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ENERGY RESEARCH

Enabling the European hydrogen economy – Executive Summary

March 2021

Hydrogen demand will be greatest in the industry and chemicals sector, followed by transport and heating

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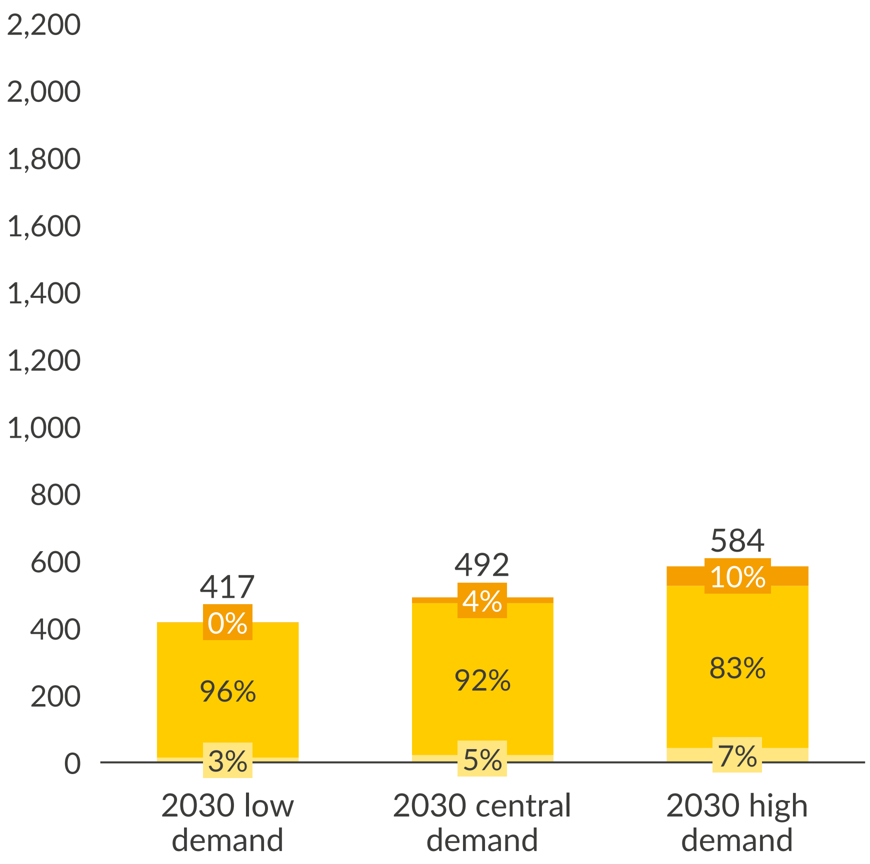
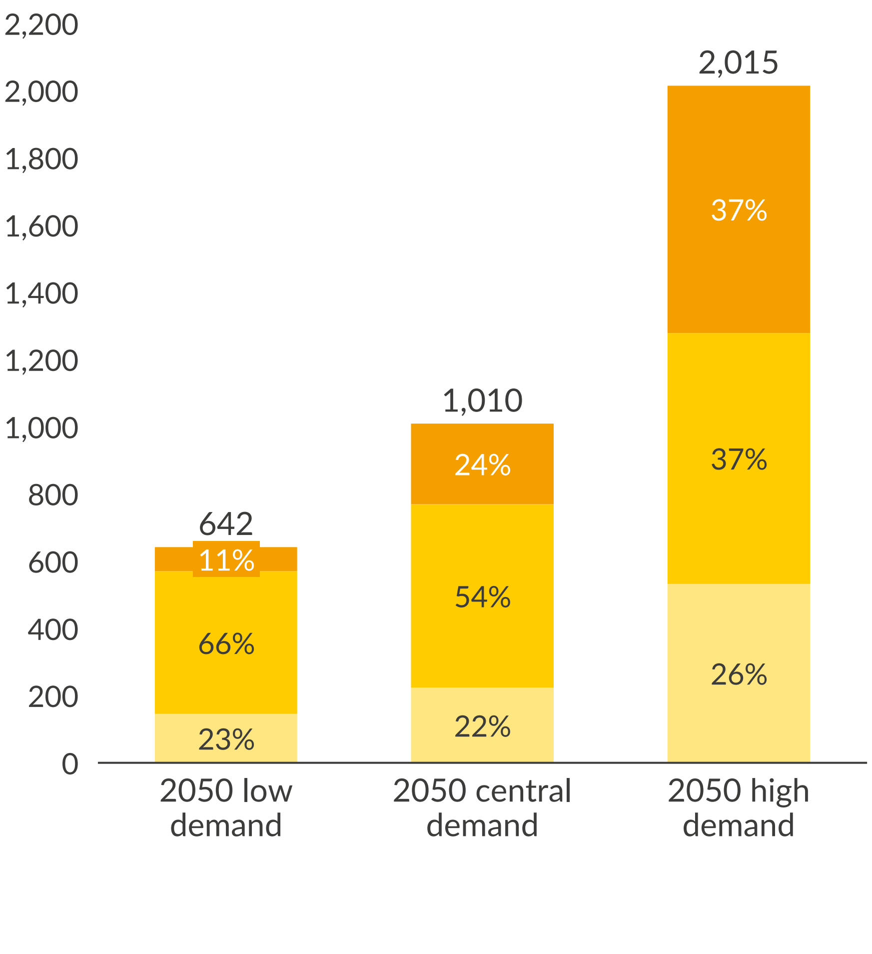
Potential H_2 demand, 2030
TWh



