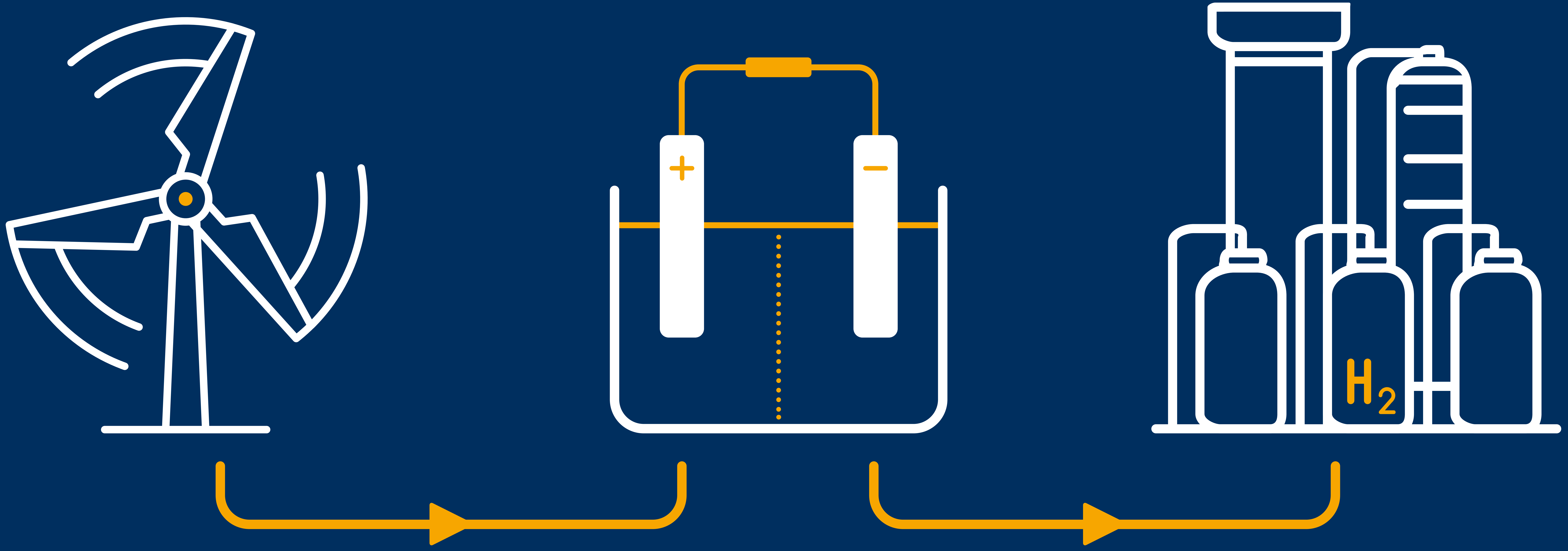
LCP INSIGHT CLARITY ADVICE

The investment case for green hydrogen

October 2021



Executive summary

Green hydrogen has a significant role to play in helping the UK reach Net Zero. It can utilise excess renewable generation, decarbonise hard to electrify sectors and displace blue hydrogen production. This makes it a key technology in allowing the UK to decarbonise multiple sectors and provide system benefits that would otherwise not be realised. The challenge is to ensure that green hydrogen investors can convert system cost benefits into a viable business case, and that an appropriate level of capacity is incentivised.

LCP's analysis shows that there is a place for significant investment in electrolysers and that these can provide system benefits including:

- Increased utilisation of renewable capacity, requiring less investment to achieve the same level of renewable capacity to replace blue hydrogen production. This means less investment is needed to achieve the same reduction in overall carbon emissions.
- Displaced blue hydrogen production, avoiding residual carbon emissions and fuel costs.
- Reduced generation and balancing costs by dampening volatility through electrolysers acting as flexible demand.

Key findings:

Under its commitments to build **5GW of low carbon hydrogen production** capacity by 2030, the UK Government should aim for at least **1GW of electrolyser capacity**.

Electrolyser capacity built in 2030 will require support to monetise the system cost benefits provided. We estimate that the Government would need to provide support in the region of **£9-20/MWh** or **£14-30/kW/year** to make these projects viable.

The level of support required for 1GW of electrolyser capacity built in 2030 would be between **£0.5bn and £1bn** over the asset's lifetime.

Between 2030 and 2040 we forecast that **15GW of electrolysers can be deployed** to provide a system benefit by reducing blue hydrogen production costs. These projects would utilise excess renewable generation which is otherwise unused. In 2040, we estimate this will occur in 44% of hours, with **57TWh of excess renewable energy** over the year.

By 2050 **electrolyser capacity could reach 26GW** to maximise system benefits. Using this deployment figure, we estimate that by 2050, **£13bn of investment** will be needed in green hydrogen electrolysers.

If only 1GW of electrolyser capacity is built, it is forecast to achieve load factors of **20-25% through to 2050**. However, as more electrolysers are built and compete, these opportunities become susceptible to cannibalisation. This makes future projects' profitability more sensitive to CAPEX assumptions, competition and the level of support.

