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Hydrogen Conference

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Frederik Beelitz

Advisory Principal,
Aurora

AURORA KEYNOTE

SECURITY OF DEMAND: A ROADBLOCK FOR THE HYDROGEN ECONOMY?

Rate of new electrolyser projects has slowed down and announced projects face challenges in reaching FID

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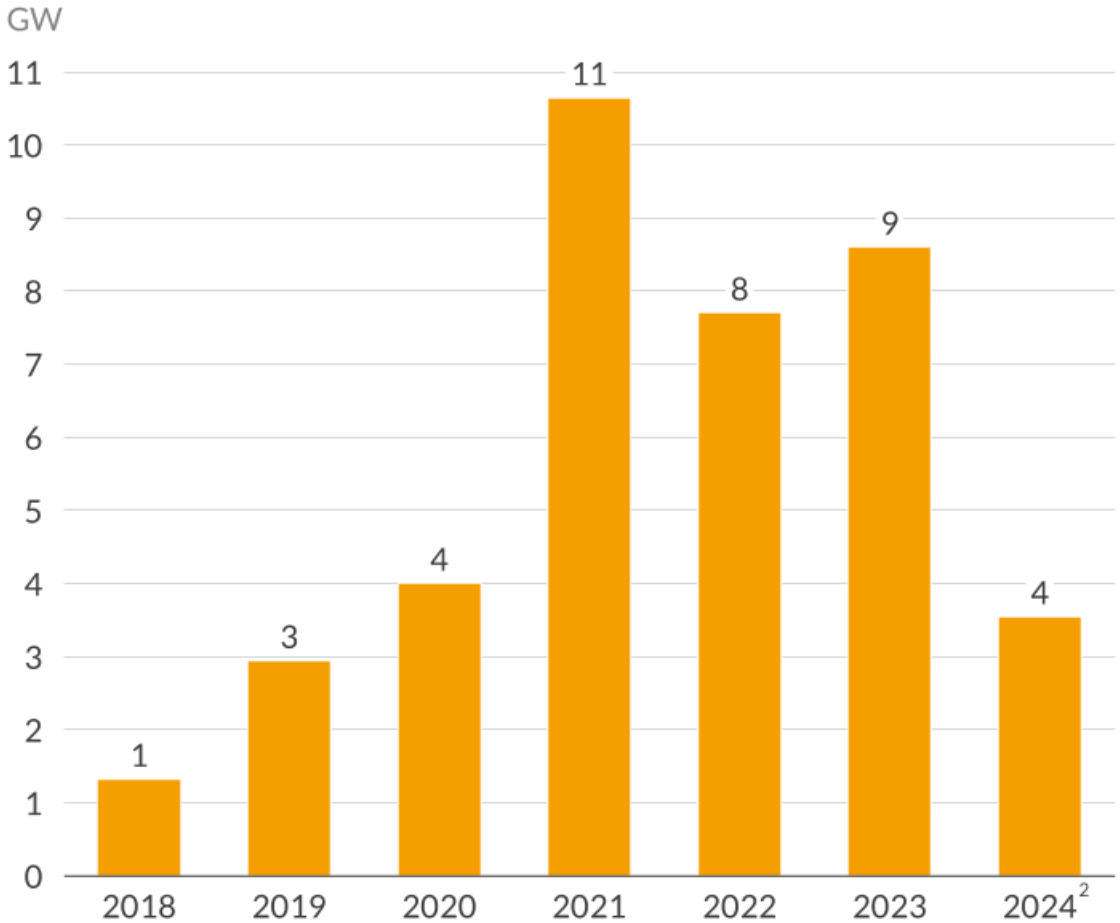
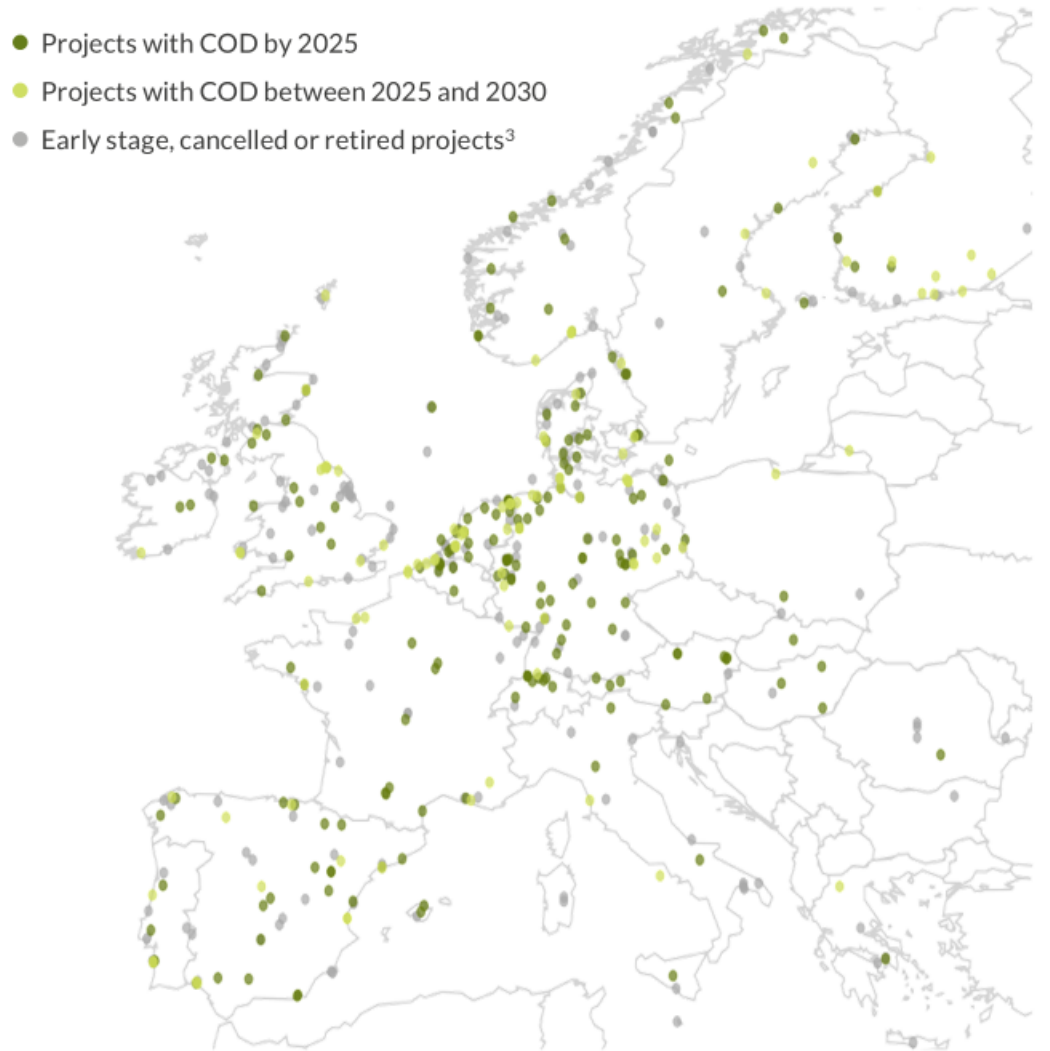
Electrolyser capacity by announcement date[1]





