AURORA ENERGY RESEARCH

BIEE Research Conference

The role of hydrogen in meeting UK’s net-zero target by 2050

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Executive summary

1. Hydrogen (H_2) is a viable option for decarbonising a significant share of the GB energy system

2. Systems modelling linking hydrogen and power is important for the understanding of the implications of large scale hydrogen adoption

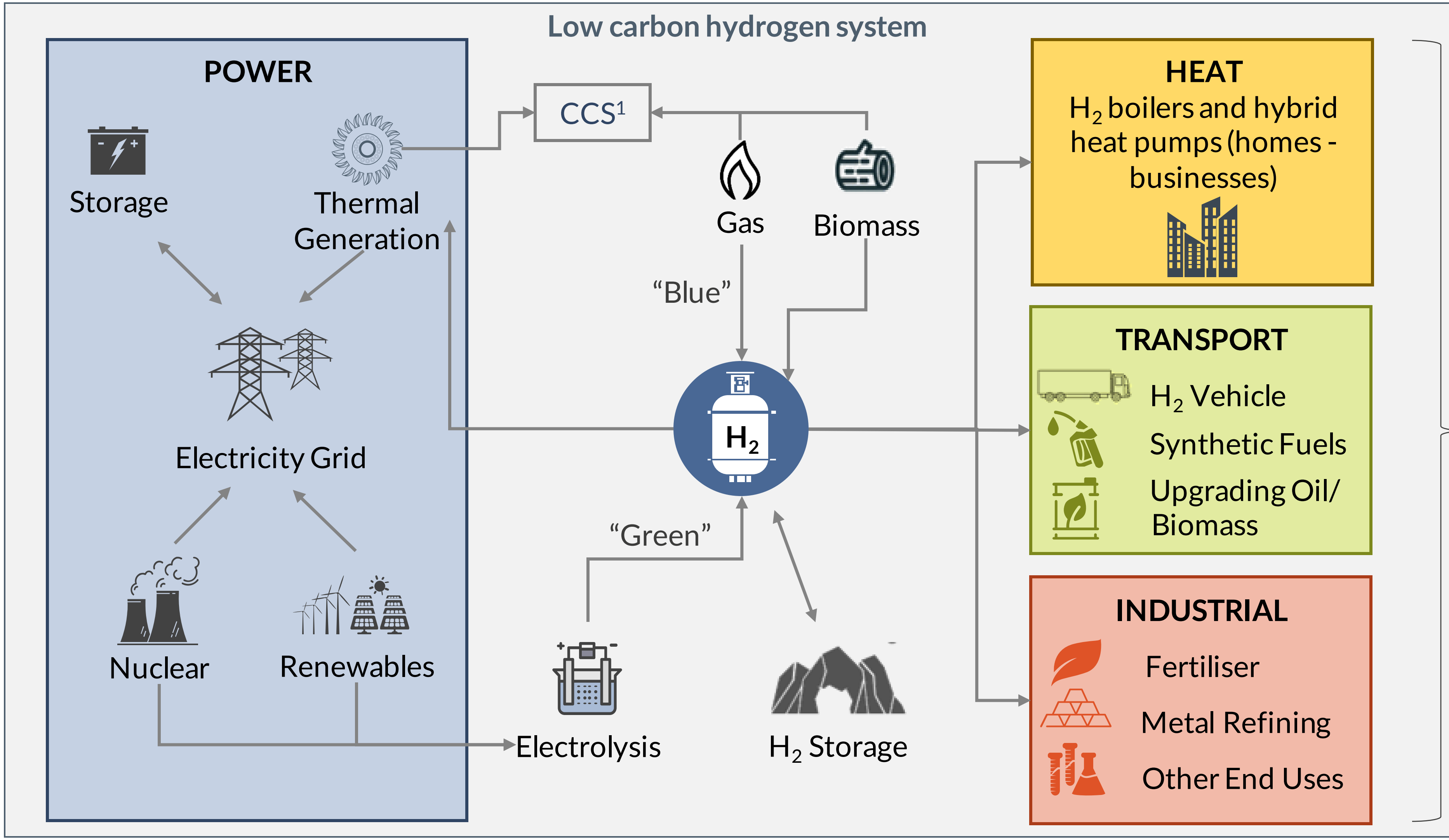
3. Early hydrogen adoption will likely take place in industry. Adoption in heating and transport are major potentials, but is less certain

