen is a key challenge hindering market growth

The "floor" willingness to pay (WtP) represents the minimum price hydrogen must achieve to compete with existing technologies.

From a techno-economic standpoint, offtakers will only adopt low-carbon hydrogen if its production costs are on par with or lower than those of competing technologies.

Assuming cost parity, the difference in non-hydrogen costs defines the "floor" WtP—essentially the amount offtakers are willing to pay for H_2.

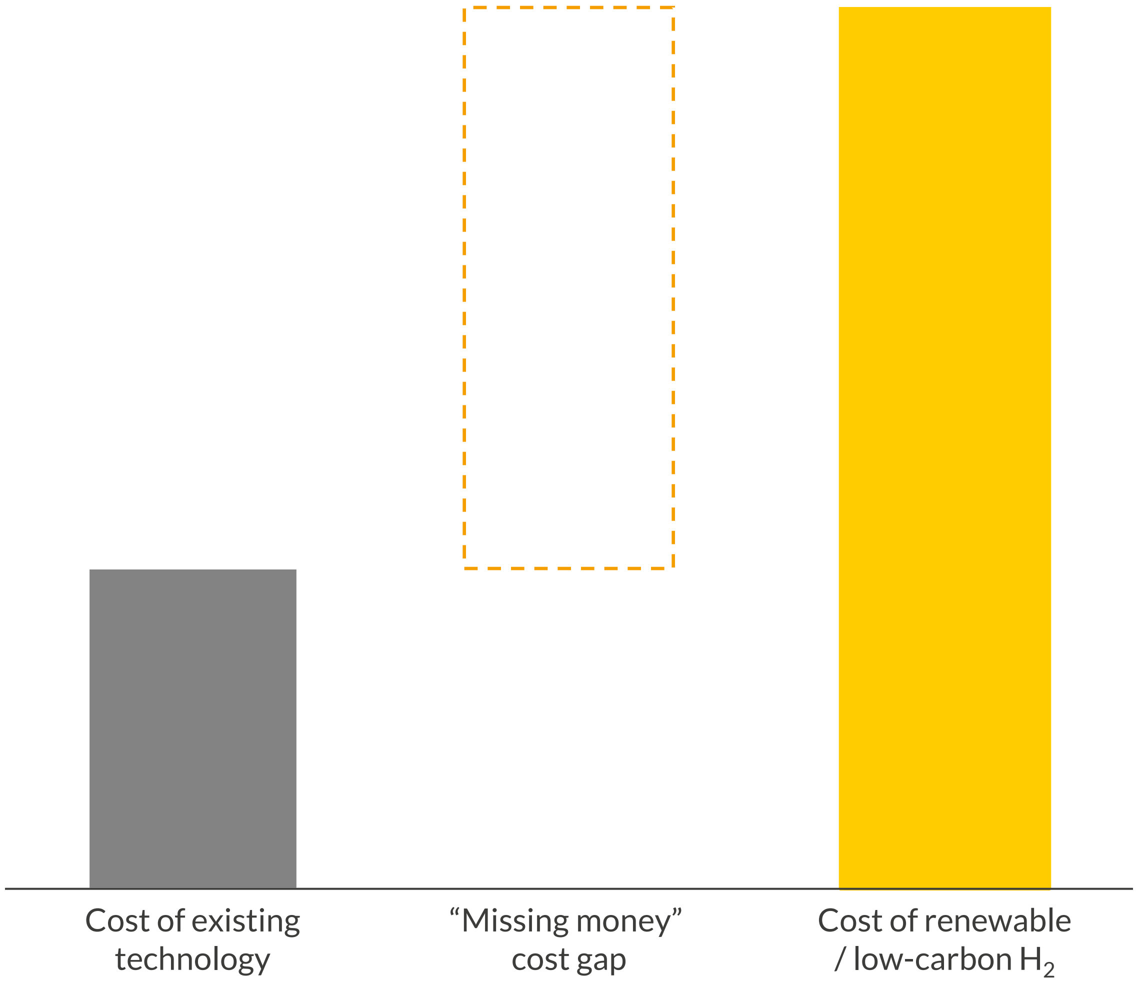
Additional costs above this floor can be mitigated through green premiums, subsidies, or avoided penalties, helping to close the "missing money" gap.

Among other aspects of the hydrogen market, this report explores:

- The floor willingness to pay across various sectors
- The levelised cost of hydrogen for low-carbon and renewable hydrogen across different electrolyser models and countries
- Policies and regulations that can help bridge the "missing money" gap

By analyzing these elements, we project future hydrogen demand and provide short-term and long-term pricing scenarios.

Illustrative graph displaying the "missing money" cost gap for sustainable[1] H_2

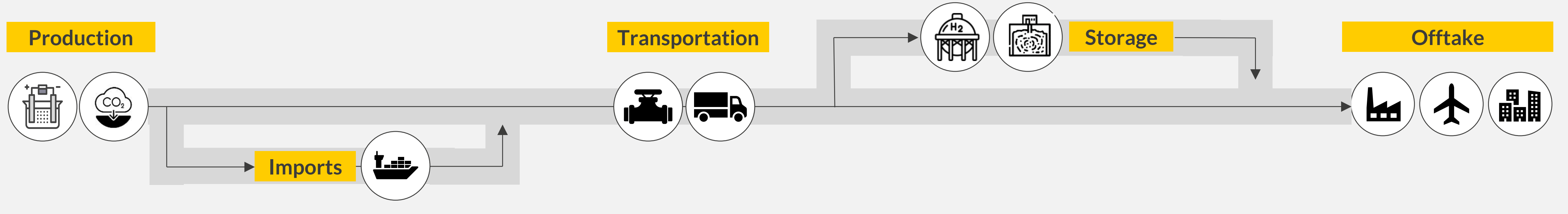


1) In this case "sustainable hydrogen" includes non-grey hydrogen, this includes, blue, renewable, low-carbon, etc.

Source: Aurora Energy Research

Given the nascent low-carbon H_2 market in Europe, there are opportunities to improve the economics of key value chain components as it grows

Challenges in developing a renewable/ low-carbon hydrogen market



Electrolysers

The levelised cost of hydrogen (LCOH) for electrolysis is high compared to grey H_2, primarily due to the combined costs of electrolysers and electricity.

Carbon capture storage (CCS)

Scaling up blue hydrogen and CCS faces challenges due to geographical limitations and the scale of infrastructure required.

Transportation infrastructure

- Transportation of hydrogen is expensive on a small-scale due to low volumetric energy density of H_2.
- Pipelines could be cheaper than small-scale transport options. However, newly built pipelines are capital intensive, and retrofitting could be challenging due to materials compatibility.
- Hydrogen's low energy density makes transportation difficult, with conditioning costs rising significantly when moved by truck or ship.

Import infrastructure

- Limited port capacity and infrastructure may restrict hydrogen export potential, giving an advantage to countries with more developed export facilities.

Hydrogen storage

- Above ground storage tanks are costly to construct and hold smaller amounts of H_2.
- Salt-cavern storage is less expensive than tanks but requires significant volumes of H_2 and additional infrastructure, which add costs, there are also geographical constraints.

Offtake

- Low-carbon H_2 has higher prices compared to existing fuels – a challenge to offtakers looking to transition from cheaper, but higher emissions, fuels/feedstock.
- The nascency of the market presents a lot of risks, therefore bilateral agreements are needed to derisk projects, however, offtakers hesitate committing to a long-term agreement with high prices.

Source: Aurora Energy Research

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We monitor developments in the hydrogen sector, covering market updates, policy and regulation news, and financial support announcements

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We closely track global developments across the entire hydrogen value chain. Over the past six months, we've compiled key highlights, covering essential trends and insights in the following areas:

Global hydrogen news

Market update

Key developments includes new project announcements, along with notable agreements between companies and international stakeholders. These updates offer valuable insights into shifting market dynamics, strategic partnerships, and the advancement of hydrogen infrastructure and initiatives.

Policy and regulation

News in the renewable / low carbon H_2 market focusing on government actions, legislation, and regulatory frameworks that impact the development and adoption of hydrogen technologies. This includes updates on subsidies, incentives, and funding initiatives aimed at accelerating hydrogen production, distribution, and usage.

Financial support

Announcements related to funding mechanisms and investment initiatives that drive the growth of hydrogen technologies. This includes updates on government grants, private sector investments, and public-private partnerships aimed at advancing hydrogen infrastructure, research, and commercialisation.

Electrolyser projects

Electrolyser project updates highlight advancements in deployment, capacity, and technology. These include new installations, efficiency improvements, cost reductions, and progress on large-scale projects as well as key milestones.

New projects and updates are also tracked in our electrolyser database.

Source: Aurora Energy Research

In the past six months, three hydrogen supply auctions have been launched by the EU, France, the Netherlands, and Germany

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Over the past six months, we've witnessed several significant policy and regulatory milestones, including the confirmation of future auctions supporting the production of renewable hydrogen at both an EU and national level. Progress on key transport and infrastructure developments has also been made.

Government auction-related news

18.11 **ESP** Spain is allocating between 280- 400mn € for the Auctions-as-a-Service (AaaS) scheme, using funds from its RRP.[4]

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Other policy and regulation news

13.11 **DEU** Germany approves draft law banning GHG certificate roll-overs, may boost demand for biogas and RFNBOs.[3]

REDACTED

1) IPCEI: Mitsui O.S.K Lines; 2) Sustainable Aviation Fuel; 3) RFNBO: Renewable Fuels of Non-Biological Origin; 4) RRP: Recovery and Resilience Plan

Sources: Aurora Energy Research, Hydrogen Insights, European Commission, H2Global, Dutch government, UK government

In the past six months, four projects have reached FID across Europe, accompanied by financial support for both supply and demand projects

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In the past six months, several hydrogen projects have reached final investment decision (FID), while several projects have been cancelled. Across Europe, countries continue to allocate funding to support the production of renewable hydrogen.

Financial investment decision-related news

12.09 **ESP** The first FID[1] for the HyVal project, Castellón Green Hydrogen Cluster, was taken. The 25MW plant will support the decarbonisation of operations at BP's Castellón refinery.

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Other financial investment news

6.11 **NOR** Enova has granted 65mn € in funding to five H_2 projects for end-use in maritime fuel in Norway.

REDACTED

1) Final Investment Decision; 2)Recover and Resilience Facility; 3) RRP: Recovery and Resilience Plan;

Sources: Aurora Energy Research, Hydrogen Insights, European Commission, UK government

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To grow the emerging low-carbon H_2 market, multiple policy ecosystems across various value chains at both European and national levels are required

European hydrogen ecosystems

- Targets
- Policy frameworks
- Standardisation
- Supply support mechanisms
- Demand support mechanisms
- Infrastructure

Individual EU/EEA HyMaR countries

BEL	DNK	FIN	FRA	DEU	IRL	ITA	NLD	NOR[1]	POL	PRT	ROU	ESP	SWE

In addition to the EU hydrogen ecosystems that apply to all HyMaR countries (except GBR), they also have their own country-specific frameworks that are added on top of the EU frameworks to offer more support, targets, and regulation.

Great Britain

GBR

Great Britain has its own hydrogen ecosystems that vary from the EU's.

1) Norway is not an EU member state, but is a part of EEA (European economic area) and qualifies for many EU-specific hydrogen policy ecosystems;

Source: Aurora Energy Research

All HyMaR countries have hydrogen strategies, but Germany, Spain and the UK have the highest electrolyser targets, with actionable policies

All HyMaR countries have hydrogen plans and policies, but their scope differs. The same applies to national electrolyser targets. While EU and EEA countries follow the EU's Delegated Acts (DA), the UK has established its own Low-Carbon Hydrogen Standard (LCHS).

Country	Policy and regulation (P&R)	**Targets,** *Electrolyser targets[1] (GW)*	Standardisation
EU	🟢	XX	DA[2]
BEL	🔴	XX	DA[2]
DNK	🟠	XX	DA[2]
FIN	🟠	XX	DA[2]
FRA	🟠	XX	DA[2]
DEU	🟢	XX	DA[2]
IRL	🔴	XX	DA[2]
ITA	🟠	XX	DA[2]
NLD	🟠	XX	DA[2]
NOR	🟠	XX	DA[2]
POL	🔴	XX	DA[2]
PRT	🟢	XX	DA[2]
ROU	🟠	XX	DA[2]
ESP	🟢	XX	DA[2]
SWE	🟠	XX	DA[2]
GBR	🟢	XX	LCHS[3]

🔴 Below average H_2 P&R relative to other HyMaR Countries 🟠 Average H_2 P&R relative to other HyMaR countries 🟢 Above average H_2 P&R relative to HyMaR countries

1) By 2026 for Belgium, by 2030 for all other countries; 2) DA: Delegated Acts; 3) LCHS: Low Carbon Hydrogen Standard; 4) 100GW of electrolyser capacity by 2030 is mandated by Net-Zero Industry Act;

Sources: Aurora Energy Research, National hydrogen strategies, European Union

Germany provides the most support for renewable H_2 supply and demand among HyMaR countries and boasts commitment to develop infrastructure

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Most HyMaR countries (except the UK and Norway[1]) are eligible for EU-wide support, with some also having additional mechanisms or dedicated pipeline projects. Key country-specific initiatives are outlined below and detailed later in the report.

✓ Added previously
✓ Added since Oct-24 HyMaR

Country	Supply support mechanism	Demand support mechanism	Infrastructure
EU	✓ EHB[2] auctions, IF[3], IPCEI[4], RRF[5]	✓ IF[3], IPCEI[4], RRF[5]	✓ European Hydrogen Backbone, TYNDP[6]
BEL		REDACTED	
DNK			
FIN			
FRA			
DEU			
IRL			
ITA			
NLD			
NOR[3]			
POL			
PRT			
ROU			
ESP			
SWE			
GBR			

1) Norway is not an EU member state, but is a part of EEA and qualifies for many EU-specific hydrogen policy ecosystems; 2) EHB: European Hydrogen Bank; 3) IF: Innovation Fund; 4) IPCEI: Important Projects of Common European Interest; 5) RRF: Recovery and Resilience Facility; 6) Hydrogen and Natural Gas Ten-Year Network Development Plan; 7) SAF: Sustainable Aviation fuel; 8) H2P: Hydrogen to Power;

Source: Aurora Energy Research

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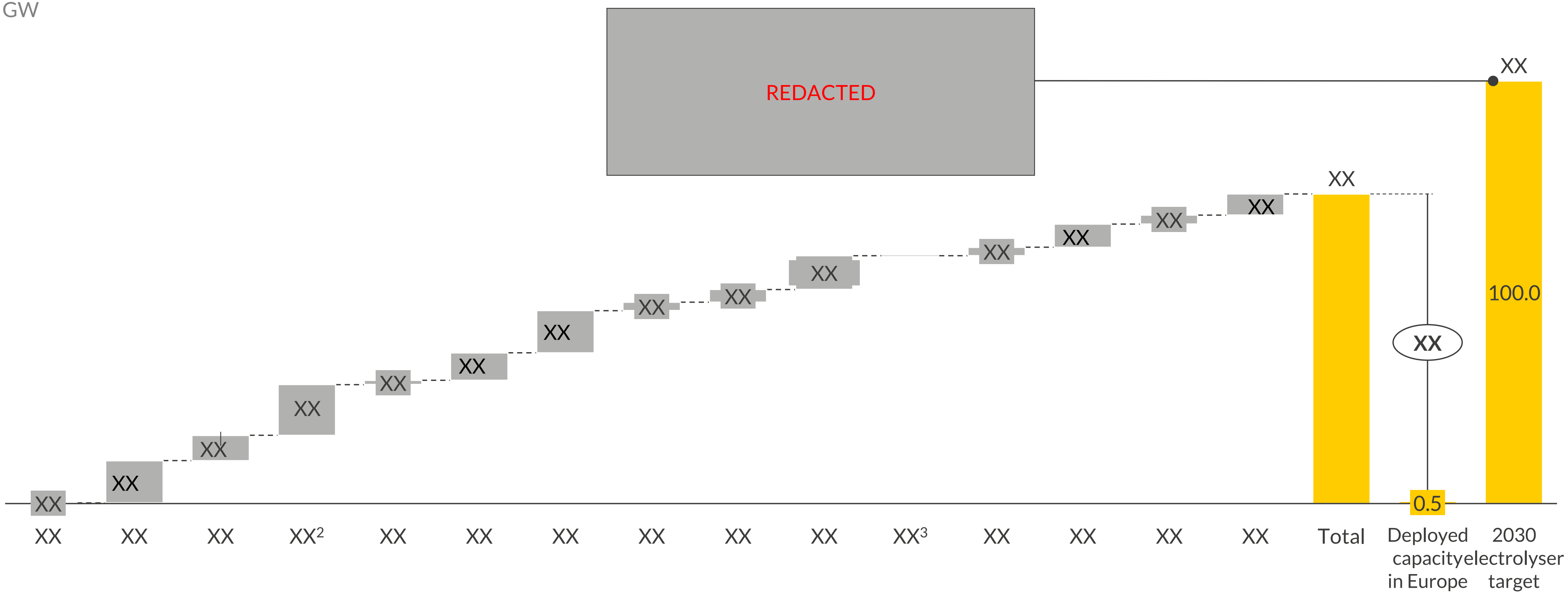
Many countries set ambitious electrolyser targets, which require REDACTED

Countries are setting targets to develop the renewable and low-carbon hydrogen market. These targets vary, with national goals focused on achieving specific electrolyser capacities and broader targets established across the EU and various sectors.

National electrolyser capacity targets in Europe by 2030 compared to global operational capacity as of end of 2023 and the 2030 EU renewable hydrogen target
GW



Sources: Aurora Energy Research, National hydrogen strategies, International Energy Agency

RED III[1] and RefuelEU[2] introduce binding targets and non-compliance penalties for Member States

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Targets and enforcement measures[3] by sector that relate to hydrogen

End-use sector	RED III Targets	Enforcement status	Liable entity	Non-compliance penalty
Industry	REDACTED			
Transport				
	RefuelEU and FuelEU			
Aviation	REDACTED			
Maritime				
	National Target			
Power	REDACTED			

REDACTED

1) RED III: Renewable Energy Directive (EU) 2023/2413; 2) Directives (EU) 2023/2405 and (EU) 2023/1805; 3) Non-exhaustive; 4) RFNBO: Renewable fuels of non-biological origin, in this case includes H_2 derivatives; 5) As of end of May 2025; 6) The fine shall be no less than twice the price difference between missing RFNBOs and conventional fuels; 7) Quotas applying from Jan 2025;
Sources: Aurora Energy Research, European Commission, BMWK

RED III[1] mandates are undergoing transposition across EU countries, with varying interpretations of its mandate

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RED III[1] mandates that 42% of industrial hydrogen comes from RFNBOs[2] by 2030, rising to 60% by 2060, with at least 1% of hydrogen in transport from RFNBOs by 2030. EU countries must transpose RED III into national legislation by May 21, 2025. However, there is still uncertainty as to when these mandates will be transposed.

Transposition	Comments	Source
	REDACTED	

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Sources: Aurora Energy Research, European Commission, BMWK Dentons, Finlex, Overheid

ReFuelEU Aviation's hefty fine, twice the amount of the missing fuel, could serve as a strong deterrent against non-compliance

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RefuelEU sets out specific mandates with detailed criteria:

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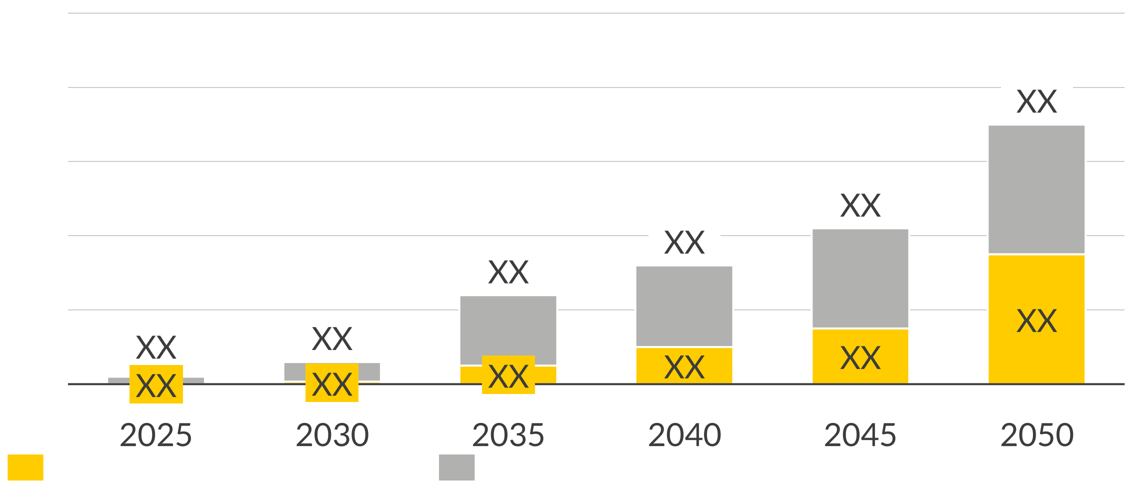

ReFuelEU has set minimum guidelines for penalties and enforcement:

REDACTED

Details of the minimum non-compliance penalty with an illustrative example:

REDACTED

In reality, this would be imposed on the fuel supplier in the following manner:

Illustrative example:

REDACTED

1) SAF: Sustainable Aviation Fuel; 2) E-fuels, also called electro-fuels or synthetic fuels include e-kerosene (also known as E-SAF); 3) RED: Renewable Energy Directive; 4) Prices for kerosene and e-kerosene are the conventional aviation fuel market price and synthetic low-carbon aviation fuel production cost estimate, respectively, as per the EASA 2024 Aviation Fuels Reference Prices for ReFuelEU Aviation. See the document here;

Sources: Aurora Energy Research, European Commission

FuelEU Maritime's steep penalties, rising costs for non-compliant fuel and strict emission reduction targets, could drive strong industry compliance

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FuelEU maritime sets out mandates in a similar way to ReFuelEU aviation

REDACTED

The decarbonisation targets under FuelEU Maritime:

	Decarbonisation % of sector
2025	XX
2030	XX
2035	XX
2040	XX
2045	XX
2050	XX

REDACTED

Under FuelEU three types of penalty have been implemented

REDACTED

1 FuelEU penalty with respect to power at berth (in €)

REDACTED

2 FuelEU penalty with respect to RFNBO[3] sub targets (in €)

REDACTED

2 FuelEU penalty with respect to compliance balance for GHG intensity (in €)

REDACTED

REDACTED

1) GHG: Green House Gas; 2) RED: Renewable Energy Directive; 3) RFNBO: Renewable fuels of non-biological origin; 4) Energy used from RFNBOs that fall short of the RFNBO target; 5) This is 1 metric ton of VLSFO which is equivalent to 41,000 MJ

Source: Aurora Energy Research, European Commission

Agenda

Agenda

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Both incentive and punitive-based frameworks are needed to drive supply and demand for the renewable/low-carbon hydrogen market

Building a hydrogen economy requires a diverse range of policy frameworks working in tandem. While no single approach is a silver bullet, a combination of these frameworks is essential to effectively generate both supply and demand for renewable/ low-carbon hydrogen across Europe.

	Types of frameworks	Definition	Example(s)
Incentive-based	**Subsidies and grants**	Government-provided financial support to lower costs and stimulate the supply of and demand for specific products or technologies.	Feed-in tariff (FiT), Contract for Difference (CfD), CAPEX/OPEX support
Incentive-based	**Financial incentives / deductions / exemptions**	Financial benefits that reduce costs for producers and consumers, encouraging both the supply and demand of targeted goods or services.	Tax incentive, retail charge exemptions
Incentive-based	**Certification and labelling**	Programs that verify and promote products meeting certain standards, boosting demand while incentivizing producers to meet supply criteria.	Green premium
Punitive-based	**Cap and trade (carbon pricing)**	A market-based system that limits overall emissions and allows trading of permits, driving demand for low-carbon options while pushing producers to supply them.	Carbon border adjustment mechanism (CBAM), EU-ETS[1]
Punitive-based	**Standards**	Regulatory requirements that set minimum performance or quality levels, compelling producers to meet supply thresholds and ensuring demand for compliant products.	RED II Delegated Acts (EU), Low-carbon hydrogen standard (UK)
Punitive-based	**Quotas and mandates**	Legal requirements that enforce minimum levels of production or consumption, ensuring a baseline supply while guaranteeing demand for specific products or energy sources.	Greenhouse gas quota (Germany), Renewable Transport Fuel Obligation (UK)

1) EU-ETS: European Union's Emissions Trading System;

Source: Aurora Energy Research

In the EU, a comprehensive decarbonisation policy framework provides targets and supports for the development of the hydrogen market

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Following the climate targets set in the Paris Agreement, the European Council and the European Commission established the European Green Deal in 2019, setting out the EU's climate strategy. A policy framework has been constructed to implement the Green Deal, and many parts of which engage with the hydrogen industry.

Fit-for-55 Package

Renewable Energy Directive (RED)

REDACTED

EC's Delegated Acts on Renewable Hydrogen[2]

REDACTED

EU ETS Reform[3]

REDACTED

RefuelEU Aviation

REDACTED

FuelEU Maritime

REDACTED

RePowerEU Plan

REDACTED

Recovery and Resilience Facility (RRF)

REDACTED

Net-Zero Industry Act

REDACTED

Net-Zero Strategic Projects

REDACTED

IMO[7] Maritime Legislation

REDACTED

EU's Low-Carbon Hydrogen Standard

REDACTED

Clean Industrial Deal

REDACTED

Clean Steel and Metals bill

REDACTED

Policy package | Standardisation | Targets | Supporting mechanism | New policy framework

xx

Sources: Aurora Energy Research, European Commission

The European Commission has many funding instruments that support renewable hydrogen initiatives across the value chain in Europe

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The EU budget facilitates the deployment of renewable and low-carbon H_2 to achieve the 55% GHG reduction target by 2030 and climate neutrality by 2050. A range of EU funding instruments supports various H_2 activities, with the possibility of combining multiple sources of funding for individual projects, if there is no overlap in cost coverage.

EC[1] funding instrument	What it funds
Connecting Europe Facility - Energy	REDACTED
Connecting Europe Facility – Transport	REDACTED
European Regional Development, Cohesion Fund (ERDF)	REDACTED
Horizon Europe	REDACTED
Innovation Fund	REDACTED
InvestEU	REDACTED
Just Transition Fund	REDACTED
LIFE programme	REDACTED
Modernisation Fund	REDACTED
Recovery and Resilience Facility (RRF)	REDACTED

1) EC: European Commission;

Sources: Aurora Energy Research, European Commission

The UK government has announced multiple policies to achieve its target of 10GW of hydrogen production capacity by 2030

	Documents	Details	Important dates
Strategy	UK Hydrogen Strategy	REDACTED	
Support mechanisms	Hydrogen Business Model and Net Zero Hydrogen Fund: Electrolytic Allocation Round	REDACTED	
Transport & Storage (T&S)	Hydrogen transport and storage infrastructure: minded-to positions	REDACTED	
	Hydrogen transport and storage: business model	REDACTED	
Fuel mandates	Sustainable Aviation Fuel (SAF[5]) Mandate	REDACTED	

1) Revised to 10GW in the August 2023 UK Hydrogen Strategy update; 2) Carbon capture, use and storage; 3) HTBM: Hydrogen Transport Business Model; 4) HSBM: Hydrogen Storage Business Model; 5) Sustainable Aviation Fuel

Sources: Aurora Energy Research, DESNZ

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With several labels for low-carbon H_2, understanding global hydrogen standards is key for interoperability across global markets

Hydrogen standardisation seeks to establish consistent standards across local, regional, and global levels. Currently, standards vary not only between regions but also across different production methods.

Country-specific hydrogen standards

Carbon emission standard

- Renewable H_2 - RFNBO[1] H_2
- Low-carbon H_2
- Low-carbon H_2
- Clean H_2
- Green hydrogen
- Clean H_2
- Low-carbon H_2
- Low-carbon H_2[3]

REDACTED

Additional "general" names used for various types of hydrogen

- **Grey H_2**: produced from natural gas through SMR or ATR without carbon capture, leading to significant CO_2 emissions.
- **Blue H_2**: produced from natural gas through SMR or ATR with carbon capture storage, leading to low CO_2 emissions.
- **Electrolytic H_2**: produced by the electrolysis of water, oftentimes using at least some renewable energy.
- **Sustainable H_2**: A broad term encompassing most sustainably-focused, non-grey hydrogen production methods.
- ❌ **Green H_2**: The term "green hydrogen" has become too ambiguous, with its meaning differing widely depending on who uses it and where. Thus, we no longer use this term.

1) RFNBO: Renewable fuel of non-biological origin; 2) Delegated Acts 1 and 2; 3) See Aurora's public webinar on the National Low Carbon Hydrogen Policy; 4) <3.38kgCO_{2eq}/kgH_2, for HHV the standard would be <4kgCO_{2eq}/kgH_2; 5) Low-carbon hydrogen standard draft in the EU is currently under review and is expected to be finalised by Q4 2024;

Sources: Aurora Energy Research, European Commission, DESNZ, AFDC, Indian Ministry of New and Renewable Energy, Renewable Energy Institute

Efforts are underway to establish a universal standard as a prerequisite for the development of a robust international low-carbon hydrogen market

Global certification for hydrogen is essential for ensuring market confidence, facilitating trade, attracting investment, and promoting interoperability of infrastructure worldwide. It also contributes to accurately measuring and mitigating the environmental impact of hydrogen production, supporting global sustainability goals. The new standard, introduced by ISO at COP28, aims at aligning basic methodologies to pave the way for a universally accepted regulatory framework.

ISO Standards

REDACTED

REDACTED

REDACTED

United States

CO2

REDACTED

United Kingdom

CO2

REDACTED

European Union

CO2

REDACTED

1) According to Inflation Reduction Act Section 45V tax credits the upper threshold to access credits. The maximum level of tax credits is available for 0.45 $kgCO_2/kgH_2$;

Sources: Aurora Energy Resource, HM Government, US DOE, European Commission

Hydrogen produced according to the UK LCHS[1] does not automatically comply with RED II, hindering potential trading between the UK and the EU

REDACTED

	RED II Delegated Act 27 & 28	Low Carbon Hydrogen Standard (LCHS)	Renewable Transport Fuel Obligation (RTFO)
Geography	REDACTED		
Additionality			
Temporal correlation			
Emission threshold			

REDACTED

1) LCHS: Low Carbon Hydrogen Standard; 2) The emissions for Low Carbon Hydrogen Standard include Scope 1, Scope 2 and partial Scope 3 emissions;

Sources: Aurora Energy Research, European Commission, UK Department for Energy Security and Net Zero, UK Department for Transport

The EU Delegated Acts set out criteria for electrolytic hydrogen to be certified as renewable

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The European Commission published two Delegated Acts in June 2023, setting out detailed rules on the EU criteria for renewable hydrogen, providing regulatory certainty to investors.

To be deemed as producing renewable H_2[1], the electrolyser must fulfil all three criteria:

Additionality: There must be a newly-built renewable asset that comes into operation at max. 36 months before the electrolyser. The renewable asset must not have received subsidies. Subsequent PPAs are allowed.

- Additionality is compulsory for assets that start operation after 1 January 2028.

Geographical correlation: The renewable asset and the electrolyser should be geographically correlated. The renewable asset and electrolyser should be within the same bidding zone or neighbouring ones.

Temporal correlation: The power generation and hydrogen production must match in a certain timeframe. This is monthly until 1 January 2030, and hourly afterwards (can be shifted with a new storage asset).

- Temporal correlation is complied with in an hourly period when the clearing price is <20 €/MWh or 0.36 times the price allowance to emit one tonne of carbon dioxide equivalent at the time of hydrogen production.

