AURORA ENERGY RESEARCH

The path to 2.5 GW of green hydrogen in Portugal

November 2021

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Head of Iberia

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- Hydrogen (H_2)
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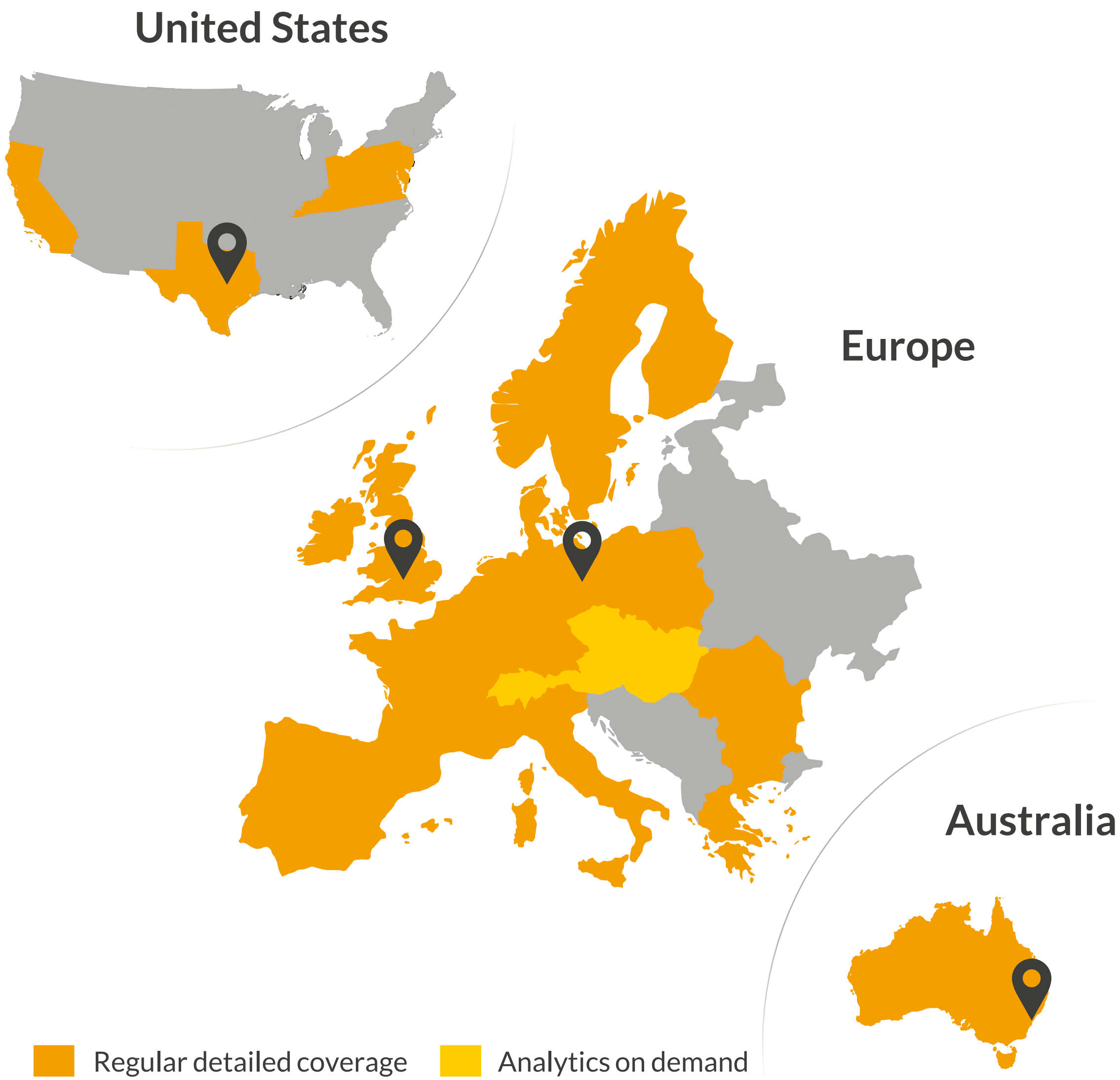

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Source: Aurora Energy Research

Aurora is already providing hydrogen market analysis to major players across the value chain

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- Department for Business, Energy & Industrial Strategy
- Bundesnetzagentur
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- Committee on Climate Change
- Department for Transport
- National Infrastructure Commission

Upstream gas and networks

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- equinor
- Naturgy
- OGE
- nationalgrid
- Thyssengas
- Vitol
- fluxys

Source: Aurora Energy Research

We are working with key Iberian and international utilities, investors, lenders, developers and government

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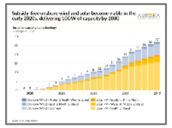
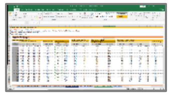
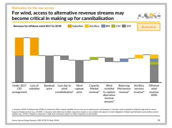
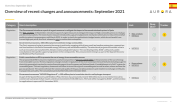
Iberia Power Market Service
Summary of service

	**Biannual market outlook reports**	▪ Full update on energy policy developments in Spain and Portugal ▪ Market outlook and capacity development to 2050 ▪ Forecast of wholesale market prices ▪ Evolution of the economics of renewables and batteries ▪ Brief quarterly updates to reflect near-term commodity price changes
	**Forecast data**	▪ Full forecast dataset in .xls until 2050 for use in investment cases ▪ Wholesale prices, capture prices, capacity and generation mix, etc.
	**Strategic Insight reports**	▪ Regular deep-dive analysis on topical issues in the evolving renewables market and new business models (e.g. pricing structures in corporate PPAs, Net Zero in Iberia, portfolio diversification, economics of batteries etc.)
	**Monthly policy and regulation updates**	▪ Monthly summaries of key policy and regulatory changes affecting the Iberian electricity market ▪ Deep-dives on major changes or auction results
	**Group Meetings**	▪ Presentation of forecast update and new research ▪ Networking opportunity with developers, investors and Government
	**Workshops and analyst support**	▪ Bilateral workshops to discuss Aurora's analysis and specific implications ▪ Ongoing analysis support to answer questions about our research
	**Aurora Spring Forum**	▪ Our annual Spring Forum brings together senior executives of the European energy industry to discuss issues that impact the industry; full day in Oxford