4. Both "Green" and "Blue" hydrogen production technologies are expected to play an important role

5. High hydrogen scenarios have similar total system costs as no-hydrogen/high-electrification scenarios

6. A nascent hydrogen system requires policy support throughout the value chain

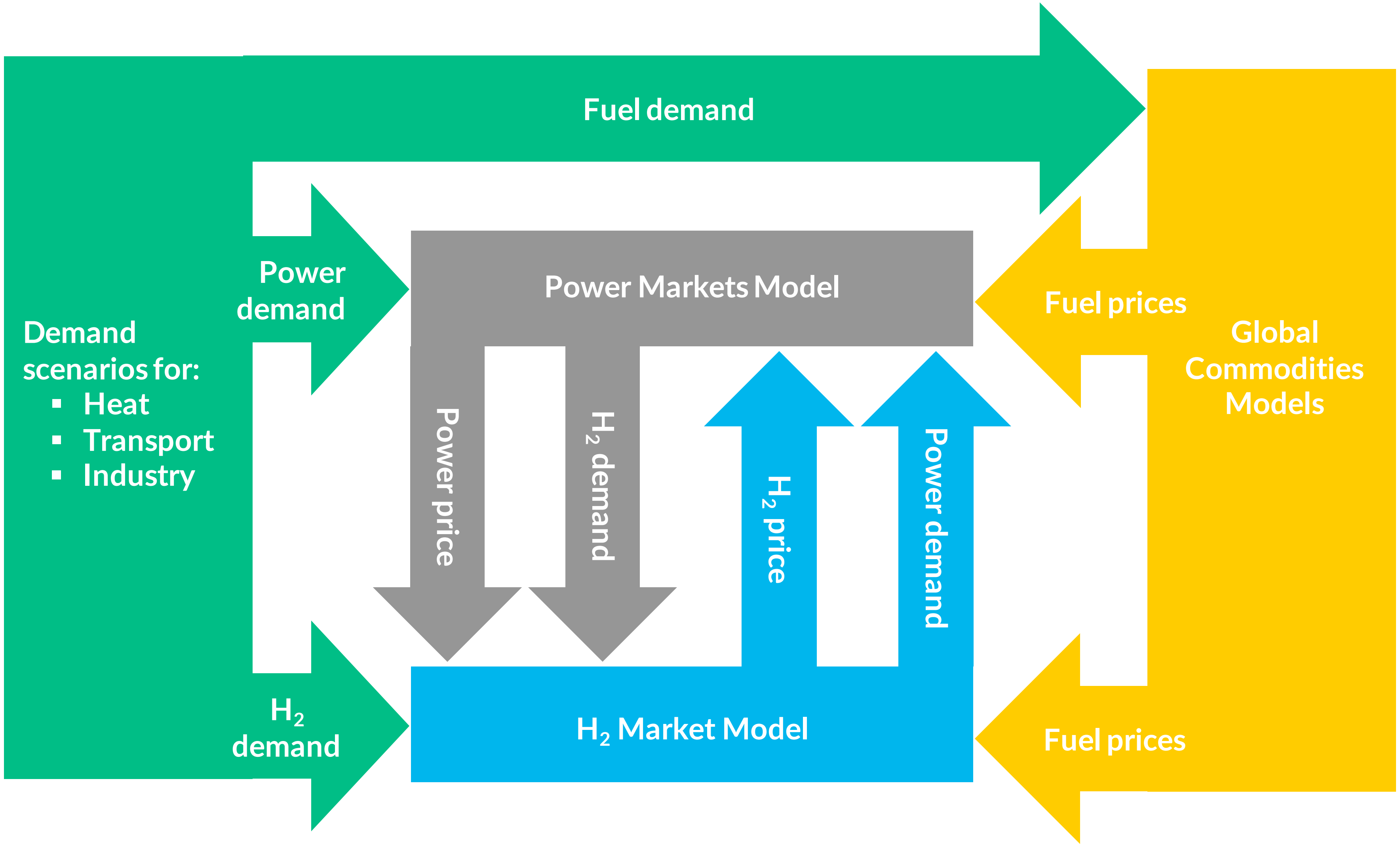
Hydrogen can be used as a low-carbon energy carrier across the energy system



Hydrogen can be used to reduce emissions from hard-to-abate energy demand sectors

1. Carbon Capture and Storage

Aurora has undertaken a comprehensive modelling exercise, which integrates hydrogen into the wider energy system



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Aurora has an integrated energy system framework:

- internally consistent gas, power and H_2 demand scenarios for heat, transport and industry
- unified commodity price forecasts
- a modelling suite that highlights feedback loops across H_2 and power markets