Scenarios when certain criteria may be exempt

Power sourcing strategy		⊕	🌐	🕓
Off-grid (islanded)	Electrolyser directly connected to a RES asset[2,3]	✗	✓	✓
Grid-connected (PPA required)	Electrolyser that is connected to the grid	✗	✗	✗
Grid-connected (PPA required)	Electrolyser located in a bidding zone with average grid carbon intensity < 64.8 gCO_2/kWh	✓	✗	✗
Grid-connected (PPA required)	Electrolyser using power that would have been curtailed otherwise	✓	✗	✗
Grid-connected	Electrolyser located in a bidding zone where average RES share in electricity mix >90%[2,4]	✓	✗	✓

✓ Criterion already fulfilled ✗ Criterion needs to be met

1) Renewable hydrogen also referred to as RFNBO (Renewable fuel of non-biological origin) hydrogen; 2) RES: Renewable energy asset; 3) However, if the RES asset is connected to the grid, smart metering is necessary to provide evidence that no electricity is taken from the grid to produce hydrogen; 4) With the condition of electrolyser running less than the renewable mix i.e. an electrolyser must not run more than 90% if the grid capacity mix has 90% renewables;

Sources: Aurora Energy Research, European Commission

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To build a low carbon and renewable hydrogen market, financial support is needed across the hydrogen value chain from governments

Section focus

	Production	Offtake	Infrastructure
	Supply support	*Demand support*	*Supply and demand support*

REDACTED

Support types

How support is offered

1) CCS: Carbon capture and storage; 2) IPCEI: Important project of common European Interest;

Source: Aurora Energy Research

Among various supply support mechanisms, auctions are the most popular in Europe, with over 13bn € committed to initial rounds

Supply-side support is needed to ease the burden on project developers and kickstart the low-carbon/renewable hydrogen value chain. Such incentives and support schemes are common across Europe and beyond, they can be broken down into three broad categories:

Non-bidding selection	General incentives	Competitive bidding

Selection

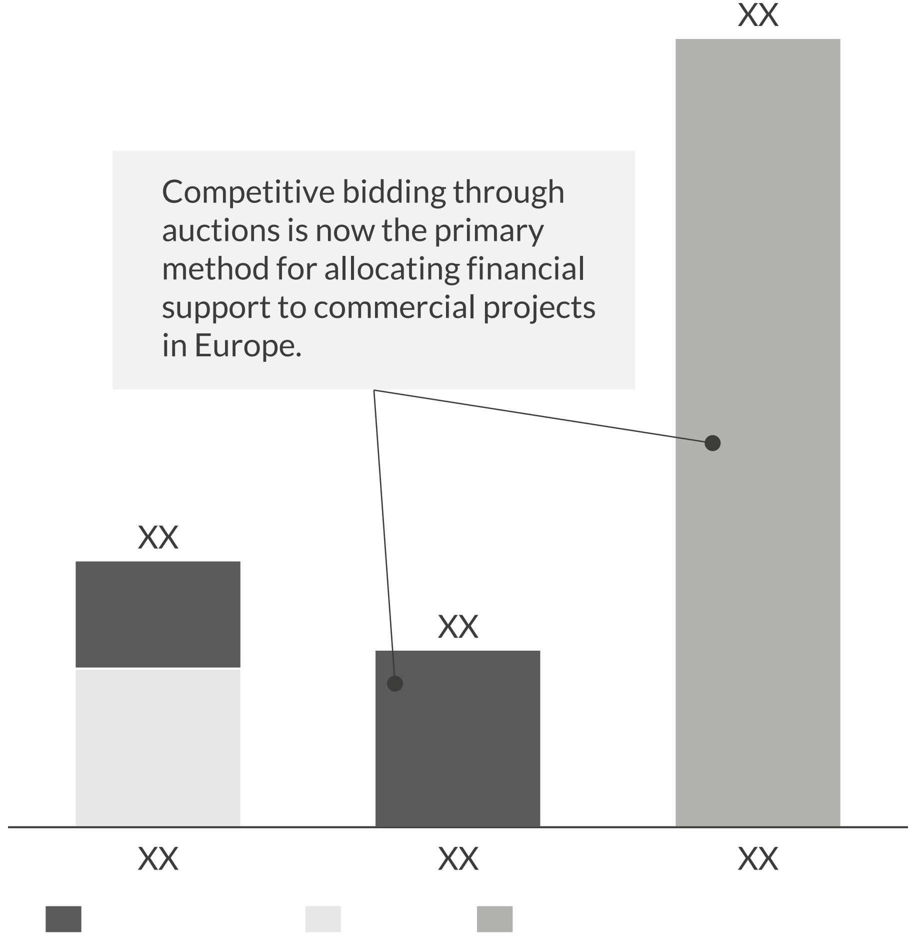
Examples

Support

REDACTED

Financial support to H_2 production projects by initiative and funding source

million €



REDACTED

Sources: Aurora Energy Research; European Commission

There are four main auction designs, each suited to specific use cases and often combined for added benefits

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1 Fixed premium

REDACTED

Strike price

2 Contract for difference

REDACTED

3 Direct CAPEX support

REDACTED

Long-term HPA

4 Double-sided auction

REDACTED

1

1 Fixed premium

- A preset, fixed amount of revenue at regular intervals
- Applied to demand or supply

2 Contracts for difference

- Payment based on the auction strike price relative to a reference price
- Support payment if strike price < reference price; payout[1] if strike price > reference price
- For CCfDs[2] which are applied to the demand-side, the support/ payout may be hedged to the cost of carbon externalities[3]

3 Direct CAPEX support

- Financial assistance/funding to cover upfront capital expenses
- Applied to demand or supply

4 Double-sided auction

- Buyers and sellers both bid, the intermediary uses funds to fill in the monetary gap

1) Payout refers to the amount that must be paid back by the producer to the counterparty; 2) CCfD: Carbon Contracts for Difference; 3) For instance, EU-ETS market;

Sources: Aurora Energy Research, IPECO, European Commission

Since Q3 2023, 4.3bn € of funding has been distributed via auctions to electrolyser projects in Europe, funding more than 1.9GW+ of capacity

Starting in Q3 2023, countries and regions have begun announcing the results of the winners of their renewable/low-carbon auctions.

	Scheme	Auction type	Awarded budget	Contract	Capacity	# of winning projects	Average grant amount	Main end-use	Date announced	Aurora deep dive
	PtX scheme	Fixed premium	167.7mn €	10 years	150MW	5	0.17 – 1.25 €/kg H_2	Industry and transport	Oct 2023	Insights report (pages 9 and 10)

REDACTED

1) This is the weighted average strike price, which is equal to £241/MWh (equivalent to £9.5/kg H_2); 2) This is fixed price contract; 3) A total budget for H2Global 1 is 900mn €, with the additional funds going towards other parts of the two-sided auction, additional rounds; 4) A purchase contract worth up to 397mn €, at a total price of 1,000 €/tonne of ammonia and a net product price of 811 €/tonne of ammonia; 5) EHB: European Hydrogen Bank;

Source: Aurora Energy Research

Building on the success of recent auctions, Europe has announced several new auctions, offering over €8bn in funding to accelerate hydrogen production

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Overview of current and upcoming key hydrogen auction schemes[1]

Scheme	Auction type	Support	Budget	Contract	Key milestone
EHB[4] Round 2	Fixed premium	4 €/kg	1.2 bn €	10 years	Launch: Dec 2024

REDACTED

REDACTED

Sources: Aurora Energy Research, European Commission, Hydrogen Insights

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To build a low-carbon and renewable hydrogen market, financial support is needed across the hydrogen value chain from governments

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Section focus

	Production	Offtake	Infrastructure
	Supply support	*Demand support*	*Supply and demand support*
Support types	REDACTED	REDACTED	REDACTED
How support is offered			

1) CCS: Carbon capture and storage; 2) IPCEI: Important project of common European Interest;

Source: Aurora Energy Research

There are several demand support mechanisms available; however, most auction-based support focuses on supply

Demand-side support is essential to stimulate market uptake and accelerate the adoption of low-carbon or renewable hydrogen across various sectors. These incentives and assistance mechanisms, commonly seen throughout Europe and globally, can be categorised into three main areas:

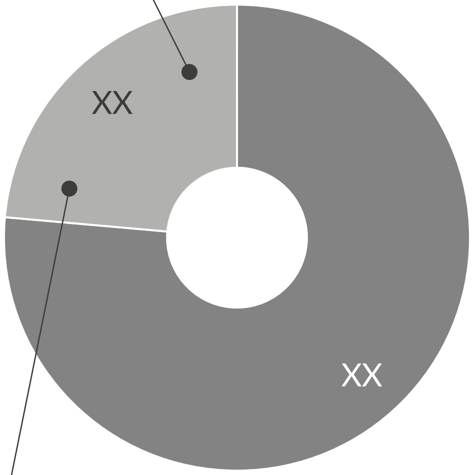
	Non-bidding selection	General incentives	Competitive bidding
Selection	▪ Project-related criteria	▪ Eligibility/qualification criteria[1] ▪ Environmental impact and fairness[1]	▪ Financial bid ▪ Project-related and eligibility/qualification criteria[2]
Examples	▪ Grants and direct funding (IPCEI[3], RRF[4], IF[5] projects) ▪ Public procurement	▪ Tax credit (USA) ▪ Carbon pricing (ETS) ▪ Renewable fuel quotas (GHG Quota – deep dive, RTFO)	▪ Contracts for difference (CfD) ▪ Purchase agreement auction (H2Global – deep dive)
Support			

Investment | Construction | Operation | Lump sum support | Production-based support

Number of auctions in Europe with financial supply and demand support

%

In Europe, most auctions taking place are focused on supply-support with H2Global offering demand-support along with supply-support.



UK Government recently announced it is minded to use a DPA[6]-style agreement for its H2P[7] Business model.

Auctions with supply support | Auctions with demand support

1) Prerequisite for different initiatives include lifecycle GHG emission intensity and specific production technologies; 2) Including but not limited to innovation, maturity, replicability, lifecycle emission, cost efficiency, hydrogen production process constraints; 3) Important Projects of Common European Interest; 4) Recovery and Resilience Facility; 5) IF: Innovation Fund; 6) Dispatchable Power Agreement; 7)Hydrogen to Power

Sources: Aurora Energy Research, European Commission

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Several infrastructure projects are planned across Europe, with many targeting completion in the 2030s

Overview of key hydrogen network initiatives and projects across Europe

Initiative	Region /Country	Description
European Hydrogen Backbone	Europe	A plan to create a pan-European hydrogen pipeline network, connecting hydrogen supply and demand across Europe.

REDACTED

1) PCI: Projects of Common Interest; 2) EC: European Commission;

Sources: Aurora Energy Research, European Hydrogen Backbone, Entsog, Elering, Nordic hydrogen corridor, H2Med, SoutH2 Corridor, Baltic Sea Hydrogen Collector, National Gas

The European Hydrogen Backbone proposes four[1] major hydrogen supply corridors by 2030, with over 70% of pipelines repurposed from gas

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A North Africa & Southern Europe

REDACTED

B Southwest Europe & North Africa

REDACTED

C Nordic and Baltic regions

REDACTED

D East and South-East Europe

REDACTED

Five supply corridors proposed by the European Hydrogen Backbone

X Proposed supply corridors

Positive factors

Potential uncertainties

Countries included in the European Hydrogen Backbone

1) The fifth proposed corridor - the North Sea corridor, was recently cancelled in September 2024 citing lack of funding and demand;

Sources: Aurora Energy Research, European Hydrogen Backbone

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Aurora's electrolyser database has a total capacity of

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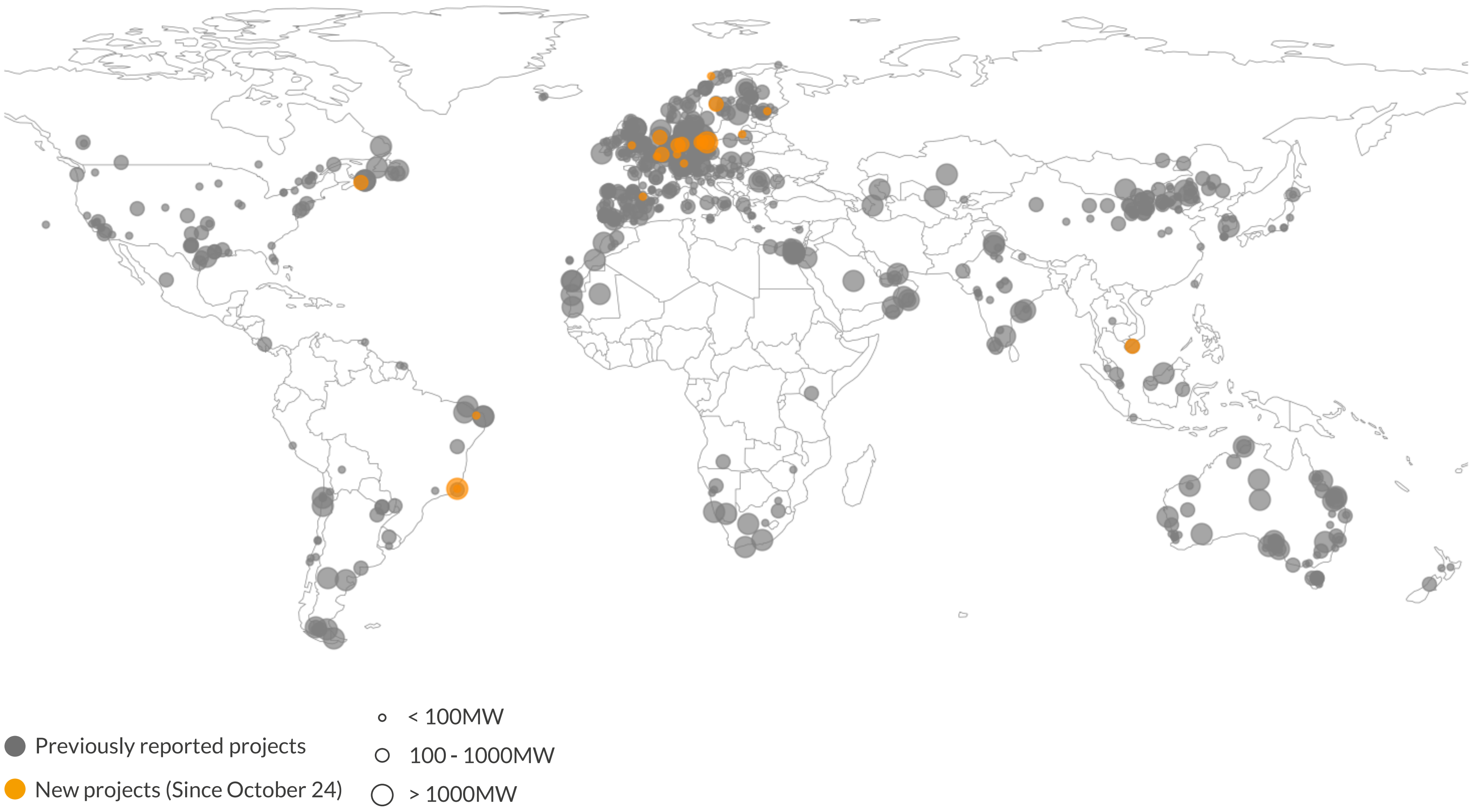

REDACTED

Source: Aurora Energy Research

Of the total 1.3TW, 114GW of projects are at the development stage, 32% of which is planned to be commissioned by the end of 2026

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Global cumulative electrolyser project capacities

Since October 2024, 6.1GW of new projects have been added to Aurora's global electrolyser database, along with updates to existing projects, particularly regarding status and capacity.

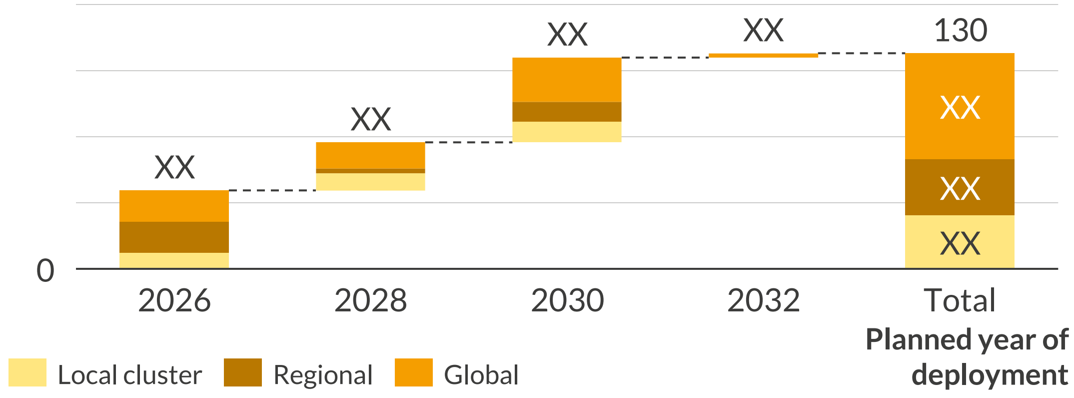
1

2

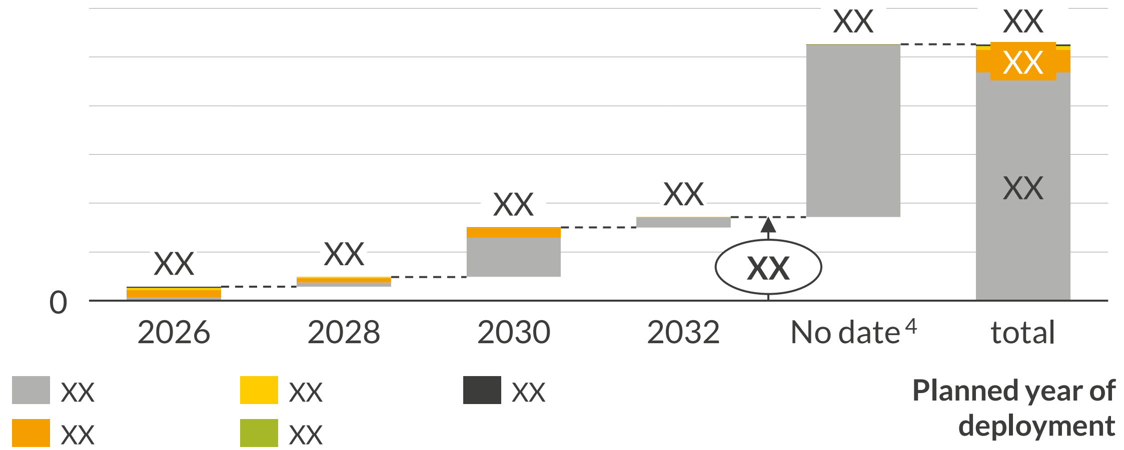
3

REDACTED

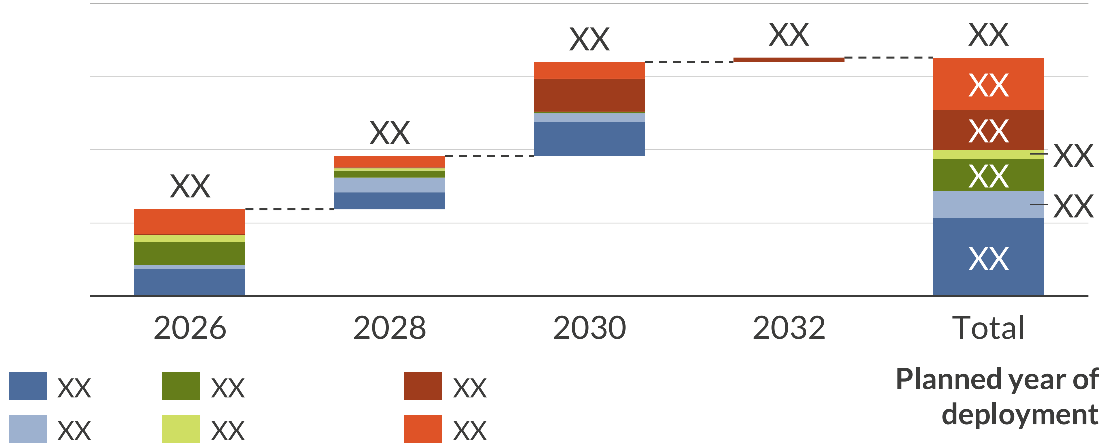
2 REDACTED



1 REDACTED



3 Capacity by continent (excluding early-stage projects)[3], GW



XX

Source: Aurora Energy Research

Since Sep-2024, four new projects totalling 275MW reached FID, with refineries expected to offtake 255MW

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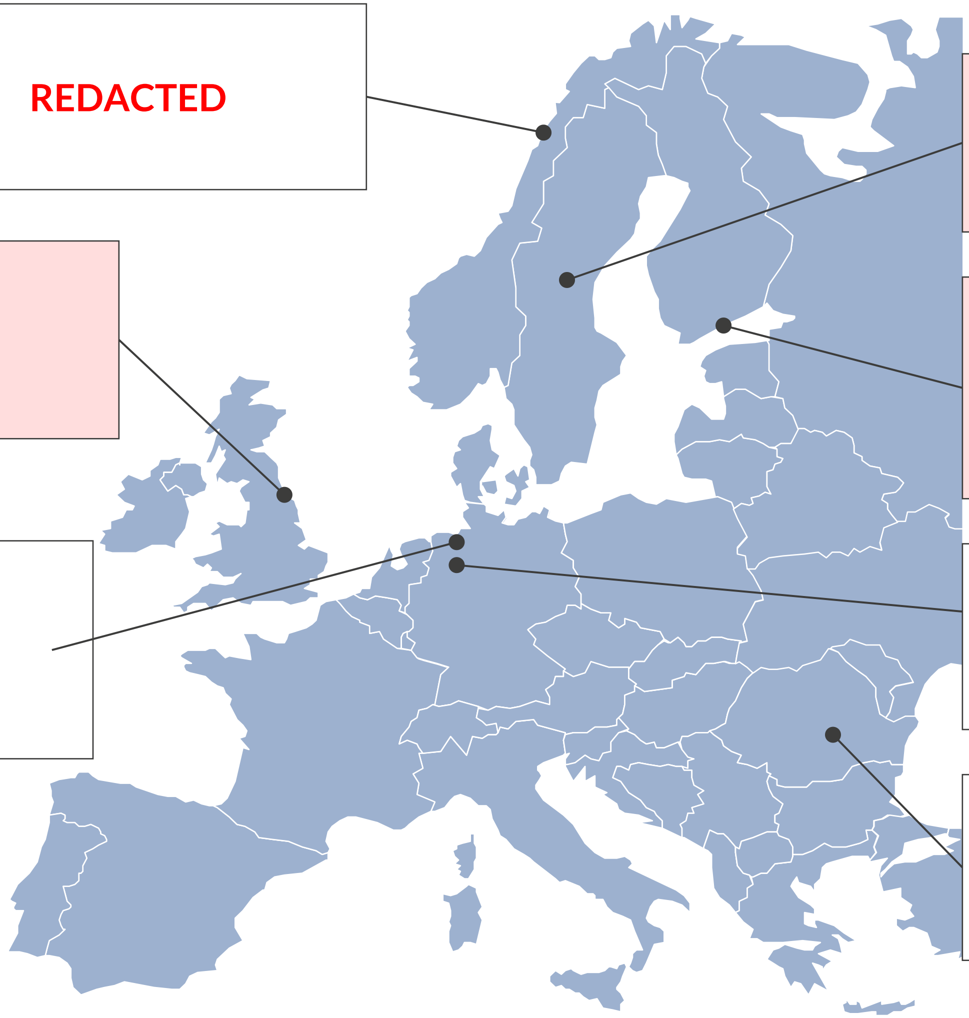

REDACTED

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Refineries are a key offtaker for projects reaching FID, this is driven by several factors:

- RED III regulation targets 42% renewable industrial hydrogen and 1% for transport by 2030, driving up demand for RFNBO[1] hydrogen.
- Existing hydrogen infrastructure in refineries enables an easier switch to RFNBO, allowing oil and gas companies to internally finance projects and reduce external risks.

REDACTED

1) RFNBO: Renewable Fuels of Non-Biological Origin;

Source: Aurora Energy Research

Over the past two years, a total of 6.2GW has reached FID globally, while 7.3GW has been cancelled—signalling a re-shaping of the market

Projects that have reached FID in Europe (2024 -2025)					
Name	Capacity	Partners	Offtaker	Location	FID announced
REDACTED					

Projects that have been cancelled in Europe (2024 - 2025)					
Name	Capacity	Partners	Offtaker	Location	Cancellation date
REDACTED					

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Germany continues to lead the way in Europe, with almost 9GW of projects at advanced development stages by 2030

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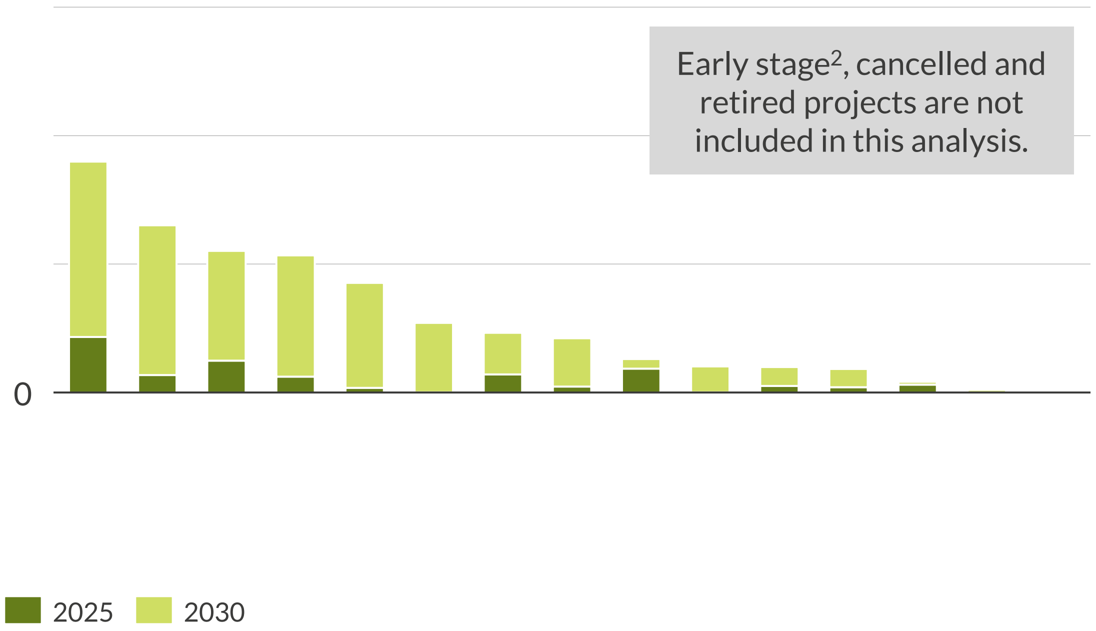
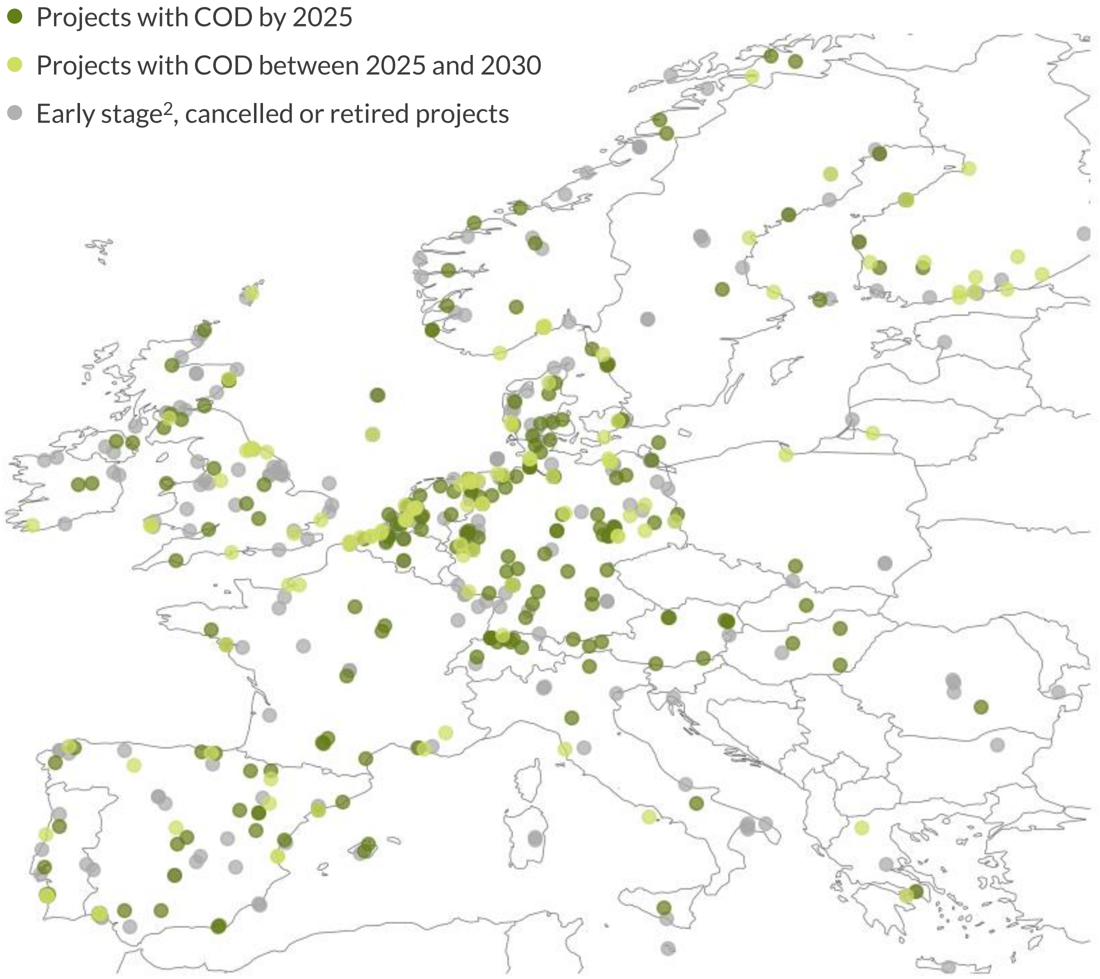
Since October 2024, 19 new European electrolyser projects have been added to Aurora's global electrolyser database

REDACTED

REDACTED





1) These project capacities are extracted from Aurora's global electrolyser database, which keeps track of all announced electrolyser projects globally. The timeline and the capacities provided in these charts might not necessarily be achieved fully; 2) Early-stage projects are in planning or discussion stages without clear timeline or capacity plans or projects that are planned to be commissioned in +8 years;

Source: Aurora Energy Research

Mobility is the most named hydrogen offtaker by number of projects, but industry wins out in terms of capacity

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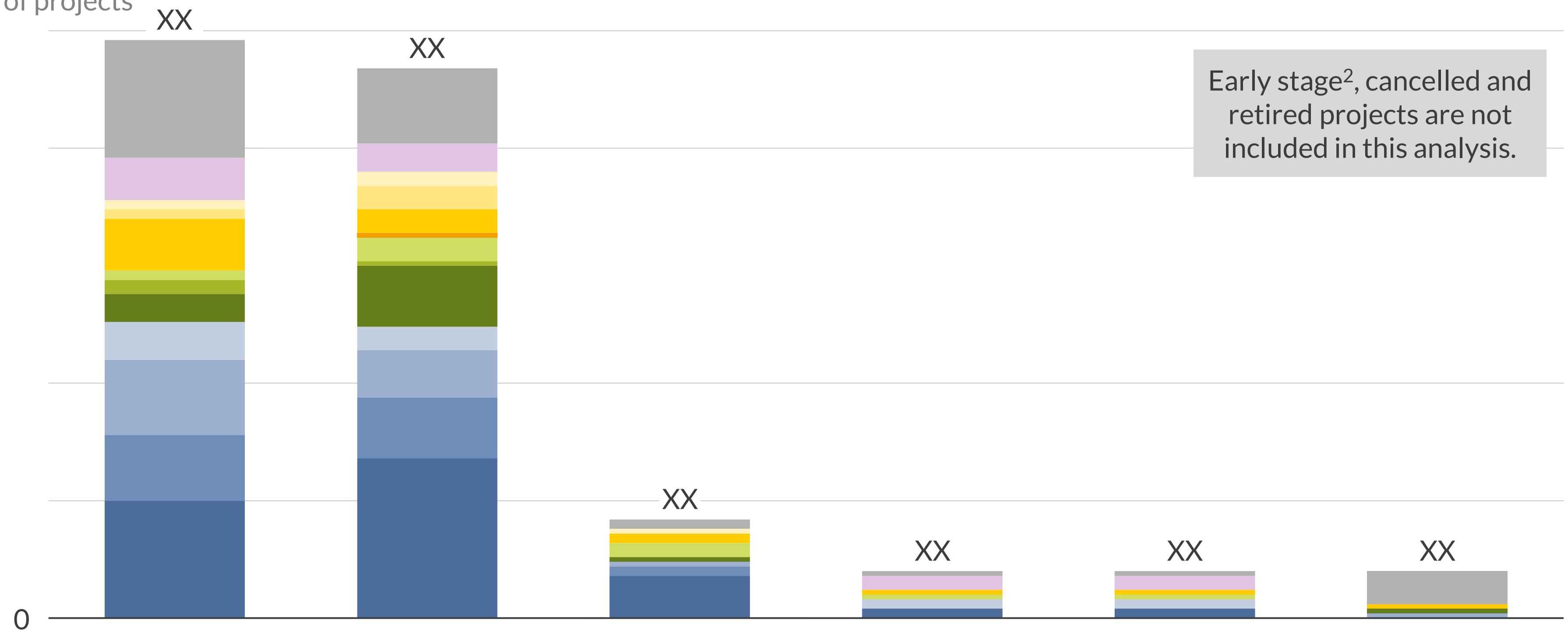
Number of projects by end-use for European countries