Green hydrogen would make up 16% of total hydrogen supply under the Climate Change Committee's (CCC) Further Ambition scenario which forecasts **annual total hydrogen demand of 270TWh by 2050.** This means that blue hydrogen will still be needed to meet overall hydrogen demand and will also set the marginal price for hydrogen in most periods.

The power sector's role in the route to Net Zero

The energy industry is at the centre of delivering a Net Zero economy which means that virtually all carbon emissions need to be removed by 2050. The power sector needs to go even further than just eradicating its own carbon emissions and is forecast to be carbon negative in the 2030s[1], helping to offset emissions from other sectors that cannot decarbonise as quickly. It is clear that all future scenarios show that achieving a Net Zero power system will require significant growth in renewable generation.

There are parts of the economy that either cannot be electrified easily, or at all. For these sectors alternative energy options will be needed, with hydrogen being seen as a potential option to decarbonise these areas. The **Energy White Paper**[2] places hydrogen firmly at the centre of decarbonisation efforts to achieve Net Zero which is set out in more detail in the **Hydrogen Strategy**[3].

1 Made possible through the use of Bioenergy with carbon capture and storage (BECCS)
2 https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
3 https://www.gov.uk/government/publications/uk-hydrogen-strategy

One of the biggest issues is how the hydrogen is produced. There are two main types of hydrogen production:

Blue hydrogen

Blue hydrogen requires natural gas to be split to separate the hydrogen and CO_2. This is normally through a process called Steam Methane Reformation (SMR) which is a carbon-intensive process, but one which can be made low carbon through the addition of carbon capture.

Green hydrogen

Green hydrogen is produced by splitting water using electrolysis. This produces hydrogen and oxygen. The electrolysis process can be powered with either electricity imported from the grid or electricity produced from onsite assets.

In this analysis, LCP Energy Analytics looks at the investment case for green hydrogen, specifically looking at production levels, how much electrolyser capacity can be deployed while still providing a system benefit, interactions with blue hydrogen, and how this production interacts with an electricity system with significant levels of renewable energy.

What the Government's Hydrogen Strategy commits to

The publication of the Government's Hydrogen Strategy[4] sets out a series of commitments and actions which show how the Government, in partnership with industry, will deliver a UK hydrogen economy.

The Hydrogen Strategy re-commits the Government's ambition to see **1GW** of low carbon hydrogen production by 2025, and **5GW** of production capacity by 2030. **Scotland** has also announced that it is focusing its efforts on supporting the development of hydrogen production capability to meet an ambition of **at least 5GW of renewable and low carbon hydrogen production capacity by 2030**.

The UK has also committed to a 'twin track' approach to hydrogen production, supporting hydrogen production from both electrolysis and Steam Methane Reformation (SMR) with Carbon Capture, Usage and Storage (CCUS), ensuring different production methods are used to deliver the level of hydrogen needed to meet Net Zero.

While the Hydrogen Strategy provides a comprehensive overview of how the Government expects to develop a hydrogen economy in the UK, it lacks detail on specific capacity targets for green hydrogen deployment. The strategy states that by the early 2020s we could see small scale (up to **20MW**) electrolytic hydrogen projects going ahead, with larger (**100MW**) electrolytic hydrogen projects by the mid-2020s. This would coincide with CCUS-enabled hydrogen production and growth of industrial clusters. This equates to a 2030 ambition to produce up to **42TWh** of low carbon hydrogen for use across the economy.

The strategy sets out the reasons for developing a hydrogen economy, including the sectors that may be able to decarbonise though using hydrogen over the coming decades. However, understanding what level of green hydrogen production will be efficient, and what support will be needed from the Government, is yet to be established.

The economics of green hydrogen production are much more complex than those of blue hydrogen production. Green hydrogen uses electricity to power the electrolysers that split water to create hydrogen. This process requires the whole power system to be modelled to forecast the number of hours where the power system will have high or excess levels of renewable power. This will drive the price down to levels low enough to run the electrolyser and provide a system benefit by using the excess renewable power that would otherwise be wasted. **The amount of electrolyser capacity is also extremely sensitive to cannibalisation from other electrolysers which will lower the load factors of the entire fleet.**

Establishing the optimal deployment level of electrolysers capacity and support levels needed for early projects is important in ensuring the successful development of this technology. Our analysis looks to provide the answer to these questions and explore how different level of electrolyser capacity will interact with the GB power system.