1) 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) 2024 includes early-stage projects too, while 2018-2023 only includes operational, construction and development status 3) 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

Industry becoming the most important offtaker for planned European electrolyser projects

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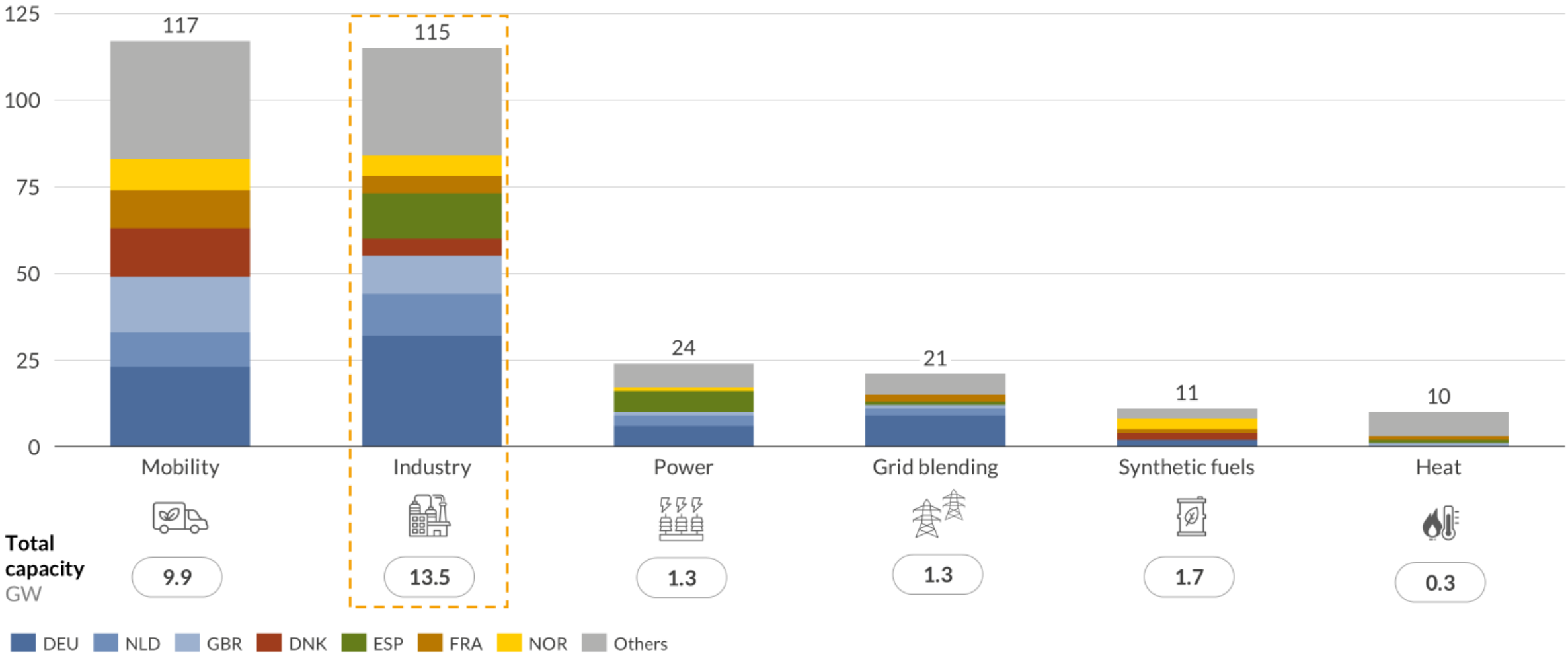
Number of project by end-use for European countries
# of projects