# of projects



REDACTED

Total capacity
GW

XX	XX	XX	XX	XX	XX

Comments:

REDACTED

1) "Others" includes CZE, GRC, ISL, SVK, FIN, UKR, and POL; 2) Early-stage projects are in planning or discussion stages without clear timeline or capacity plans or projects that are planned to be commissioned in +8 years;

Source: Aurora Energy Research

XX of European projects will be powered by wind energy only, followed by solar (XX) and other renewables (XX)

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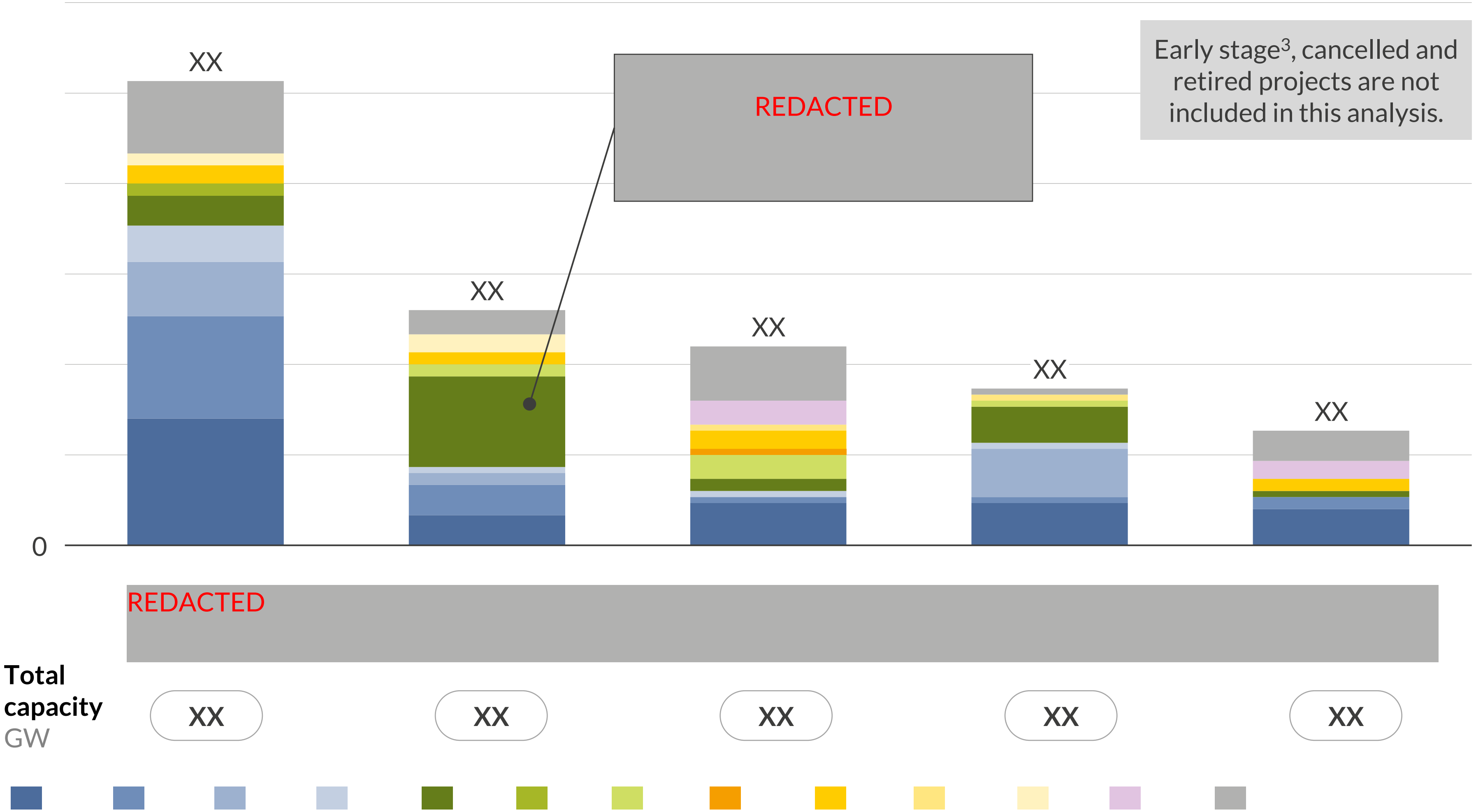
Number of projects by power source for European countries

of projects



Comments:

REDACTED

1) Includes hydropower, geothermal, tidal and projects that only indicate the power comes from renewables; 2) A combination of more than one renewable power source; 3) Projects are in planning or discussion stages without clear timeline or planned to be commissioned in +8 years; 4) "Others" includes CZE, GRC, ISL, SVK, ROU, POL, UKR, BGR and HUN;

Source: Aurora Energy Research

By 2030 Plug Power leads in number of projects in Europe, followed by NEL and ITM Power

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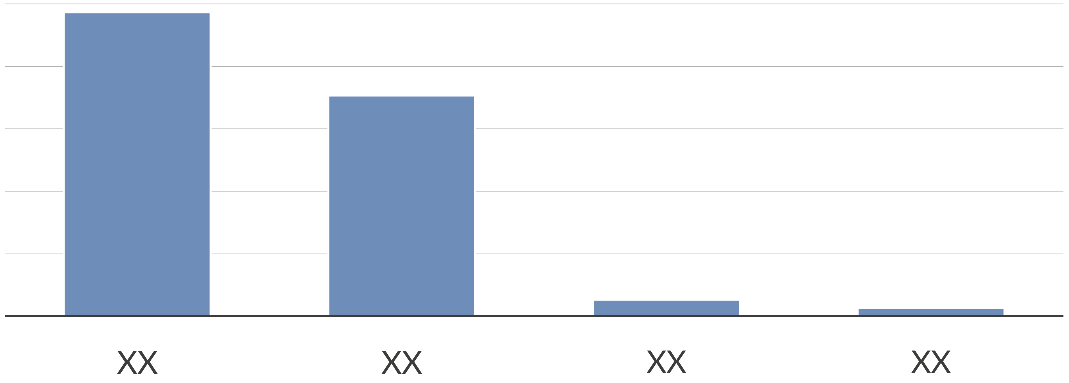
REDACTED

REDACTED

184 European projects to be commissioned by 2030 have specified an electrolyser manufacturer

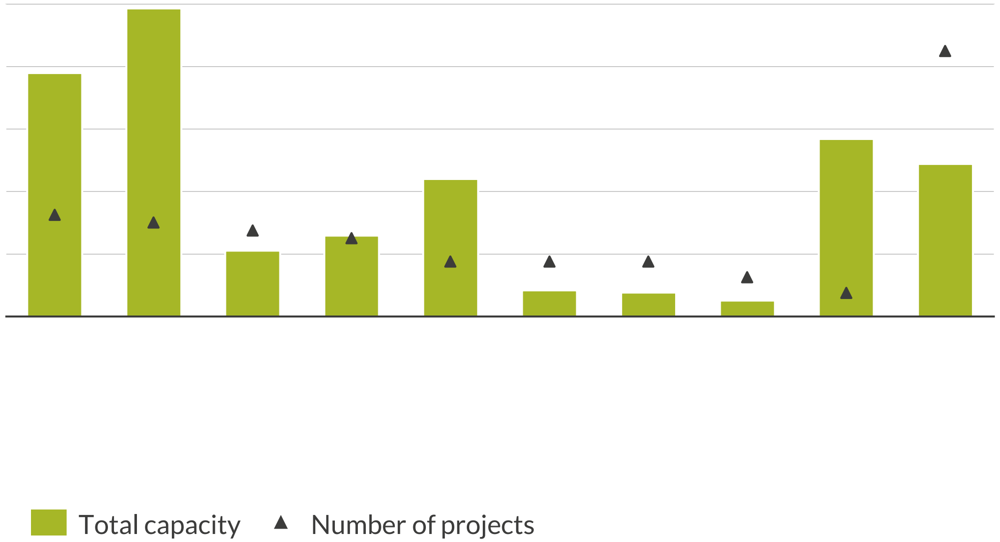
REDACTED

REDACTED



Total planned capacity by 2030 for Europe
GW

Total number of projects by 2030
# of projects



1) “Others” include Metacon, Elogen, Stiesdal, Ceres, Stargate, Carbotech, Battolyser, Topsoe, Hystar, FEST, Clean Power, Hydrogen, and CPH2;

Source: Aurora Energy Research

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European electrolyser capacity grows to more than 16GW in 2030, missing RePowerEU targets by 83%

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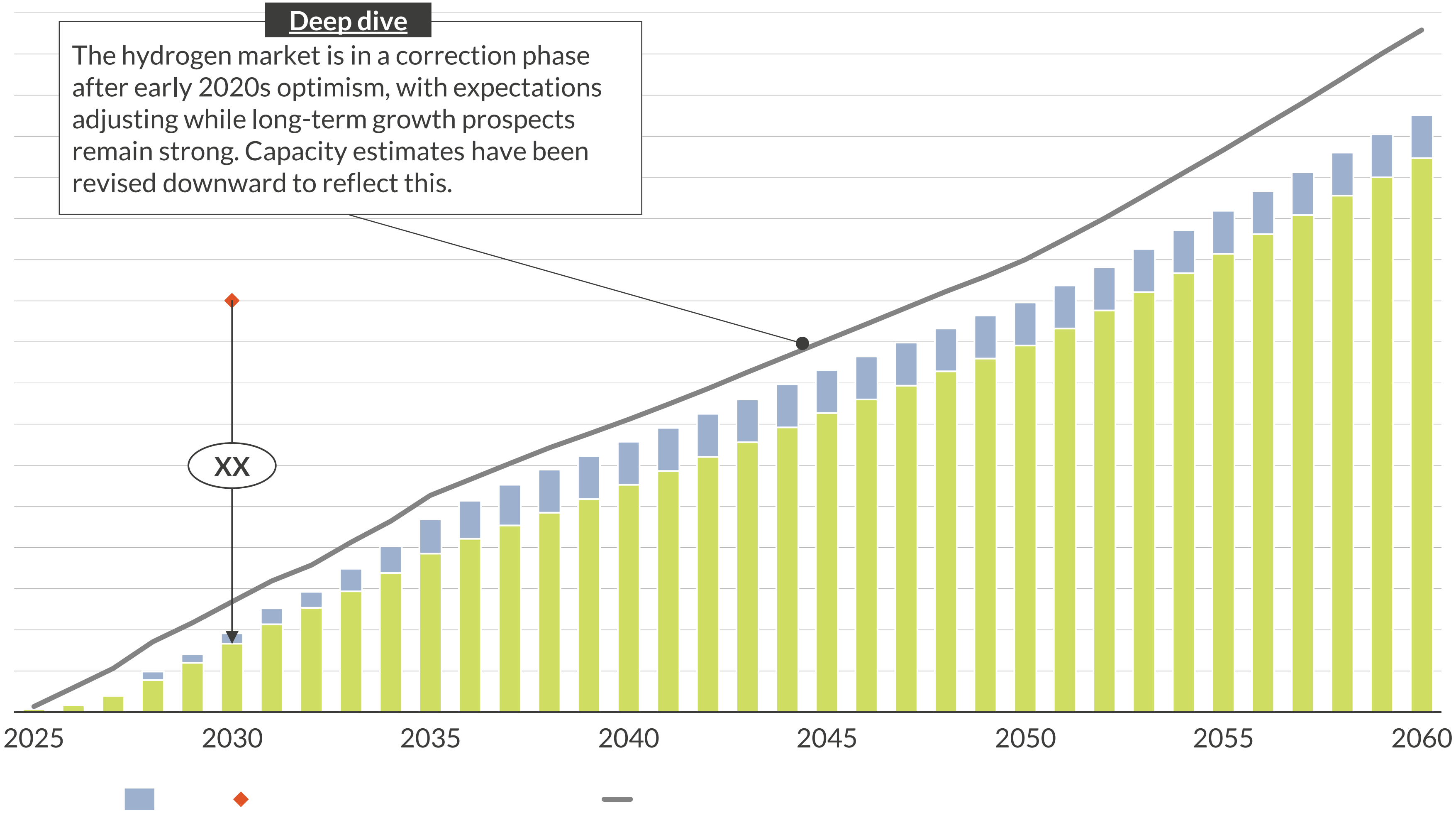


REDACTED

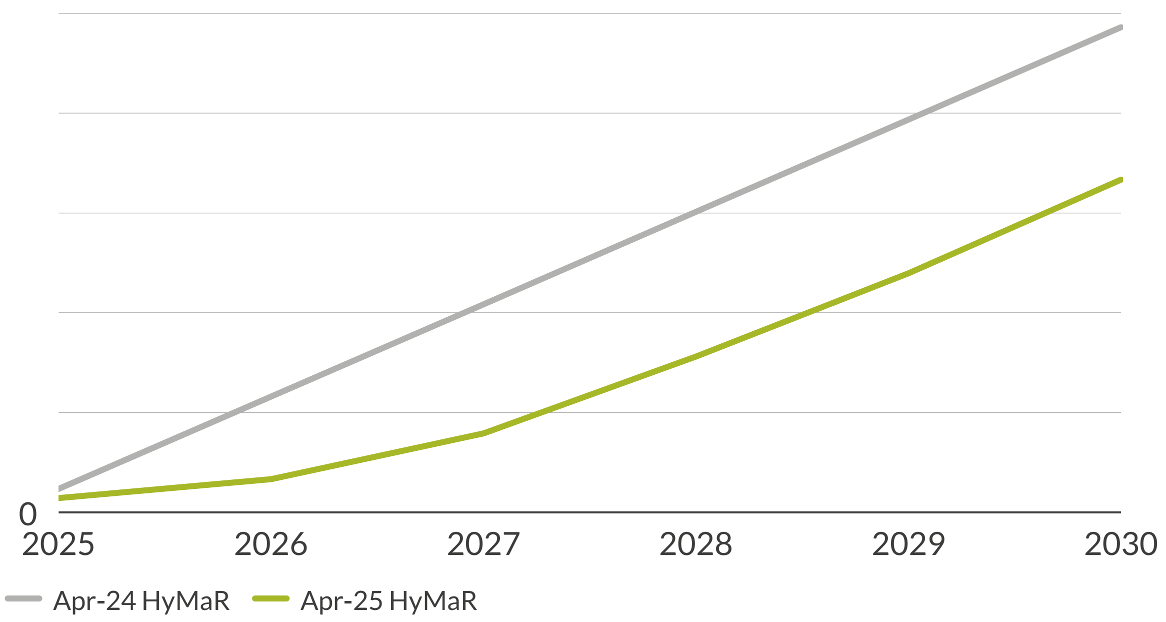
1) Only covers HyMaR countries, including the UK and Norway; 2) Grey and by-product hydrogen is excluded due to high carbon intensity. Extra-European imports are not included in this graph; 3) 100GW of electrolyser capacity by 2030 is mandated by Net-Zero Industry Act, which aligns with 10Mt 2030 domestic renewable hydrogen production target set out by RePowerEU;
Sources: Aurora Energy Research, European Commission

Electrolyser capacity has been adjusted to align with Aurora's electrolyser database, creating near-term downward pressure

Methodology for estimating short-term electrolyser capacity:

Short-term capacity is derived from our in-house electrolyser database[1], focusing only on projects with high certainty of realisation—those that are final investment decision (FID)-approved, under construction, operational, or supported by state aid.

REDACTED



The past optimism about H_2 uptake and investment costs is now waning away as more projects entered development revealing unforeseen contingencies:

REDACTED

REDACTED

1) Latest version of the electrolyser database can be found on Aurora's EOS platform; 2) Only covers HyMaR countries, including the UK and Norway;

Source: Aurora Energy Research

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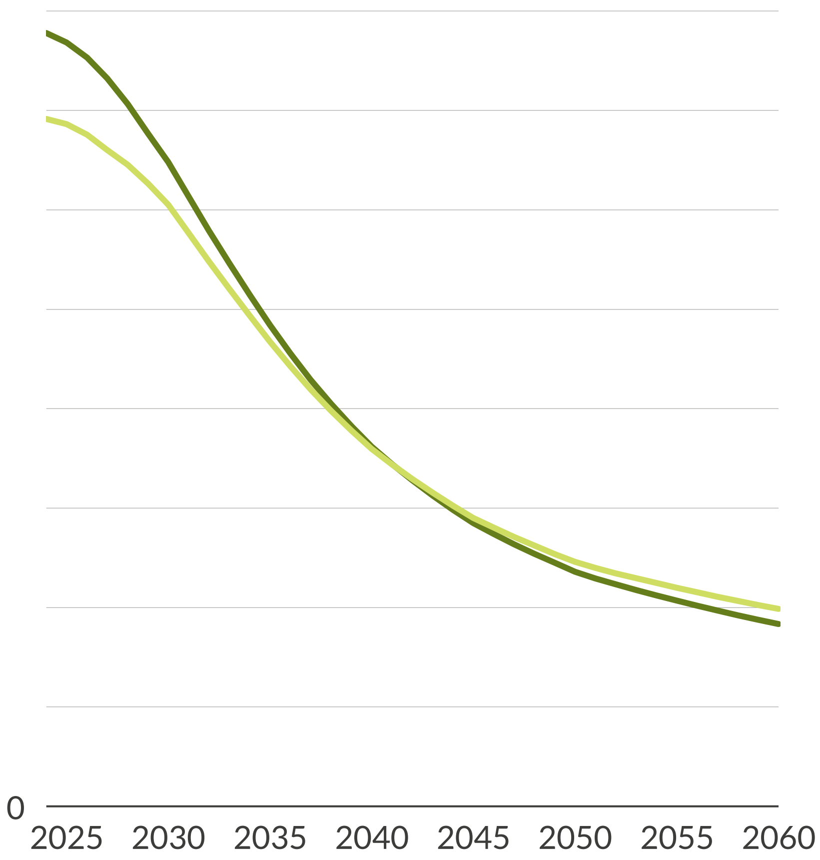

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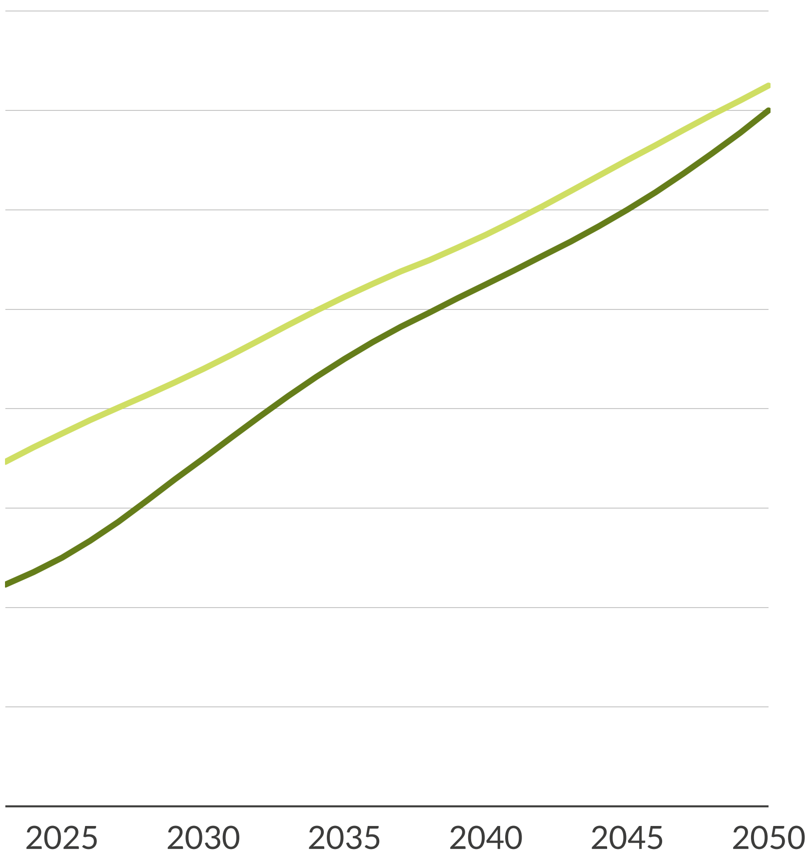

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Source: Aurora Energy Research

Aurora's electrolyser CAPEX forecast consists of five components

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Total capital expenditures (CAPEX)

Electrolyser stack	Balance of plant	Grid connection	EPC[1] and development	Contingency
REDACTED	REDACTED	REDACTED	REDACTED	REDACTED

1) Engineering, procurement, and construction;

Source: Aurora Energy Research

REDACTED

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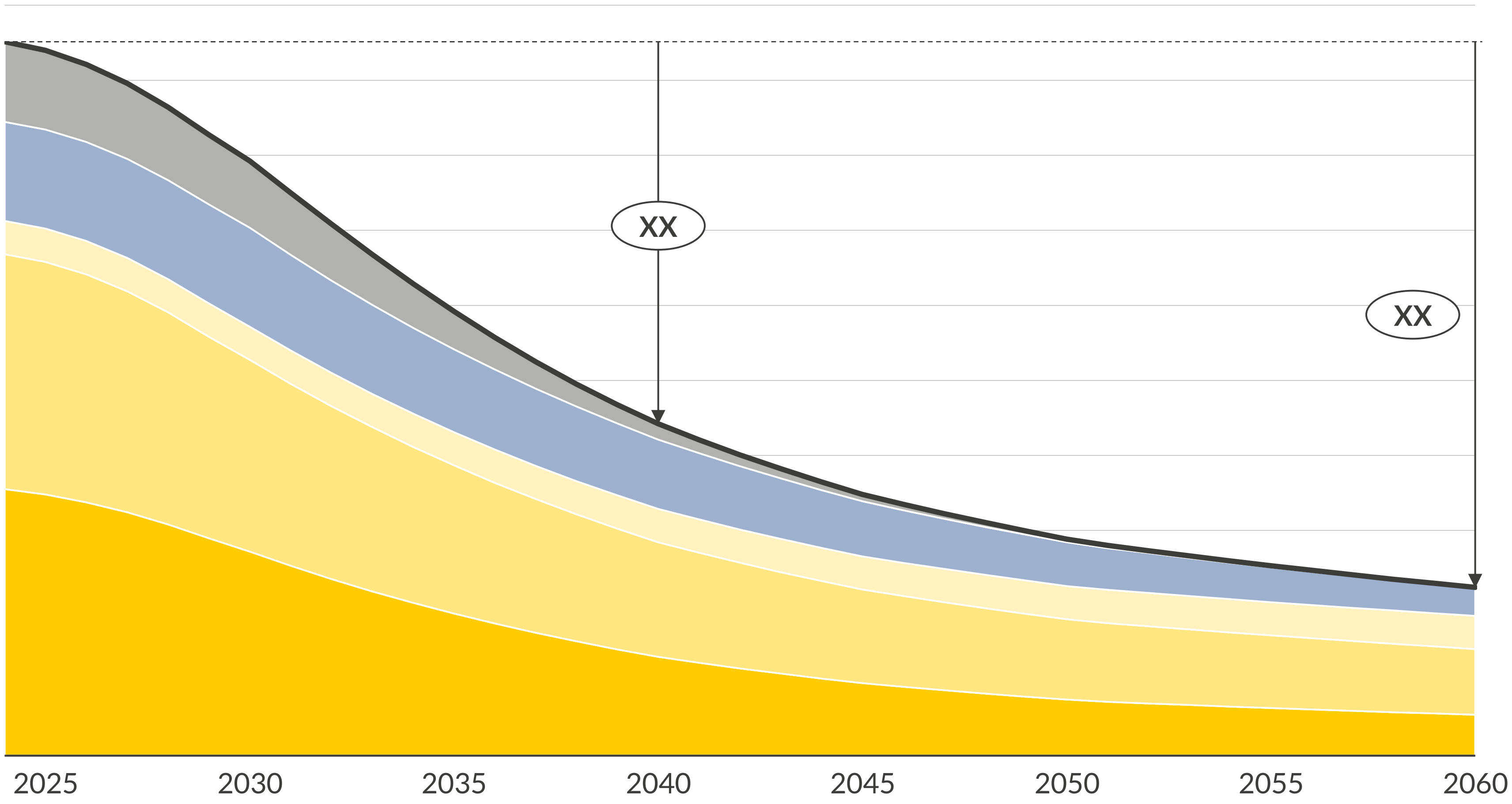

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1) CAPEX assumptions apply for an average project with at least 100MW electrolyser size and can differ significantly for different sizes and locations;

Sources: Aurora Energy Research, IRENA, Fraunhofer Institute, Danish Energy Agency, Institute for Sustainable Process Technology

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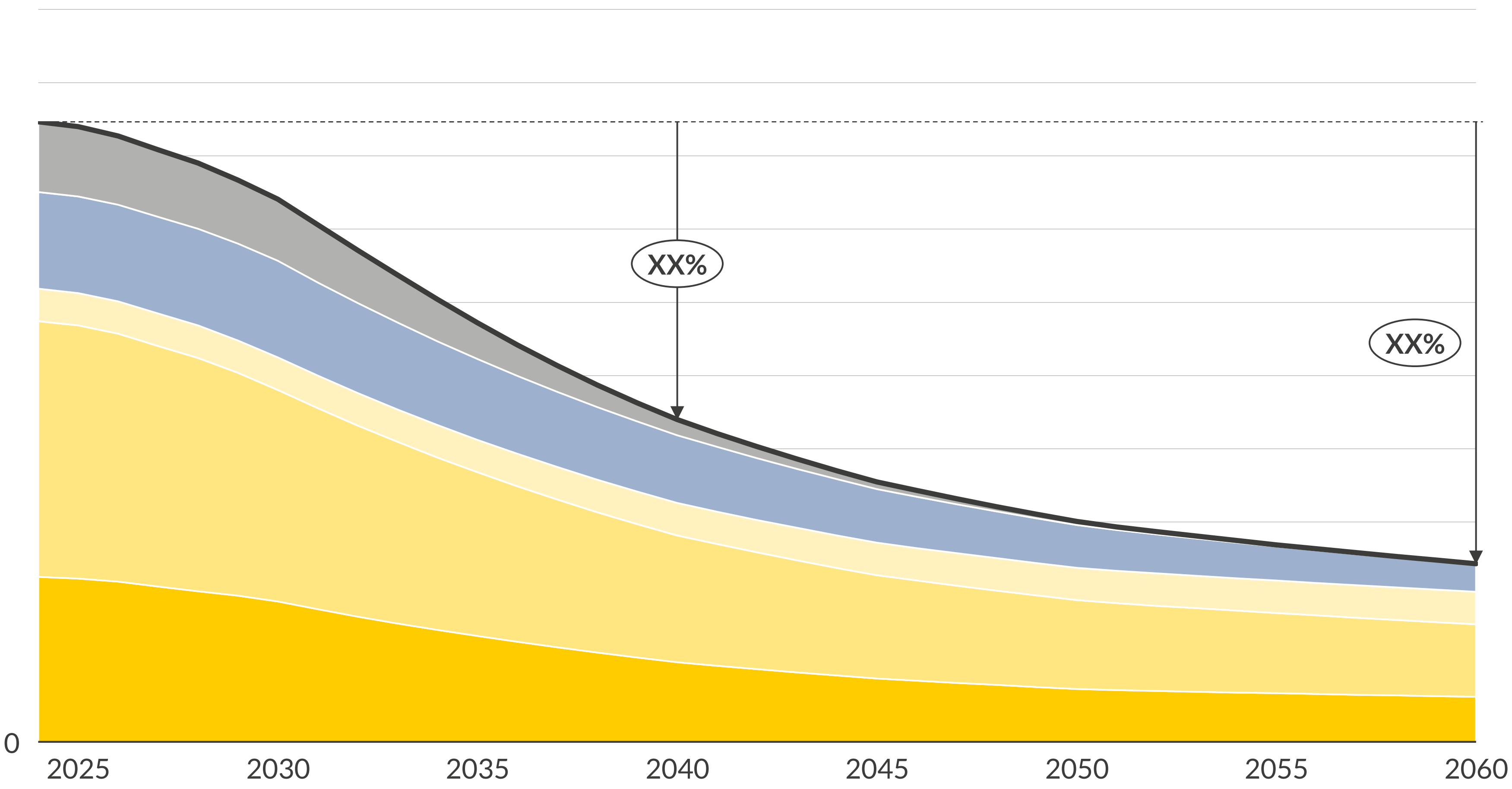
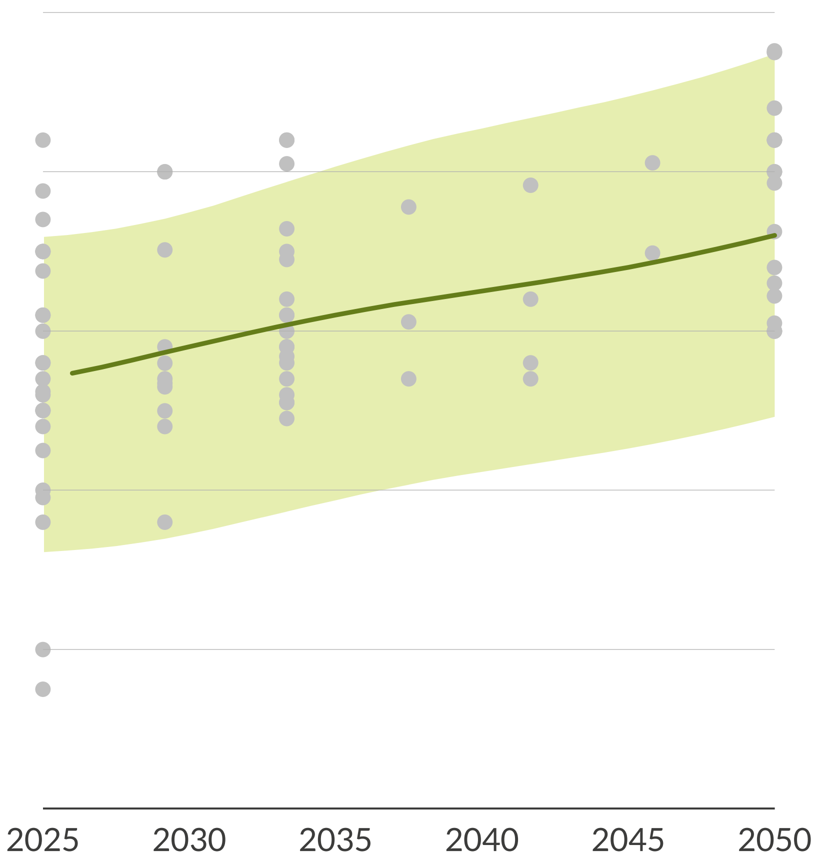