Access anytime via EOS online platform[1]

1) Subscribing companies can set up unlimited user accounts on EOS

Source: Aurora Energy Research

We offer Power Market Intelligence Services across key markets and specialised products for renewables, flexibility and hydrogen

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Power market	Renewable power	Flexible and distributed power
GB Power Market Service	GB Renewables Service	GB Distributed & Flexible Energy Service
Ireland Power & Renewables Market Service		Ireland Flexibility Service
German Power Market Service	German Renewables Service	North-West European FCR Forecast
French Power & Renewables Market Service		
Dutch Power & Renewables Market Service		
Belgian Power & Renewables Market Forecasts		
Iberian Power & Renewables Market Service		
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Romanian Power & Renewables Market Forecasts		
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ERCOT Power & Renewables Market Service		
Australian Power & Renewables Market Service		Australian Flexibility Service

H_2 market

European Hydrogen Market Service

Wind software

'AMUN' Locational wind valuations

Gas market

European Gas Market Service

Gas recip software

'REV Tool' GB Gas reciprocating engine valuations

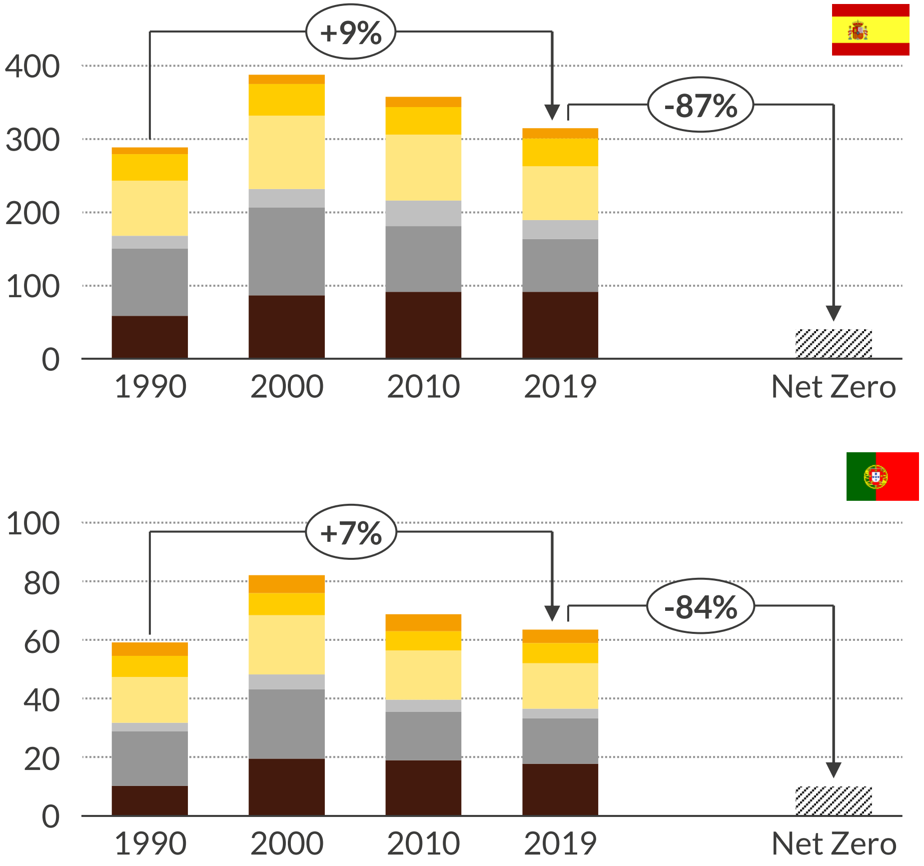
Source: Aurora Energy Research

Agenda

The Iberian economy still relies heavily on fossil fuel consumption, particularly for the transport and industry sectors

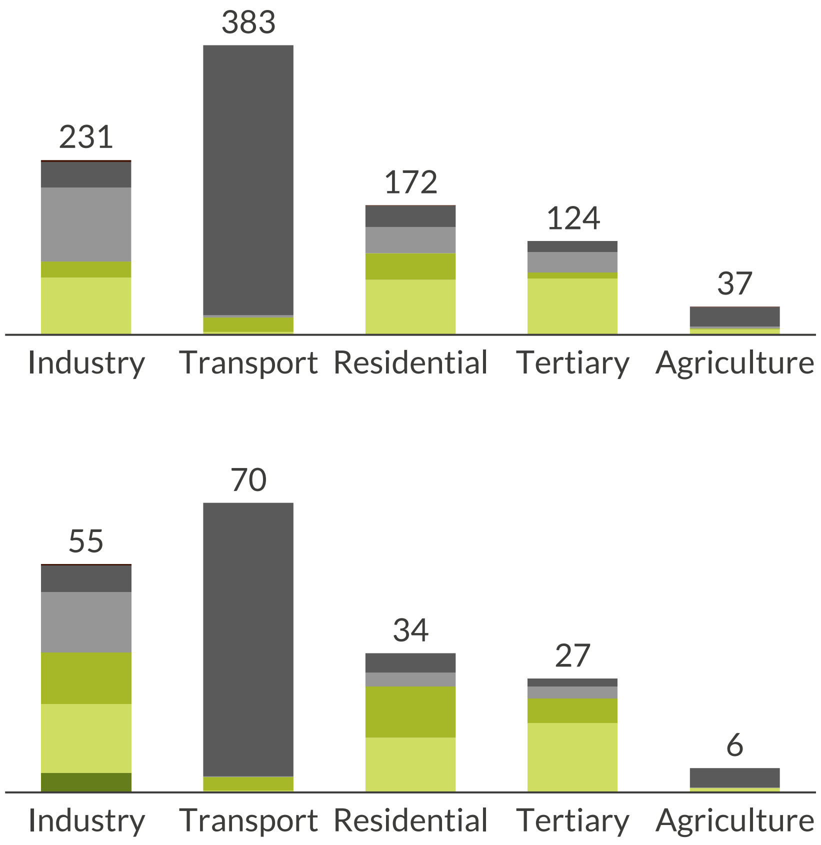
Total GHG emissions[1]