4 Hydrogen Strategy: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

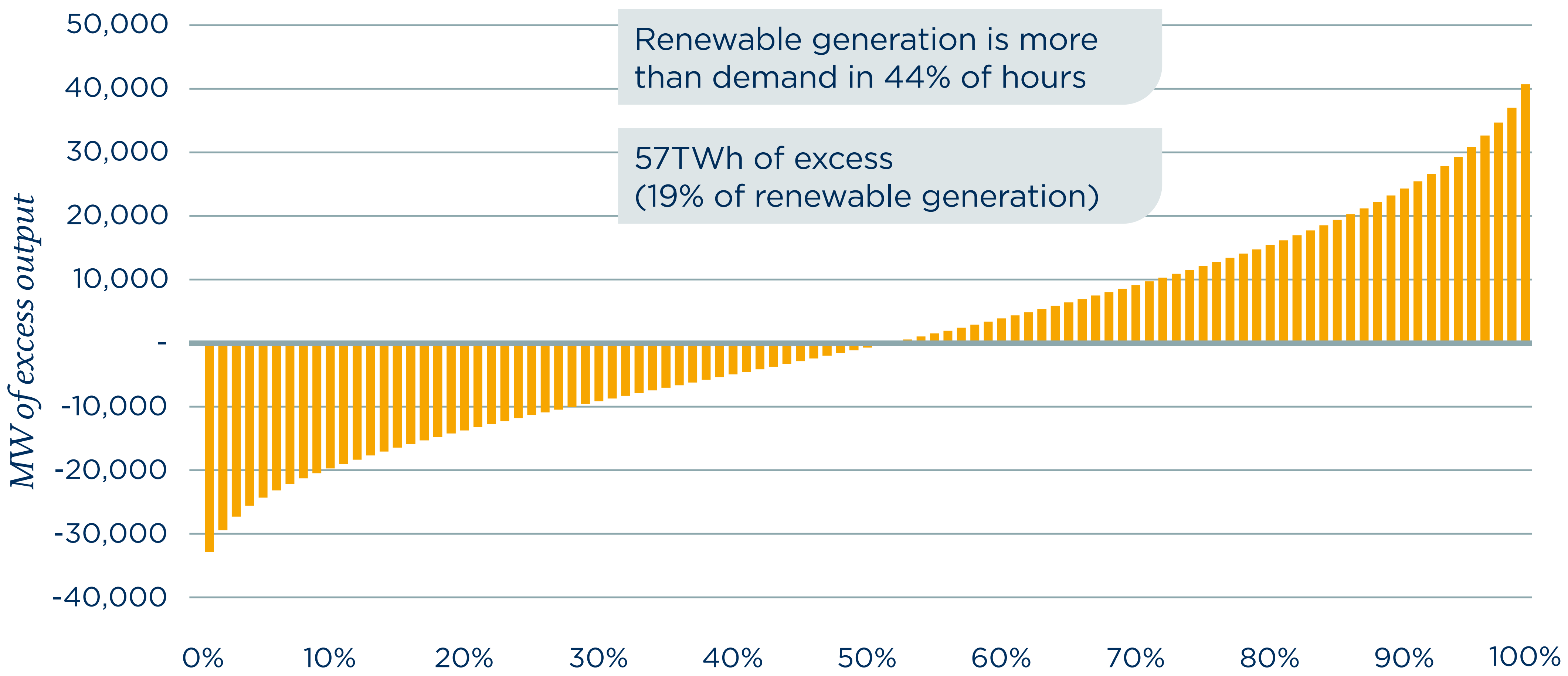
How green hydrogen interacts with the future power system

Achieving Net Zero in the power system will require a significant increase in the amount of renewable generation capacity. **The LCP scenario analysed in this report projects that there will be 105GW of installed wind and solar capacity by 2040.** Although there will still be a need for firm capacity to back up the system during low renewable generation periods, there will be a significant number of hours where there will be excess renewable generation and power prices will be low or zero.

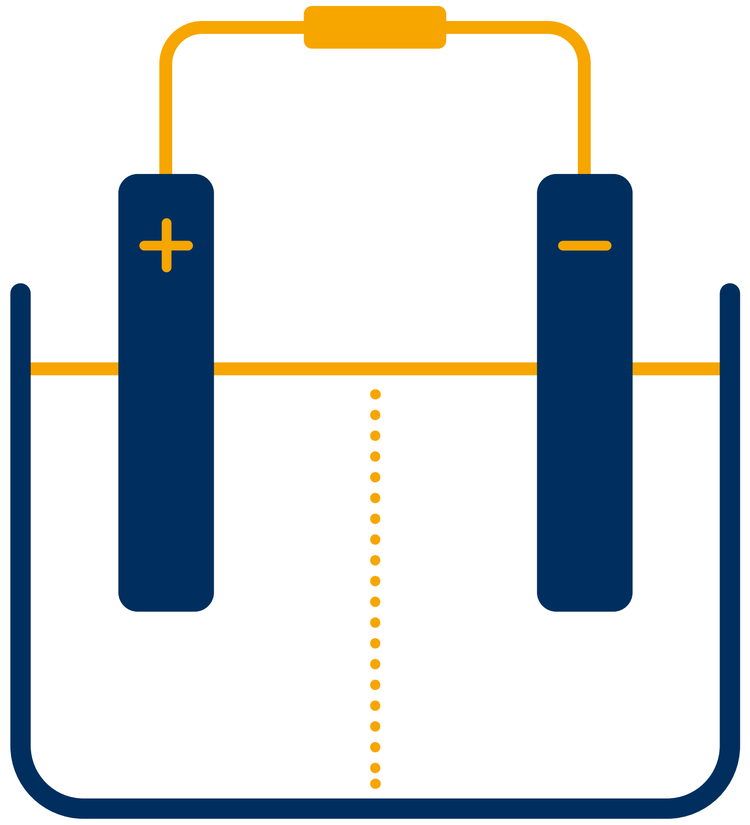
LCP's power market model, LCP EnVision[5], models every power asset operating to maximise its profit across all markets within each asset's operational limits. Using this approach, we examine the expected utilisation of an electrolyser as part of the GB power system and explore how these units can reduce overall system costs by using excess green power that may otherwise be wasted.