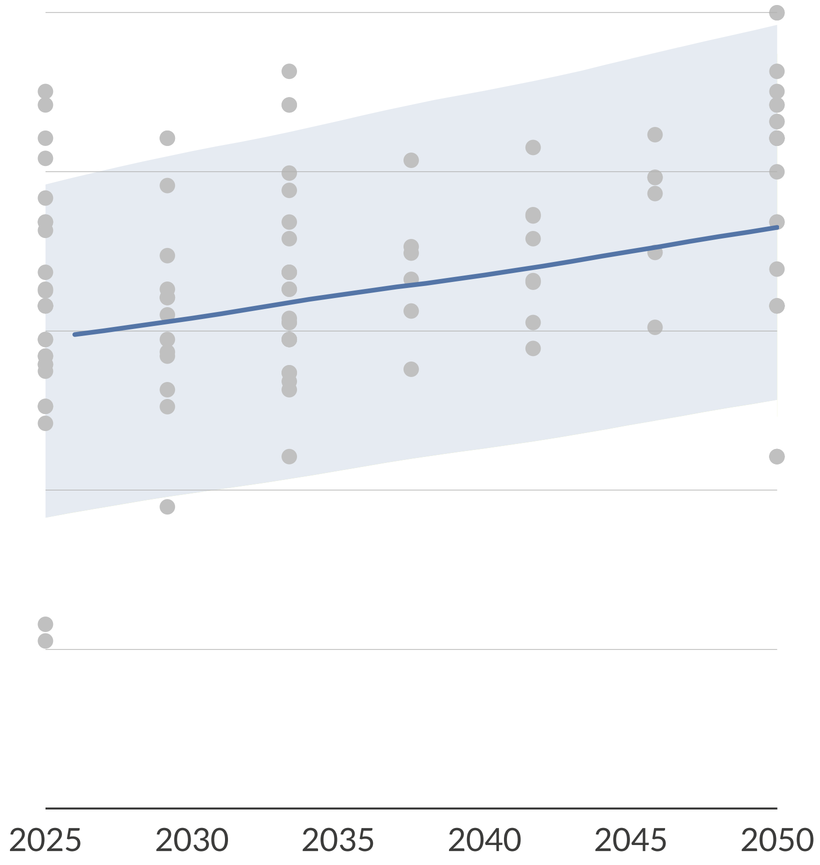
REDACTED

1) CAPEX assumptions apply for an average project with at least 100MW electrolyser size and can differ significantly for different sizes and locations;

Sources: Aurora Energy Research, IRENA, Fraunhofer Institute, Danish Energy Agency, Institute for Sustainable Process Technology

Alongside a declining CAPEX, electrolyser efficiency is expected to increase from 66% today to 69% in 2030 and 76% in 2050





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Chinese produced electrolysers cost 80% less for alkaline and 46% for PEM compared to European produced electrolysers

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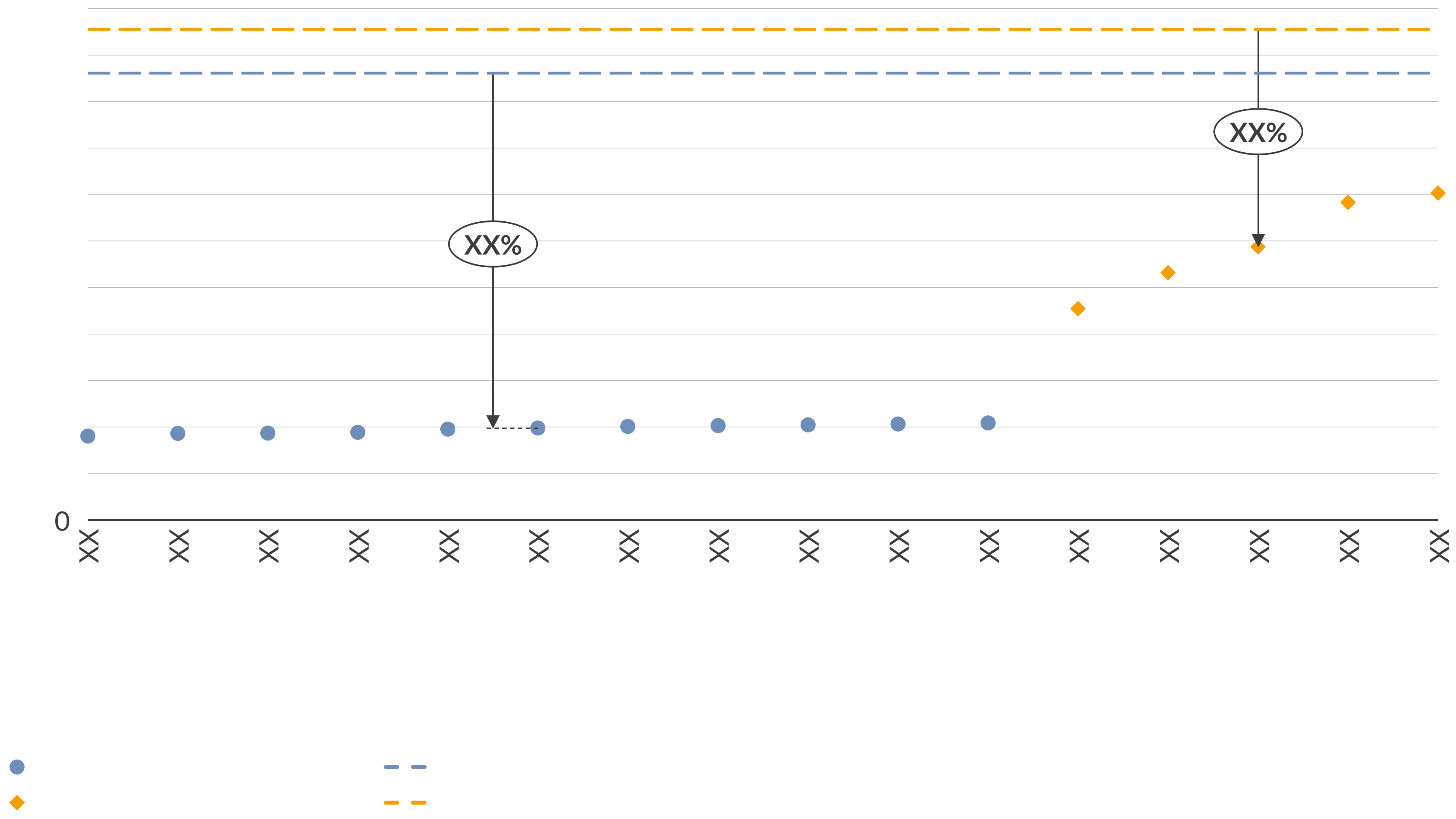

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Sources: Aurora Energy Research, Hydrogen Insight

Alkaline and PEM electrolyser technologies are the most mature and offer the greatest potential for cost reduction in the near term

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	Alkaline (ALK)	Proton exchange membrane (PEM)	Solid oxide electrolyser cell (SOEC)
Development	REDACTED	REDACTED	REDACTED
Year			
CAPEX (€$_{2024}$/kW)			
Efficiency			
Cold start			
Voltage response[2]			
Minimum load[3]			
Temperature			
Pressure			
Conclusion			

REDACTED

Demonstrate advantages over other electrolyser types

1

2

3

4

REDACTED

1) This refers to how quickly the electrolyser can adjust its power demand 2) The lowest percentage of the nominal capacity at which the electrolyser can safely and efficiently operate;

Sources: Aurora Energy Research, IRENA, Schmidt et al., Nami et al.

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H_2 demand is driven by bridging the cost gap with existing technologies via policy, regulation, and technological advances, especially for new applications

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Drivers of renewable/low carbon H_2 demand in Europe

- **Hydrogen costs**: The biggest driver, as lower costs make hydrogen more competitive and widely adopted.
- **Access to infrastructure**: Without a distribution network, hydrogen adoption remains limited.
- **Pace of total decarbonisation**: The urgency of net zero targets will determine hydrogen's role.
- **Carbon Border Adjustment Mechanism (CBAM)**: Strong border mechanisms can prevent offshoring and maintain industrial H_2 demand.
- **Technology readiness level of alternatives:** If alternatives to hydrogen mature quickly, demand could be reduced.
- **Industrial growth and geopolitics:** Europe's ability to maintain industries like steel and ammonia affects hydrogen demand.
- **Supply chains/skills:** Uninterrupted supply chains and skilled workers are needed, but less of a driver than cost, policy, and infrastructure.

Sector	Description of hydrogen use	Role of H_2
Feedstock	Used in chemical industry such as ammonia, refineries	●
E-fuels[1]	Synthesis of fuels e.g. e-ammonia and e-SAF	◕
Steel	Essential input in the DRI-EAF[2] process	◕
Industrial heat	Combustion of H_2 in furnaces for energetic purposes	◑
H_2 in power	Use in H_2 CCGTs/OCGTs to replace traditional thermal assets	◑
Road transport	Use in H2 ICEs[3]/fuel cells in HGVs/other road vehicles	◔
Rail transport	Use of H_2 to power trains in regions with limited electrification	◔
Space heating	Direct use of hydrogen in boilers for residential space heating	○

Uncertainties / risks which could affect H_2 demand:

- It is possible that some industries e.g. steel may offshore to cheaper locations, reducing H_2 demand in Europe.
- Uncertainty of the H_2 infrastructure timeline, such as the European backbone could lead to supply chain shortage.
- The role of blue and other low-carbon hydrogen options (including electrolytic business models), with cost and deployment changes potentially impacting demand.

1) E-fuels include e-ammonia, e-kerosene, e-methanol, e-methane, etc., and are used in the maritime and aviation sectors; 2) DRI-EAF: Direct reduced iron–electric arc furnace; 3) ICE: Internal Combustion Engine;

Source: Aurora Energy Research

In the near-term, renewable H_2 is expected to play a role in sectors with limited decarbonisation options, strong policy incentives, and financial support

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Hydrogen is expected to play a role in sectors, especially in the near-term, with limited or costly decarbonisation options. However, renewable / low-carbon hydrogen remains expensive compared to current methods, making mandates, subsidies, and penalties essential to closing the cost gap and driving demand.

Sector	Drivers	Bottlenecks	Alternatives[3]	Policy incentives	Financial support[4]
Feedstock					
E-fuels[1]					
Steel					
Industrial process hea					
H_2 in power					
Road transport					
Rail transport					
Space heating					

REDACTED

Sectors expected in near-term

1) E-fuels include e-ammonia, e-kerosene, e-methanol, e-methane, etc., and are used in the maritime and aviation sectors; 2) This includes, but is not limited to, RES, nuclear, biofuels, fossil fuels, etc.; 3) Fossil fuel alternatives are not considered except for carbon capture storage application and grey hydrogen in the feedstock sector; 4) For feedstock and e-fuels we assume financial support comes from a myriad of support, including support from European H_2 Bank auction, CCfDs, IPCEI projects, etc.;

Source: Aurora Energy Research

As policy support, infrastructure, and decarbonisation efforts expand, H_2 demand is will increase across existing and new sectors in the near and mid-term

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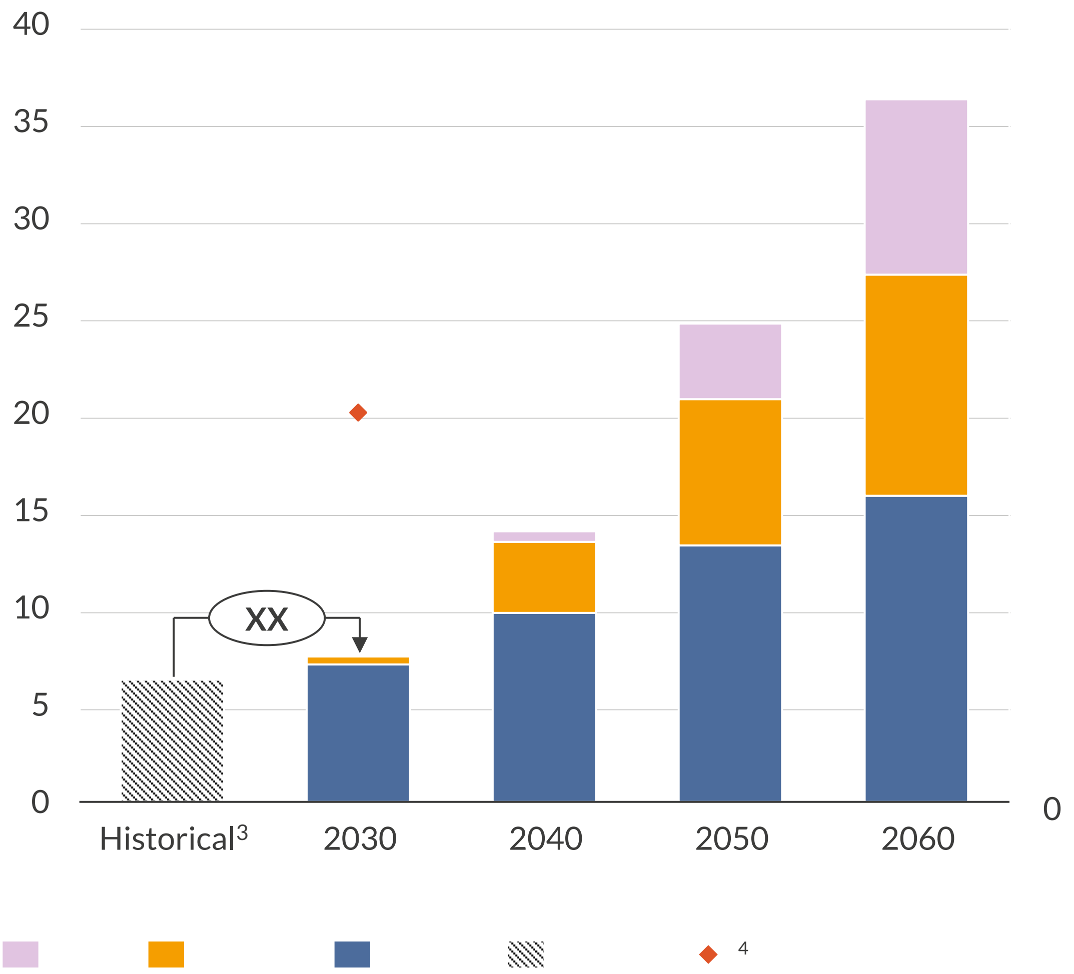

Current-market

REDACTED

Near-term (2027-2040)

REDACTED

Long-term (2040-2060)

REDACTED

Sources: Aurora Energy Research, European Hydrogen Observatory

Hydrogen demand varies significantly by country, depending on policy support, the scale of existing industries, and infrastructure pipelines

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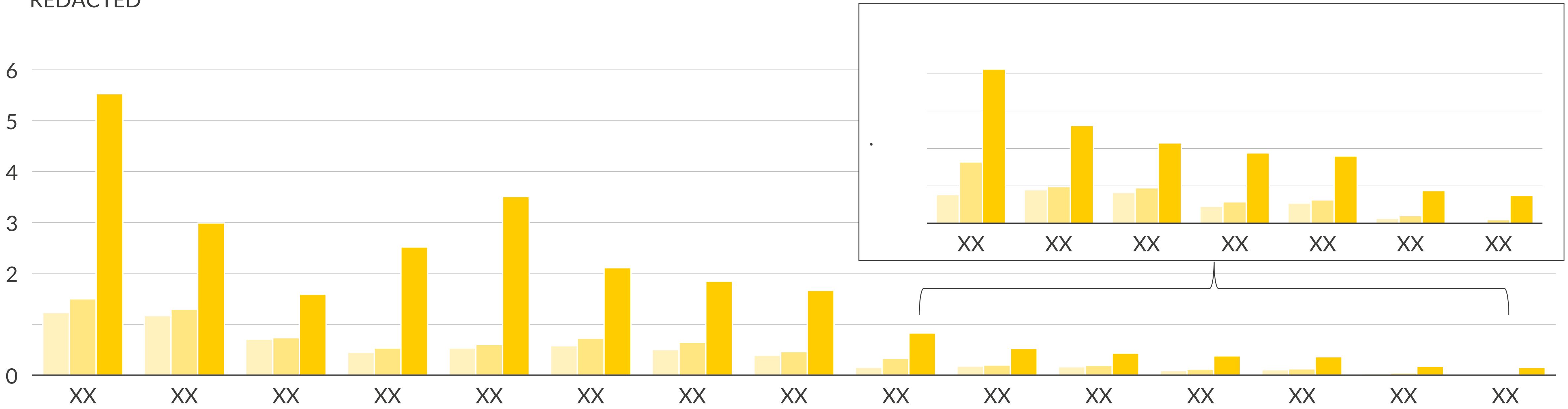

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Current 2030 2050

Source: Aurora Energy Research

In the near to mid-term, Germany and the Netherlands will lead H_2 demand in feedstocks thanks to existing industry, policy, and government support

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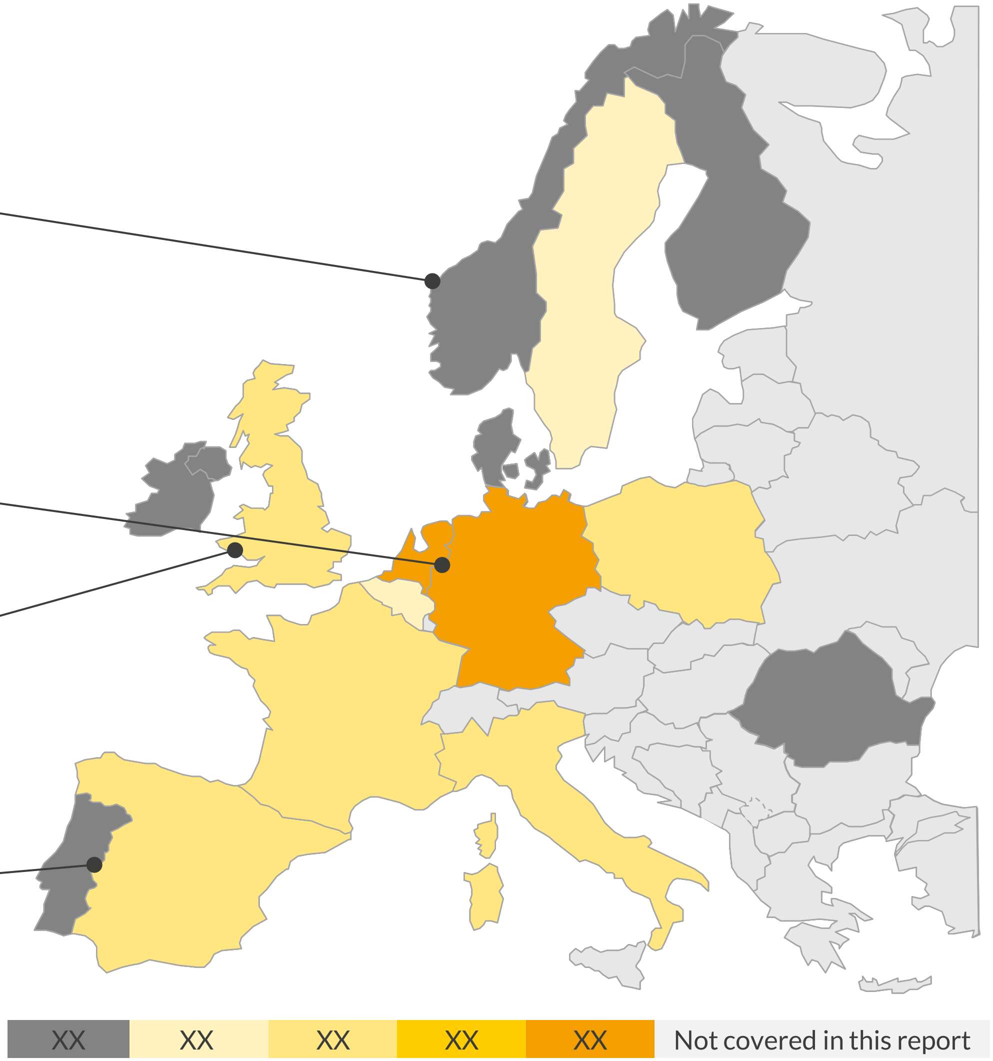

1) Only covers 15 HyMaR countries (DEU, NLD, POL, ESP, ITA, GBR, FRA, BEL, FIN, SWE, NOR, ROU, PRT, DNK, and IRL);

Source: Aurora Energy Research

If key drivers align, REDACTED

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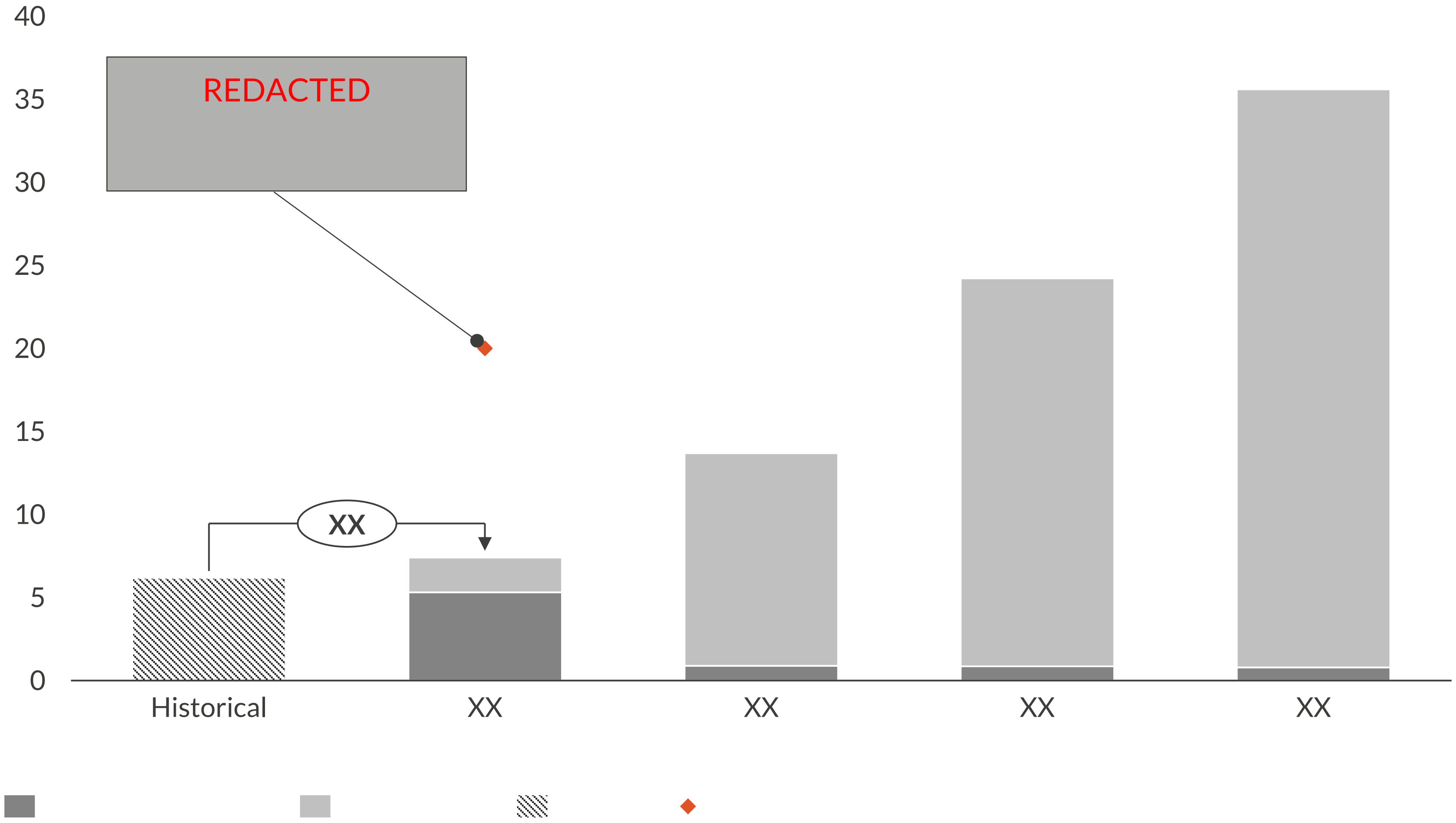

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Source: Aurora Energy Research

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We have revised our gas export forecast of Russian flows into Europe following the end of the Ukraine gas transit agreement on 31 December 2024

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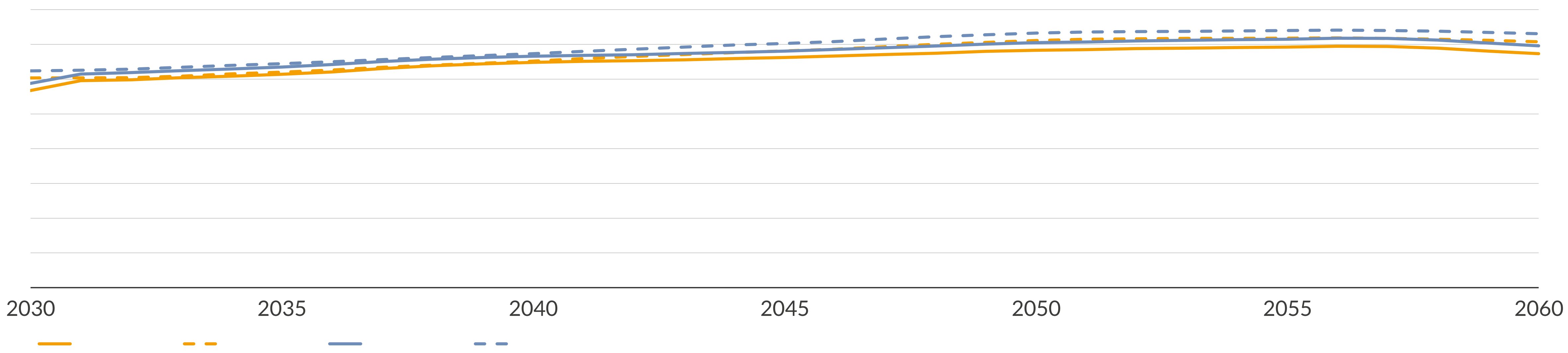


Why has our price forecast dropped in the 2030s?

Early 2030s

REDACTED

Late 2030s

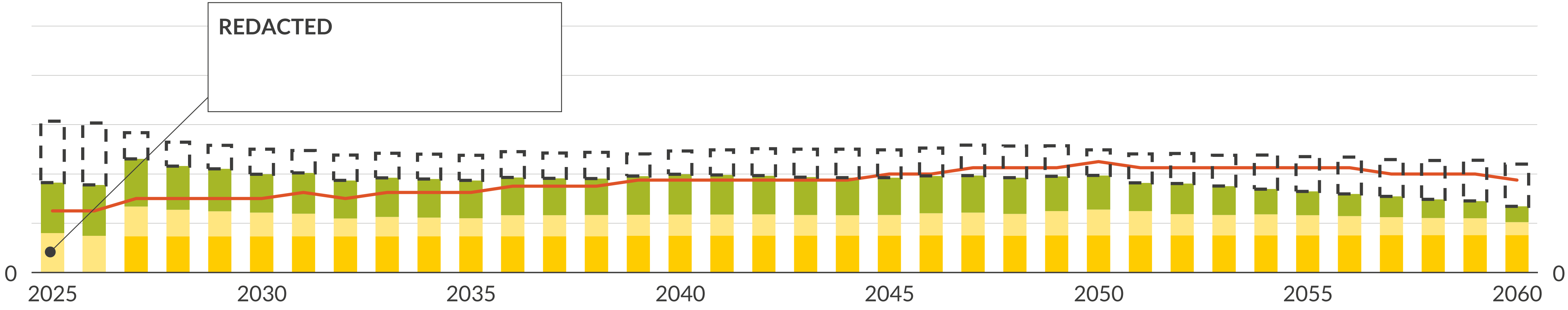
REDACTED

From 2040

REDACTED

Sources: Aurora Energy Research, EEX, CME

We have revised our gas export forecast of Russian flows into Europe following the end of the Ukraine gas transit agreement on 31 December 2024



Jan-25 Russia gas assumptions

REDACTED

Changes for Apr-25 forecast

REDACTED

1) EU27 + United Kingdom, Norway, and Switzerland.

Source: Aurora Energy Research

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Across HyMaR countries, baseload power prices vary

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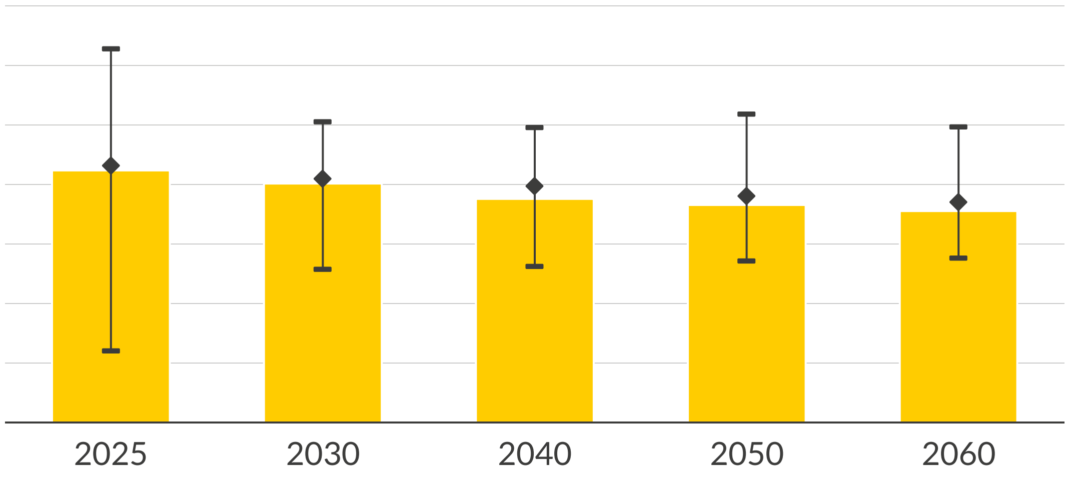

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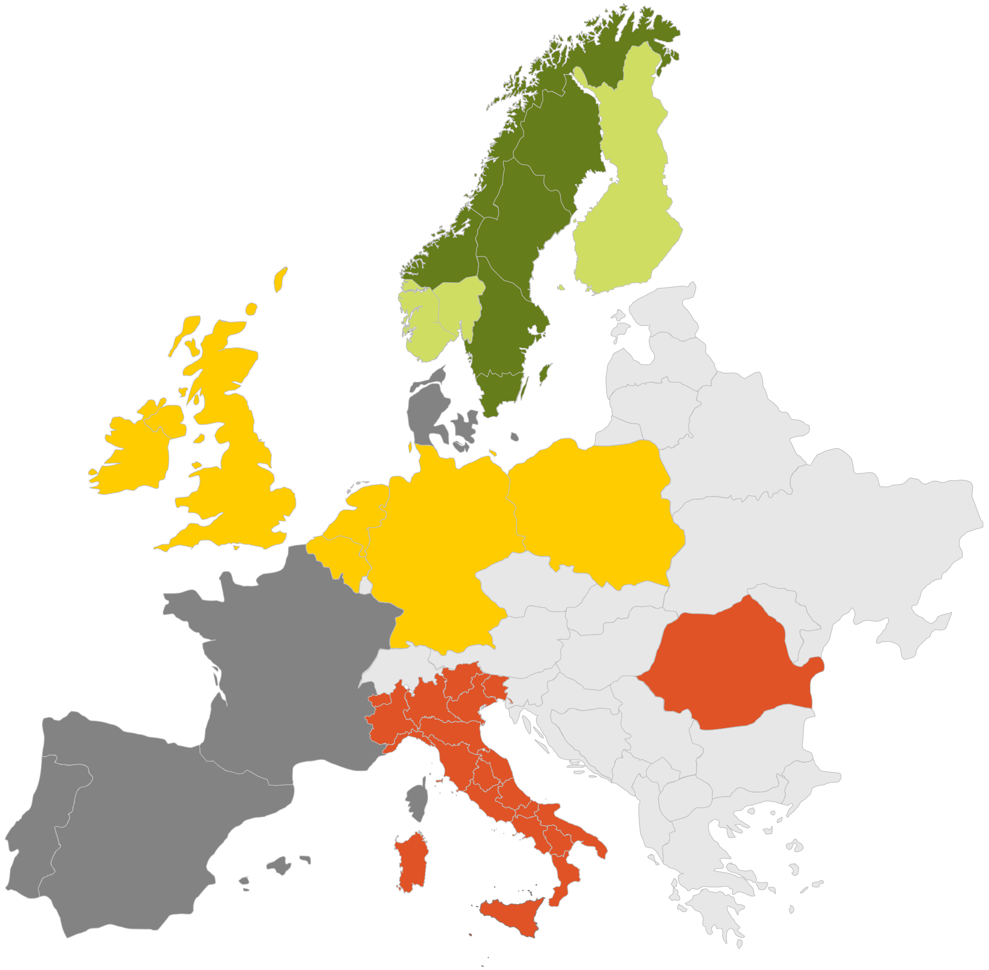

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Source: Aurora Energy Research