1) "Others" includes CZE, GRC, ISL, SVK, FIN, UKR, and POL 2) Early-stage projects are not included in this analysis

Refineries, chemical industry and steel making projected by Aurora to make up the bulk of industrial hydrogen offtake by 2030

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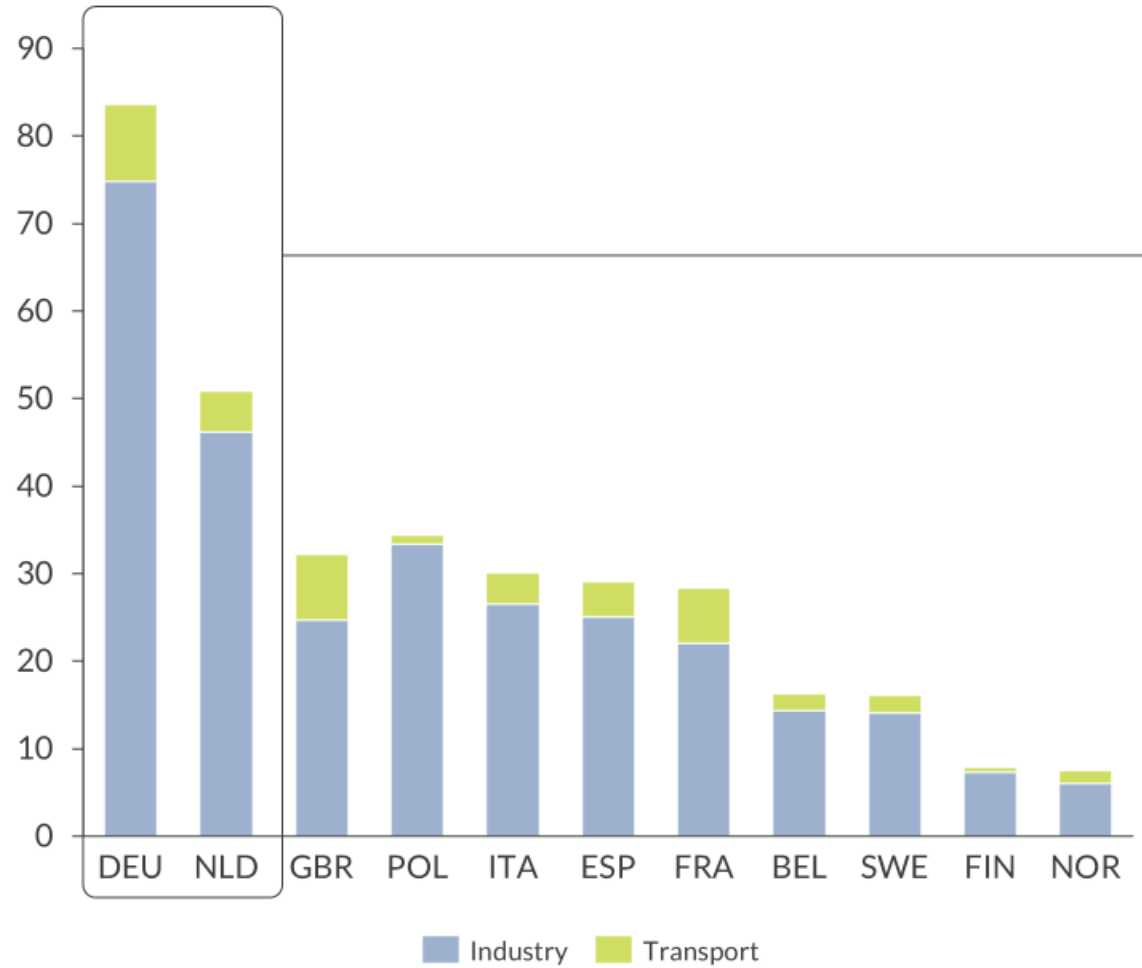
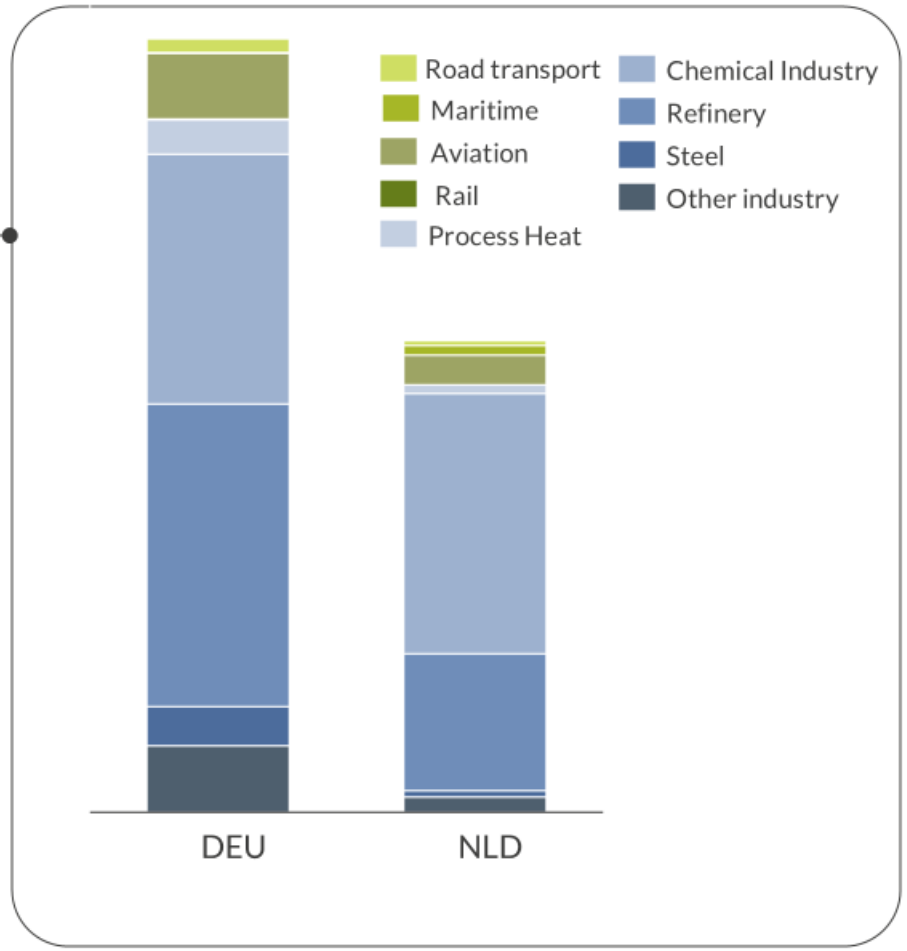
Hydrogen demand by sector in Central in 2030
TWh_{HHV}, final energy consumption