$MtCO_2e$



Final energy consumption in 2019

TWh



Transport | Energy supply | Tertiary and residential | Industry | Agriculture | Waste | Residual emissions[2]

Coal | Oil | Gas | Renewables | Electricity | Other[3]

1) Excludes LULUCF (Land Use, Land Change and Forestry) 2) Residual emissions would need to be offset through carbon sinks. 3) Includes non-renewable waste and nuclear heat.

Sources: Aurora Energy Research, UNFCC, EUROSTAT

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Emissions in Iberia

- To reach net zero, emissions will have to decrease by over 80% compared to today's levels, with the rest being offset with carbon sinks

Final energy consumption

- Iberia still relies heavily on imported fossil fuels to cover the energy demand
- While electrification can help to decarbonise some sectors, this alone will not suffice
- Hydrogen emerges as a key complementary solution for the decarbonisation of certain industrial sectors, heavy-duty transport, and others

A set of goals have been defined in order to foster the early deployment of hydrogen technologies

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"Roadmap for Renewable Hydrogen" approved by the Govt. in October 2020, and to be updated every three years

Spanish Hydrogen Goals	2030
Fueling Stations/Buses/FCV[1] (L&H[2] Duty Vehicle)	100-150/150-200/5K-7.5K
Electrolyser installed capacity[3]	4 GW
Share of green H_2 for industry consumption	25%
Carbon emission reductions	4.6 Mton

"National Portuguese Hydrogen Strategy" released by the Govt. in May 2020, and to be updated every three years

Portuguese Hydrogen Goals	2030	2050
Fueling Stations / Buses / FCV[1]	50-100 / 200-350 / 750-1K	1k-1.5k / 4.5k-6k / 25k-30k
Electrolyser installed capacity[4]	2 – 2.5 GW	10 GW
Volume of H_2 in gas power plants	5% - 15%	75% - 80%
Contribution to energy demand	1.5% - 2%	15% - 20%
Share of H_2 for industry consumption	2% - 5%	20% - 25%

1) Fuel Cell Vehicles; 2) Light and Heavy. 3) Milestone of 300-600 MW of electrolyser capacity to be installed by 2024. 4) Milestone of 250-500 MW of electrolyser capacity to be installed by 2025

Sources: Aurora Energy Research, MITECO, Ministry of Environment and Climate Action

Most of the electrolyser projects in Iberia are still in early stages, but the pipeline almost doubles the Government pledges

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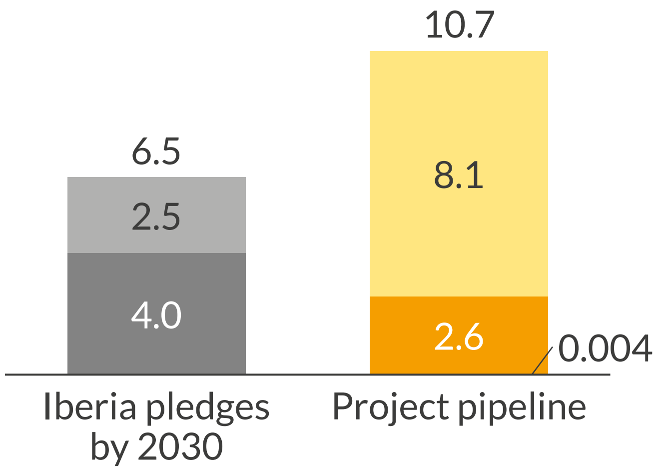
Breakdown of electrolyser projects in Iberia

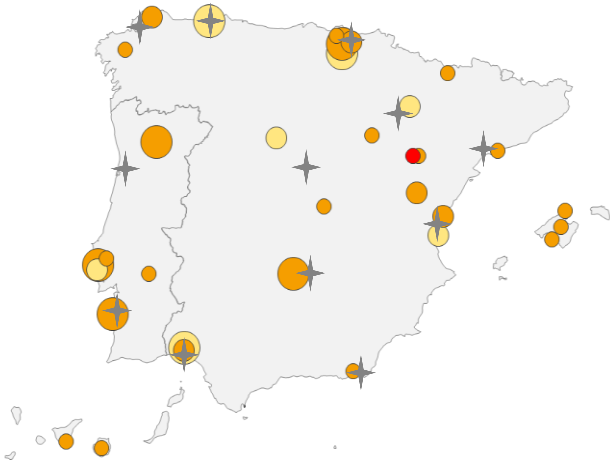
GW



- The current pipeline of projects almost doubles the Government pledges
- 8.1 GW of the pipeline is still in early planning stages with 2.6 GW in development and just 4 MW already operational

Portugal | Early stage | Operational
Spain | Development

Locations of electrolyser projects in Iberia



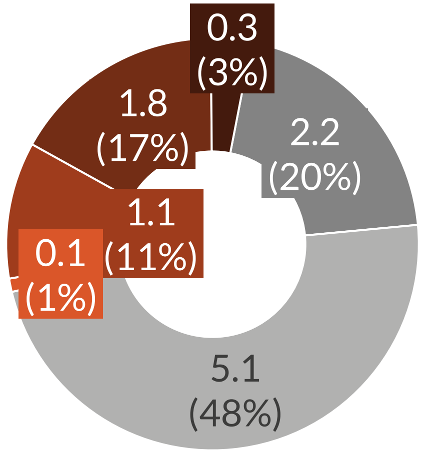
- Iberia boasts a total pipeline of 36 announced projects widely distributed across the region
- A number of projects are strategically located close to high emission density areas (e.g. petrochemical industrial areas)