Renewable capture prices across European countries vary significantly

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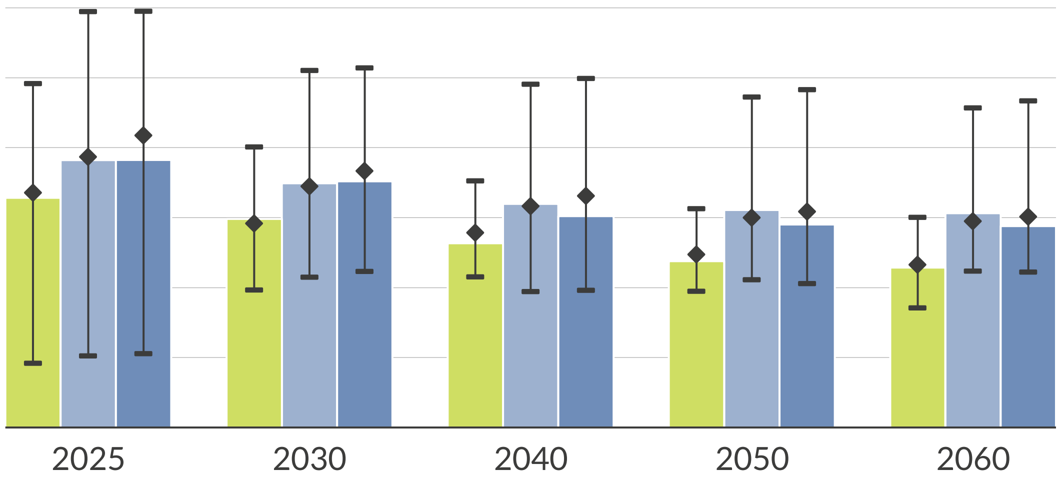

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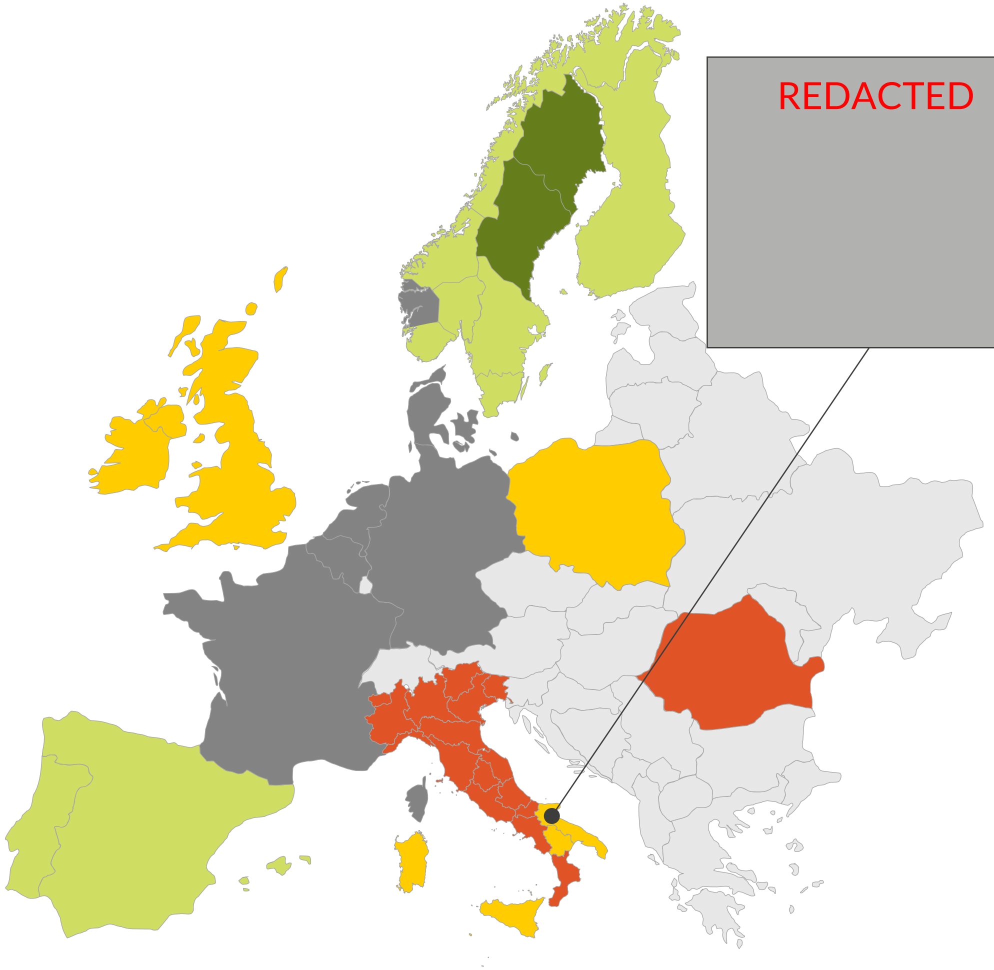

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Source: Aurora Energy Research

Retail fees play a significant role in LCOHs

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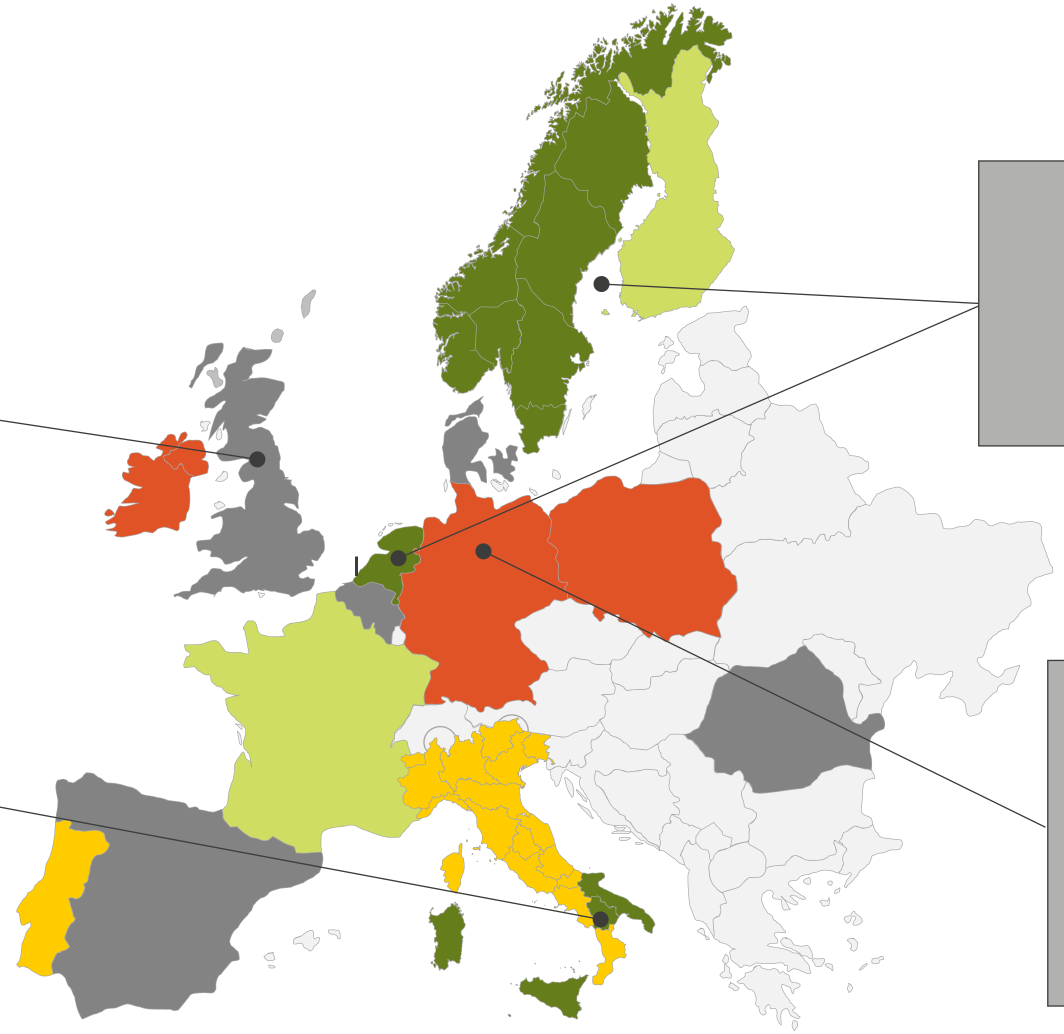

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Sources: Aurora Energy Research, ARERA, UK Department for Energy Security and Net Zero, Eurostat

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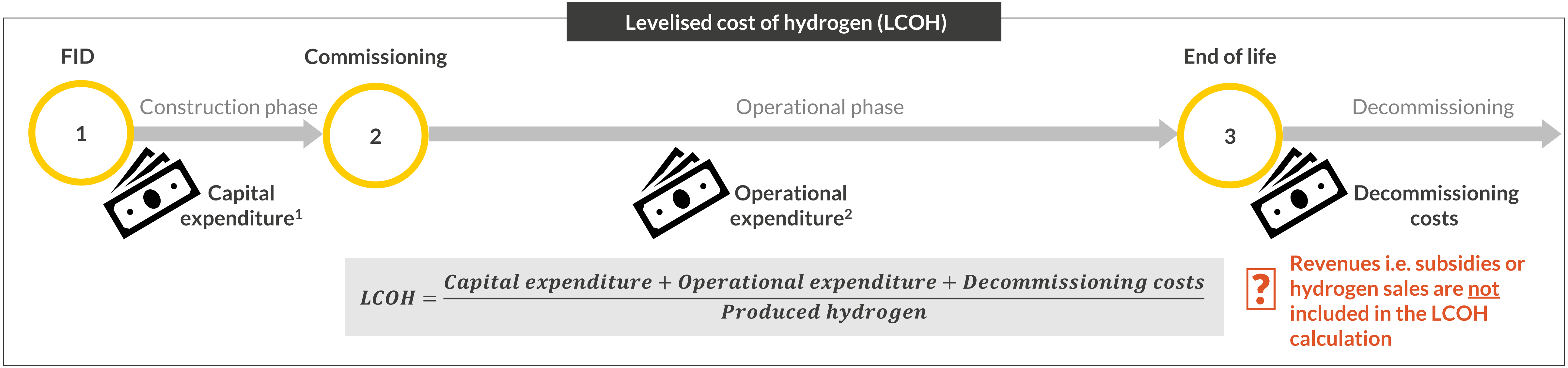
Using the levelised cost of hydrogen allows for comparing production costs across countries and business models, as well as against other energy vectors



Why do we use LCOH?

- The levelised cost of hydrogen (LCOH) enables comparisons between different production methods and other energy sources by providing a standardised cost metric.
- This approach accounts for all cost factors over a project's lifetime and ensures a technology-neutral comparison of production methods such as electrolyser and steam methane reforming, biomass gasification, etc.

How is LCOH calculated?

- LCOH is calculated by dividing the net present value (NPV) of the total lifetime costs of the asset by the NPV of the total hydrogen production over the lifetime. While this analysis does not account for revenue components (i.e. subsidies or hydrogen sales), we include some country-specific cost exemptions.
- This gives one value of LCOH for the lifetime of the asset e.g. an LCOH of 5 €/kg H_2 in 2030 represents the lifetime average production costs for that plant which becomes operational in 2030.
- The actual production costs within a year can vary significantly e.g. an electrolyser connected to the grid without hedging is exposed to the hourly power prices.

1) Includes construction costs, planning and permitting costs, development costs, etc.; 2) Includes fuel costs, maintenance, grid connection costs, land rent, debt servicing (if applicable), repairs;

Source: Aurora Energy Research

Project developers must balance offtaker needs, certification requirements, and power procurement, all of which impact LCOHs

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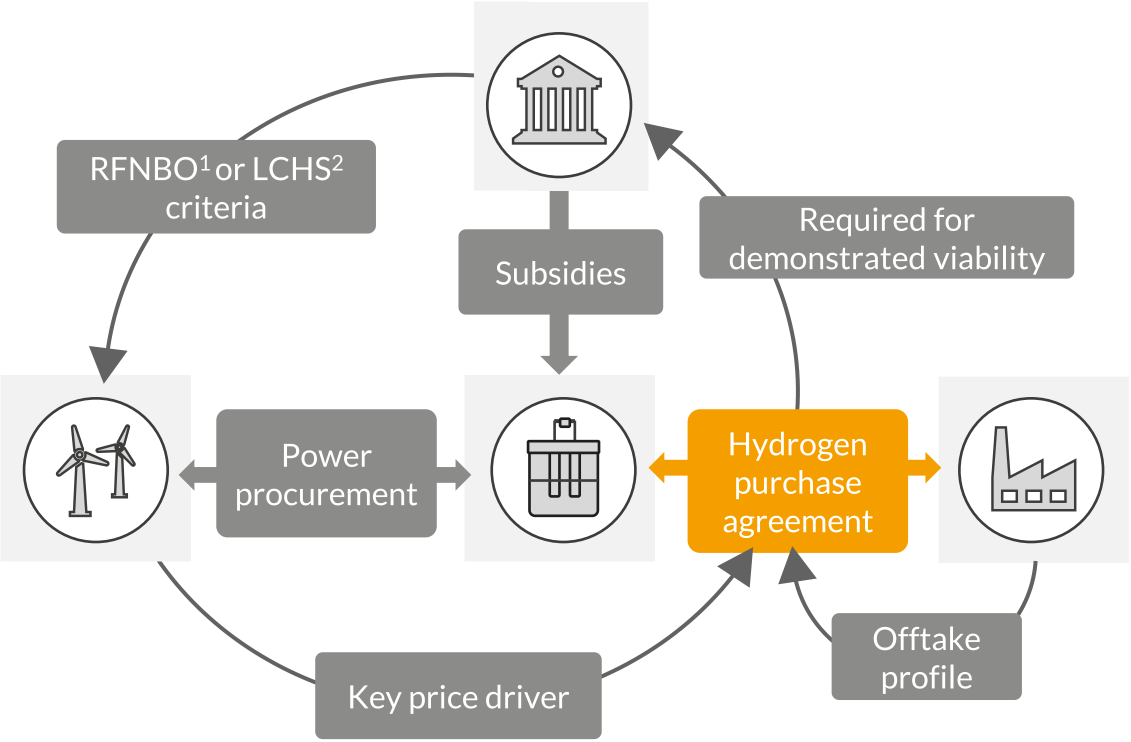
Visual overview of the main elements shaping electrolyser business models



To get projects off the ground it is important to consider a range of factors, particularly on the buyer's side, as hydrogen remains a buyer's market

Parameter	Challenge	Implication
Offtake profile (*deep dive*)	REDACTED	
Regulatory compliance (*deep dive*)		
Proximity to offtaker(s)		
Choice of technology		

1) RFNBO: Renewable fuels of non-biological origin; 2) LCHS: Low-carbon hydrogen standard;

Source: Aurora Energy Research

There are several ways to manage intermittency in renewable / low-carbon hydrogen production

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Hydrogen production intermittency can be managed in several ways, including storing and shifting hydrogen, storing and shifting power, or accessing baseload grid power.

	Energy Vector	Description	Cost[1]	Location[2]	Advantages	Disadvantages
Ways to manage options explored in HyMaR	Gaseous storage tanks				REDACTED	
	Grid imports					
	Energy storage					
	Oversized or baseload PPA					
	Underground storage					

1) Based on CAPEX and OPEX estimates; 2) Locational constraints vary from site to site. In general, gaseous storage and island battery setups can be used for most sites. Grid imports and PPAs depend on grid connections availability, while the availability of salt caverns is dependent on existing salt bed deposit; 3) Renewable Energy Directive II and the Low carbon hydrogen standard enforce quality standards for H_2 in the EEA and the UK respectively; 4) RFNBO: Renewable fuels of non-biological origin;

Source: Aurora Energy Research

Strategies to ensure RFNBO[1]-compliant hydrogen is produced depends on the power system composition

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1 **Provision in RED II[2] for exemption from additionality**

REDACTED

2 **A bidding zone with a fully renewable grid (>90% RES)**

REDACTED

3 **EU's low-carbon hydrogen: 70% GHG reduction relative to fossil H_2**

REDACTED

Timelines indicating when specific HyMaR regions are exempt from a particular criterion[3]

Sources: Aurora Energy Research, European Commission

An electrolyser developer must design their business model considering factors such as power procurement cost, offtake requirements, and grid sustainability

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Electrolyser business model / power procurement strategy

Power procurement agreement (PPAs)

- This approach is typically the preferred method for power procurement by developers as it offers price certainty and mitigates risks associated to the largest LCOH component.

PPA structure		Description
Single-RES asset	Solar-only	PPAs sourced from solar PV assets
	Onshore wind-only	PPAs sourced from onshore wind assets
	Offshore wind-only	PPAs sourced from offshore wind assets
Hybrid		A combination of multiple PPAs from different RES technologies
Oversized		Drastically oversized PPAs relative to electrolyser capacity
PPA + grid		A combination of PPAs and imports from the day-ahead market

Risk:

- In a typical pay-as-produced PPA, the electrolyser operator bears the risk of excess renewable generation, often needing to the sell power at a discount in the spot market. This is challenging as the hours when the PPA is available often coincide with low market prices.
- Without proper PPA profile shaping, it is difficult to align the variable renewable supply with the desired offtake profiles.

Grid-connected

Description: Electrolyser leverages power from the wholesale market.

Market type: Markets with a renewable or a low-carbon grid.

Risk: Full exposure to wholesale power price volatility.

Co-located

Description: Electrolyser is directly connected to a co-located renewable asset(s) owned by the same entity.

Market type: Regions with ample land availability.

Risk: Upfront investment in both electrolysers and renewables is bore by the entity. Additionally, balancing proximity to offtake with access to high-potential renewable regions introduces locational risk.

Electrolyser with BESS[1]

Description: A battery asset is integrated into a co-located or a PPA-powered setup to improve electrolyser utilisation.

Market type: Regions with promising solar load factors, and access to capacity and ancillary markets.

Risk: Constraints in optimising multiple value streams - battery opportunities in other markets vs increasing H_2 production.

1) BESS: Battery energy storage system;

Source: Aurora Energy Research

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The EU's RED II exempts grid-powered electrolysers from additionality and temporal correlation in bidding zones with over 90% renewable energy

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Illustration of renewable share estimation

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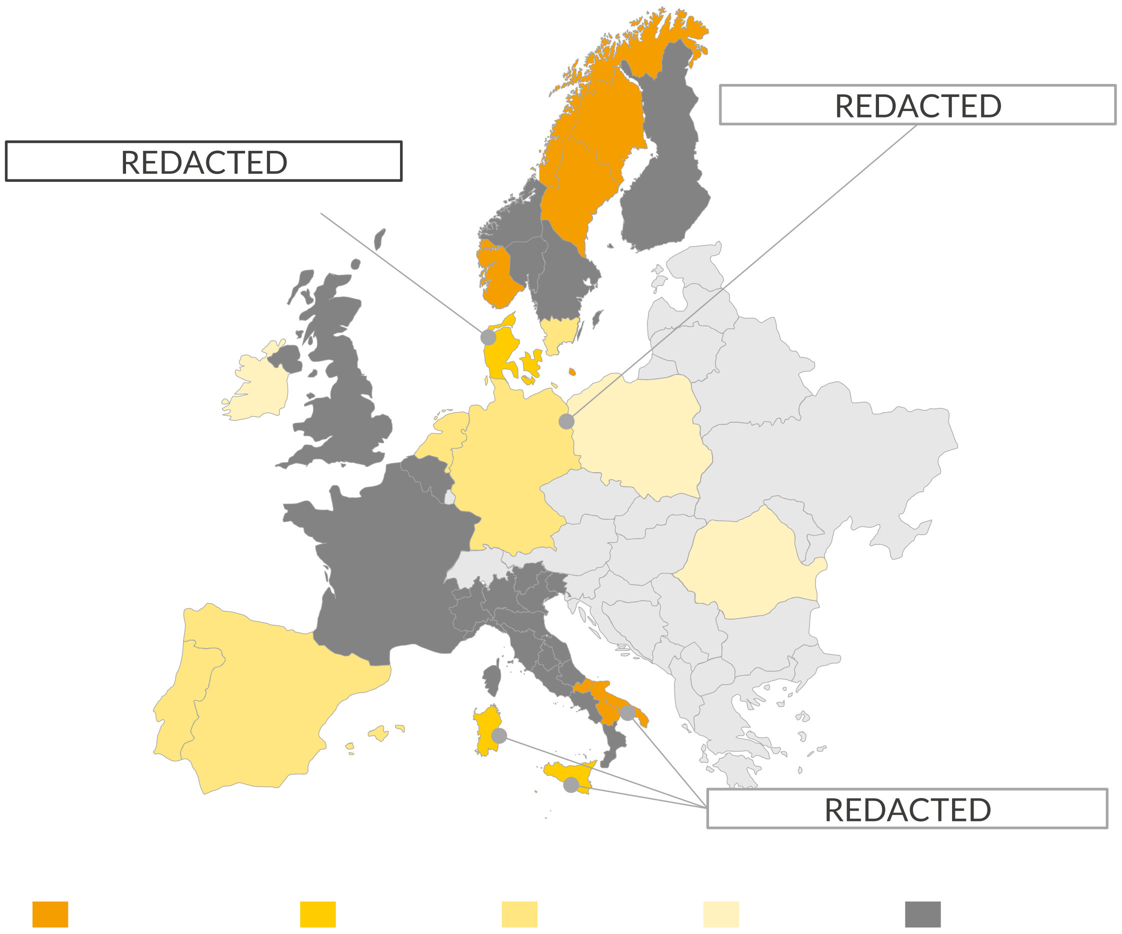
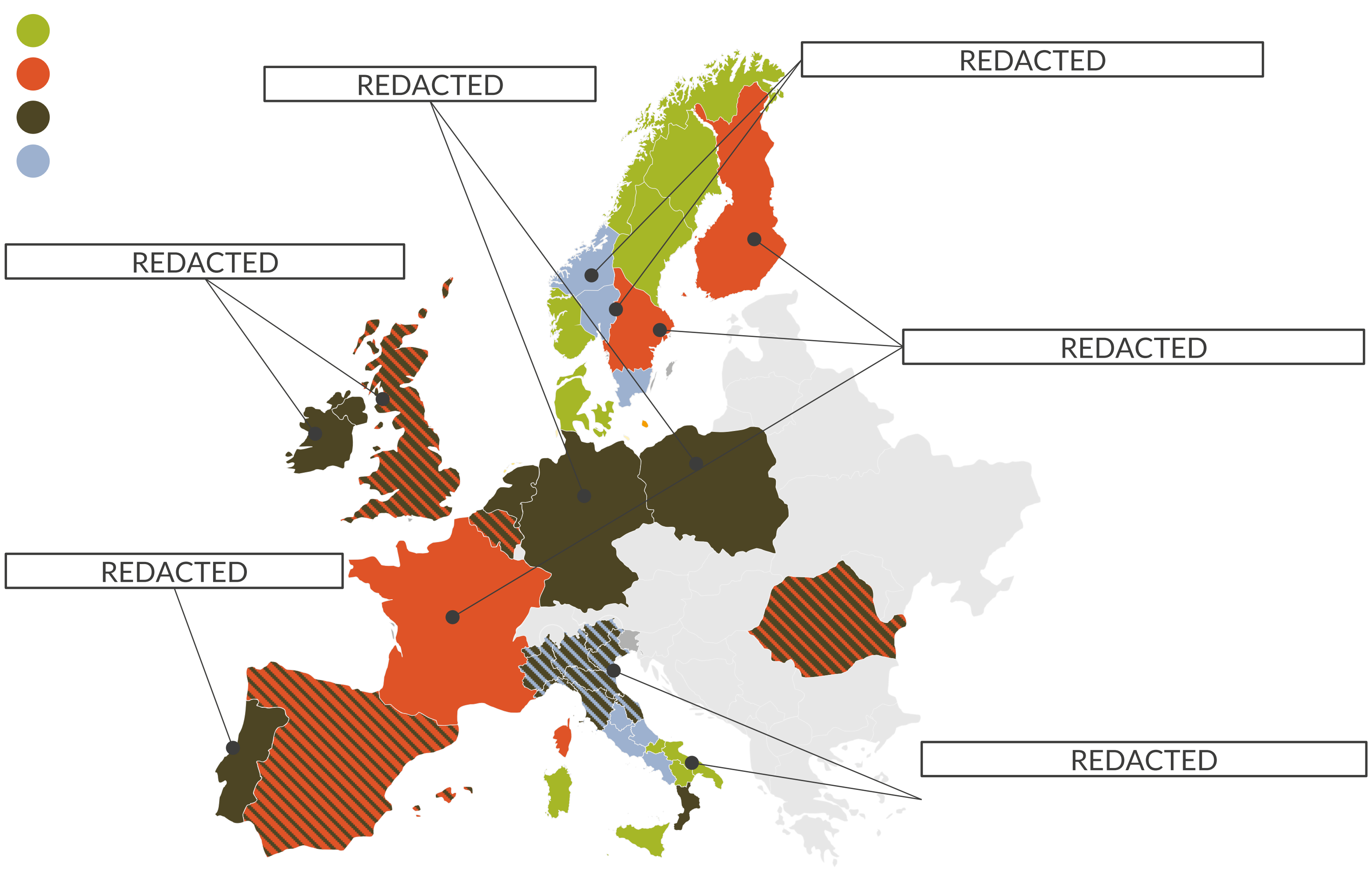


1) Renewable shares are calculated using Aurora's January 2025 Central Power Market forecasts; 2) For calculation of 'gross final consumption of electricity from renewable sources', all biofuels, bioliquids and biomass fuels are assumed to fulfil the sustainability and GHG saving criteria laid down in Article 29(2) to (7) and (10) of EU Directive 2018/2001;

Sources: Aurora Energy Research, European Commission

By 2030, at least 10 bidding zones—including parts of Italy and Scandinavia—are expected to earn the 'fully renewable' label

2030 snapshot of power system mix



Timeline of bidding zone RED II grid compliance[1]

REDACTED

LCOHs of grid-connected electrolysers

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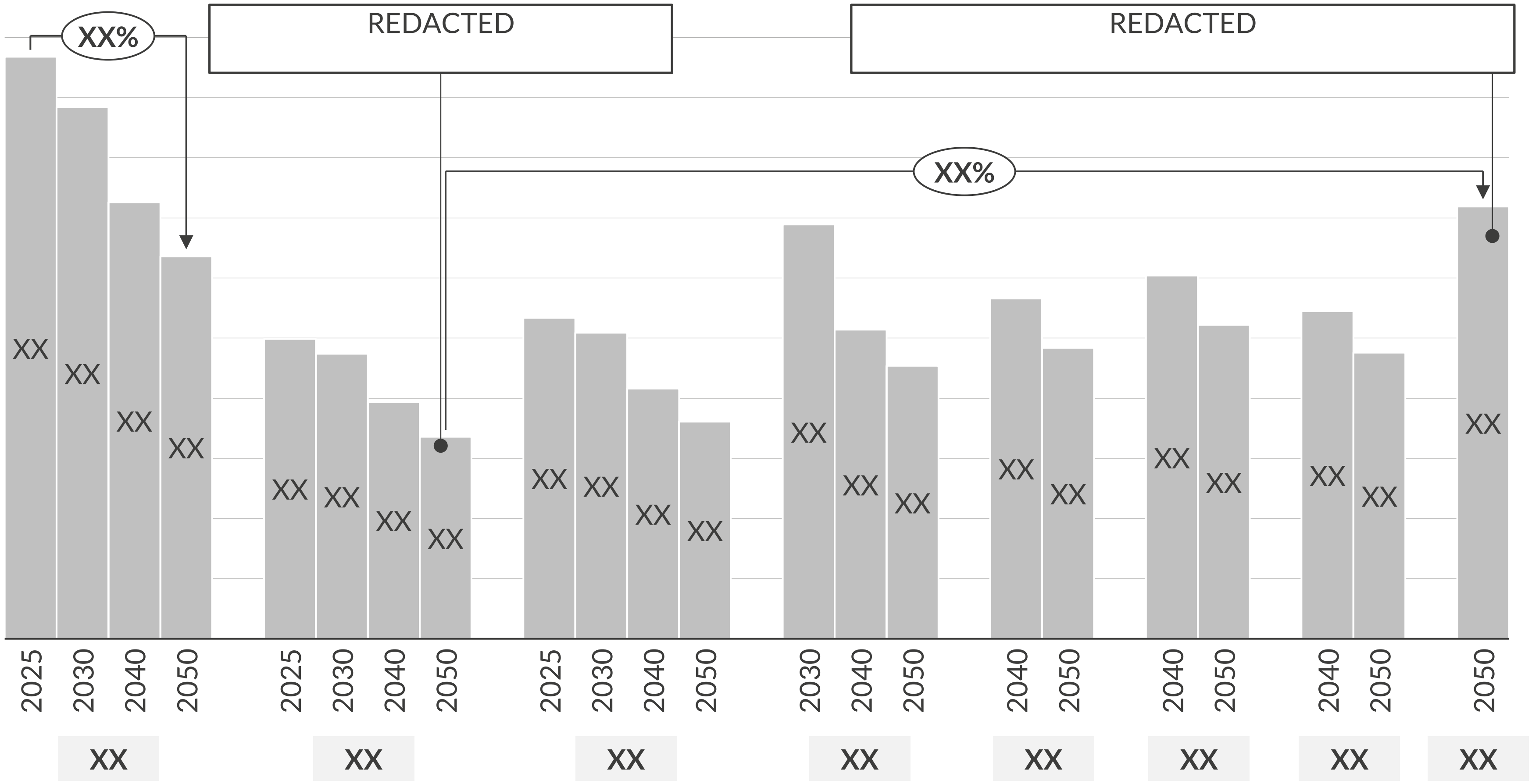

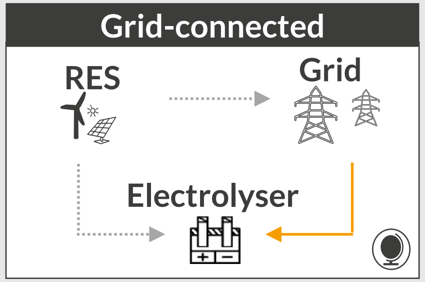

REDACTED

1) Electrolysers in this business model provide baseload hydrogen at 90% load factor throughout a year. This business model was calculated only for bidding zones that have achieved a 90% renewable grid one year before the reported LCOH; 2) Italy South bidding zone considered; 3) SE2 bidding zone considered; 4) NO4 bidding zone considered; 5) DK1 bidding zone considered;

Source: Aurora Energy Research

Hybrid PPAs

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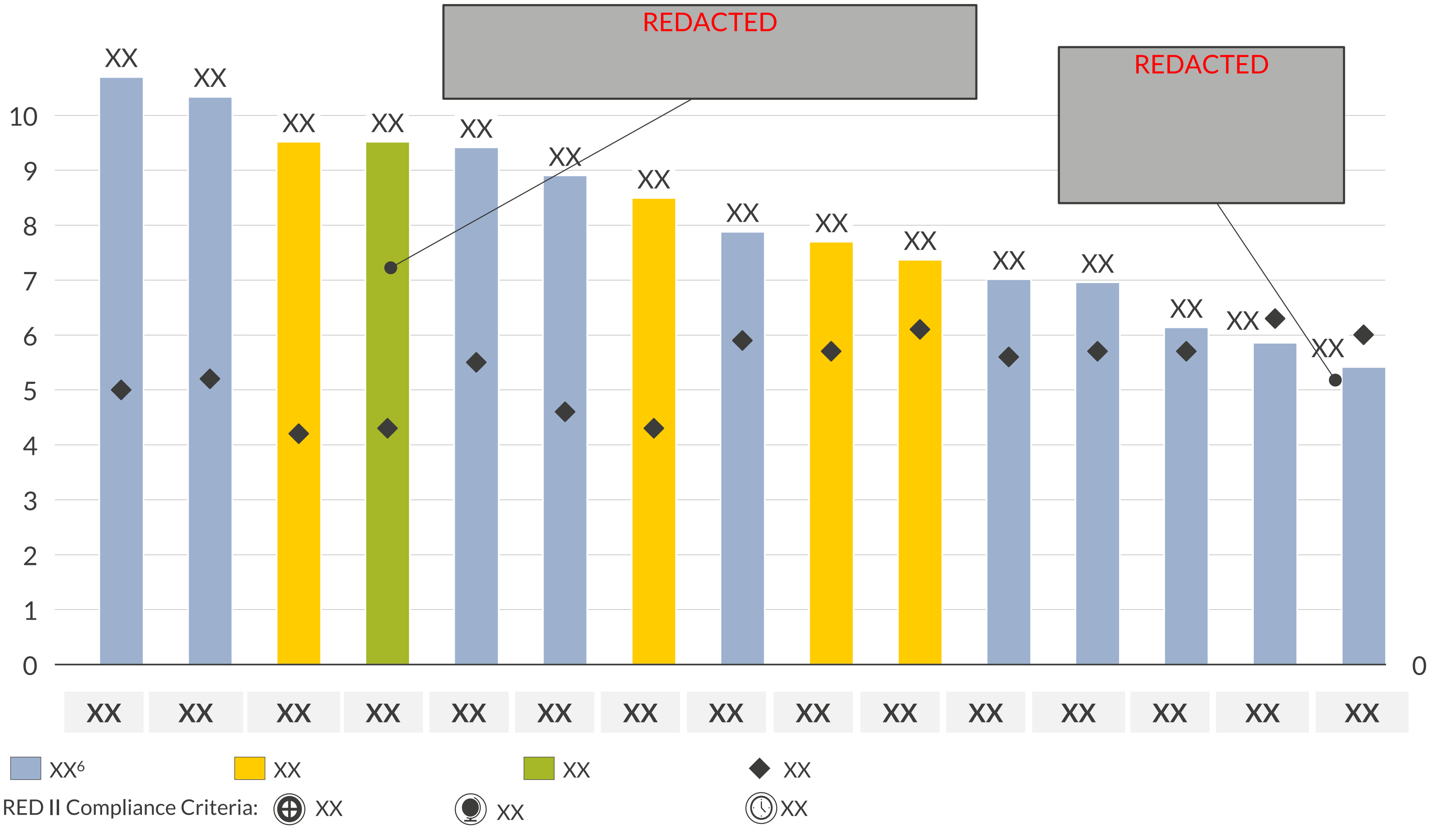