Hydrogen demand by sub-sector in Central in 2030
TWh_{HHV}, final energy consumption



Source: Aurora Energy Research

Currently the main obstacle for green hydrogen offtake for early adopters is the differential between willingness to pay and expected hydrogen prices

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New applications →

	Current hydrogen consumers	Hard-to-abate industries	Hard-to-abate transport	Others
First-mover sectors[1]	Ammonia, Refining	Steel	n.a.	n.a.
Other sectors	Methanol[2] and others[3]	Process heat, Power generation	Maritime, Aviation	Road transport, Space heating
Decarbonisation alternative	n.a.	Natural gas, RES[4] based electrification, CCS[5]	Biofuels, Electricity	Biofuels, Electricity
Competitiveness of hydrogen	◕	◑	◑	◑

1 Focus sector: Ammonia

Four of seven European Hydrogen Bank winning projects are dedicated to ammonia

2 Focus sector: refining

One of the largest current hydrogen consumin sector and target driven policy focus

3 Focus sector: Steel

Europe has at least 52Mtpa hydrogen-ready steel capacity in pipeline, backed by private funding and 9.6bn € of state aid.

Main obstacle for adoption: gap between offtakers' willingness to pay and high costs for producing low-carbon hydrogen

1) Sectors with the highest offtake potential for low-carbon hydrogen in the short-term based on public offtake information. 2) Majority of methanol production relies on hydrogen currently. Biomass could contribute to mass production of methanol in the future. 3) Other includes hydrochloric acid production, hydrogenation, hydrogen as a coolant, etc. 4) RES: Renewable energy sources. 5) CCS: Carbon capture and storage.