Potential H_2 demand, 2050
TWh



- In 2030, H_2 penetrates otherwise hard-to-abate industrial sectors. Demand in transport and heating is minimal in all scenarios as necessary infrastructure roll-out will not take place in this timeframe.
- In 2050, industry still dominates H_2 demand as other abatement pathways are limited.
- In transport, electrification is more efficient for small vehicles, but for HGVs[1], mass transport, shipping and aviation, hydrogen-switching[2] occurs, especially in our high case.
- Replacing natural gas with H_2 in heating is possible, but requires widespread infrastructure conversion. In both our low and central scenario, more efficient options like heat pumps prevail.

1) Heavy Good Vehicles 2) Switching to hydrogen or hydrogen-derived fuels

Sources: Aurora Energy Research,

By allowing the use of all forms of RES and decarbonised electricity to produce hydrogen, the EU will be able to meet its demand

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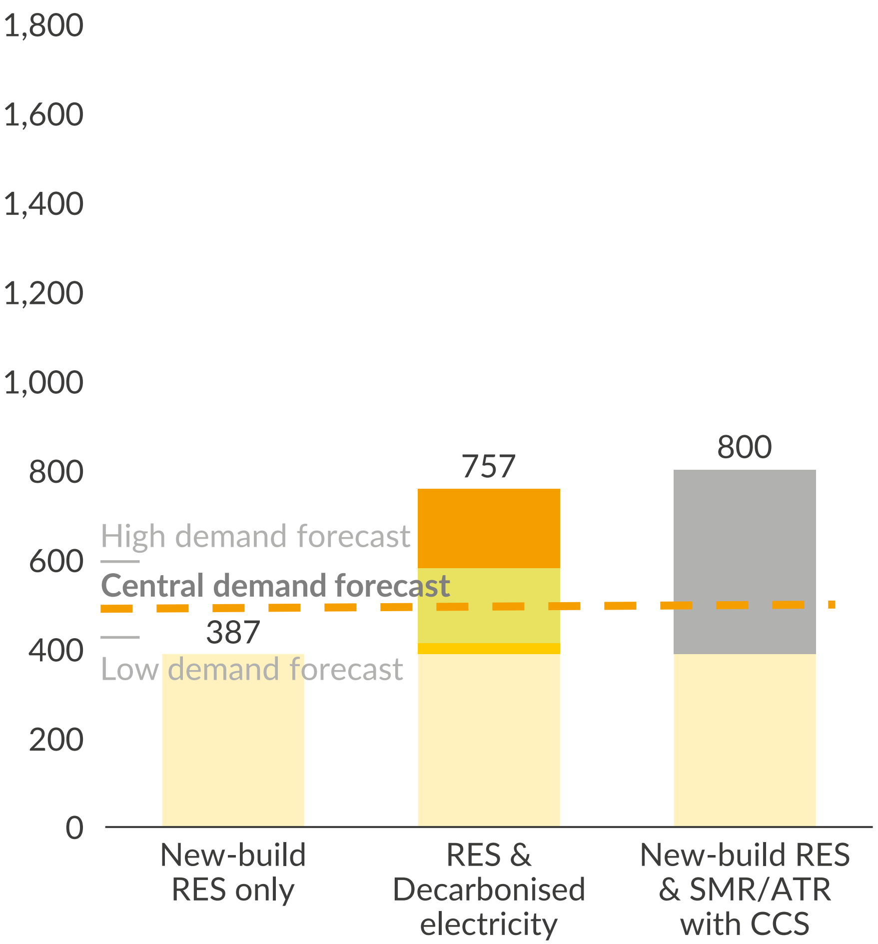
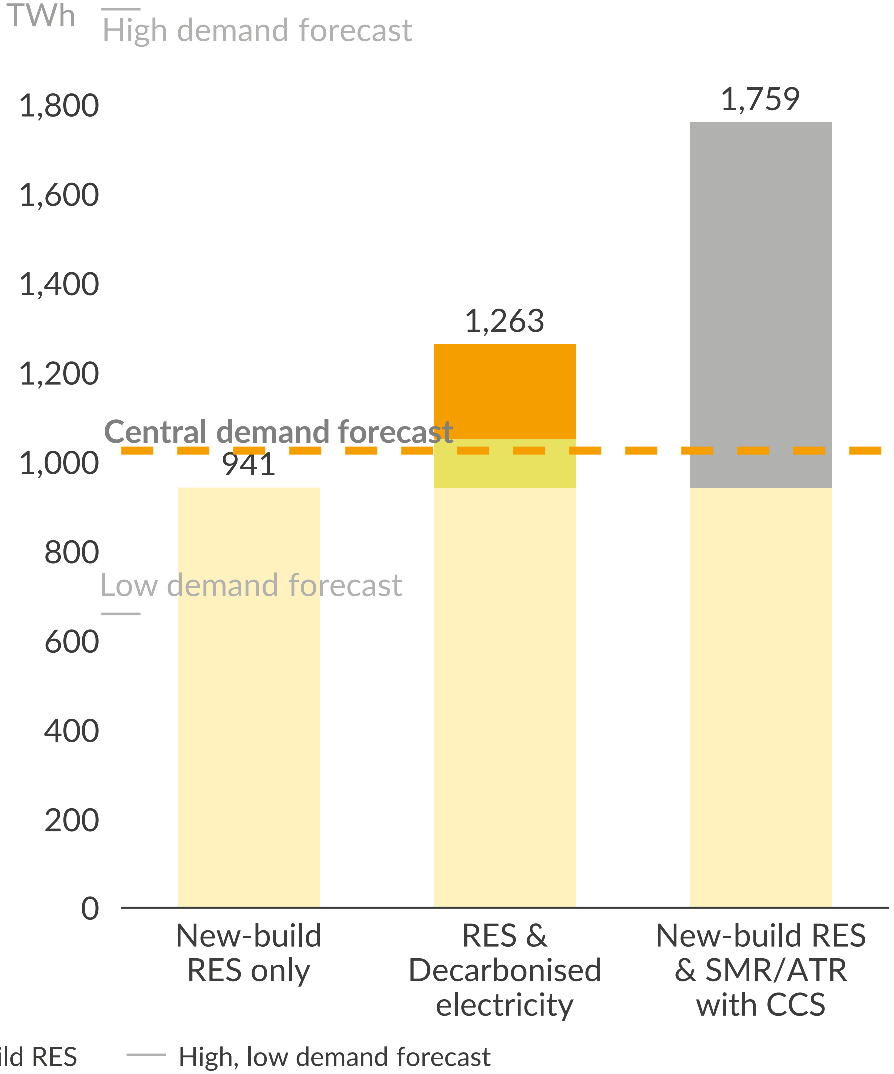
Potential H_2 supply, 2030
TWh



Potential H_2 supply, 2050
TWh



- By allowing all forms of RES and decarbonised electricity in H_2 production, the EU can meet its H_2 demand in both 2030 and 2050 in our central case.
- The volume of H_2 that could be produced from new-build additional renewable capacity only, which would be compatible with the approach laid out in the RED II directives, will not be sufficient to meet our central demand forecast in either 2030 or 2050.
- Additional volumes of H2 could be produced from SMR/ATR with CCS. However acceptability and technical feasibility vary greatly across countries and SMR/ATR with CCS is also not the ultimate goal favoured by the EU H2 strategy.