Excess Renewable Generation in 2040

LCP scenario - 105GW of Wind & Solar



Being able to model how different participants would behave in the power market allows us to model the expected utilisation of an electrolyser as part of the GB power system and explore how these units can reduce overall system costs by using excess green power that may otherwise be wasted.



The chart above shows that in this scenario, renewable generation will outweigh demand in 44% of hours by 2040 with 57TWh of excess renewable generation on the system. This excess generation is increased further by inflexible baseload generation such as nuclear. Although some of this excess power can be exported over interconnectors to other countries or used in storage, there will be significant volumes that can be utilised by electrolysers to create green hydrogen.

5 LCP EnVision is our in-house electricity market model, which delivers quick, insightful analysis into investment opportunities through the fundamental modelling of policy impacts, dispatch decisions and investor behaviour. https://www.lcp.uk.com/energy/energy-market-forecasting-and-scenarios

Modelling electrolyser deployment

In this analysis we have assumed that SMR CCUS deployment can be justified if demand is guaranteed and the offtake price is high enough to cover the CAPEX and OPEX[6] costs of producing blue hydrogen. For our analysis we use SMR CCUS to set the marginal price of hydrogen on the system which is used to determine whether electrolysers can be profitable under different deployment assumptions.

The value of green hydrogen to the wider energy system is closely linked to the deployment of renewable generation and the wider power market background. The EnVision model captures the key dynamics which determine the system cost benefits of electrolysers, including:

- **Green hydrogen improving the utilisation of renewable capacity, requiring less investment to achieve the same level** of renewable capacity to replace blue hydrogen production, meaning less investment needed to achieve same reduction in overall carbon emissions.
- **Green hydrogen production displacing blue hydrogen production, avoiding residual carbon emissions and fuel costs**.
- **Reduced generation and balancing costs by dampening volatility.**
- **Cannibalisation of electrolyser opportunity: the benefit of additional electrolyser capacity is diminishing, and so there will be an optimal level of investment given a set power market scenario.**

6 Expenditure on operating and maintaining an asset.

The opportunity for green hydrogen production

Evaluating a scenario with 1GW of electrolyser capacity

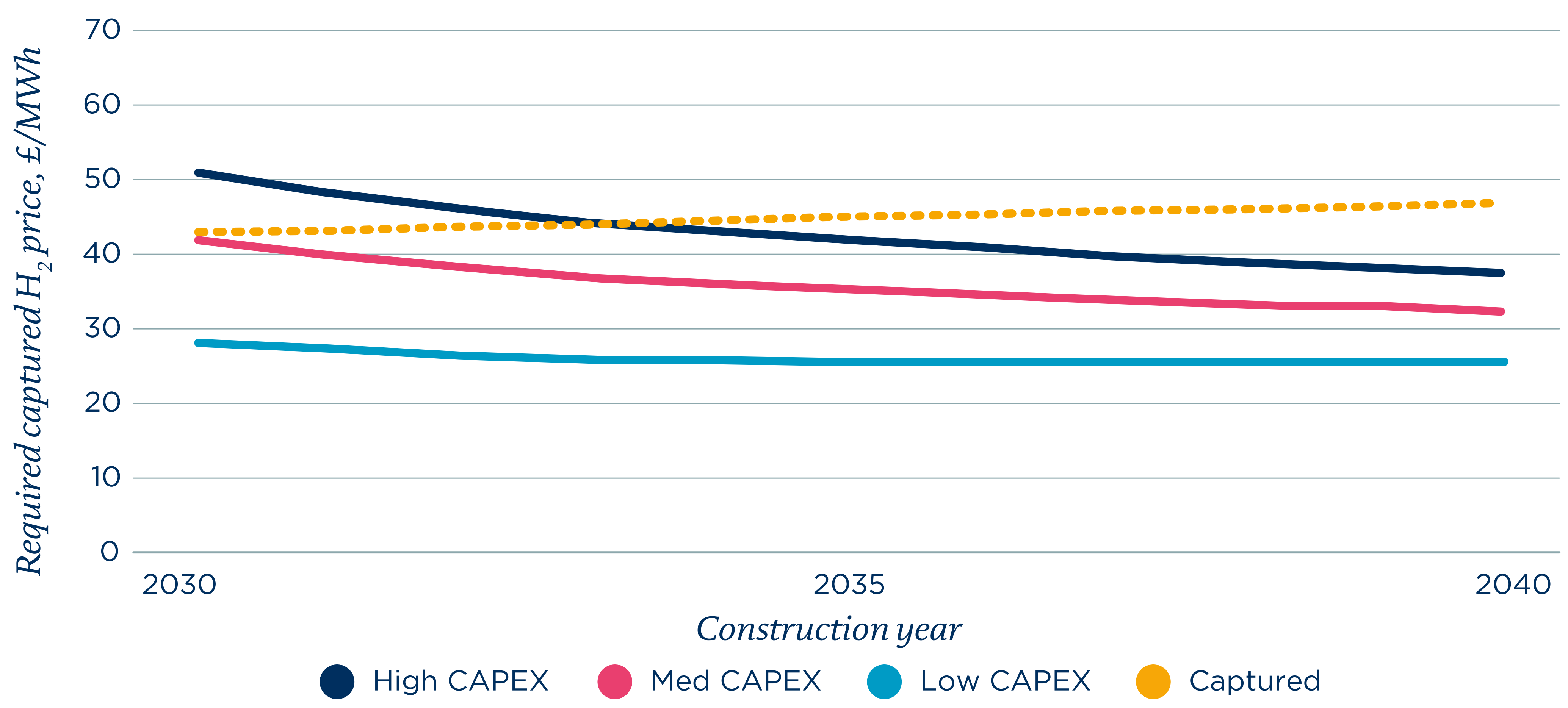
To evaluate how electrolysers will interact with the GB power system, we look at **1GW of electrolyser capacity build in 2030** and how it operates throughout its lifetime. We assume here that no other electrolysers are built. The first chart compares its levelised costs against an estimated captured price of hydrogen if it is built in each year between 2030 and 2040. These values are captured values for the full lifetime of the electrolyser[7].