Sources: Aurora Energy Research, The Chemical Engineer

Willingness to pay as an indication on the 'floor' price hydrogen has to reach to match the cost of reference competing technology

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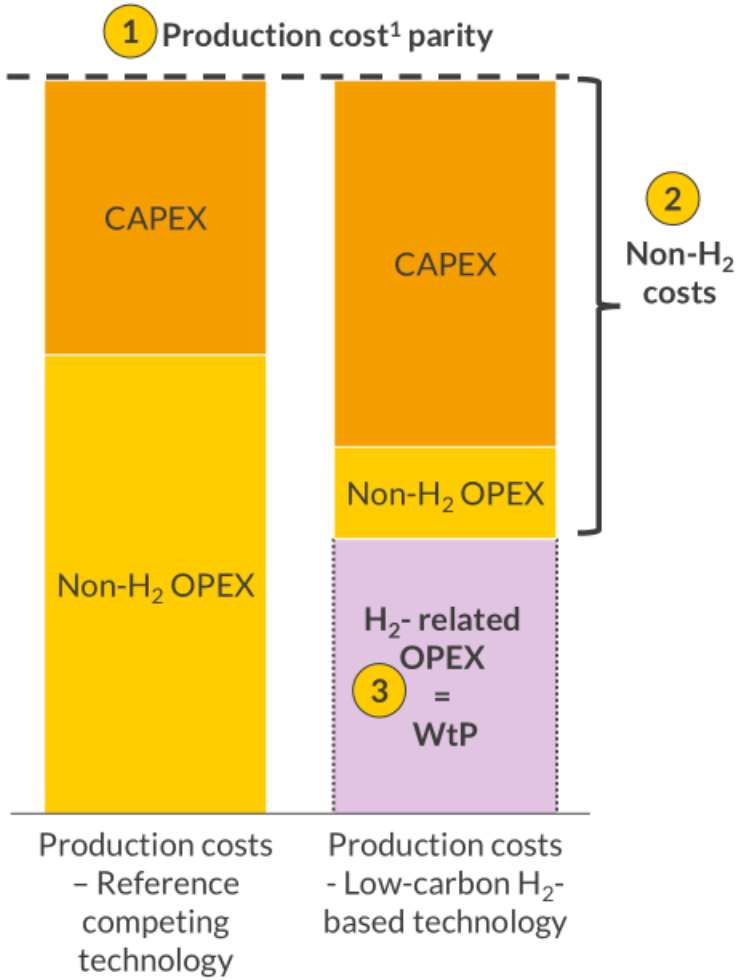
Illustrative alternative technology costs



Estimating willingness to pay for H_2

1. Switch only if H_2-based production is lower or equal than, the reference competing technology
2. Assuming cost parity, **the difference in non-H_2 costs is the amount offtakers are willing to pay for H_2**. This constitutes the "**floor**" to WtP[2].
3. WtP for low-carbon hydrogen is transformed to per unit of hydrogen from the H_2-related OPEX, by accounting for the H_2 intensity of the process.

Additional factors contributing to WtP

- Green premium
- Subsidy
- Avoided penalty

Geographical coverage in this presentation

1) Production costs between different technologies are compared on a levelised basis. 2) WtP: Willingness to pay.

Source: Aurora Energy Research

The incorporation of RED III[1] mandates and penalties on a national level will increase WtP[2] of Ammonia producers

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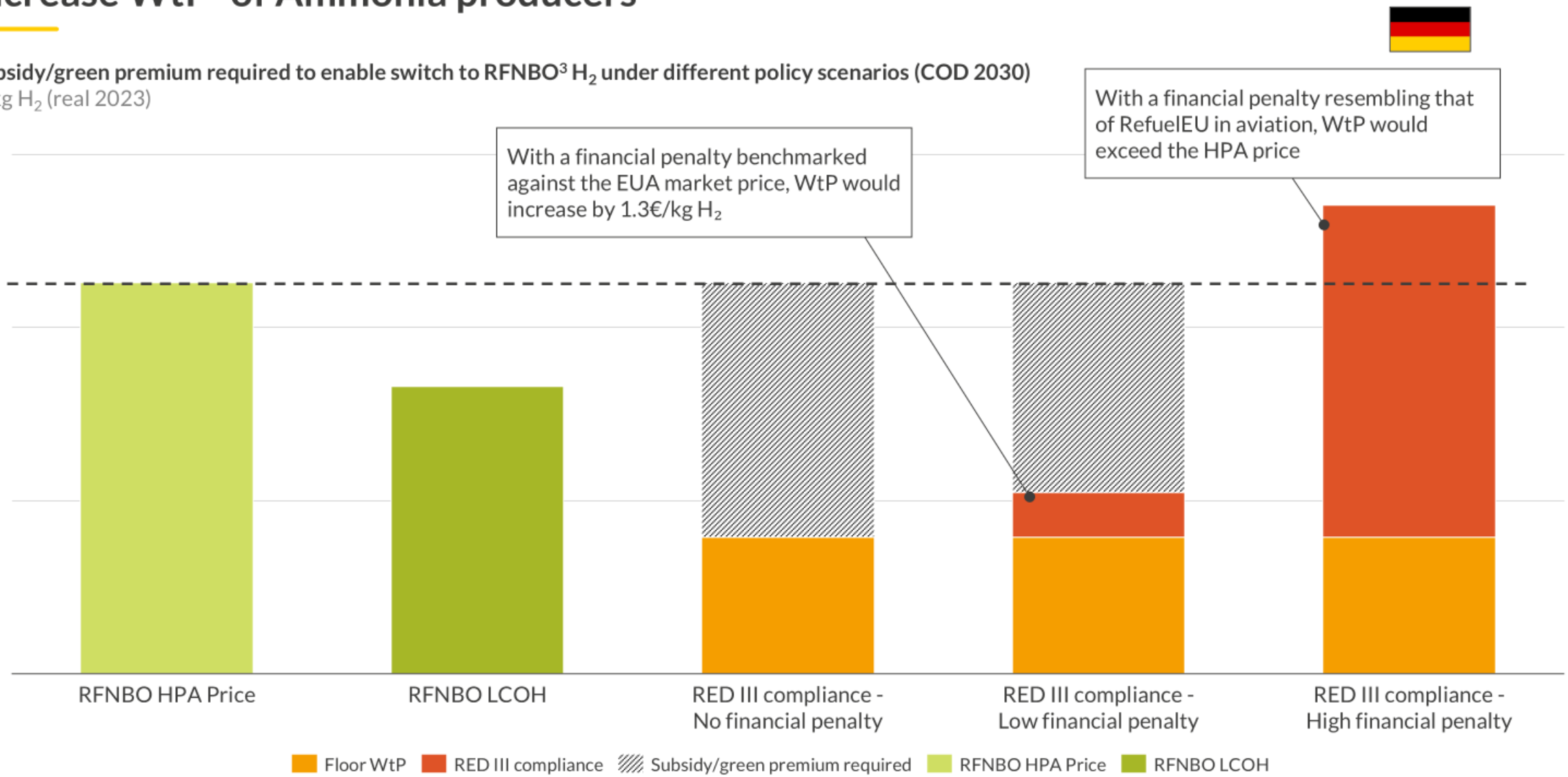
Subsidy/green premium required to enable switch to RFNBO[3] H_2 under different policy scenarios (COD 2030)
€/kg H_2 (real 2023)