Source: Aurora Energy Research

By 2050, the levelised cost of hydrogen (LCOH) is lowest when all forms of RES & decarbonised electricity are used

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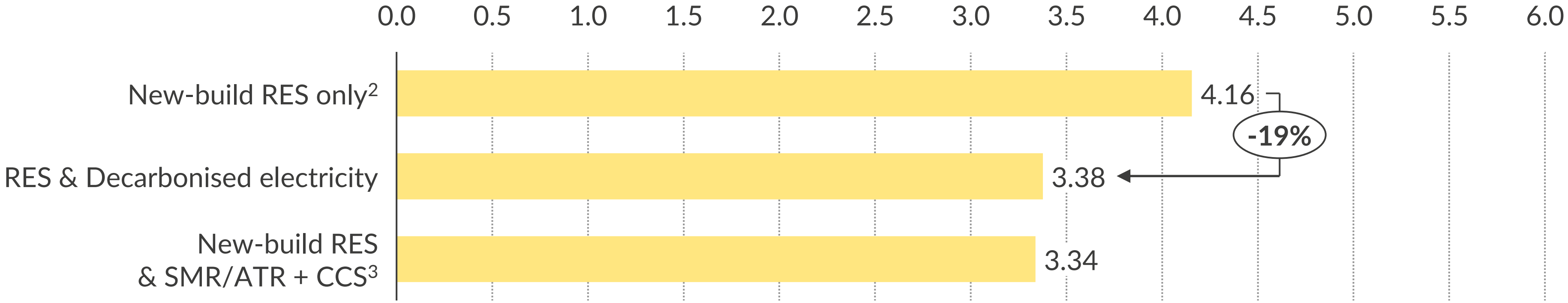
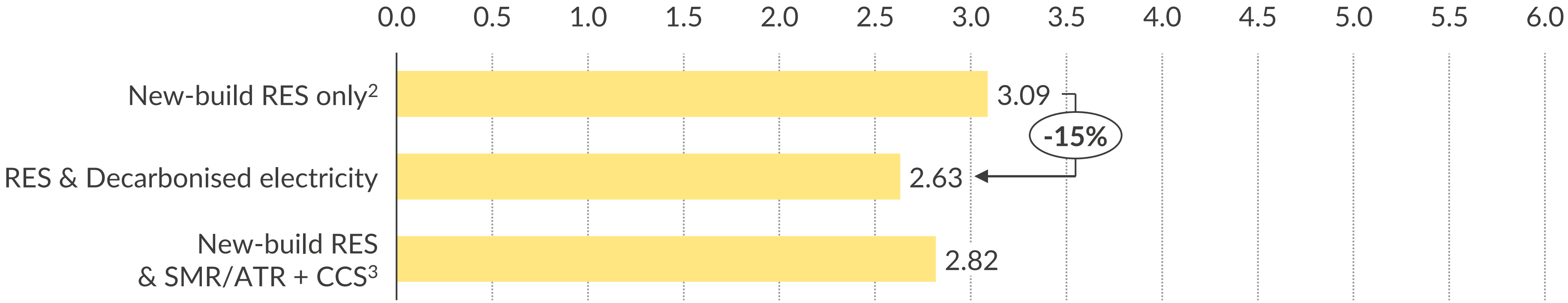
Average LCOH[1], 2030

€/kg H_2, real 2019



Average LCOH, 2050

€/kg H_2, real 2019



- In 2030, the average LCOH can be reduced by 18% by utilising all RES and decarbonised electricity, compared to a new-build, additional RES only scenario.
  - This is driven by rapid deployment of electrolysers which can run at higher load factors, accessing RES and decarbonised grid electricity.
  - In 2030, LCOH can also be reduced by considering hydrogen production from SMR/ATR with CCS
- By 2050, using RES and decarbonised electricity for H_2 production is the cheapest available option. Average costs are reduced in all cases as CAPEX costs decrease and electrolyser efficiency increases.