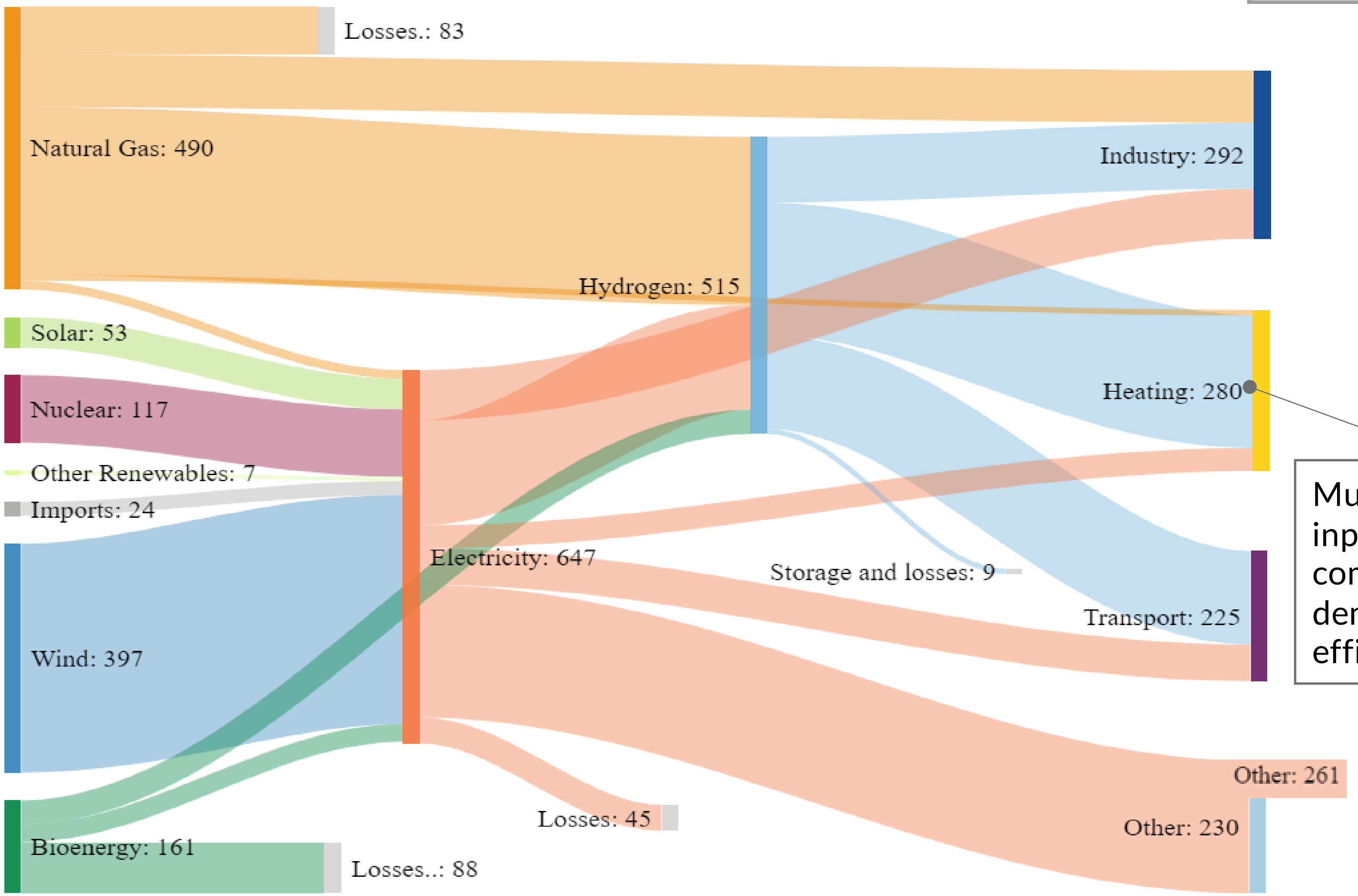
By integrating H_2 and power market modelling, Aurora's approach captures the interactions of power and H_2, and specifically the mutual benefits of H_2 adoption and deployment of renewables

Source: Aurora Energy Research

Hydrogen could provide c.50% of total final energy demand by 2050 in a high adoption scenario

Energy flow in 2050, TWh

High H_2 scenario



Much higher H_2 input flow compared to demand due to low efficiency of boiler

- In a high H_2 scenario, widespread adoption in the heat and transport sectors will result in c. 50% of the final energy demand being met by H_2 in 2050
- More than 50% of that H_2 demand is produced by natural gas, even in a scenario with high renewables
- The market scenario sees accelerated deployment of wind, which provides c. 61% of the electricity requirement in 2050
- Up to 7TWh of H_2 could also be used for power generation, mainly as reserve generation to back up renewables

Source: Aurora Energy Research

Early hydrogen adoption will likely take place in industry. Adoption in heating and transport are major potentials, but is less certain

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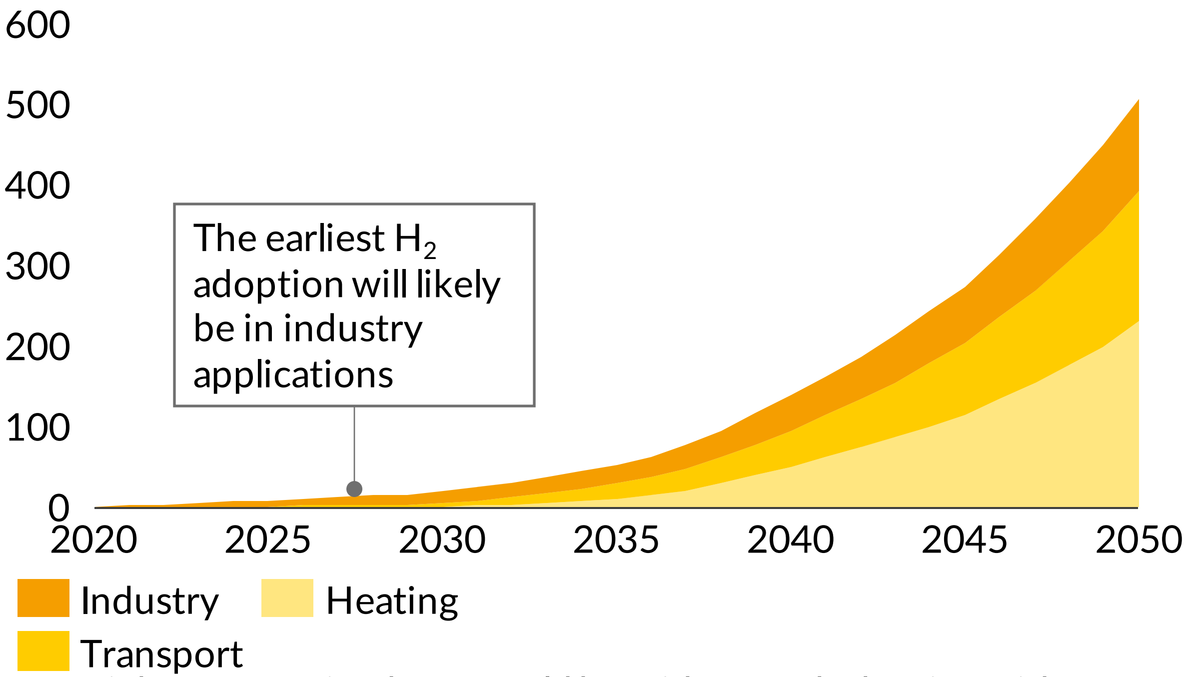
High H_2 scenario