Capacities (MW) 1-49 | 50-149 | ≥150 | Petrochemical industrial areas

Project status Early stage | Development | Operational

Electrolyser projects in Iberia by developer[1]

GW



- Albeit still in early stage of development, the 5 GW H_2 Sines project is the largest project in Iberia's pipeline
- Endesa has the largest portfolio as a single developer of 340 MW, while most other developments are partnerships

Endesa | Iberdrola | H2 Sines
Enagas;Hydrogenious | Petronor | Others

1) Includes solo developments and partnerships of referenced developers

Source: Aurora Energy Research

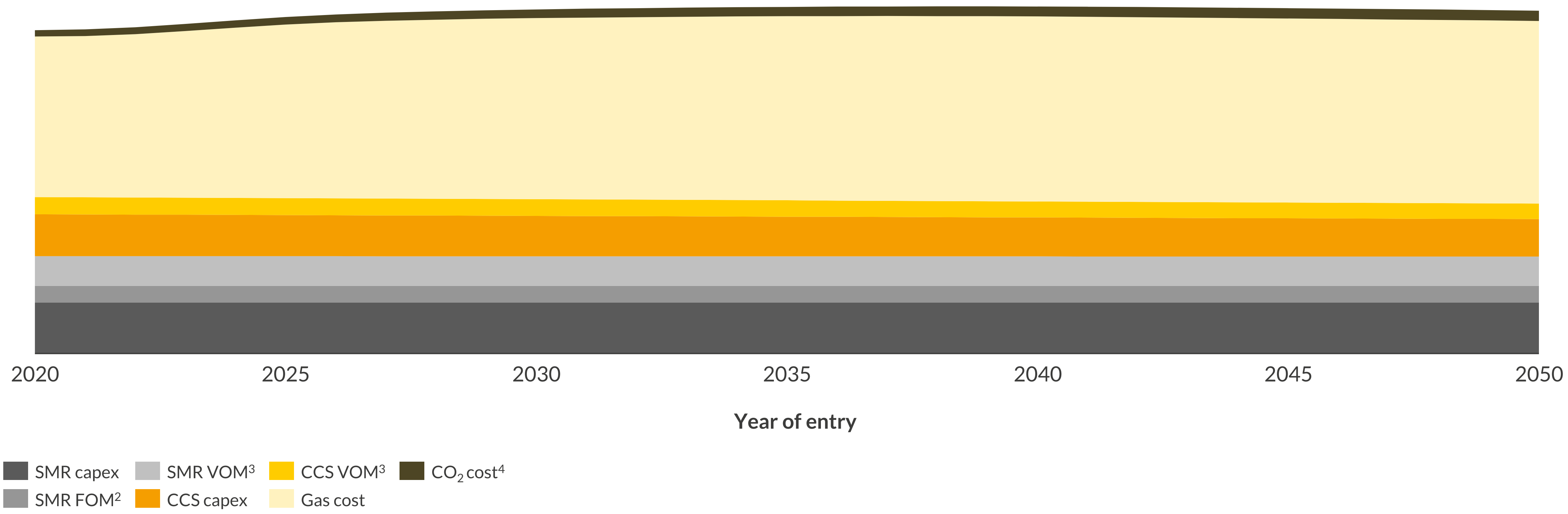
Agenda

In order to be cost competitive with blue hydrogen in Europe, green hydrogen needs to beat a target of ~2.5 €/kg H_2

Blue Hydrogen

LCOH breakdown (large scale SMR+CCS[1] in Great Britain, 95% load factor)

€/kg H_2



1) Carbon capture & storage. 2) Fixed operation & maintenance costs (4% of CAPEX of SMR, 5% of CAPEX from CCS). 3) Variable operation & maintenance costs. 4) Cost arising from the taxation of residual emissions (currently ~5%)

Source: Aurora Energy Research

We have identified four business models to produce hydrogen via electrolysers

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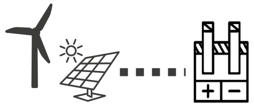
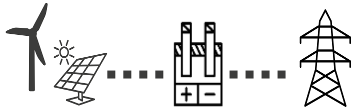
Focus of this session





	1 Inflexible	2 Flexible	3 Co-located (island)	4 Co-located (grid)
Description	▪ Grid electricity **only** and runs at **95%** load factor	▪ Grid electricity **only** and ability to choose operating hours to minimise LCOH[2]	▪ Electrolyser connected to renewable asset only (no grid connection)	▪ Electrolyser and co-located on-site renewable assets plus direct connection to grid
Key drivers	▪ Can **decouple electrolyser location from RES[3] location** to be closer to demand ▪ High load factor achievable	▪ **'Smart' operation** avoids periods of high power prices and high grid charges, accessing lower LCOH ▪ Can **decouple electrolyser location from RES location** to be closer to demand	▪ Availability of **zero carbon, low marginal cost renewable energy** ▪ Can optimise capacity ratio of electrolyser:RES in order to minimise LCOH	▪ Combines the benefits of grid connected and co-located business models ▪ Option to 'top up' electrolyser with grid electricity, or to sell renewable energy to the grid
Key Constraints	▪ Electrolyser potentially subject to costly **grid charges** ▪ Uncertain **carbon intensity** of hydrogen output	▪ Lower average load factor results in less hydrogen production ▪ Some offtakers require continuous hydrogen production	▪ **Intermittency of RES** results in inconsistent hydrogen production ▪ Optimal electrolyser:RES size can result in significant spilled power	▪ Electrolyser potentially subject to costly grid charges ▪ Carbon intensity of grid electricity ▪ Must be located near to RES - often far from demand

1) GoO: Guarantees of origin, PPA: Power purchase agreement 2) LCOH: Levelised cost of hydrogen 3) RES: Renewable energy systems