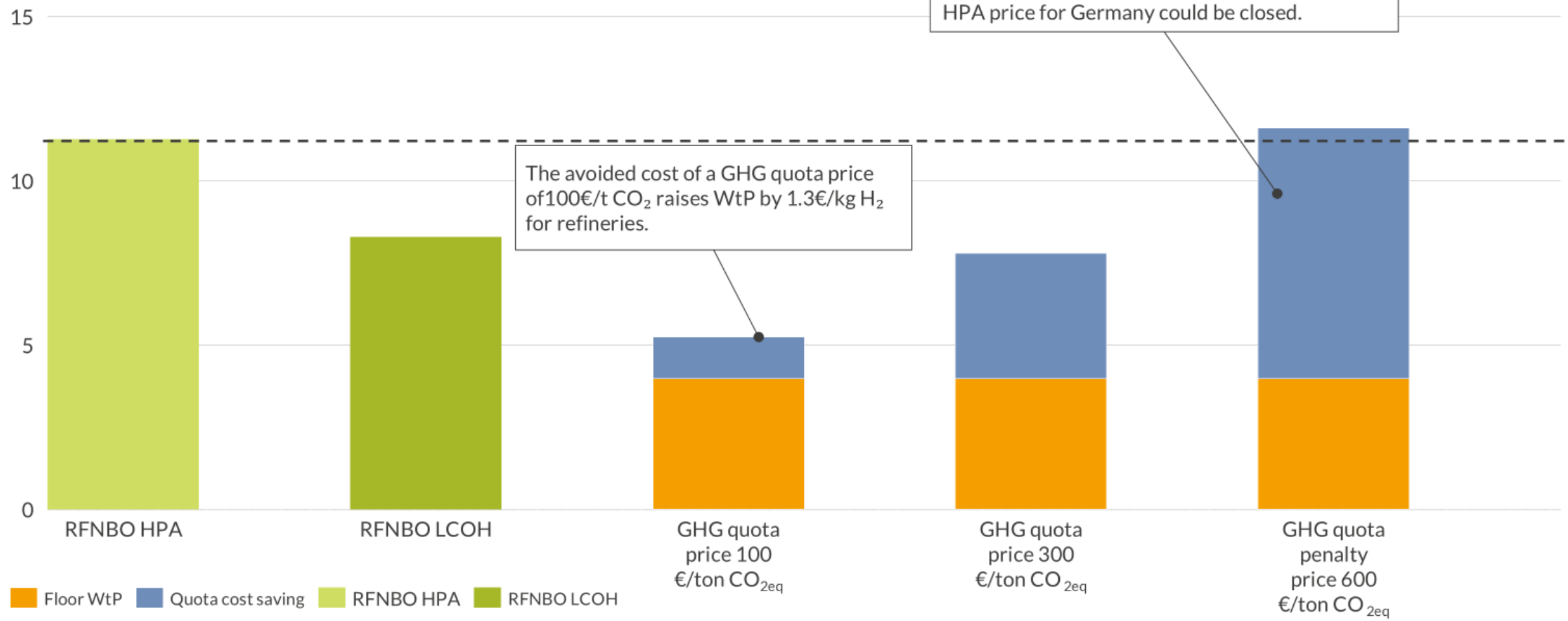


1) RED III: Renewable Energy Directive, i.e. (EU) 2018/2001 revised by (EU) 2023/2413. 2) WtP: Willingness to pay. 3) RFNBO: Renewables fuels of non-biological origin..