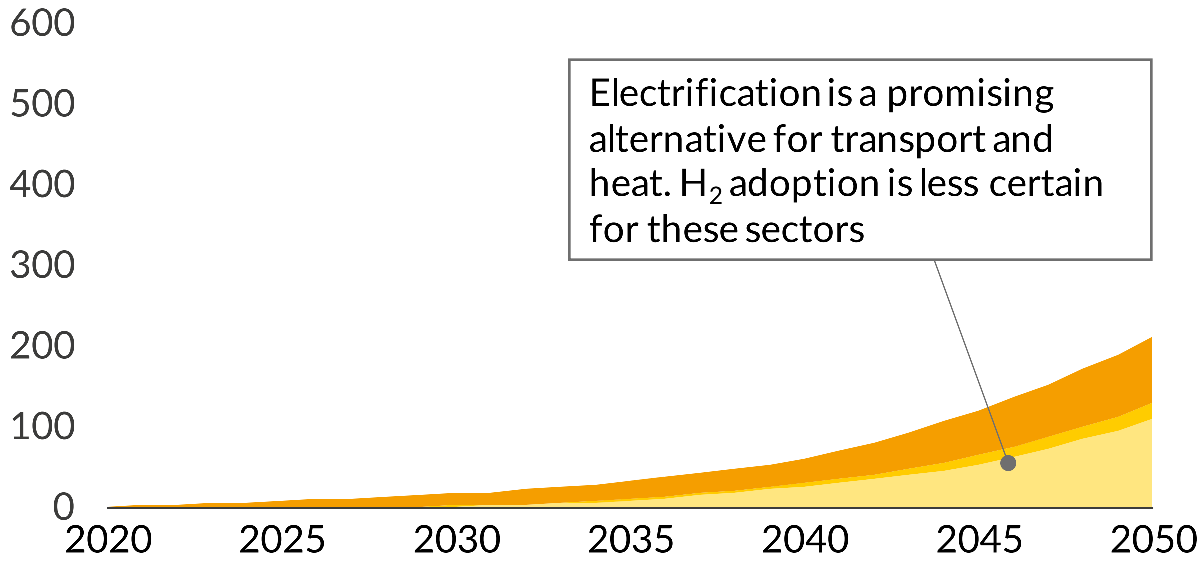
H_2 demand[1],
TWh H_2 HHV/year



In a High H_2 scenario, there would be widespread adoption with deployment of up to 14 million hydrogen boilers and more than 75% H_2 penetration in heavy-goods vehicles, resulting in a total of more than 500TWh of hydrogen demand by 2050

Low H_2 scenario

H_2 demand[1],
TWh H_2 HHV/year



A Low H_2 scenario sees H_2 use in high-grade heat applications in industry and limited penetration in private transport and heat, which are largely electrified by 2050