1) The LCOE was used for new-build RES electricity prices and the 20th power percentile was used (as a proxy for when decarbonised generators are setting the grid price) where appropriate Aurora's nuclear capture price forecast.. 2) The LCOH in the new-build RES only scenario is shown for a 50/50 spilt of electrolysers that are temporally linked to a specific RES plant and co-located. 3) An EU-ETS carbon price of €38.34/t in 2030 and €71.0/t in 2050 was applied to residual emissions as a result of CCS.

Source: Aurora Energy Research

The levelised cost of imported hydrogen is typically higher than hydrogen produced in the EU

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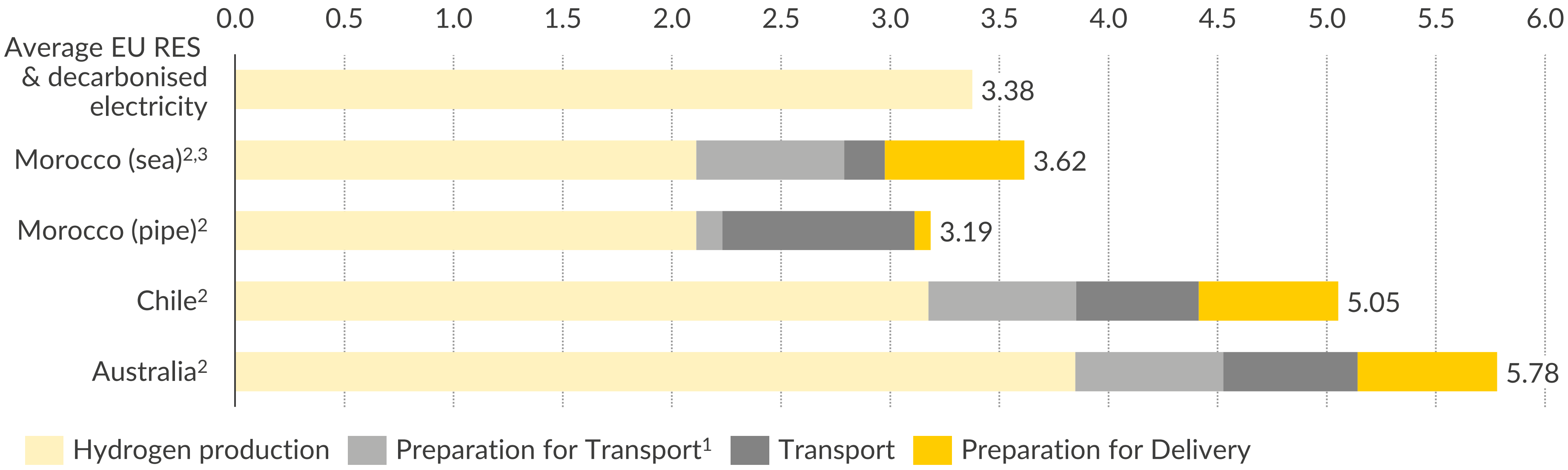
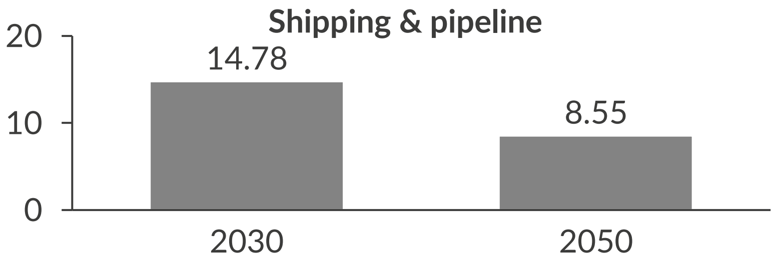
Levelised cost of delivered hydrogen to Germany, 2030

€/kg H_2, real 2019



Total yearly import costs

billion €, real 2019



- If new-build additional renewables only were utilised for H_2 production, the EU would face a H_2 supply gap.
- The lowest LCOH delivered to Germany (which has the biggest supply gap) is from Morocco.
- However, Morocco (and other North African countries) will not produce enough H_2 to meet EU demand as decarbonisation of the Moroccan grid is also required if H_2 is to be produced on a level playing field. Thus imports are also considered from Chile and Australia.
- Policymakers will need to consider how to ensure a level playing field between H_2 producers inside and outside of the EU, to ensure H_2 imports are subject to the same traceability criteria.