This analysis shows that under all but the highest CAPEX[8] assumptions, the captured price of hydrogen is adequate to cover the levelised costs of the electrolyser. As CAPEX costs fall, this project becomes profitable without support in all scenarios if commissioned after 2035.

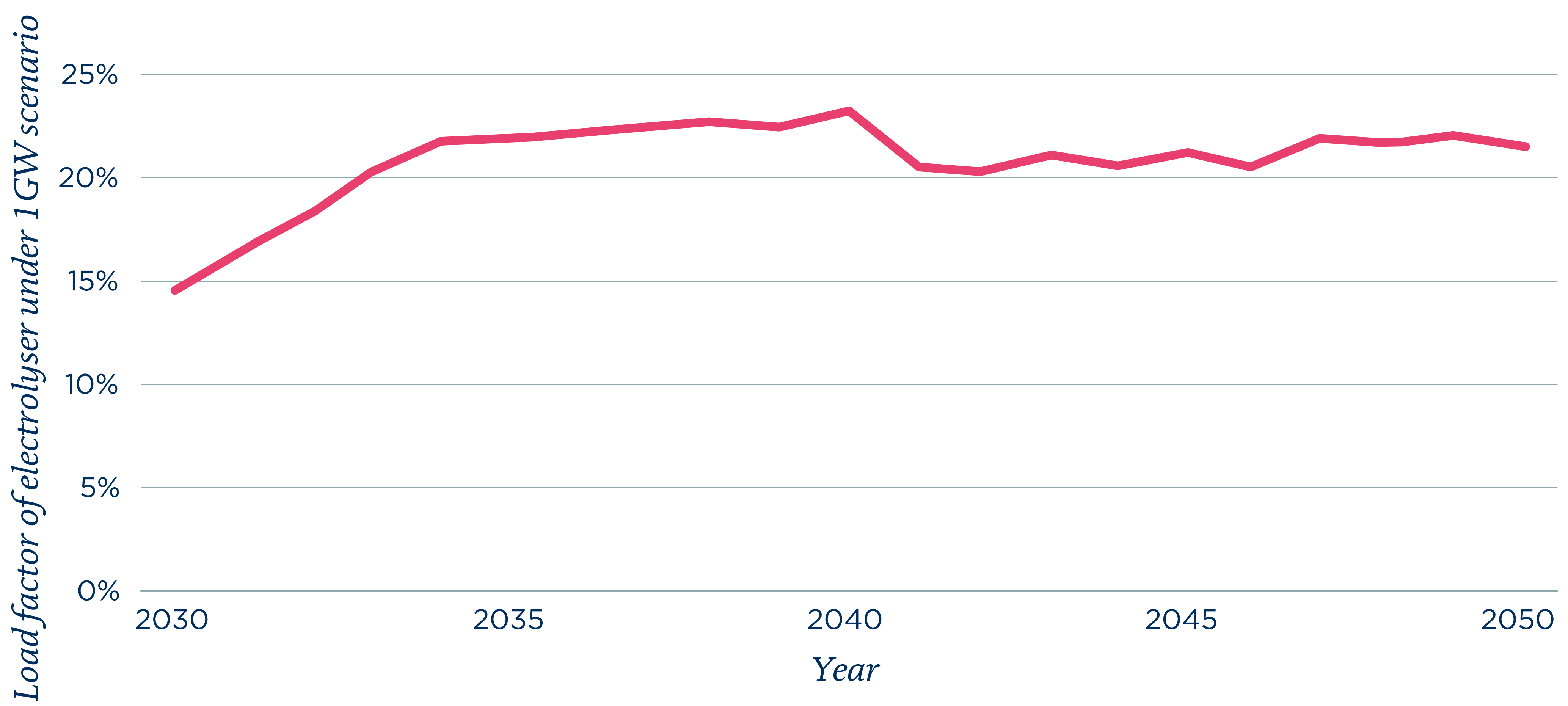
The second chart shows the load factor of a 1GW electrolyser between 2030 and 2050. The load factor increases early in its lifetime with higher renewable deployment. In later years, the load factor remains between 20% and 25%. Although there will be more than 1GW of curtailed renewables in more than 25% of hours in later years, the production of green hydrogen will be limited by the daily and seasonal profiles of hydrogen demand and the availability of hydrogen storage.