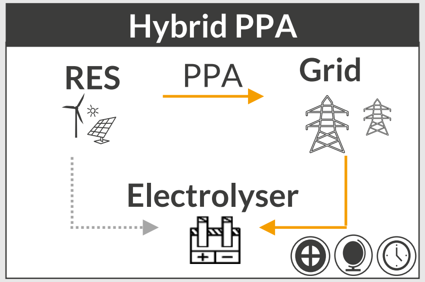

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Source: Aurora Energy Research

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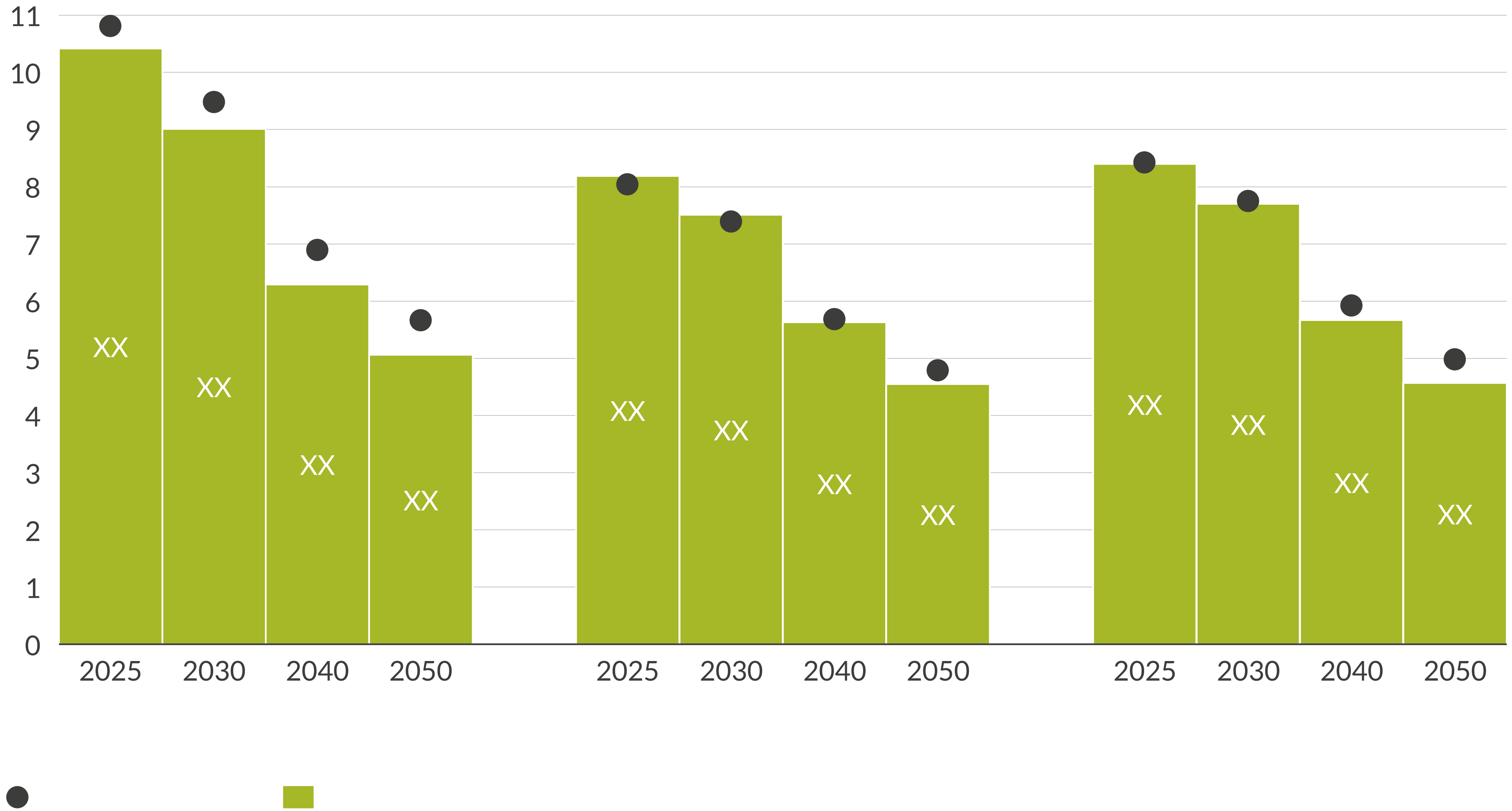

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1) Italy South bidding zone considered; 2) Hybrid 2x PPA load factors: 43-61%; 3) Solar only 4x PPA load factors:43-44%;

Source: Aurora Energy Research

Co-locating with a battery

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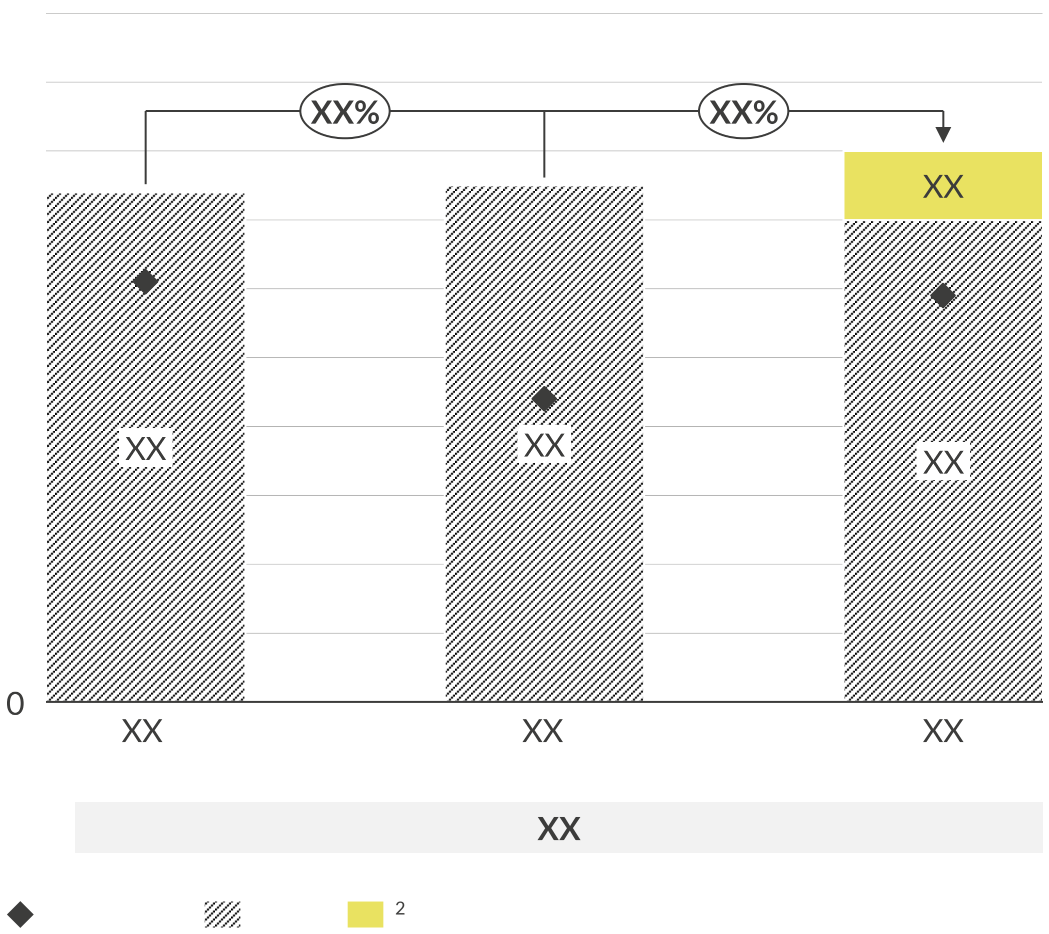

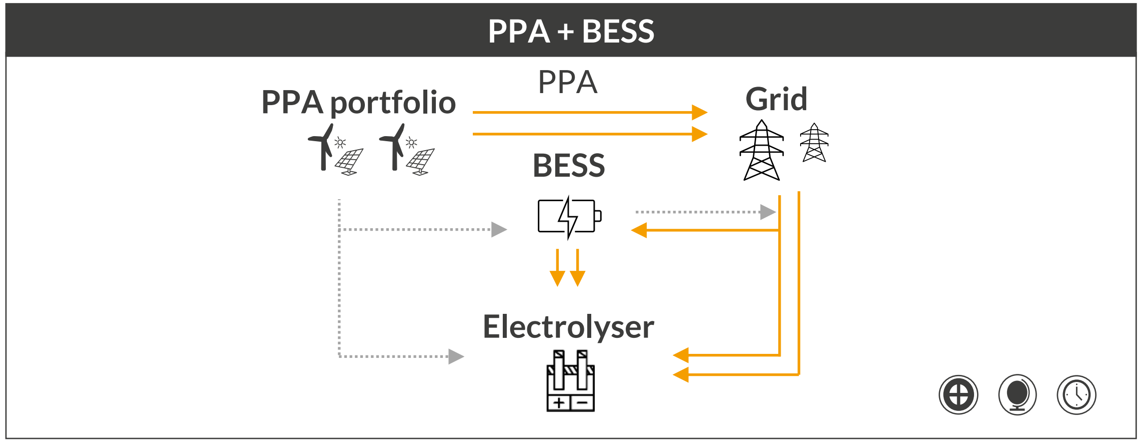

Comments on PPA + BESS:

REDACTED

Red II Compliance Criteria: Additionality Geographical correlation Temporal correlation

REDACTED

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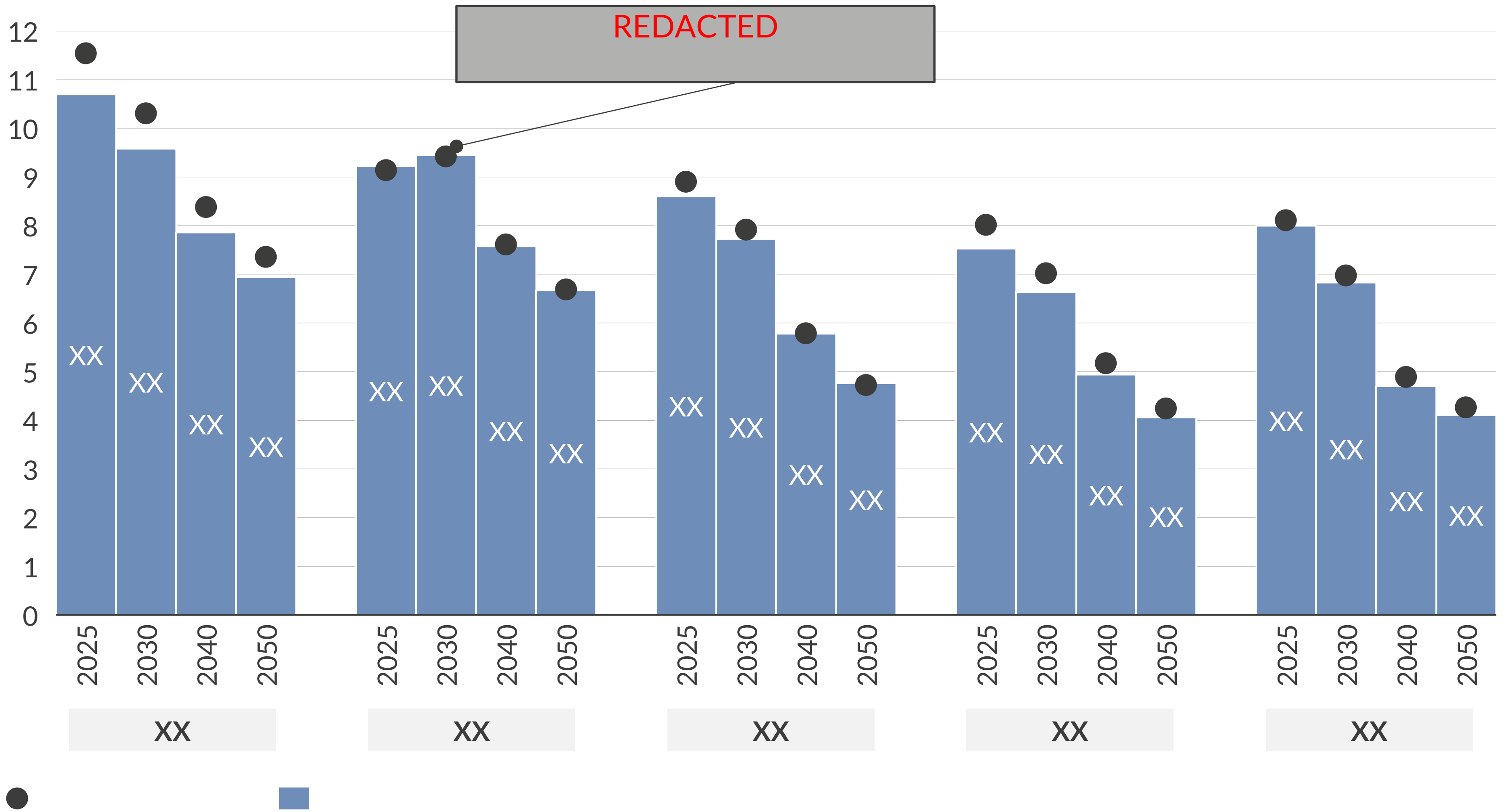

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Source: Aurora Energy Research

Producing low-carbon hydrogen through grid imports can lower LCOHs ~10% versus hybrid PPAs, but market appeal is lower for non-RFNBO[1] hydrogen

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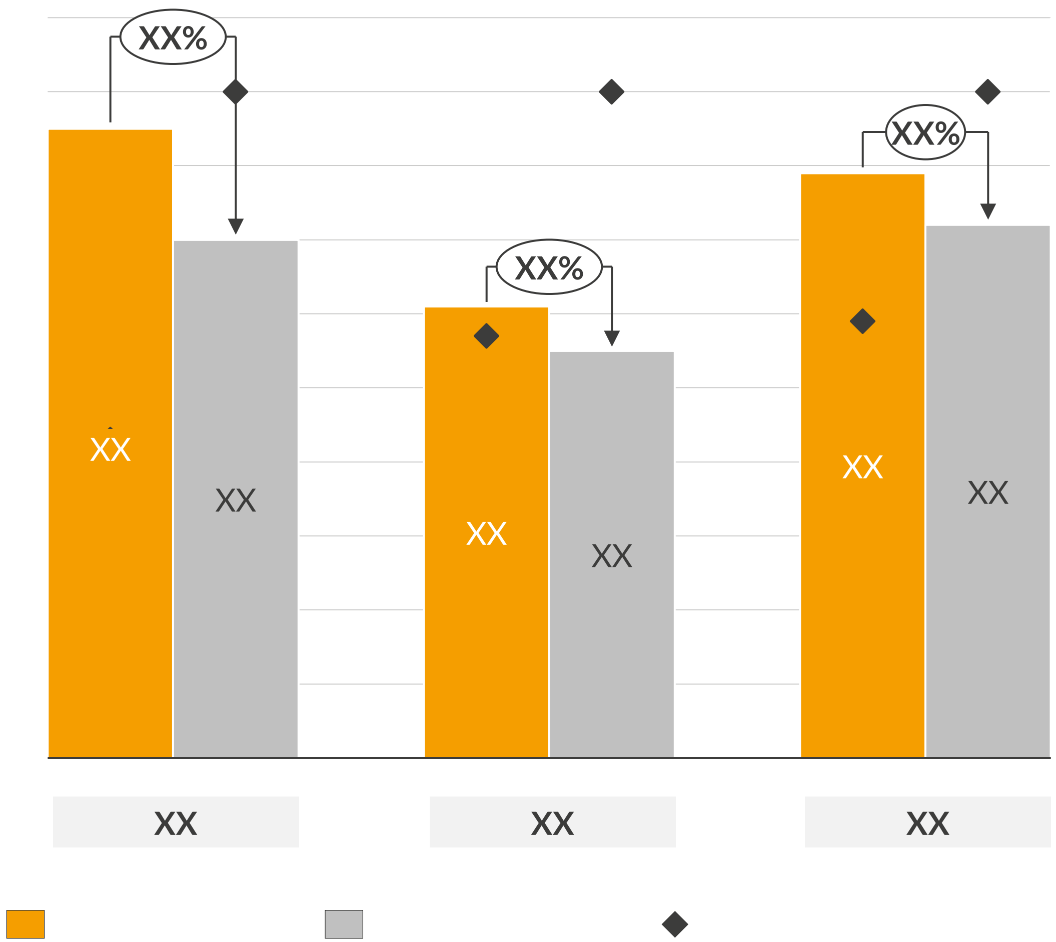

What low-carbon hydrogen means for electrolyser projects in different regions

Regulation	Explanation
UK's Low-Carbon Hydrogen Strategy	Requires H_2 emissions below 2.4 $kgCO_2/kgH_2$ to be classified as low-carbon.
EU Low-Carbon hydrogen (pending[2])	Requires a 70% GHG reduction compared to grey hydrogen (3.4 $kgCO_2/kgH_2$).

REDACTED

1) RFNBO: Renewable fuels of non-biological origin as defined in the RED II; 2) Low-carbon hydrogen standard draft in the EU is currently under review and was expected to be finalised by Q4 2024;

Sources: Aurora Energy Research, European Commission, UK Department for Energy Security and Net Zero

Regions with low-carbon grids are waived from additionality, unlocking the potential to sign a PPA with hydropower and produce cheaper hydrogen

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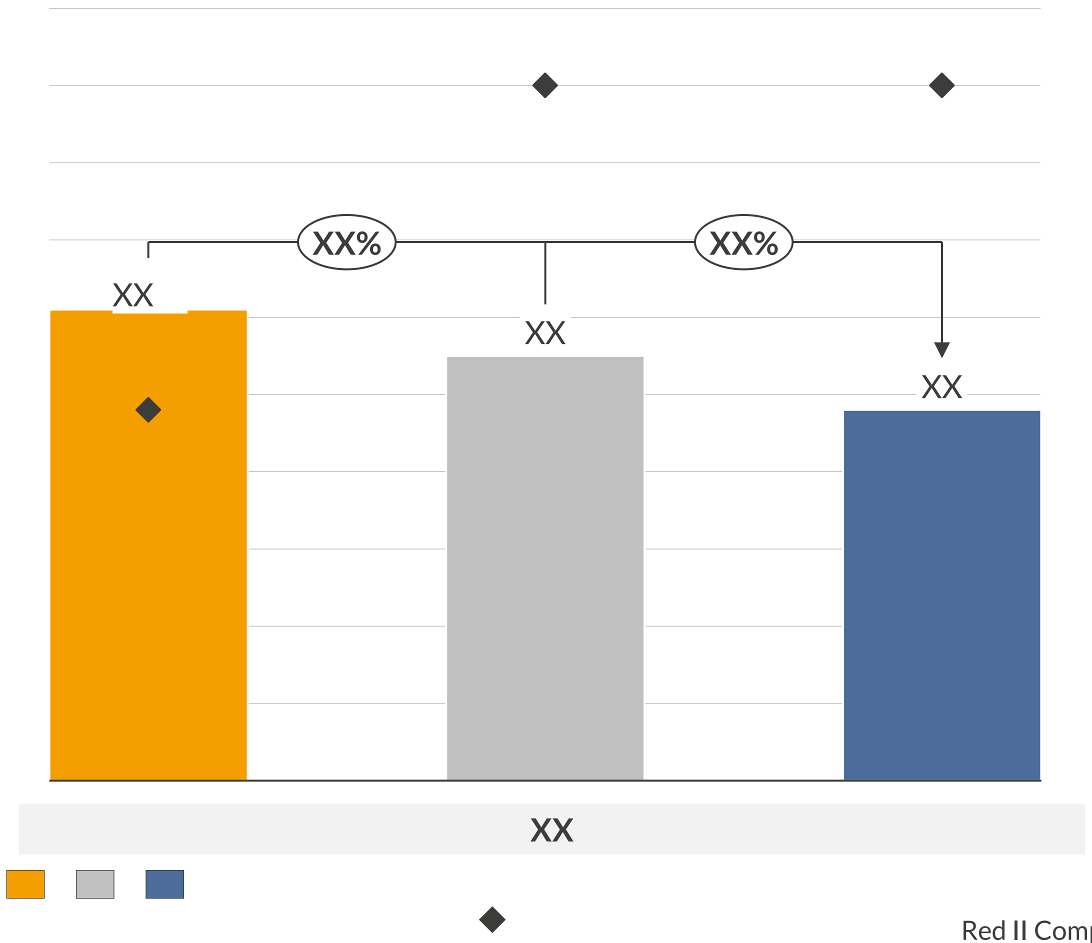

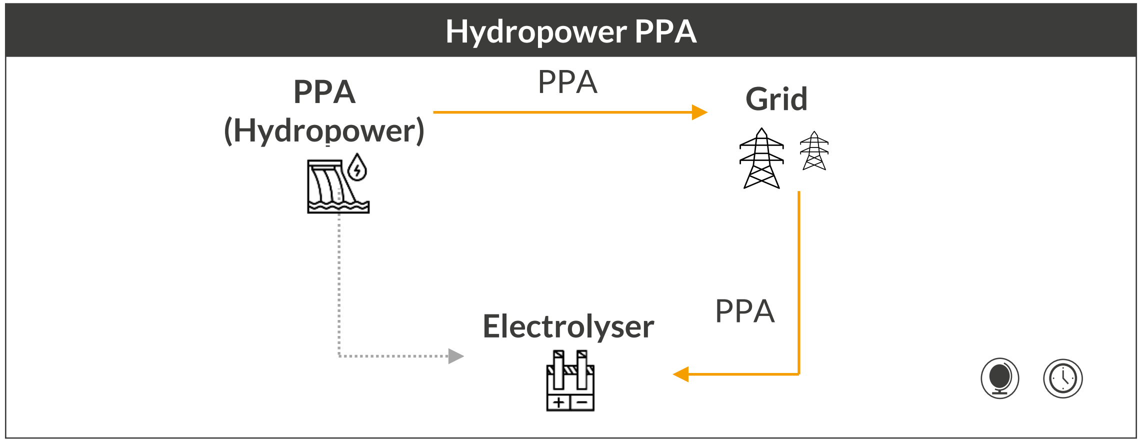

REDACTED

Red II Compliance Criteria: Geographical correlation Temporal correlation

Source: Aurora Energy Research

Oversizing a PPA can cut costs by 11% and boost electrolyser load factors by 21p.p., but may be challenging to acquire in an undersupplied market

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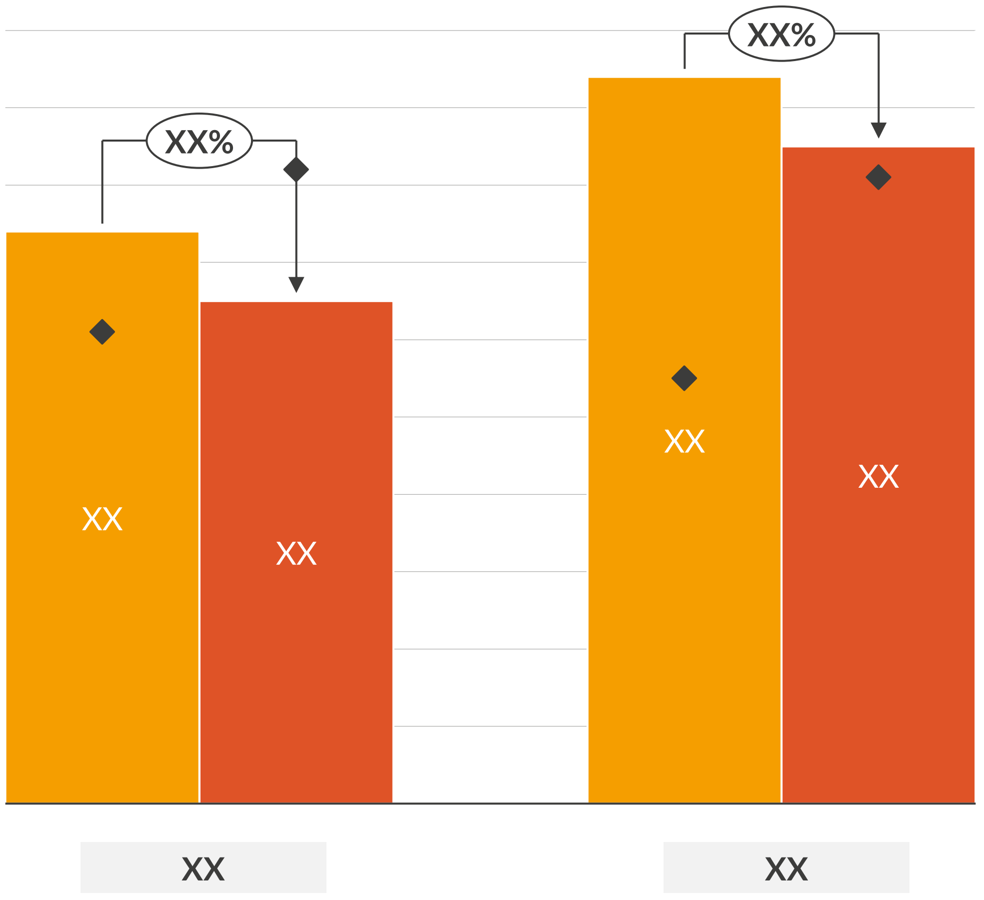

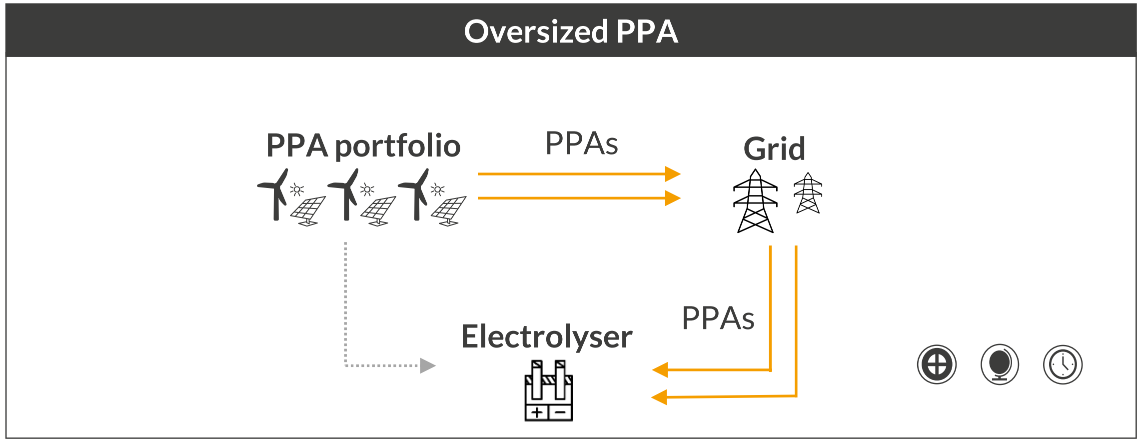

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Red II Compliance Criteria: Additionality Geographical correlation Temporal correlation

Source: Aurora Energy Research

Topping up PPA-power via grid imports offers the lowest cost of hydrogen production in comparison to fully-grid-powered electrolysers

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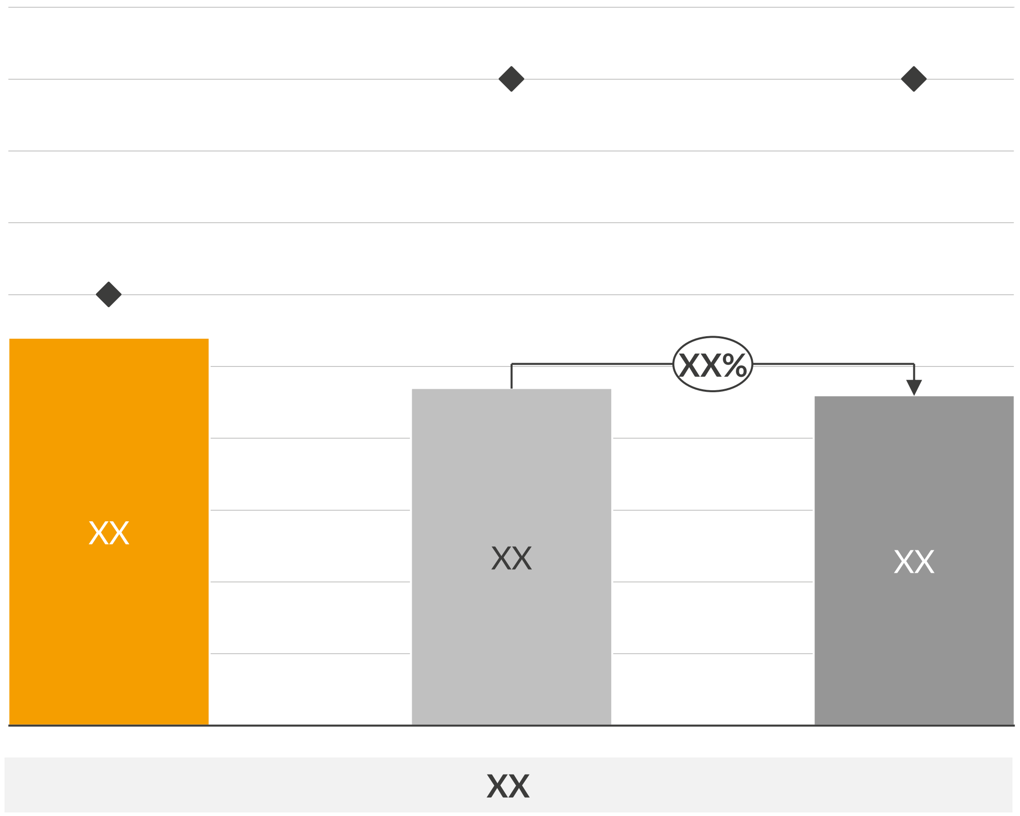
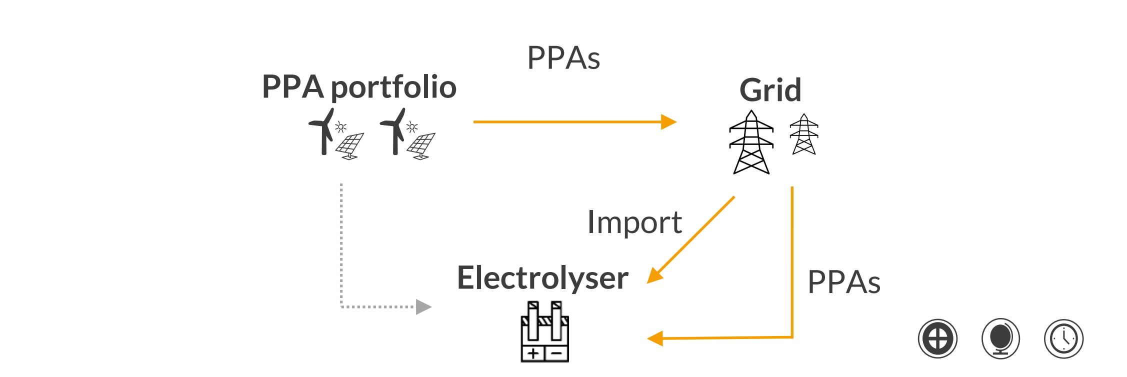