1) Preparation for transport includes conversion into ammonia, preparation for delivery includes conversion from ammonia to H2. 2) H2 production costs in Morocco, Australia & Chile were calculated based on a discounted wholesale price. 3) Transports costs assume new-build pipeline

Source: Aurora Energy Research, IEA

Considering full life cycle emissions, per unit emissions are lowest when all forms of RES and decarbonised electricity are utilised

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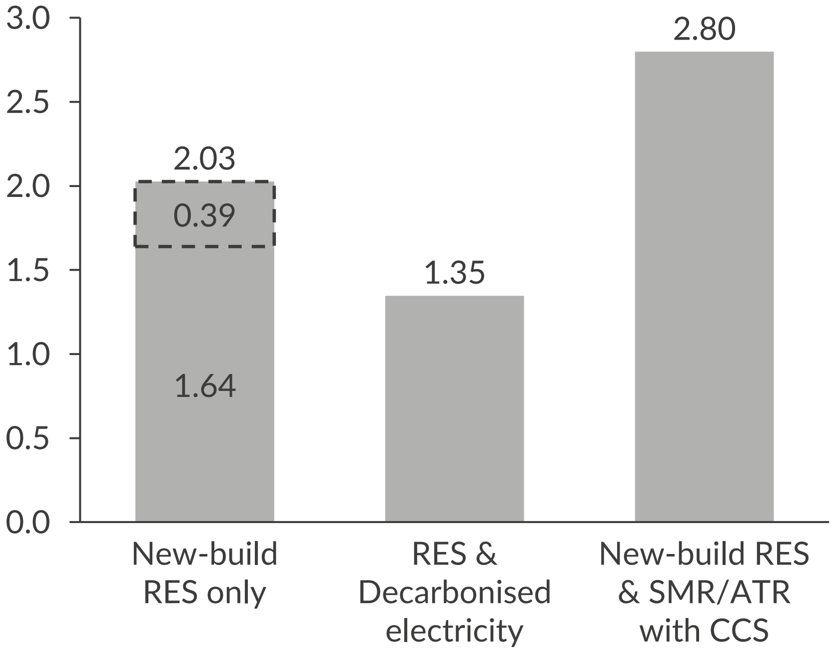
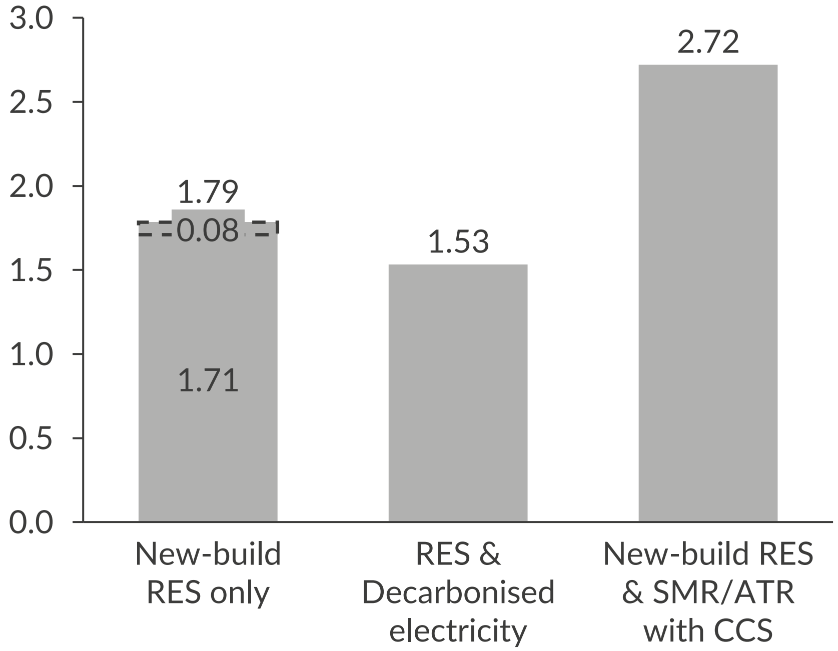
Average lifecycle emissions[1], 2030
$kgCO_2$/ kgH_2