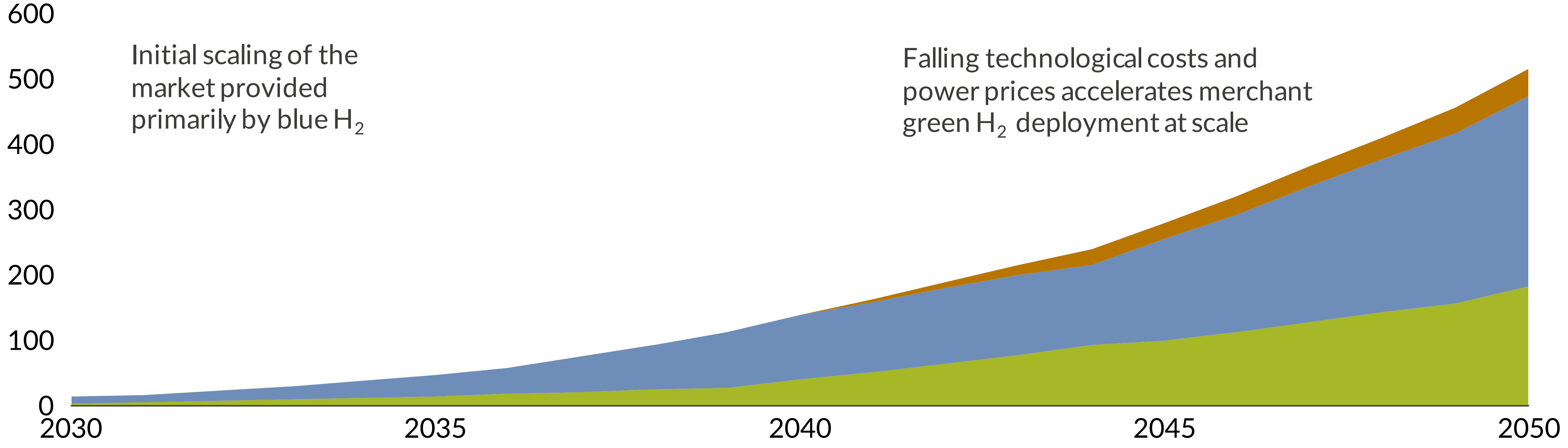
1. Excluding H_2 demand from the power sector.

Source: Aurora Energy Research

Blue and Green hydrogen both have a role. Falling costs and power prices will lead to accelerated Green deployment in the long term

High H_2 scenario

Supply mix,
TWh H_2



Proportion of total supply,
%[1]

	2030	2040	2050
Blue H_2	76	72	57
Green H_2	24	28	35

Green H_2 · Blue H_2 · Biomass gasification

Source: Aurora Energy Research

Blue hydrogen provides baseload supply across the year, while green hydrogen exhibits intermittency due to its use of wind generation

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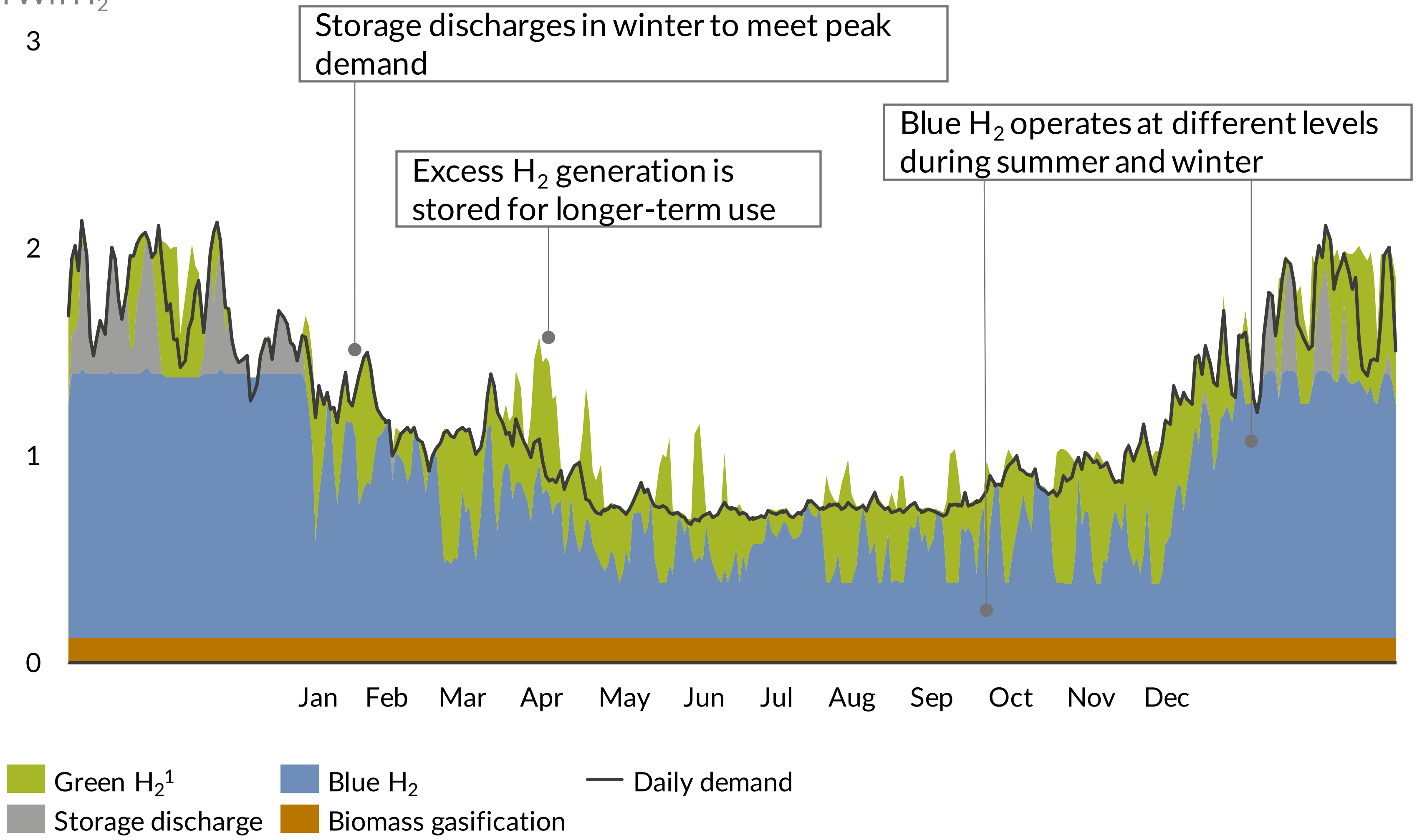
H_2 production in 2050,
TWh H_2