PPA + grid connection



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Red II Compliance Criteria: Additionality Geographical correlation Temporal correlation

1) SE2 bidding zone considered;

Source: Aurora Energy Research

One strategy to avoid high retail charges is by co-locating electrolysers with renewables via direct connection, if land availability permits

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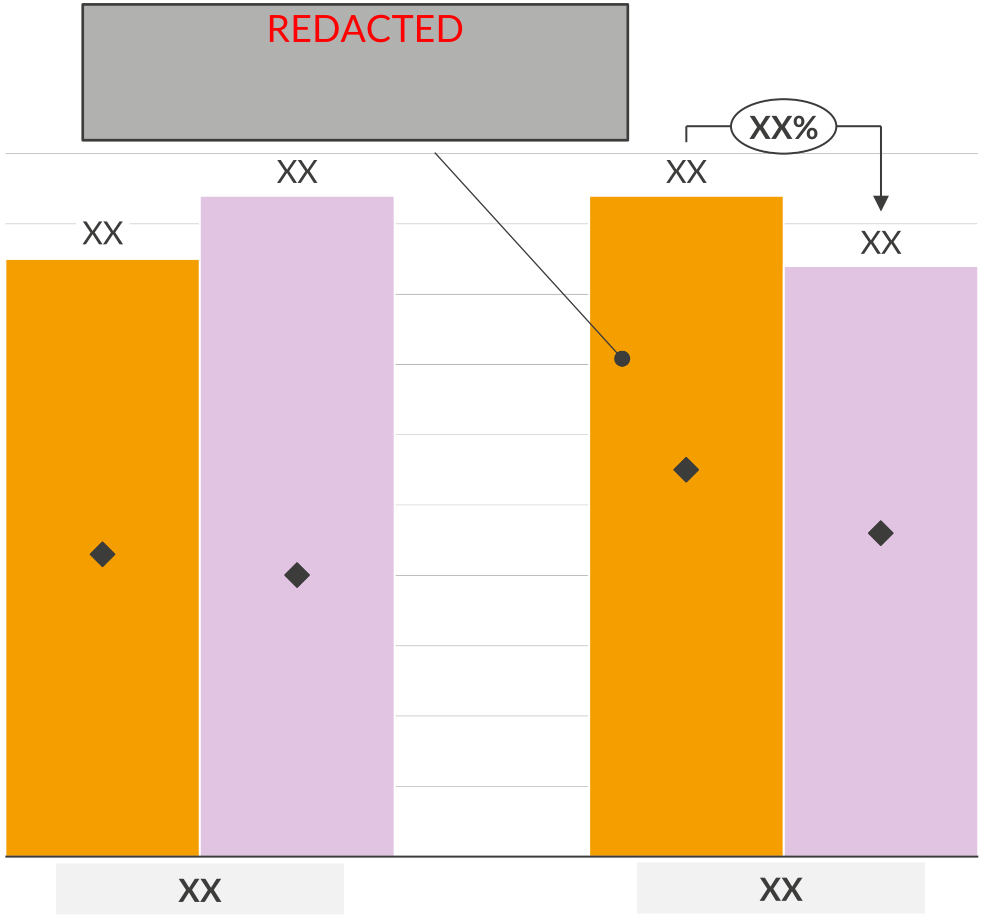
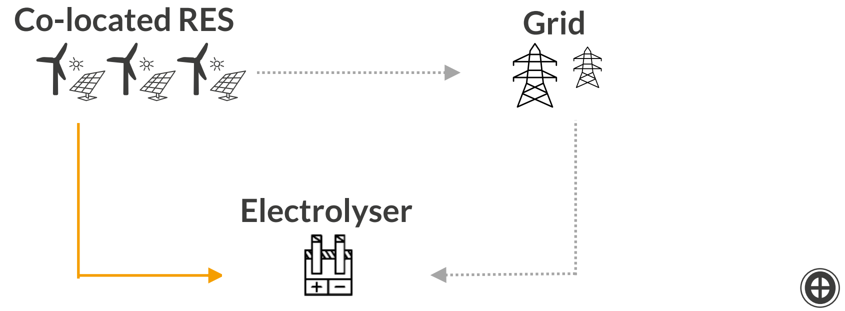


Co-location



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Red II Compliance Criteria: Additionality Geographical correlation Temporal correlation

1) Currently, electrolysers in Germany are exempt from retail charges until 2029; 2) Due to generally higher wind/solar rations, updated technology load factors, and updated renewable CAPEX/OPEX, the co-located LCOHs are not comparable to Oct-24 HyMaR;

Source: Aurora Energy Research

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A hydrogen purchase agreement is crucial for hydrogen projects to be financeable

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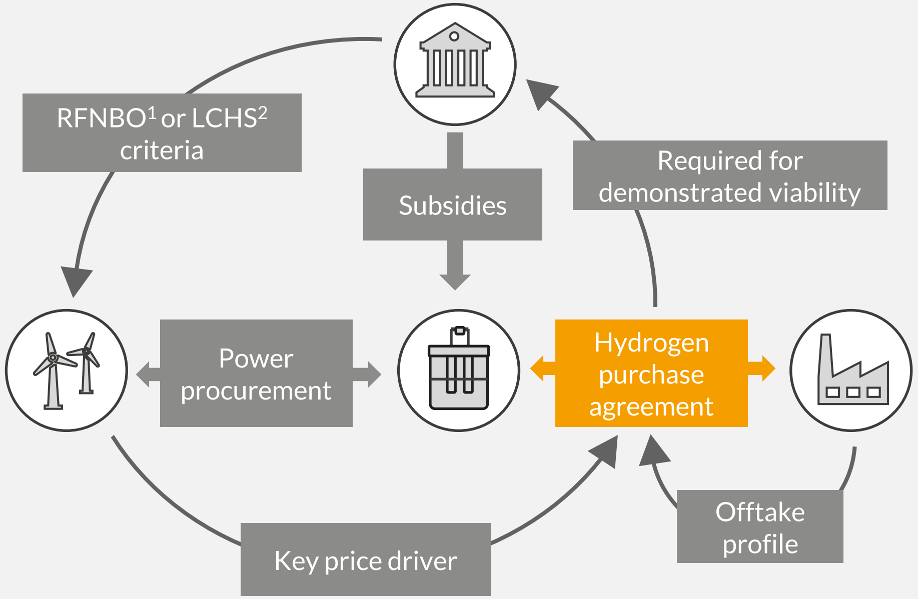
What is a hydrogen purchase agreement (HPA)?
An HPA is a bilateral contract between a producer and an offtaker, defining H_2 sale terms, including price, volume, quality, delivery, and dispute resolution.

Why does the renewable/low-carbon hydrogen market need HPAs?

- HPAs help de-risk the emerging H_2 market by securing demand for producers and ensuring a reliable supply for offtakers.
- Projects move forward only when the agreed HPA price aligns with the offtaker's willingness to pay.
- This willingness to pay reflects the cost required for the offtaker to achieve the same end-use as their existing process or technology[1].



The key challenges for mobilising the financing needed for hydrogen projects relate to technology, regulatory and economic risks

	Risks	Enablers
Economic	Competitiveness	REDACTED
	Offtake	
Technology	Operational	
	Value chain	
Policy & regulation	Regulatory	
	Policy	

1) To assess this, Aurora has developed benchmark models based on economic fundamentals from real-world projects, calculating the willingness to pay. A deep dive on this topic can be found on Slide 111; 2) EPC: Engineering, procurement, and construction; 3) O&M: Operation, and maintenance;
Source: Aurora Energy Research

HPA1 pricing reflects electrolyser costs, offtaker needs, and capital at risk—factors that can be reduced via subsidies and mandates

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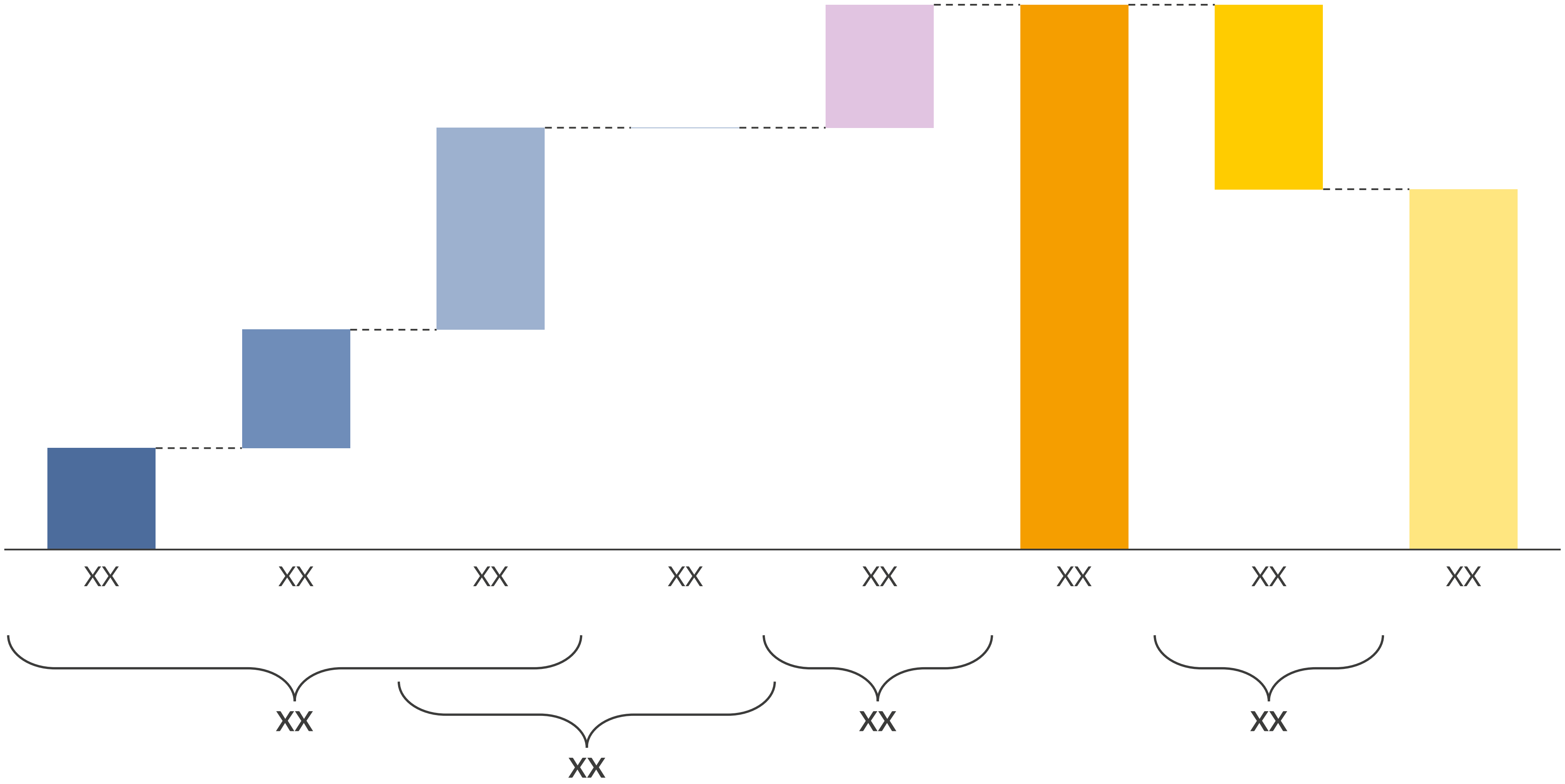

1) HPA: Hydrogen purchase agreement;

Source: Aurora Energy Research

Commercial clauses establish contract agreements between buyers and sellers of hydrogen, mitigating risk on both sides

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	Component	Description
Commercial clauses	Price	REDACTED
	Volume	
	Tenor/term	
	Quality	
	Delivery and transport	
Legal clauses	Dispute resolution	
	Liability and indemnification	
	Termination rights	
	Lender's rights	
	Force Majeure[1]	

Current trends for Hydrogen Purchase Agreements (HPAs)

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Sources: Aurora Energy Research, Estudio Legal Hernández, U.S. Securities and Exchange Commission, European Commission

The pricing structure in an HPA can vary

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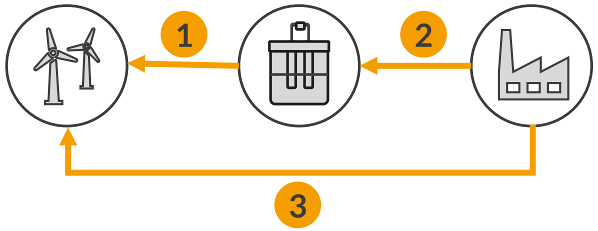
Price clause

Payment flows:



Case study inputs

REDACTED

Price model	REDACTED	REDACTED
Fixed pricing (1) (2)		

REDACTED

Indexed pricing (1) (2)		

REDACTED

Tolling (2) (3)		

REDACTED

1) The recovery of capital includes electrolyser CAPEX and OPEX;

Source: Aurora Energy Research

Offtake profile plays a significant role in the project design, stricter offtake profiles could make hydrogen much more expensive

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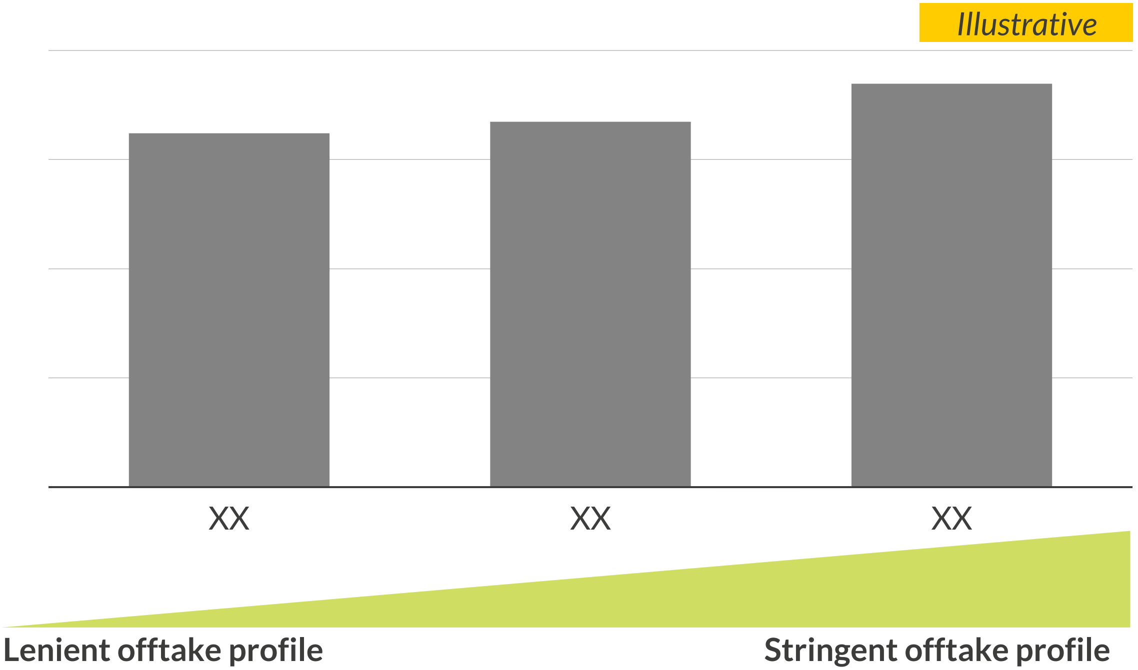
Volume clause

Volume clause	Risk allocation Offtaker / Developer
As produced REDACTED	REDACTED
Fixed pattern REDACTED	REDACTED
Baseload REDACTED	REDACTED

REDACTED



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Higher tenor in hydrogen purchase agreements derisks price uncertainty, yet offtakers don't want to lock themselves into a long tenor

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Tenor clause

Tenor clause | **Risk allocation** (Offtaker — Developer)

Short-term (≤5 years)

Not preferred for debt financing. Because of revenue uncertainties, hydrogen projects with short tenor are not successful reaching FID.

Medium-term (6-9 years)

Allows debt financing of smaller projects. Revenue uncertainty is lower in comparison to short tenor, yet it persists.

Long-term (≥10 years)

Allows for highly debt-leveraged finance, provides revenue certainty. However, finding an offtaker who is willing to lock themselves in a long tenor is challenging.

Quality clause

How are subsidy eligibility criteria incorporated into HPAs?

Quality clauses

- Quality clauses are how hydrogen specifications are traditionally incorporated into an HPA.
- Within quality clauses there are specification clauses, which include: *technical product*, *additional*, and *sustainability*.
- Stakeholders stipulate in the *additional* and *sustainability* specification requirements how their H_2 adheres to:

EU's RED II Delegated Act 27 & 28

UK's low-carbon hydrogen Standard (LCHS)

Additional requirements

- Eligible offtakers[1].
- Further social and environmental standards[2].

1) E.g. UK scheme rules out risk intermediaries to avoid speculators taking advantage of the subsidy scheme; 2) E.g. required in the EU scheme H2Global, which is designed for H_2 imports from outside the EU;

Source: Aurora Energy Research

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We assess the willingness to pay in hard-to-abate sectors relative to a reference technology to better understand H_2 market development

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Hard-to-abate sector focus and sensitivities[1]

REDACTED

Ammonia

Refinery

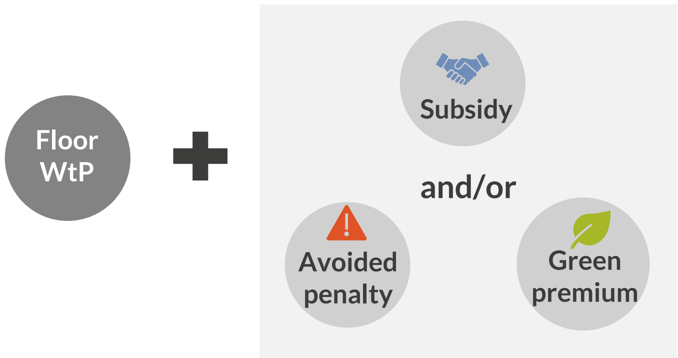
Steel

Industrial heat

H_2-

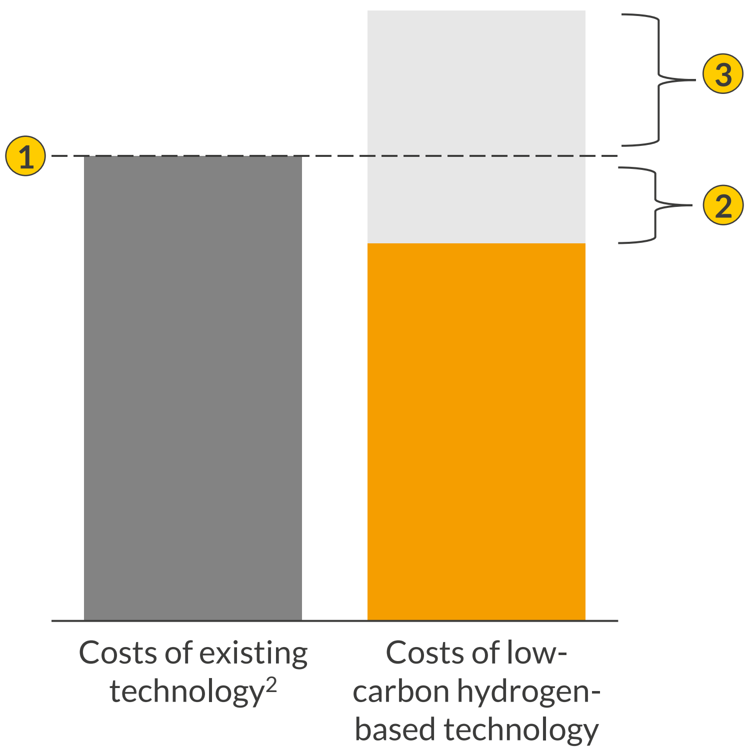
Defining willingness to pay for H_2

1. From a purely techno-economic standpoint, offtakers are typically only willing to adopt low-carbon H_2 technology if production costs for H_2-based production is equal to, if not lower than, the reference competing technology.
2. Assuming cost parity, the difference in non-H_2 costs is the amount offtakers are willing to pay (WtP) for H_2. This constitutes the "floor" to WtP.
3. Additional low-carbon hydrogen technology costs: the additional costs that go beyond the willingness to pay, these can be addressed by green premiums, subsidies, and/or avoided penalties:



Visual representation of willingness to pay

Illustrative example of willingness to pay



1) While we show numbers only for Germany and the UK, the WtP in other EU countries is expected to be similar to Germany owing to very similar commodity prices; 2) Production costs between different technologies are compared on a levelised basis;

Source: Aurora Energy Research

The methodology to estimate willingness to pay varies slightly depending on whether the incumbent technology already uses hydrogen

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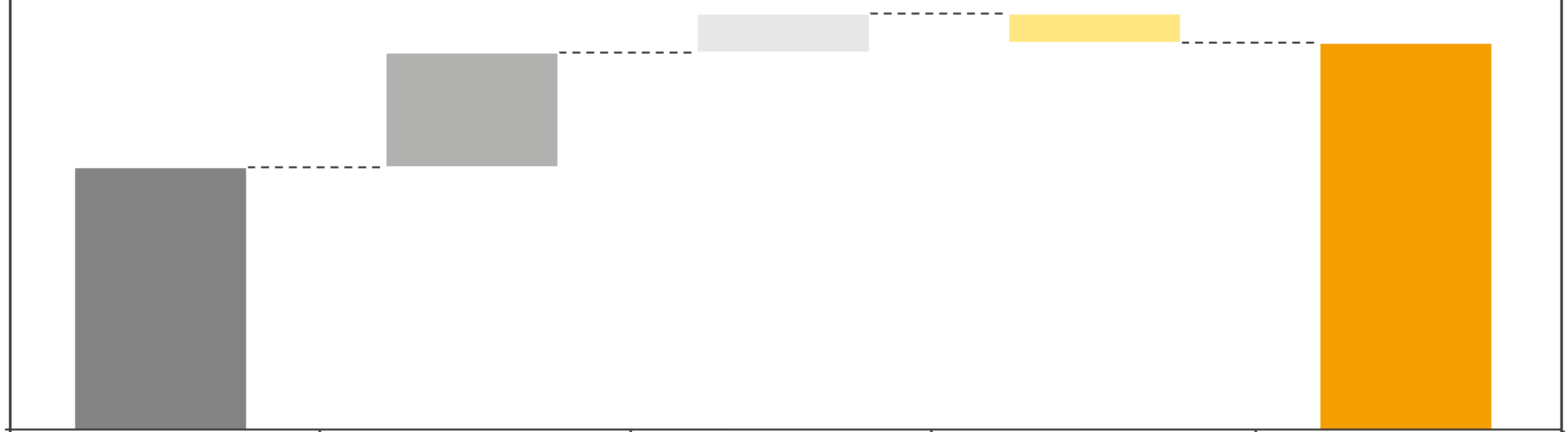
WtP[2] methodology for sectors currently using hydrogen (ammonia, refinery)

Floor willingness to pay price build up in sectors currently using hydrogen

€/kgH_2

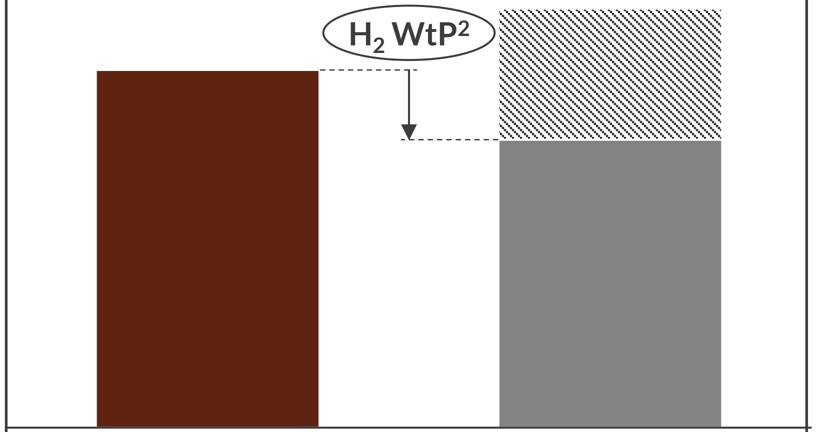


Grey H_2	Carbon	Free allowances	Additional equipment	Floor WtP[2]
The cost of producing H_2 from the incumbent fossil fuel-based process which includes the cost of fossil feedstock and equipment operation	The cost associated with securing ETS[1] allowances for the emissions from the incumbent fossil-fuel based process	Certain end-use sector receive free ETS allowance which can now be sold for extra revenue given the decarbonised nature of the alternative pathway	Integrating electrolytic H_2 into existing production systems may necessitate new process units; for e.g. an ammonia facility would now require an air separation unit	By combining the components, we arrive at floor willingness to pay, which represents the minimum payout required to justify making a switch

WtP[2] for new sectors (steel and high-grade heat)

Illustrative levelised cost of steel or heat

€/tonne crude steel or €/MWh of heat



Traditional process (BF-BOF[3] or gas furnace)	H_2 based process (DRI-EAF[4] or H_2 furnace)

- The difference between levelised cost of steel/heat for the traditional processes and non-hydrogen related costs of the H_2-based processes gives the floor willingness to pay per unit of steel/heat
- The difference, calculated in €/tonne of crude steel and €/MWh of heat, must be divided by the hydrogen intensity[5] of the processes to express the willingness-to-pay in €/kgH_2

Non H_2-related costs H_2 cost

1) ETS: Emission Trading Scheme; 2) WtP: Willingness to pay; 3) BF-BOF: Blast furnace – Basic oxygen furnace; 4) DRI-EAF: Direct reduction of iron – Electric arc furnace; 5) We assume a case where 50% of the steel produced is of primary nature requiring 28.4 kgH_2/kg crude steel output;

Source: Aurora Energy Research

Willingness to pay is influenced by various factors that shape pricing, which vary across different hydrogen sectors

Driver	Impact on WtP price	Explanation	Sectors impacted
Natural gas price		REDACTED	
UK/EU ETS[1] price			
Free allowance phase-out			
Coal price			
Hydrogen subsidies			
Green premium			
Mandates and penalties			

Source: Aurora Energy Research

Willingness to pay for ammonia remains around XX €/kg, which is less than half of production cost of low-carbon hydrogen in Germany

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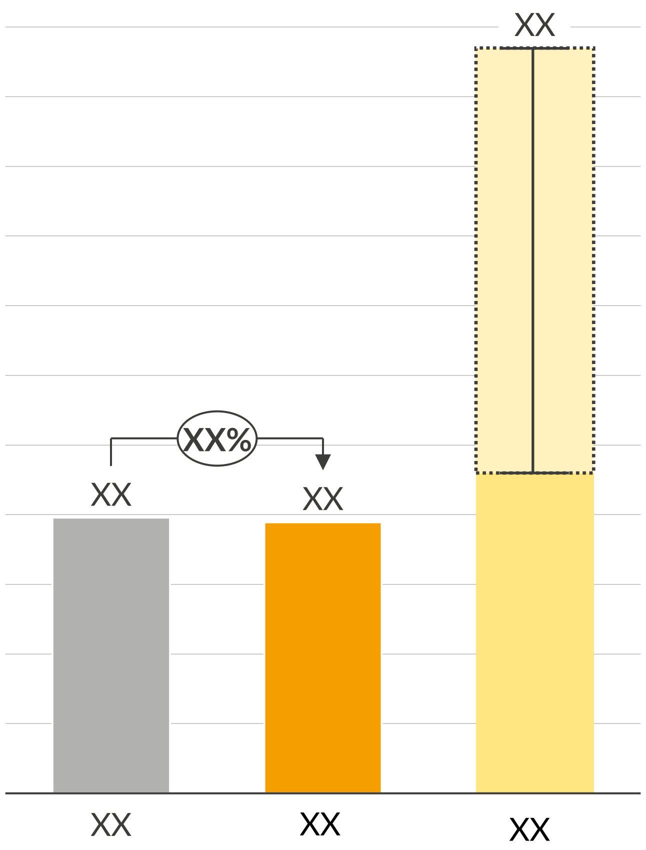

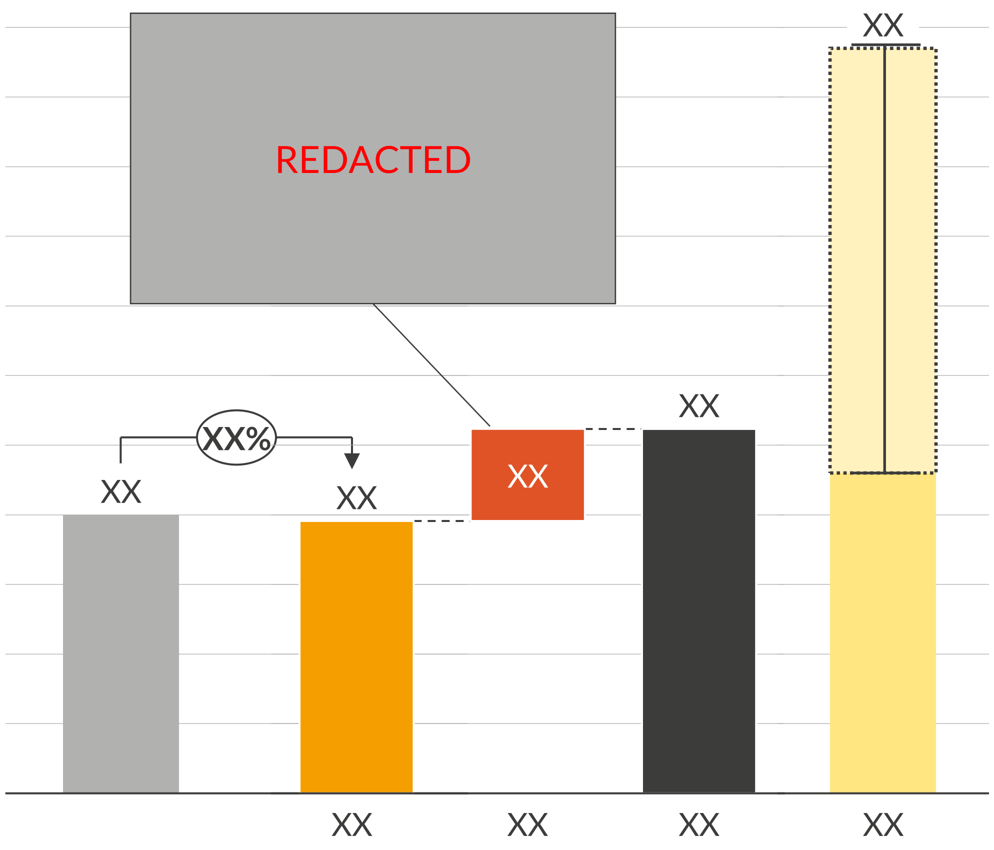

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Source: Aurora Energy Research

While the H_2 floor willingness to pay for refineries is XX€/kg in 2030, consumption mandates in industry could increase this by around XX%