Average lifecycle emissions[1], 2050
$kgCO_2$/ kgH_2



Emissions from imports

Extra cost to avoid per tonne CO_2, compared to meeting demand with grey hydrogen only[3]
€/ tonne CO_2

	New-build RES only	RES & Decarbonised electricity	New-build RES & SMR/ATR with CCS
2030	350	194	228
2050	151	62	89

- Average full-lifecycle emissions[2] are lowest in a scenario where all forms of renewable and decarbonised electricity are utilised for H_2 production in both 2030 and 2050.
  - Emissions from the production and shipping of imported H_2 in new-build RES only scenario are included, assuming 30% import from Australia, 50% from Chile, and 20% from Morocco.
- Average full lifecycle emissions are higher in 2050 compared to 2030, as a higher proportion of H_2 is produced through solar electricity, which has the highest full lifecycle emissions[2] of any technology studied.

1) Including emissions from the production and shipping of imported H2. Methane emissions not accounted for. 2) Based on the lifecycle emissions of each technology (including albedo effect) from IPCC figures 3) Assume grey hydrogen LCOH €2.2/kg H_2 in 2030, €2.5/kg H_2 in 2050. Results are calculated dividing total extra costs by CO2 emission avoided in each scenario.
Source: Aurora Energy Research, IPCC, IMO

A number of critical policy decisions made today will shape how the hydrogen economy evolves over the coming decades

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Key policy decisions

Types of hydrogen to support	▪ Current policy, laid out in the RED II directives, focuses on supporting H_2 production from new-build additional RES. ▪ Aurora's analysis shows this approach means the EU will not meet hydrogen demand in our central case resulting in a reliance on costly imports. Overall emissions and total costs of meeting hydrogen demand will be lower than if a more flexible approach was taken, allowing hydrogen production from all forms of renewable and decarbonised electricity.
Guarantees of Origin schemes	▪ GoOs will reallocate costs of decarbonisation to customers willing to pay for it. ▪ A simplified, technology-agnostic definition of hydrogen for the GoO scheme, based on full life cycle emissions from hydrogen production would minimise emissions, whilst allowing hydrogen demand to be met. ▪ However, this is not the approach that has been taken by the existing CertifHy scheme.
Carbon Contracts for Difference	▪ A well designed subsidy regime for hydrogen would provide payments that reflect the value of abatement of carbon emissions and provide long-term investment certainty. ▪ There are several key questions that need to be addressed prior to the implementation of such a scheme.
Demand mandates	▪ Mandates can be a powerful tool in driving the switch to less-emitting forms of hydrogen. ▪ Existing regulations, such as demand mandates in fuel, should be modified to allow the use of hydrogen from all forms of res and decarbonised electricity. ▪ Hydrogen blending into existing gas networks could be an early step on a path towards a wider hydrogen economy, but would be costly and could risk fragmentation of the EU's gas markets.

Source: Aurora Energy Research

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We have benchmarked our demand forecast against a range of external sources, where available