High H_2 scenario

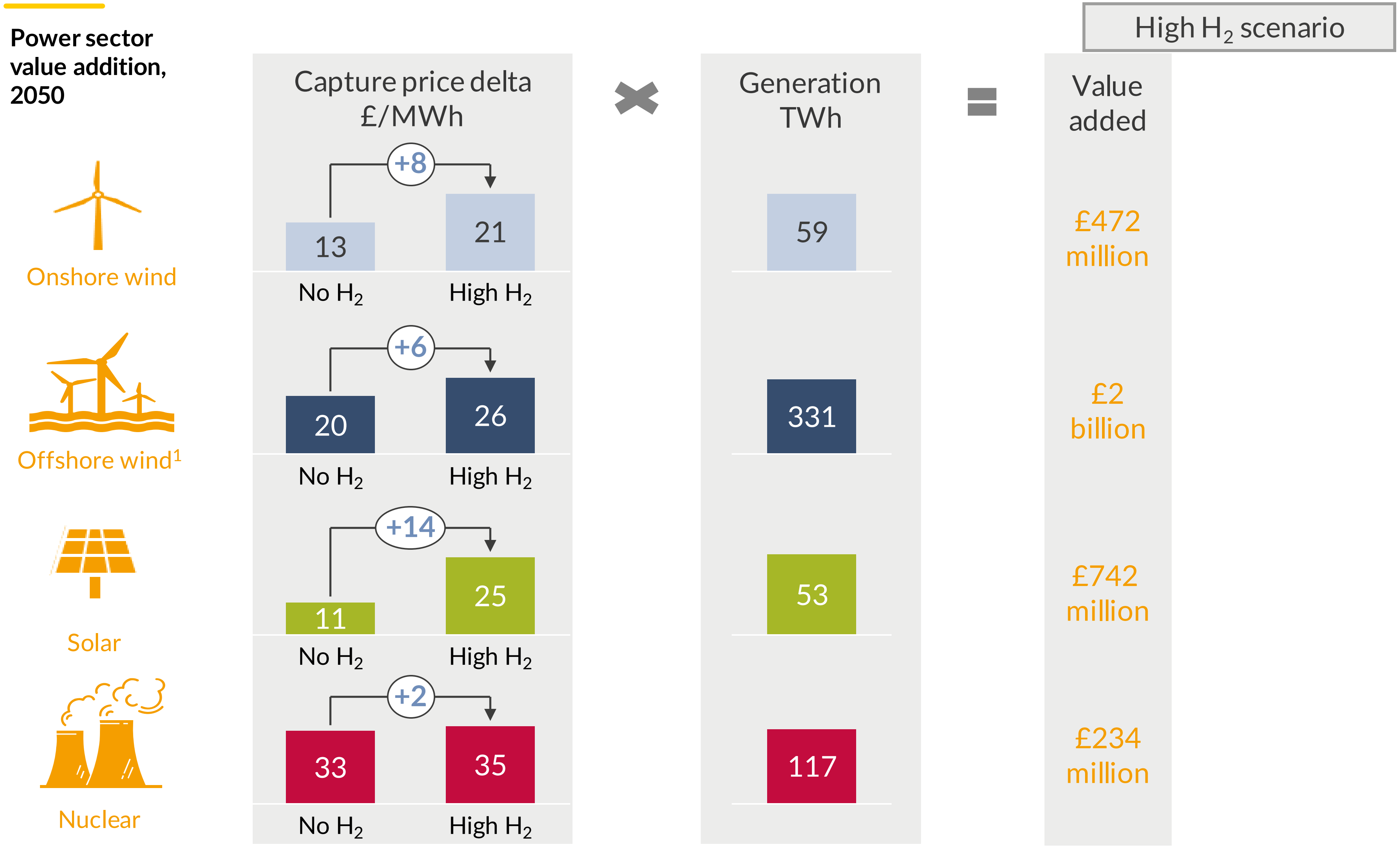


- During summer, when demand is lower, blue H_2 and biomass gasification are expected to provide baseload supply
- Salt caverns store excess supply to time-shift H_2 inter-seasonally
- During winter, blue H_2 generation ramps up. Storage mainly discharges to meet increased demand
- Green H_2 production is intermittent throughout the year, depending mainly on wind output
- While Green H_2 can produce at a steady rate, power prices are not sufficiently low and stable for it to do so optimally

1. Does not include green hydrogen supply from embedded generation, which does not participate in the market

Source: Aurora Energy Research

High penetration of hydrogen could expand the renewable energy market by c. £3 billion/year by 2050