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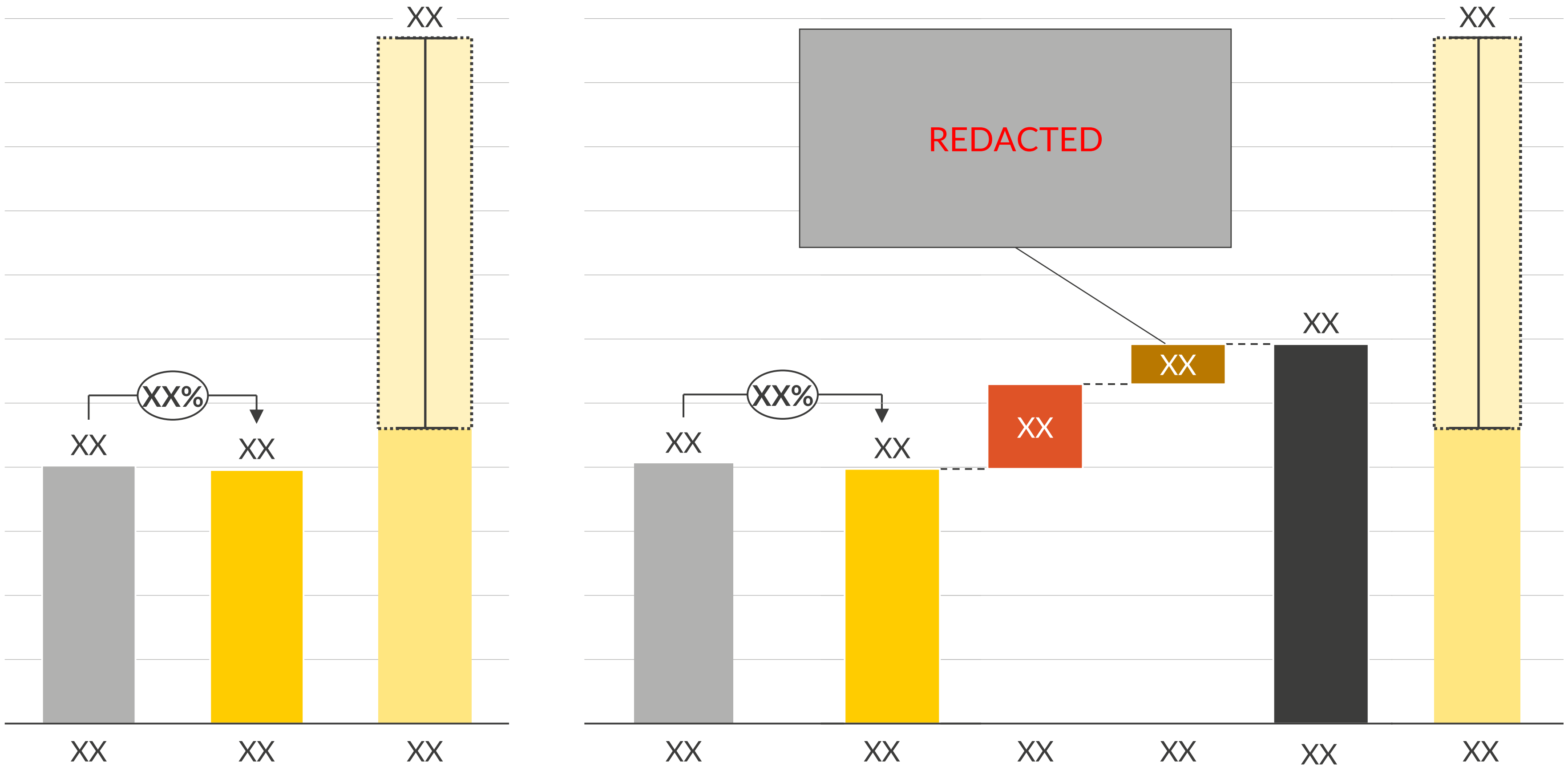

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1) RED III: Renewable Energy Directive; 2) For more information on how the 'high' and 'low' penalties are defined please see the report here; 3) Here we examine a scenario where the RED III penalty is equal to the EU-ETS price; 4) GHG Quota: Greenhouse Gas Quota; 5) LCOH range for all HyMaR electrolyser business models - see section VI here; 6) WtP: Willingness to pay;

Source: Aurora Energy Research

While the H_2 floor willingness to pay in steelmaking is around XX€/kg in 2030, a XX% CAPEX subsidy, could raise it by XX €/kg

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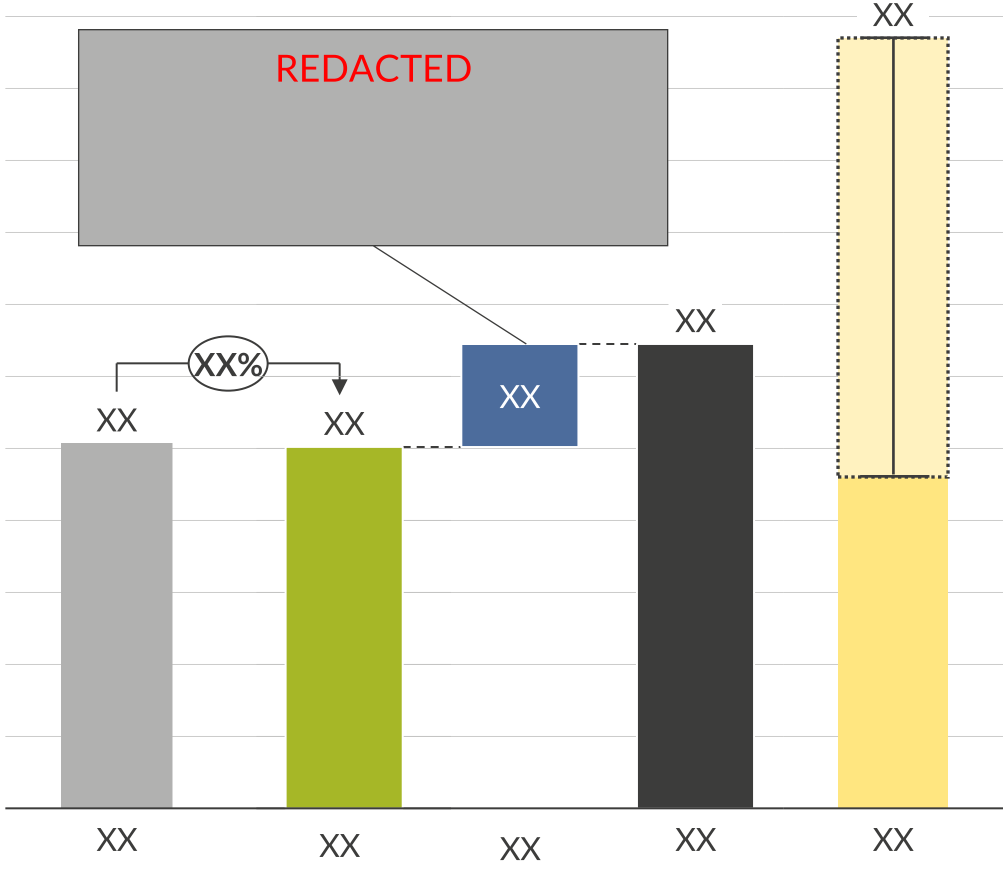

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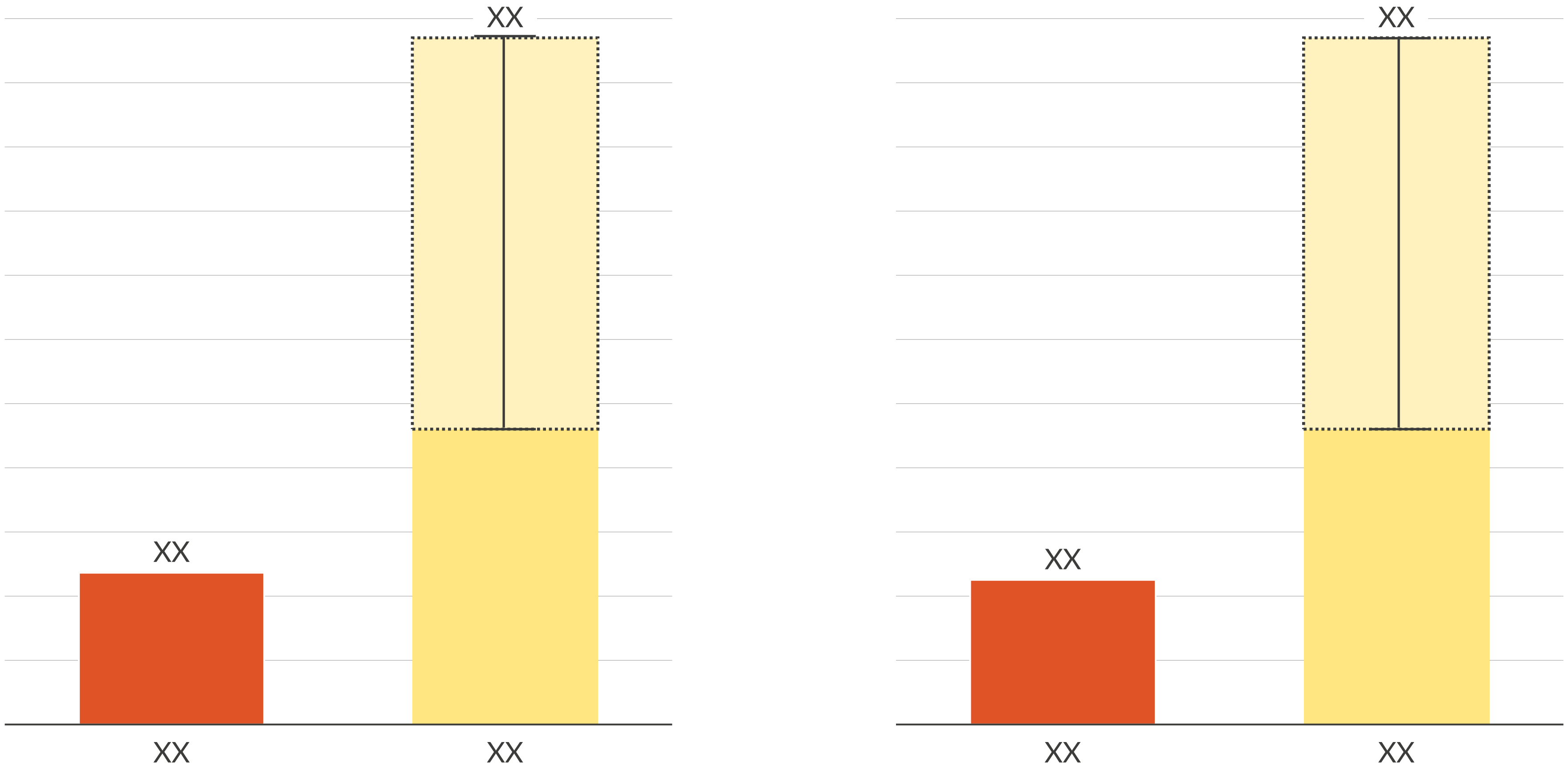
1) Here, we consider a case with a subsidy of 360 million €/Mtpa, nearly half of the CAPEX, which is approximately the average subsidy granted in Europe; 2) This is the range in LCOHs for all HyMaR countries and electrolyser business models for more information see section VI here; 3) RED III: Renewable Energy Directive; 4) WtP: Willingness to pay;

Source: Aurora Energy Research

H_2 in high-grade industrial process heat has a low WtP[2] due to low gas prices, requiring mandates and support to bridge the cost gap



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1) This is the range in LCOHs for all HyMaR countries and business models for more information see section VI here; 2) WtP: Willingness to pay; 3) HAR: Hydrogen Allocation Round; 4) CCfD: Carbon Contracts for Difference;
Source: Aurora Energy Research

Rising ETS[1] prices drive up floor WtP[2], with steel seeing the sharpest spike owing to the emission-intensive nature of the traditional steelmaking process

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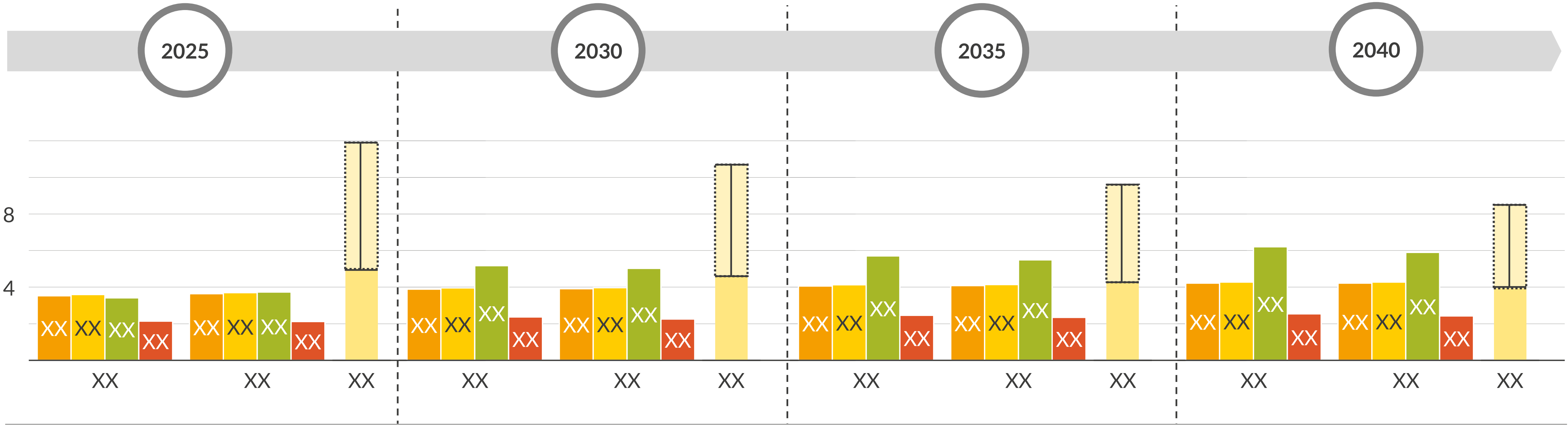

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Source: Aurora Energy Research

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The long-term hydrogen market outlook will depend on global developments, ranging from a fully bilateral market to a liquid market or a hybrid of both

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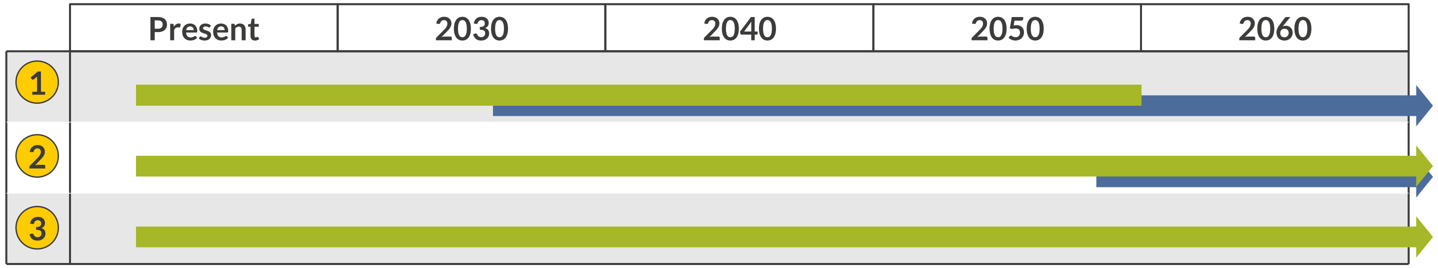
There are several factors that contribute to uncertainties surrounding the long-term European hydrogen market

Key uncertainties	Level of uncertainty
Electrolyser deployment	Medium uncertainty
Blue H_2 deployment	High uncertainty
Phase out of grey H_2	Low uncertainty
Demand for H_2 and e-fuels	Medium uncertainty
Build out of hydrogen infrastructure	Medium uncertainty
Availability of cheaper H_2 imports from outside Europe	Medium uncertainty
Security of supply restrictions for domestic H_2 production	Medium uncertainty
Industrial offshoring of green steel	Medium uncertainty

Low uncertainty Medium uncertainty High uncertainty

Depending on how the factors evolve, there are several ways the long-term H_2 market can develop

Long-term hydrogen market scenarios



1

2

3

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Bilateral agreements (Hydrogen Purchase Agreements) Liquid market

In a liquid hydrogen market, prices will be determined by the most expensive technology in the merit order curve, influenced by key factors

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What is required to establish a liquid hydrogen market?

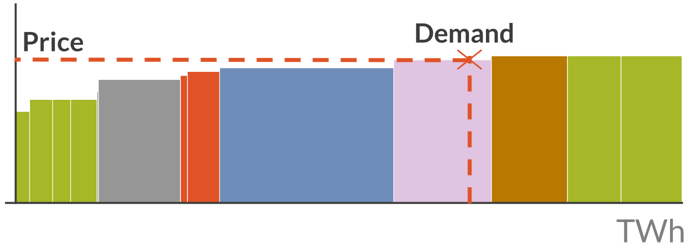
The current hydrogen market primarily relies on bilateral purchases, with production located near demand. For this to evolve into a liquid hydrogen market, several changes are needed:

REDACTED

How does Aurora model a liquid hydrogen market?

Merit order for hydrogen supply and demand

€/kgH_2



- Aurora's hydrogen market model features a separate 'hub' for each country, using a merit order stack to identify the price-setting technology and the short-run marginal cost for each hydrogen type and region.
- The model incorporates assumptions for demand for H_2 and its derivatives, production technology deployment and the trajectory of infrastructure development.
- This is integrated into a unified model that can be used to analyse key hydrogen market outputs.

What is included in our hydrogen market model?

Aurora's current liquid hydrogen market prices includes several different types of hydrogen which each have individual marginal costs.

- Low-carbon hydrogen which is produced by electrolysers and SMR with CCS[1] is included in Aurora's model with future development of these technologies expected in line with government support.
- Imports and exports are also accounted for, assuming transportation of low-carbon hydrogen via pipelines and shipping.
- The modelled prices exclude domestic transportation costs within a country.

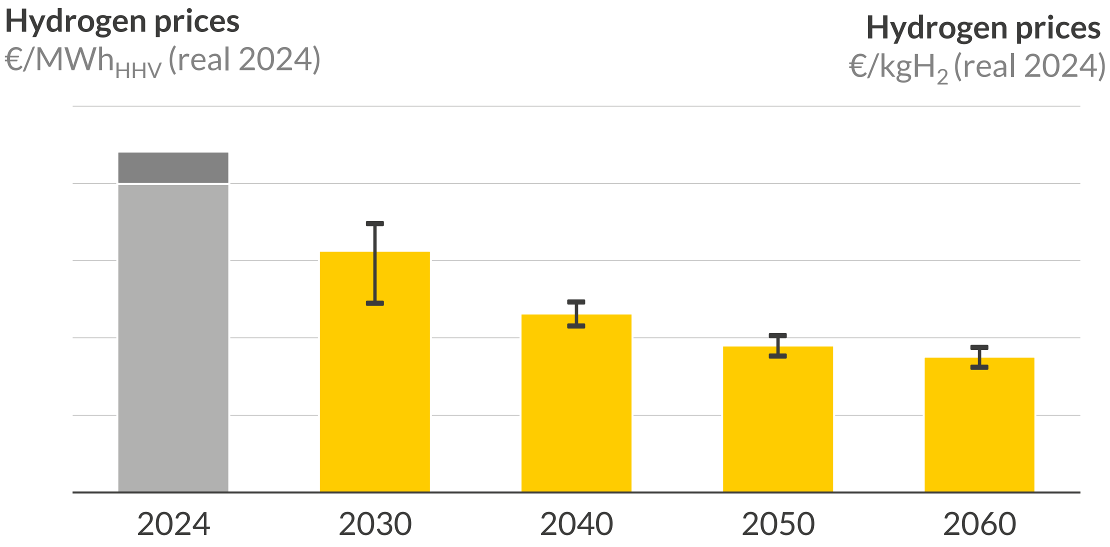
Electrolysers | International shipping | Intercontinental pipeline | Blue H_2[1] | Intra-European pipeline | Grey H_2[2]

1) Hydrogen produced from steam methane reforming combined with carbon capture and storage; 2) Hydrogen produced by steam methane reforming or as a by-product;

Source: Aurora Energy Research

If a liquid market develops, we expect long-term prices to range from REDACTED

Low-carbon hydrogen wholesale market price (Central):



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Low-carbon hydrogen prices in a completely liquid market 2050[3]:

REDACTED

<3.7 €/kg	*3.6 - 3.7 €/kg*	*3.7 - 3.8 €/kg*	*European Average 3.8 €/kg*	*3.8 - 3.9 €/kg*	*3.9 - 4.0 €/kg*	*>4.0 €/kg*	*Not in report*

HYDRIX - lower limit[1] HYDRIX - upper limit[1] Average hydrogen price[2]

1) EEX Green Hydrogen Index, which gives a market-based index based on supply and demand. Minimum and maximum price in Q4 2024; 2) Average annual prices across Europe. Error bars based on standard deviation of forecast year across all the covered European countries; 3) Low-carbon hydrogen prices reflect the costs associated to the marginal source of supply required to balance individual markets in each time step. Supply sources include domestic electrolytic and blue production, as well as imports;

Sources: Aurora Energy Research, European Energy Exchange (EEX)

The hydrogen supply mix is largely dependent on electrolyser deployment, grey H_2 phase-out, and the availability of imports

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Factors that impact long-term supply

- **Hydrogen price:** Higher hydrogen prices caused by greater demand can lead to more attractive opportunities for producers.
- **Technological developments:** Efficiency gains and cost reductions can enable more cost-effective production and increased supply.
- **Availability and cost of RES[3]:** RFNBO[2] H_2 production requires substantial RES[3] build-out, with regional disparities potentially causing bottlenecks.
- **Infrastructure build-out:** Development of pipelines and storage will lead to fewer supply bottlenecks and lower cost hydrogen imports.
- **Geopolitics and supply chains/skills :** A country's ability to invest in new technologies, maintain a stable supply chain, and provide skilled workers impacts hydrogen supply.

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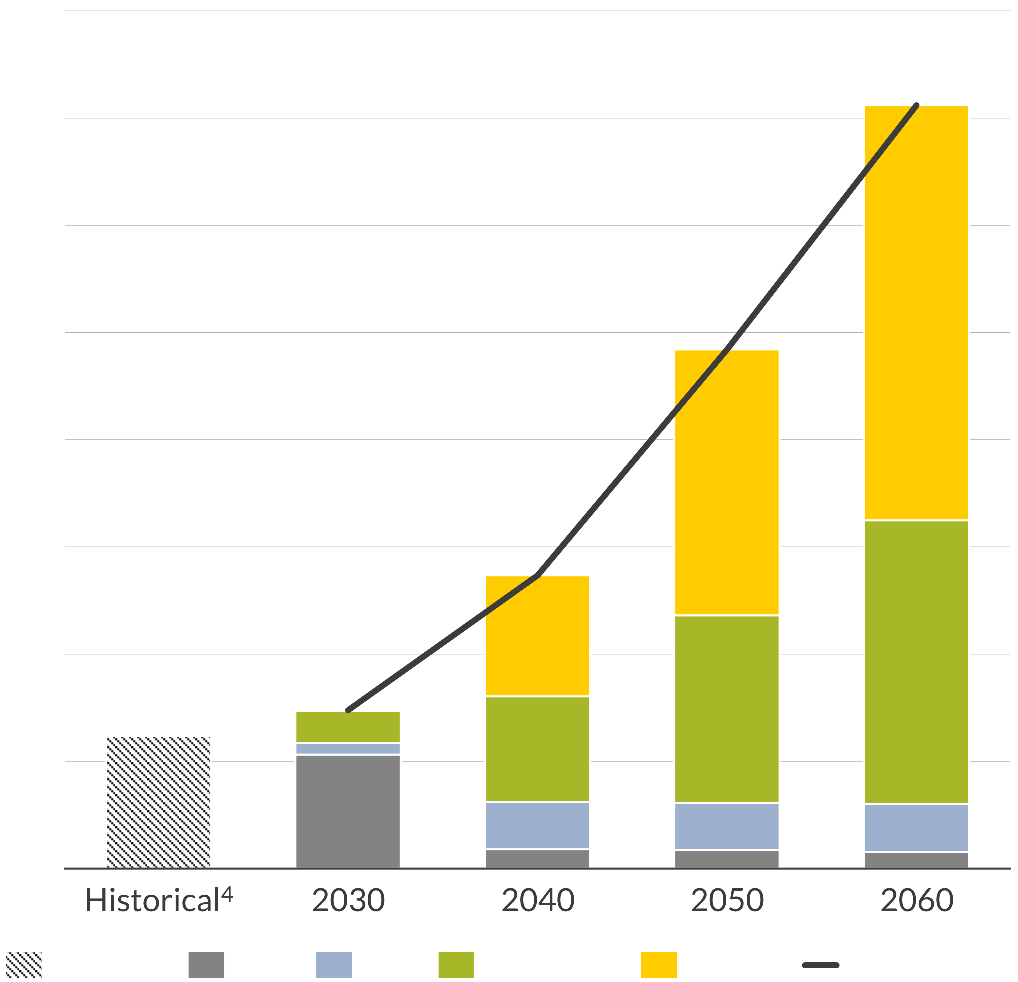


1) Includes 14 out of 15 HyMaR countries (DEU, NLD, POL, ESP, ITA, GBR, FRA, BEL, FIN, SWE, NOR, PRT, DNK, and IRL); 2) RFNBO: Renewable fuel of non-biological origin; 3) RES: Renewable Energy Systems; 4) Historic data from European Hydrogen Observatory;

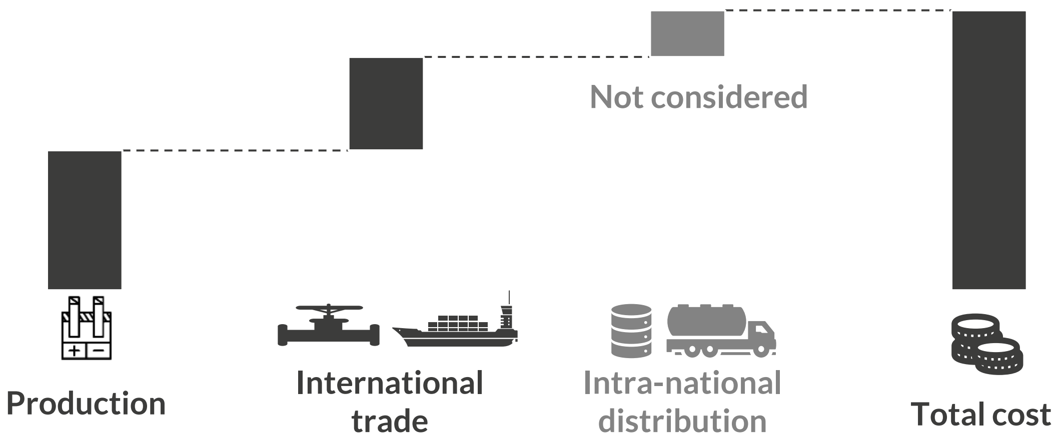
Source: Aurora Energy Research

In a liquid market, we assume the hydrogen market price to be based on the marginal cost of production required to meet demand

Definition of a hydrogen price in Aurora's European hydrogen market model

Our modelled prices reflect production and international trade

Illustrative breakdown of hydrogen price supply chain components

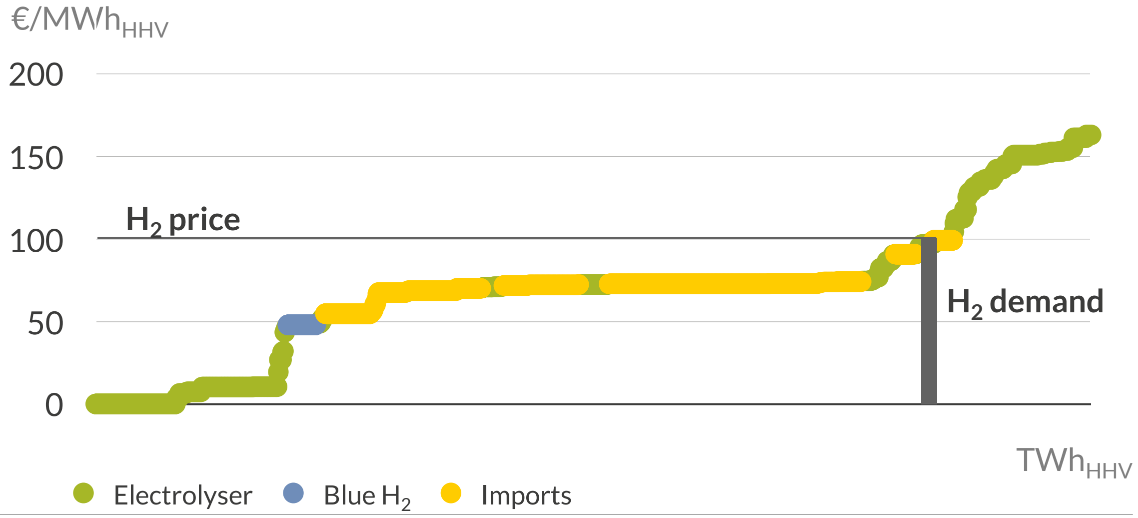


- Our price projections include the cost of production by technology (electrolysers, grey and blue H_2) as well as the cost of transporting hydrogen across regions. We do not model hydrogen distribution ***within each region.***
- In reality, we expect production to be located close to demand in the near future and hydrogen trade to be dominated by over-the-counter bilateral agreements. With the deployment of large-scale storage and pipelines, the location of production and demand can be progressively decoupled, and a liquid market can start to develop.

We assume a liquid wholesale market for hydrogen in Europe

- Currently there is <u>**no**</u> market liquidity and prices are mostly determined bilaterally between producers and consumers. In the future, we expect the development of a liquid market once there is a robust transport and storage network across Europe.
- We assume that the price in each region is determined by the most expensive unit of H_2 required to meet demand (marginal pricing), which is formed through the merit-order curve based on the short-run marginal cost of each source.

Illustrative marginal price formation



The share of wind and solar in the hybrid PPA portfolio is determined based on region-specific renewable load factors

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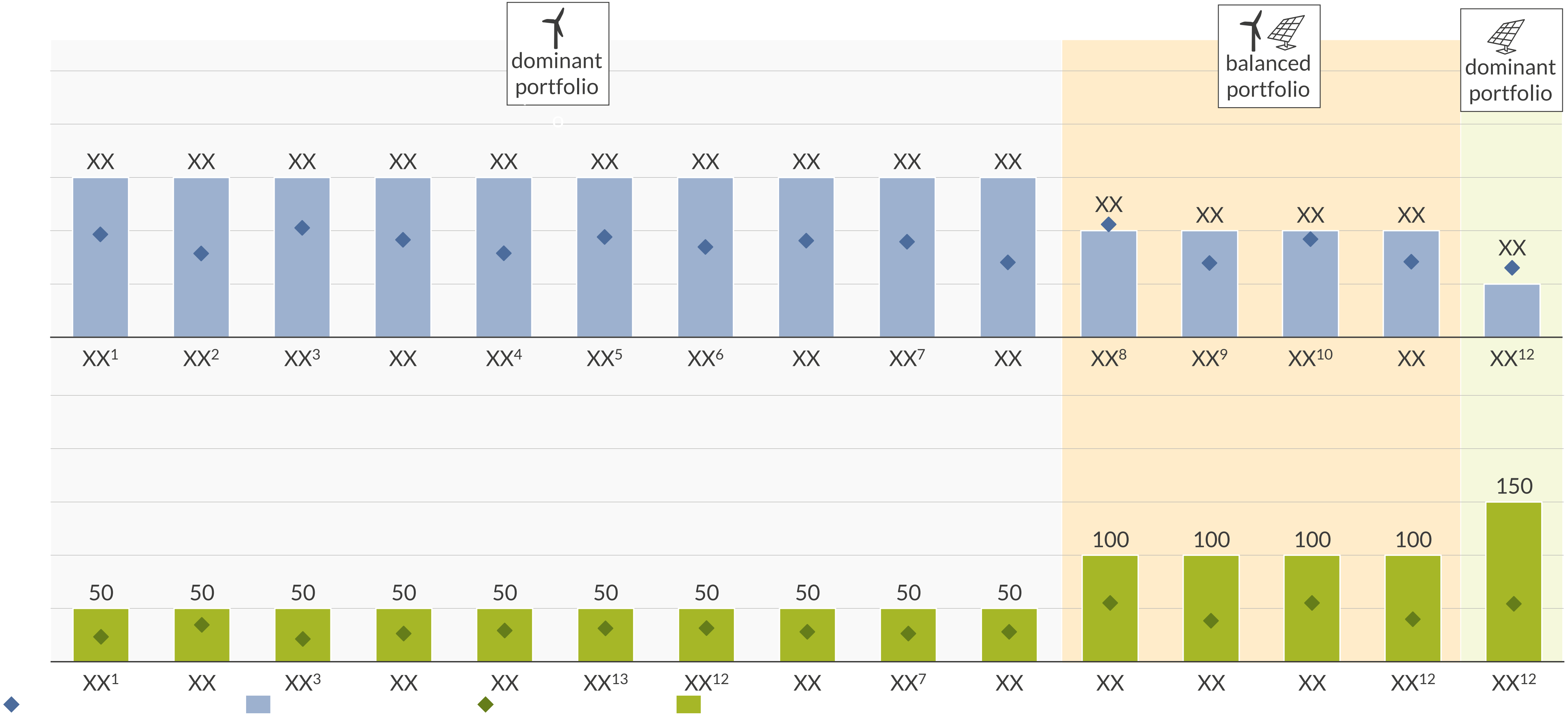

Source: Aurora Energy Research

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Details and disclaimer

European Hydrogen Market Report (HyMaR) Redacted – April 2025

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