Source: Aurora Energy Research

Electrolysers can be co-located with renewables; an optimal sizing of the renewable assets is crucial to deliver cheap hydrogen

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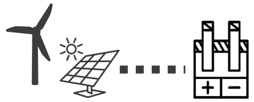
3 Co-located (island)

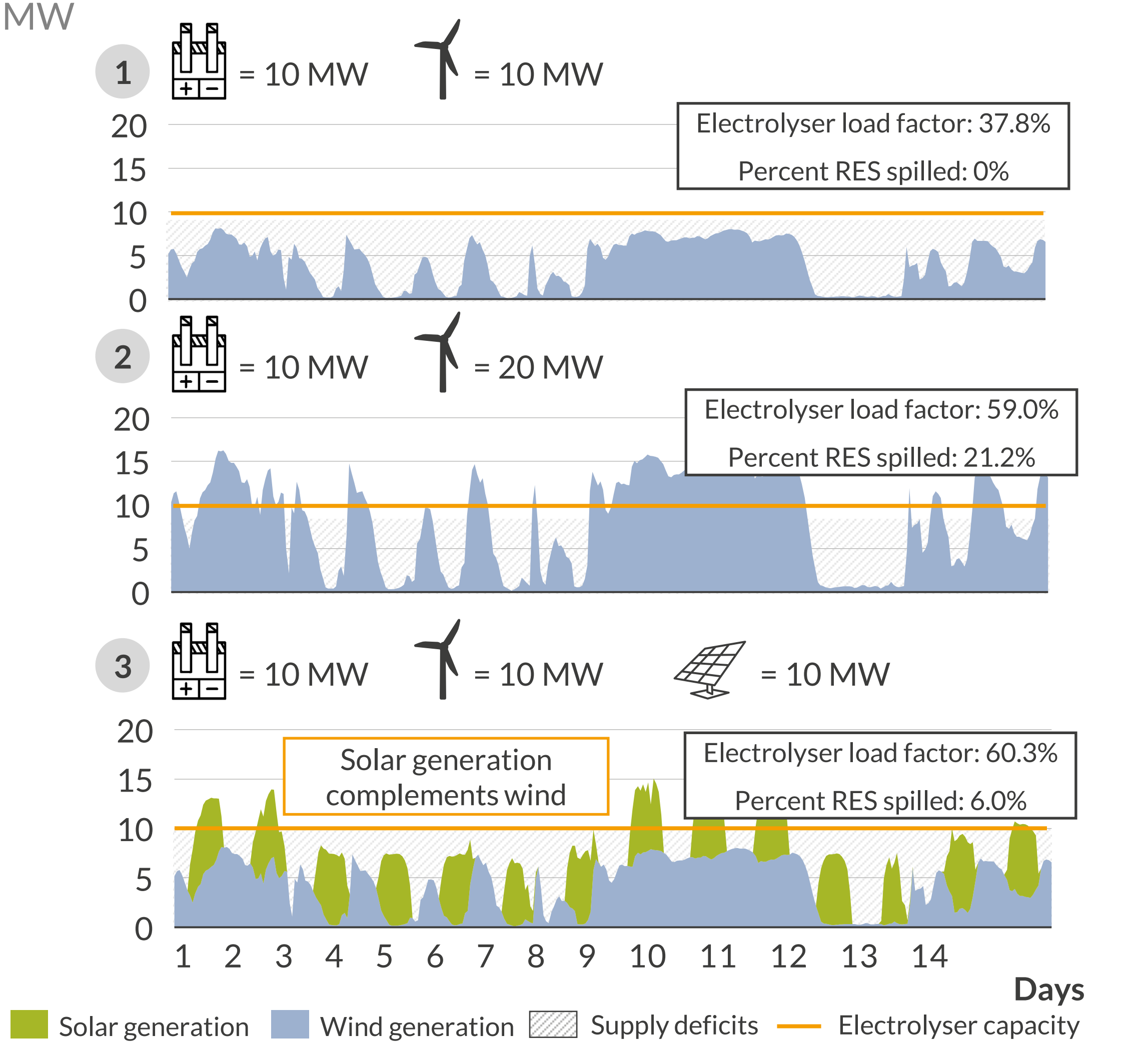


- A "co-located (island)" business model describes a electrolyser co-located with one or more renewable assets. It has **no grid connection** and thus operates as an 'island'
- **The key consideration for this business model is the size of the electrolyser relative to the renewable asset**:

1. **Under-utilised electrolyser** – Given the intermittency of renewables, if the renewable asset is not sized optimally, the hydrogen costs can be high due to a low utilisation of the electrolyser
2. **Over-sized renewable asset** – If the renewable asset is too oversized relative to the electrolyser capacity, this can lead to significant energy spillage and a high LCOH as the renewable costs are also taken into account
3. **Optimal size -** The optimal sizing can be analysed for each location to deliver the cheapest hydrogen possible. Wind and solar co-location can help to achieve the optimal solution

Example electricity generation profiles for various renewable sizings

MW



1) Curtailment is reflected in the LCOH, as energy spillage leads to a higher average cost of energy, increasing green hydrogen production costs.