Sources: Aurora Energy Research, European Commission

At the maximum GHG quota price of 600€/t CO_2, the WtP of refineries exceeds the expected HPA prices

Levelised floor WtP for RFNBO hydrogen for refineries, Germany (COD 2030)
€/kg H_2 (real 2023)



Source: Aurora Energy Research

A green premium and/or additional operational subsidy is required for RFNBO H_2 based steel production to compete with BF-BOF[1]

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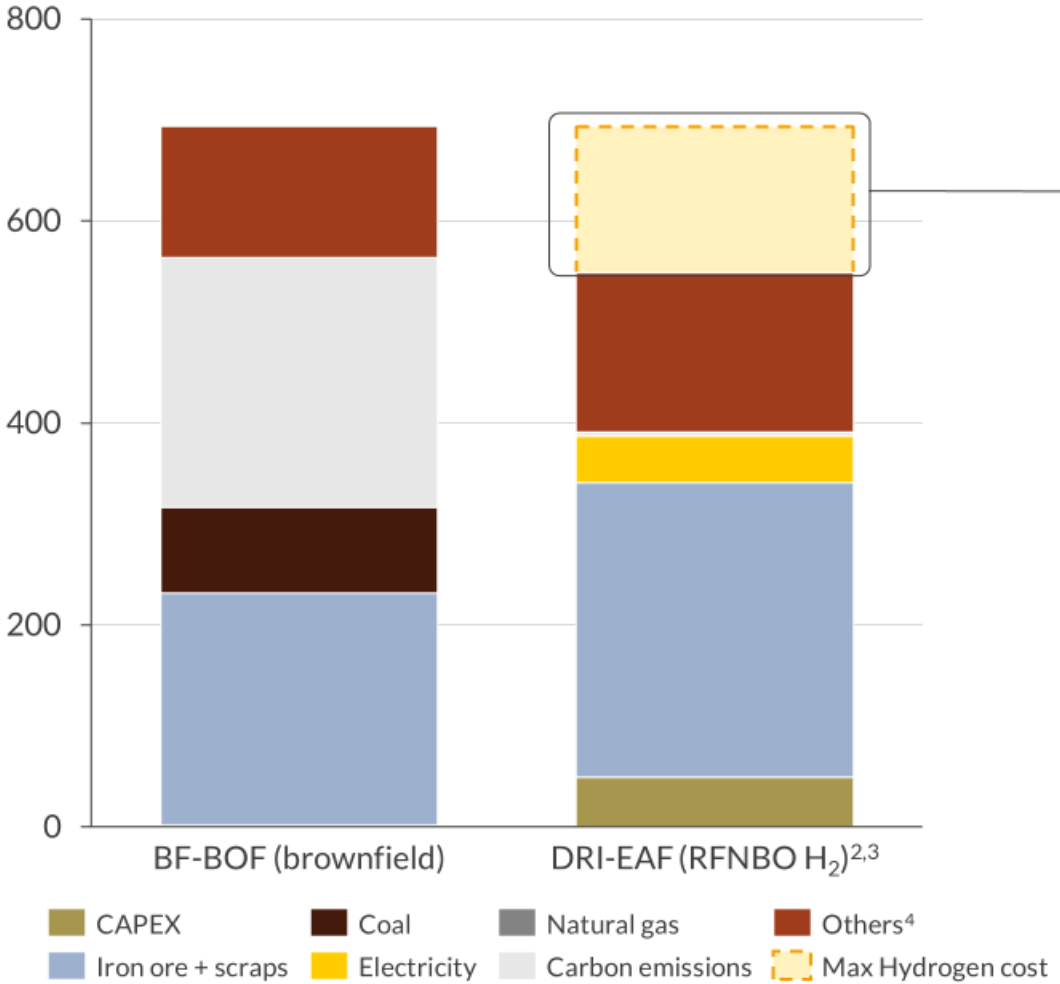
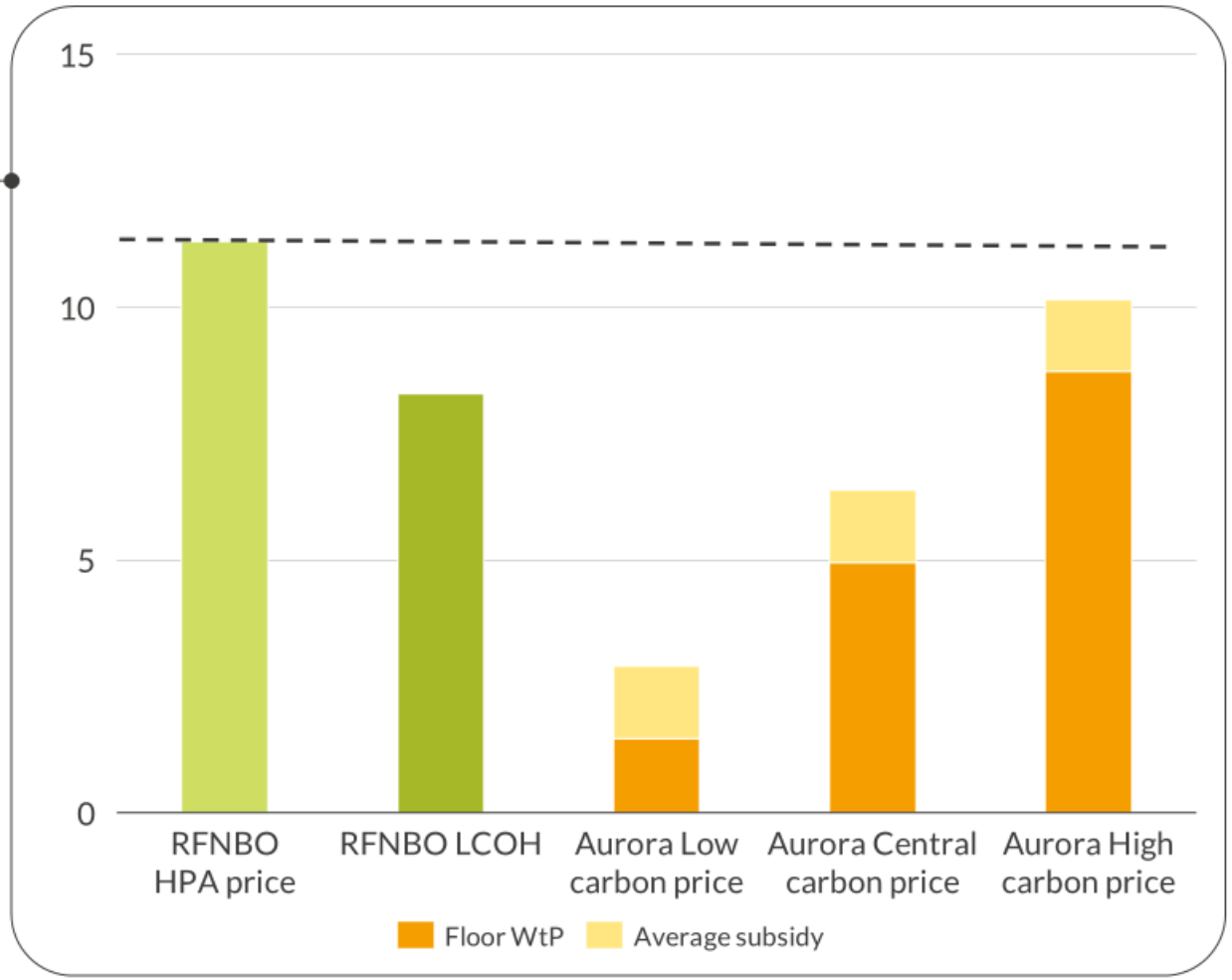
Levelised cost of steel (LCOS) production in Germany (COD 2030)
€/tonne crude steel (real 2023)