This suggests that there is a strong investment case for small amounts of electrolyser capacity in low and central CAPEX scenarios in 2030, but support might be required for higher cost projects. Under higher cost assumptions, support could reach £8/MWh of hydrogen or equivalently £14/kW/year.

Required hydrogen price under CAPEX scenarios



Load factor of electrolyser under 1GW scenario



7 Hydrogen price estimated assuming marginal SMR CCS. Both the captured price and levelised costs do not include transportation costs of hydrogen.

8 CAPEX assumptions are taken from a literature review by the International Council on Clean Transportation (ICCT).

System cost optimal electrolyser deployment

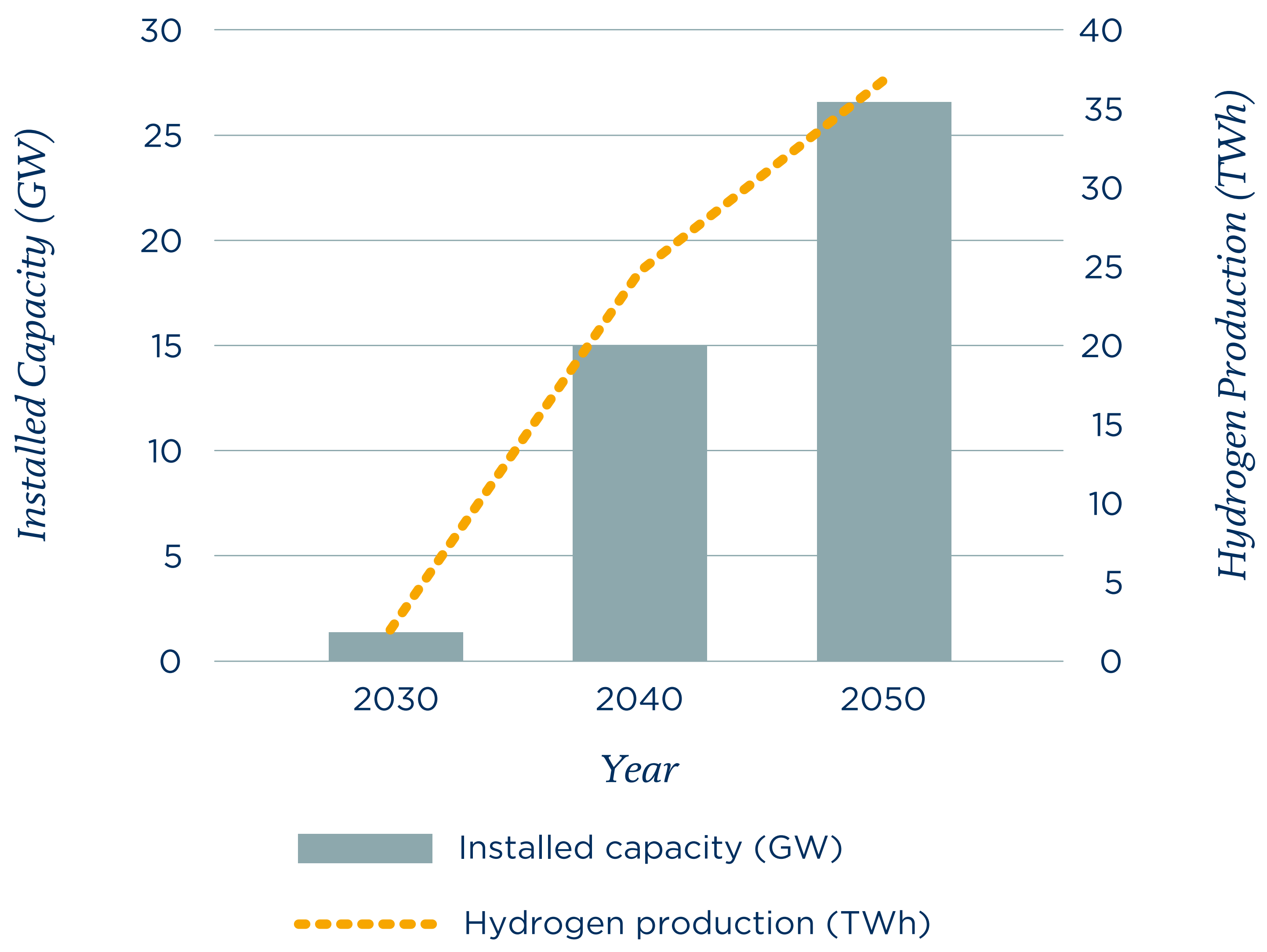
The profitability and system impact of more electrolyser capacity will depend on the background capacity of other electrolysers. With more electrolyser capacity, there will be competition to produce hydrogen using limited excess renewable generation. This will reduce the quantity of green hydrogen produced per unit of capacity, which in turn increases levelised costs and could lead to higher levels of required support.