Source: Aurora Energy Research

The lowest LCOH of 3.6 €/kgH_2 is found for a combination of 1.2 MW of onshore wind and 1 MW of solar PV for a 1 MW electrolyser

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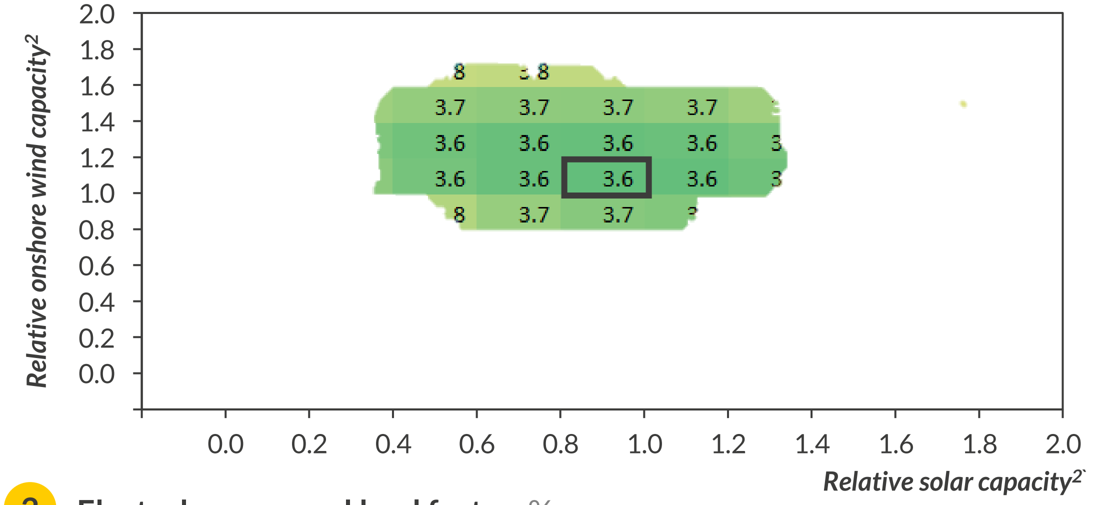
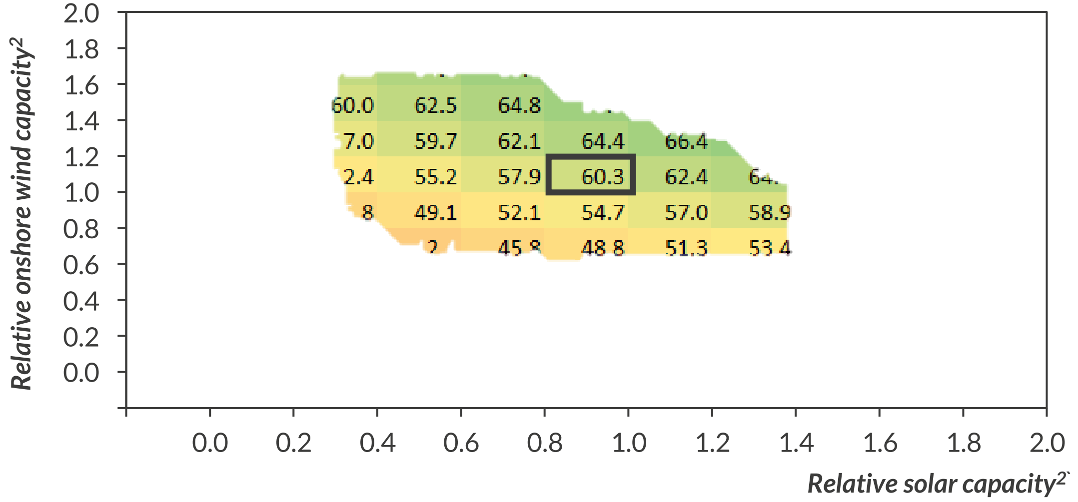
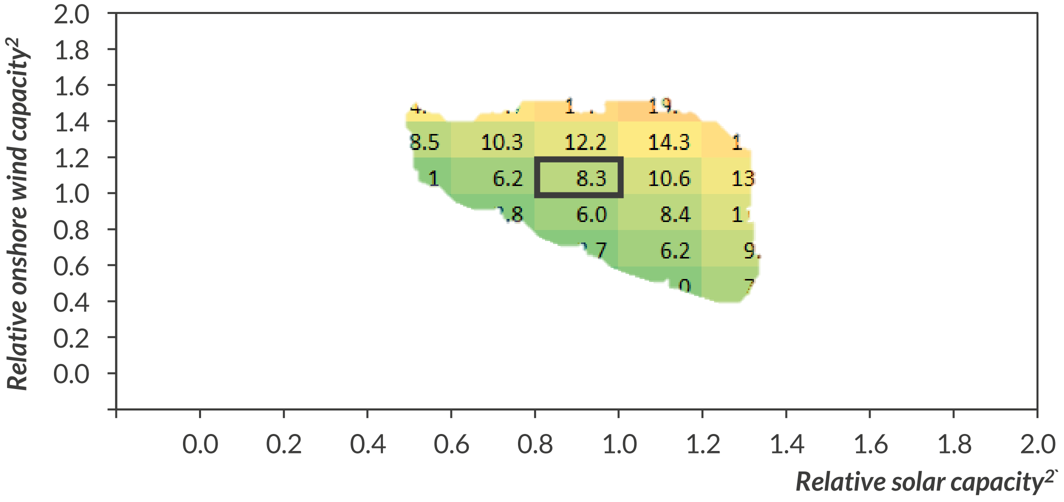
1 LCOH for 1 MW electrolyser entry in 2025[1], €/kg H_2



2 Electrolyser annual load factor, %



3 Energy spillage from the renewable assets, % of theoretical generation



- The lowest LCOH of 3.6 €/kgH_2 is found for a combination of 1.2 MW of onshore wind and 1 MW of solar PV for a 1 MW electrolyser
- Under this optimal combination, the electrolyser produces hydrogen at an annual load factor of 60%, equivalent to 5,300 hours
- Despite this optimal sizing for the co-located island business model, energy spillage reaches around 8% of the theoretical annual production
- However, because the electrolyser is not connected to the grid, it avoids grid connection costs and potentially high grid charges

1) Analysis based on a site located in Aragon, Spain. 2) Relative to electrolyser capacity. 3) Electrolyser maximum annual load factor

Source: Aurora Energy Research

Adding a grid connection to a co-located electrolyser can increase its load factor in periods of low RES output and increase revenues