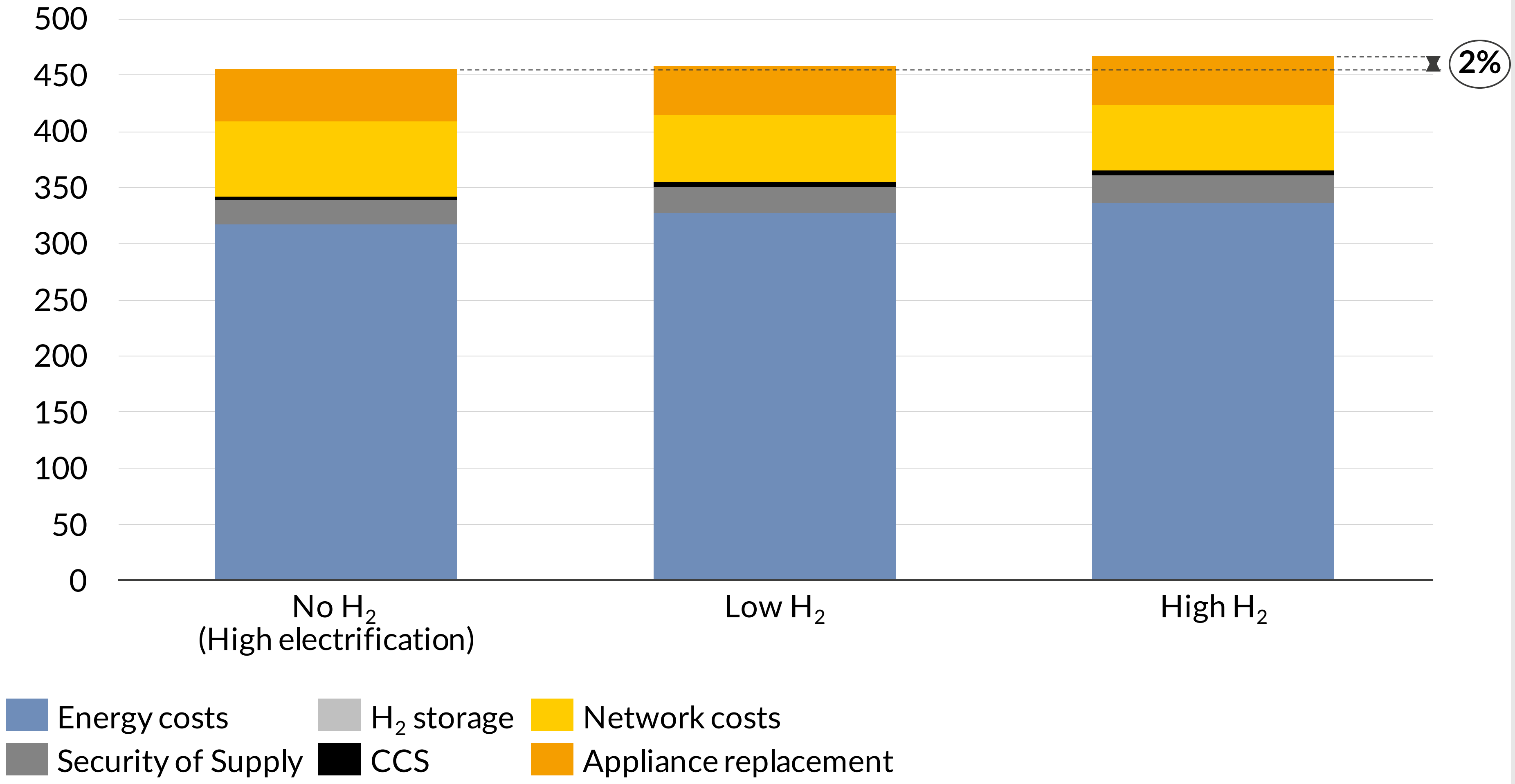
- Most of the value addition for the low-carbon power sector is expected to be driven by higher capture prices due to electrolyser demand
- For offshore wind the increase in capture prices will lead to lower economic curtailment during periods of very high wind
- For solar, the impact on capture price is very high largely due to the ability of H2 to store excess renewable generation for use in winter

1. Most of the offshore wind generation delta comes from reduced curtailment in existing fleet rather than new capacity.

Source: Aurora Energy Research

No pathway is decisively better in terms of system cost: uncertainties and strategy would drive policy decisions