Willingness to pay for H_2 in the steel sector with and without subsidy in Germany (COD 2030), €/kg H2(real 2023)



1) BF-BOF: Blast furnace- basic oxygen furnace. 2) DRI-EAF: Direct reduced iron-electric arc furnace, EAF: Electric arc furnace. 3) Traditional process assumes 15% scrap recycling while the DRI-based processes assume 50%. 4) Others include FOM, feedstock transport, delivery, industrial gases, ferroalloys, fluxes and labour.

Sources: Aurora Energy Research, European Commission

Key takeaways

1 **Slowdown in new electrolyser projects** – only 4 GW of projects have been announced in Europe this year, a marked slowdown from the past years. While many supply side factors can be attributed to this, one of the main reasons for the slowdown is uncertainty of demand.

2 **Industry as the main early adopter of bulk H2 demand -** Aurora projects industry to play a central role in the short to medium term to ramp up the hydrogen economy, specifically refineries, Ammonia production and steelmaking. These are existing H_2 offtakers and/or are expected to receive green premia, subsidies or face penalties for carbon emissions.

3 **Main barrier to securing demand is the gap between willingness to pay and projected cost of production –** For all three sectors, the WtP in Germany is significantly lower than Aurora's projected Hydrogen Purchase Agreement (HPA) prices as well as LCOH. While this depends on a range of factors, including the EU emission price, additional incentives of up to 7 €/kg will be needed to accelerate a switch to green hydrogen.

4 **Carbon pricing and target setting instruments as part of RED III implementation offer opportunities to close that gap and secure early uptake –** High trajectory EU ETS prices, penalties similar as those set in RefuelEU SAF targets and GHG quotas priced at the penalty level are policy instruments that can incentivise an accelerated switch to green hydrogen

Sources: Aurora Energy Research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