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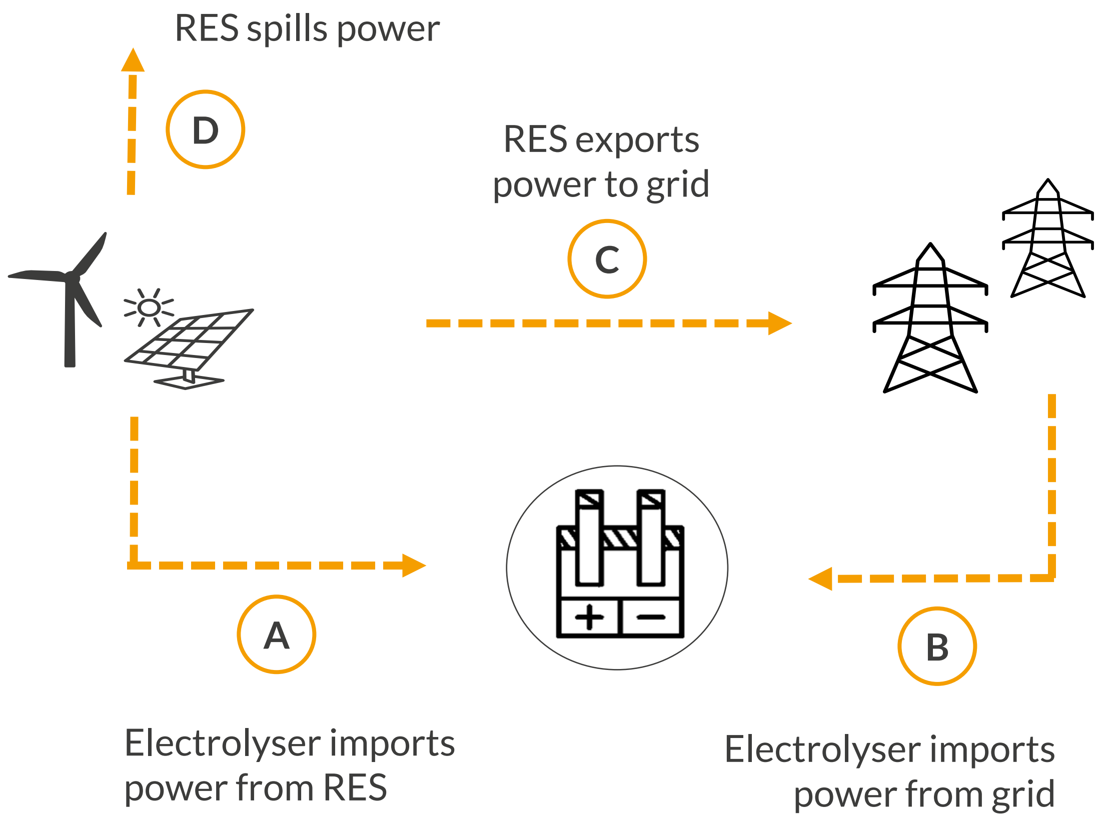
4 Co-located (grid)

Schematic of co-located electrolyser and renewables with grid connection



- A "co-located (grid)" business model expands on the island co-located electrolyser model, providing an additional grid connection which allows for greater flexibility in hydrogen production
- With a grid connection, the electrolyser can choose to purchase grid electricity to top up its production when the renewables generation is insufficient and it is still economically viable to produce hydrogen. The system can also sell any excess renewable generation, minimising spill
- However, any power purchased from the grid will have associated grid charges, which vary by time of use, voltage level, and carries an associated carbon intensity
- The hydrogen produced can be sold to an offtaker or injected into the grid[1]

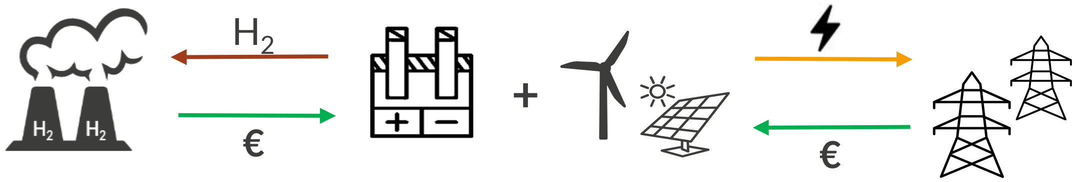
1) Additional transport costs to the consumption centre are not included in this analysis.

Source: Aurora Energy Research

However, hydrogen prices need to be high enough to incentivise RES generators to produce hydrogen vs. electricity

4 Co-located (grid)

Under this business model, revenues come from two sources:



1 Hydrogen exports

- The electrolyser produces hydrogen with power from the RES assets or the grid
- Produced hydrogen is sold to offtakers e.g. in industry

2 Electricity exports

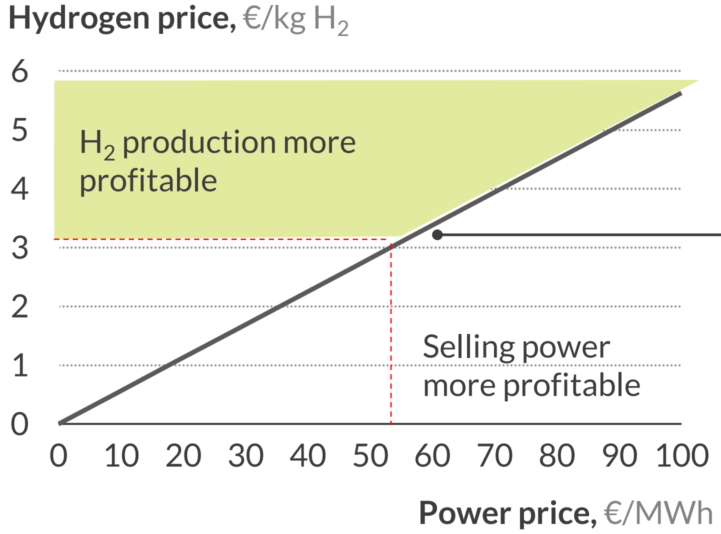
- The RES assets generate electricity and sell to the grid at wholesale prices
- Or it supplies power to the electrolyser if hydrogen is more valuable