Total system costs[1],
Billion pounds, real 2019



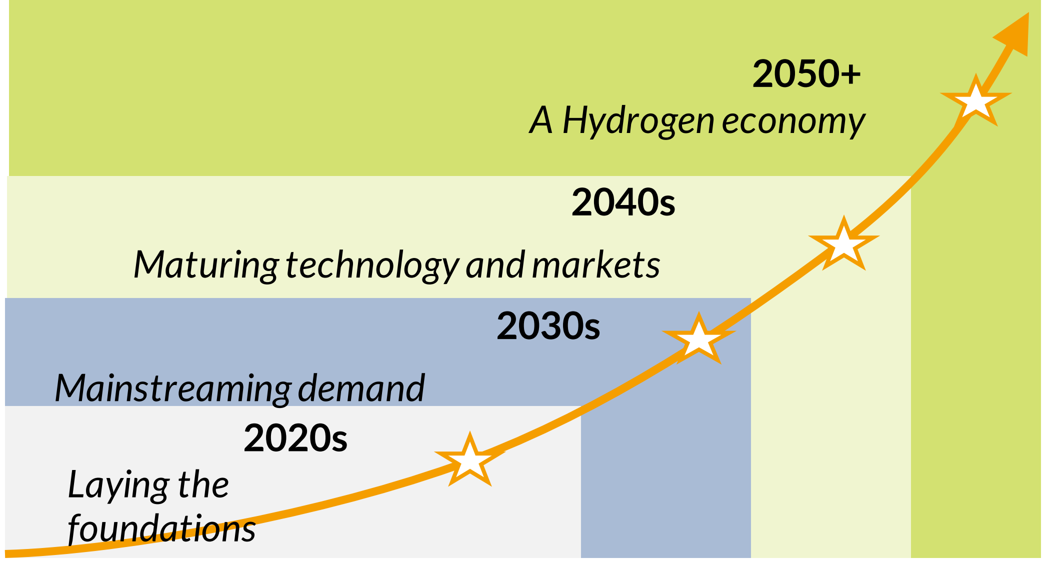
- Difference in system costs between scenarios is relatively small. Minor changes in core assumptions would easily change the cost ranking
- Significant energy infrastructure investments are needed in all scenarios to reach Net Zero targets
- With no evidently optimal pathway, the importance of second order benefits, such as industrial strategy, technology export, and diversification of energy resources can play a decisive role in policy decisions

1. Net present value (NPV) of 2020-2050 expenses for each scenario, assuming a 10% discount rate.

Source: Aurora Energy Research

Unlocking the benefits of a H_2 economy will require early signals, establishing markets and continuous investments

Roadmap to a Hydrogen Economy



- Achieving hydrogen pathways will require early market signals, structuring of bankable frameworks for key elements of the supply chain and strong policy support
- We have mapped the key milestones that would help materialise these pathways, achieving Net Zero and unlocking high levels of H_2 deployment

Period	Leap-of-faith assumptions
2020s	▪ Extensive rollout of **energy efficiency** to allow for effective heat electrification, required in all scenarios ▪ Net Zero-aligned **carbon pricing** enacted and sustained ▪ **Pathways and mandates for decarbonisation** defined for all major demand segments, especially industry, where the UK can gain an early leadership ▪ **Roll-out of pilot and demonstration projects**, especially around industrial clusters, catalyse significant CO_2 and H_2 infrastructure deployment and **standardisation**
2030s	▪ Industrial UK sector starts to leverage on competitive H_2 prices to lead **low-carbon industrial goods** markets ▪ Enabling of regional H_2 networks starts unlocking **rapid demand growth in heating and industries** with moderate growth in the **transport sector** ▪ Support enables **rapid supply growth**, mostly in regions with potential of H_2 uptake in the short term ▪ Early opportunities **spur infrastructure deployment** and help **the supply chain mature**
2040s	▪ UK established as a **leader exporter** of knowledge and technology in the global H_2 space ▪ High level of **maturity of H_2 markets** and services is achieved, including security of supply ▪ **Cost reduction** in electrolyser technologies enables **rapid penetration of green H_2**
Beyond 2050	▪ **Cross-sector synergies** effectively harnessed ▪ H_2 becomes mainstream and widely traded

Source: Aurora Energy Research

Key messages

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1 **Hydrogen (H_2) is a viable option for decarbonising a significant share of the GB energy system**
Hydrogen can play an important role in meeting GB's Net Zero emissions target by providing c.25-50% of its final energy demand by 2050

2 **Systems modelling linking hydrogen and power is important for the understanding of the implications of large scale hydrogen adoption**
All Net Zero scenarios require substantial growth in renewable generation and electrification. Aurora's modelling approach captures the interactions of power and hydrogen, and specifically the mutual benefits of hydrogen adoption and deployment of renewables

3 **Early hydrogen adoption will likely take place in industry. Adoption in heating and transport are major potentials, but is less certain**
Hydrogen can help reduce hard-to-abate emissions in industry, particularly in high-grade heating applications. Hydrogen can further be deployed in heave-goods vehicles and residential heating.

4 **Both "Green" and "Blue" hydrogen production technologies are expected to play an important role**
Natural gas reforming with carbon capture and storage (Blue) provides scale in high adoption scenarios. Electrolysis (Green) deployment accelerates with falling technological costs and power prices in the medium and long-term

5 **High hydrogen scenarios have similar total system costs as no-hydrogen/high-electrification scenarios**
All Net Zero scenarios require intensive investment across all energy sectors. The difference in system costs between high hydrogen and high electrification pathways is relatively small.

6 **A nascent hydrogen system requires policy support throughout the value chain**
Hydrogen adoption pathways will require early market signals, structuring of bankable frameworks for key elements of the supply chain and strong policy direction

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