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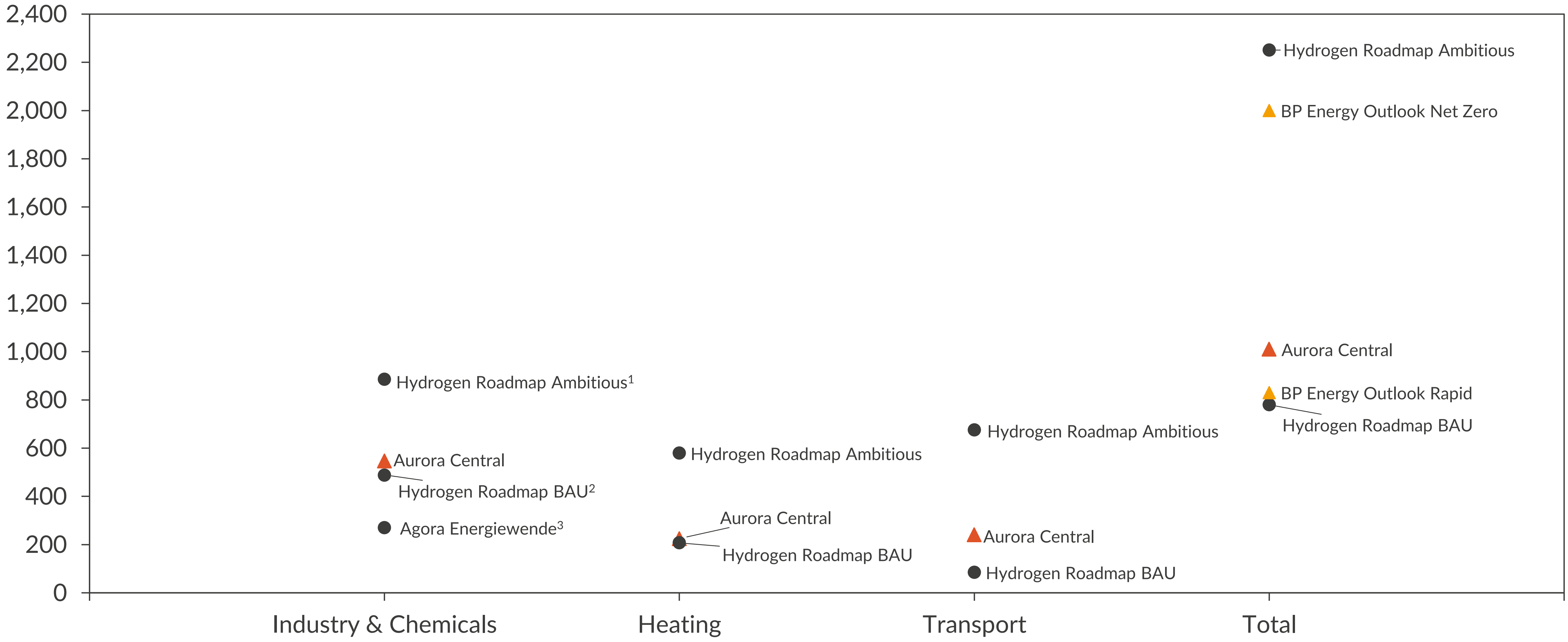
Total European hydrogen demand, 2050

TWh H_2



1) Ambitious case in Hydrogen Roadmap Europe. 2) Business as usual case in Hydrogen Roadmap Europe 3) Agora Energiewende, No-regret Hydrogen report, including only large-scale industrial demand for feedstock and chemical reaction agents.

Sources: Aurora Energy Research, European Commission, BP Energy Outlook, Agora Energiewende

A Carbon Contracts for Difference scheme would provide a payment for avoided carbon emissions which could be applied across multiple sectors

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Current EU-ETS prices are too low to drive decarbonisation and as future carbon prices are uncertain, securing funding for abatement projects is challenging. CCfDs are designed to hedge against volatile carbon prices. Under a CCfD scheme, investors would be guaranteed a carbon price needed to finance their project.

CCfD Payment = (Carbon Strike Price − Actual Carbon Price) × Avoided Carbon

Avoided Carbon = (Reference Carbon Intensity − Project Carbon Intensity) × Project activity

How could the carbon strike price be designed? Sector or project specific CCfDs would be needed, with specific strike prices. A single strike price for all industries would mean for many sectors the strike price would be too low to support decarbonisation.

How could CCfDs be auctioned? Sector-specific auctions would fairly allocate CCfDs across all sectors, allowing segments such as steel to realise the full potential of decarbonised H_2.

Would a CCfD scheme be implemented at a national or EU level? A CCfD scheme would likely be implemented at a national level, however efforts would have to be made to ensure compatibility with state aid rules.

What would the duration of a CCfD be? CCfD contracts should be designed to cover the full investment period of a project. Decarbonisation of many industrial sectors will introduce high technological and financial risks and support is needed for the entire investment period for a project to be successful.

Source: Aurora Energy Research