Revenue optimisation

To maximise its revenues, the asset will need to optimise its operations based on the profits from both sources, which is dictated by:

i. Hourly power prices – we use Aurora Central scenario for the analysis

ii. Hydrogen price – we assume a fixed purchase price by industrial offtakers



At a power price of 55 €/MWh, a hydrogen offtake price of at least ***3 €/kg H_2*** *would be required to incentivise hydrogen production over power generation*

Source: Aurora Energy Research

Even with attractive production economics, policy support will be needed to incentivise green hydrogen investments in Iberia

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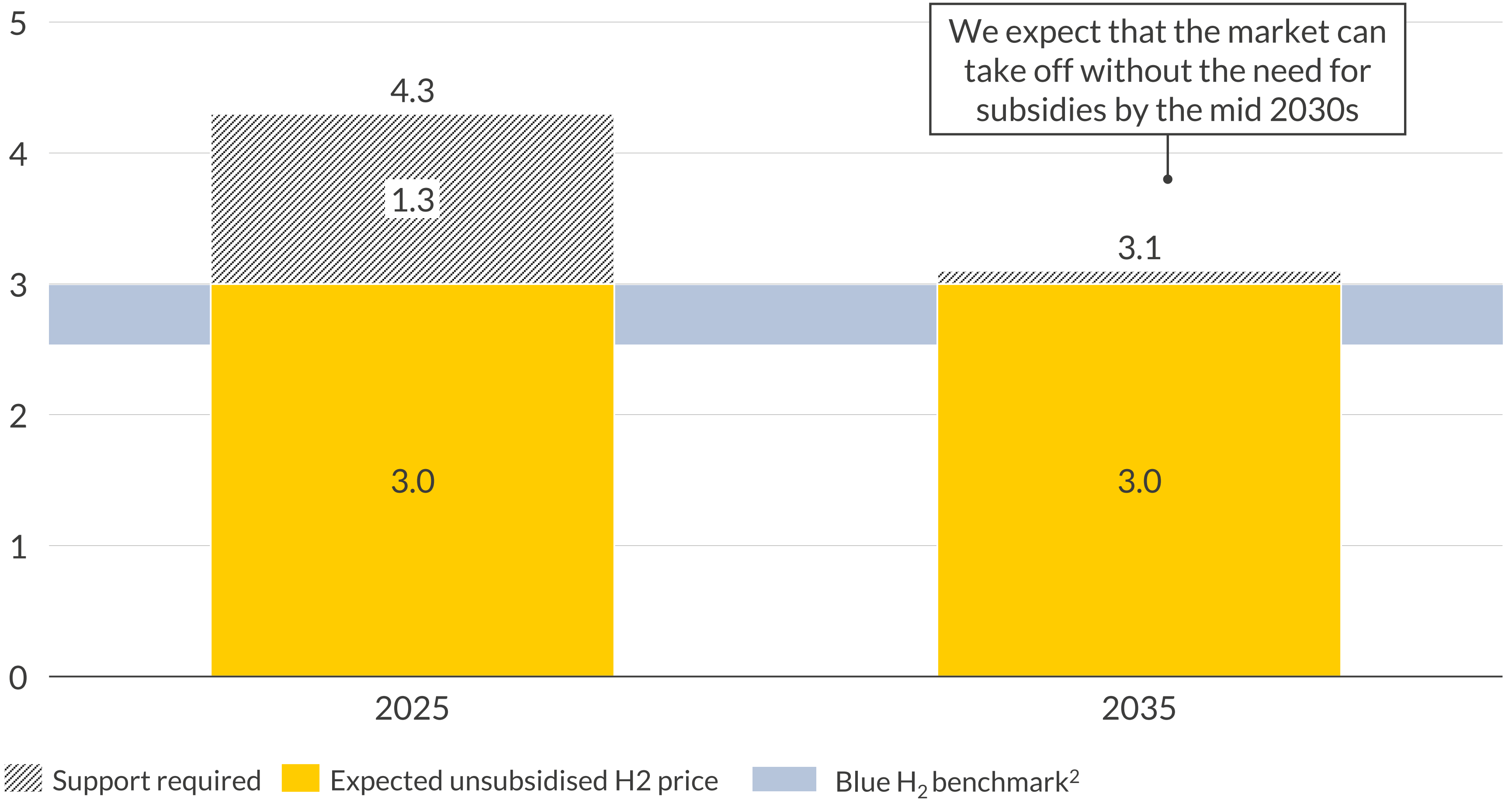
Minimum H_2 offtaker price required for an electrolyser to positively contribute to IRR of RES asset[1], €/kgH_2



- By 2025, a hydrogen offtaker price of ~4.3 €/kg H2 is required for the addition of an electrolyser to a grid connected 50:50 solar-plus-onshore wind RES asset to increase the system's IRR
  - Below this level, it is more profitable for the renewable asset to sell electricity
- This would require a support equivalent to 1.3 to 1.8 €/kg H2 by 2025 to encourage co-located electrolyser business models

1) Based on a grid-connected electrolyser co-located with 50:50 solar-plus-onshore wind RES asset. Analysis based on a specific site in Aragon. 2) A range of 2.5 – 3 €/kg H_2 is assumed for Blue H_2 to reflect transport costs

Key takeaways

1. The Spanish and Portuguese governments have set ambitious green hydrogen targets, particularly as it relates to electrolyser installed capacities. While most of the electrolyser projects in Iberia are still in early stages, the pipeline of projects far exceed the Government pledges

2. Electrolyser co-location with renewables can help guarantee compliance with EU emission standards for hydrogen, but minimising the LCOH requires careful siting and sizing analysis

3. Before 2030, using renewables to produce electricity will remain the profit-maximising strategy unless hydrogen prices are above 3.8 €/kgH_2. Therefore, incentivising hydrogen production might require subsidies equivalent to around 0.8 to 1.3 €/kgH_2

Source: Aurora Energy Research

Details and disclaimer

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