To understand these effects, we have developed a system cost optimal pathway for electrolyser deployment against the wider LCP scenario. System costs in this context are the costs associated with the production and delivery of power and hydrogen, including the costs of building, maintaining and operating generation and transmission infrastructure. This is commonly used by BEIS and Ofgem to measure the impact of new policies, regulatory changes or technologies on the GB power system and would take the form of cost-benefit analysis or an impact assessment.

Building electrolyser capacity could reduce system costs up to a point, until the savings from producing less blue hydrogen are outweighed by the additional costs of building and maintaining the additional electrolyser capacity.

At 10-year intervals from 2030 to 2050, we tested a range of electrolyser deployment scenarios to calculate the level of electrolyser capacity which minimises system costs under the LCP scenario. The deployment is summarised opposite:

System cost optimal pathway for electrolyser deployment



To maximise system benefits 15GW of electrolyser capacity should be built by 2040 and over 26GW should be built by 2050.

Evaluating the profitability of electrolysers in the system cost optimal scenario

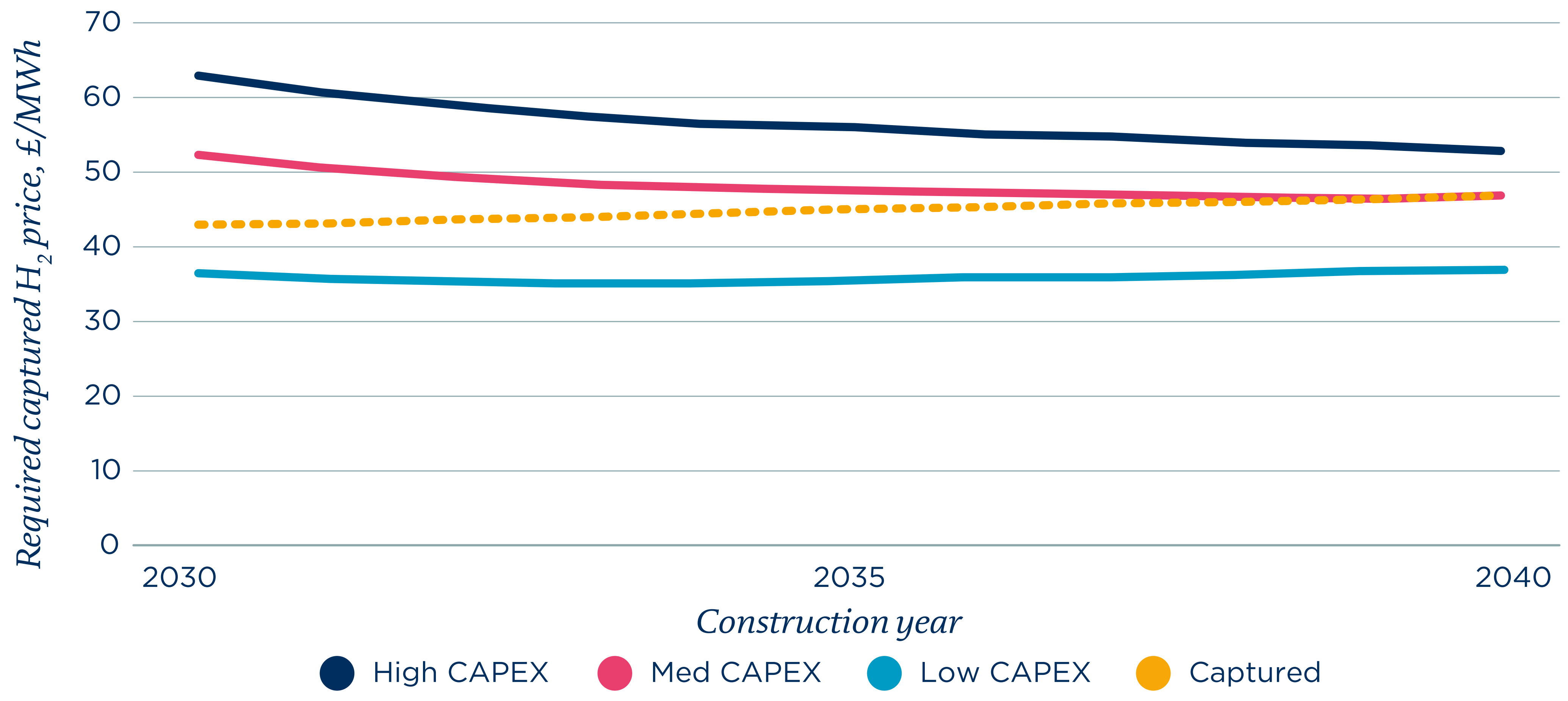
Here we have assessed the opportunity for green hydrogen again, looking instead at the marginal 1GW built under the 'System cost optimal pathway for electrolyser deployment'. This shows lower load factors and reduced profitability compared to 1GW scenario.

The second chart shows the load factor of the electrolyser capacity between 2030 and 2050 in this higher deployment scenario. As expected, load factors are reduced due to competition. However, **load factors remain above 15%** throughout the lifetime of the asset.

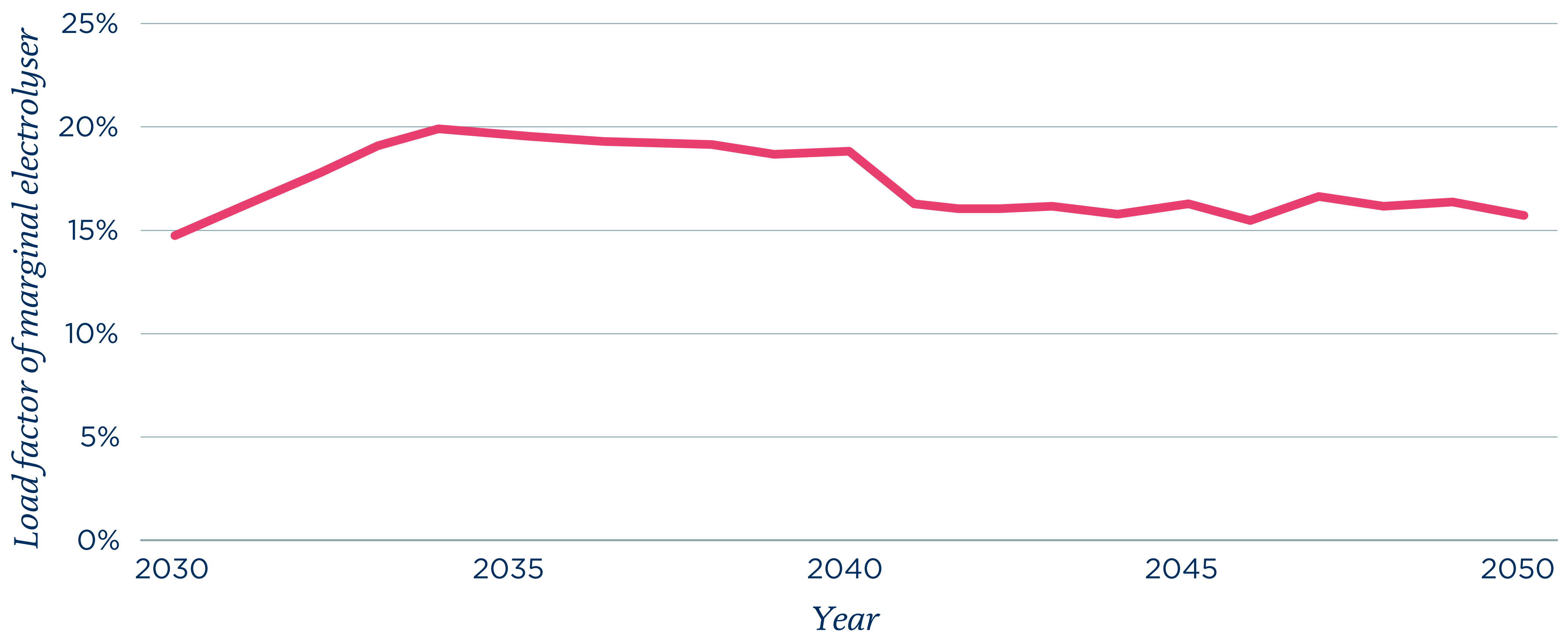
This analysis shows that under low CAPEX assumptions, the captured price will cover costs in 2030. However, at medium or high CAPEX assumptions, **support would be required from the Government for these projects to be viable in 2030, £9-20/MWh of hydrogen production**. This is equivalent to receiving £14-30/kW/year. By 2040, due to assumed falls in the electrolyser CAPEX and increases in the number of low electricity price periods, new projects are able to break even without support.

Contractual payments to producers and regulatory returns models could be designed to deliver low carbon hydrogen production by 2030. **The level of support required for these early projects would be between £0.5bn and £1.0bn over the lifetime of these projects.** The required support would be higher if the UK and Scottish Governments aim to build more than 1.1GW of electrolysers when meeting their combined 2030 low-carbon hydrogen target of 10GW. This is due to greater cannibalisation and more capacity to support.

Required hydrogen price under CAPEX scenarios



Load factor of marginal 1GW electroyser



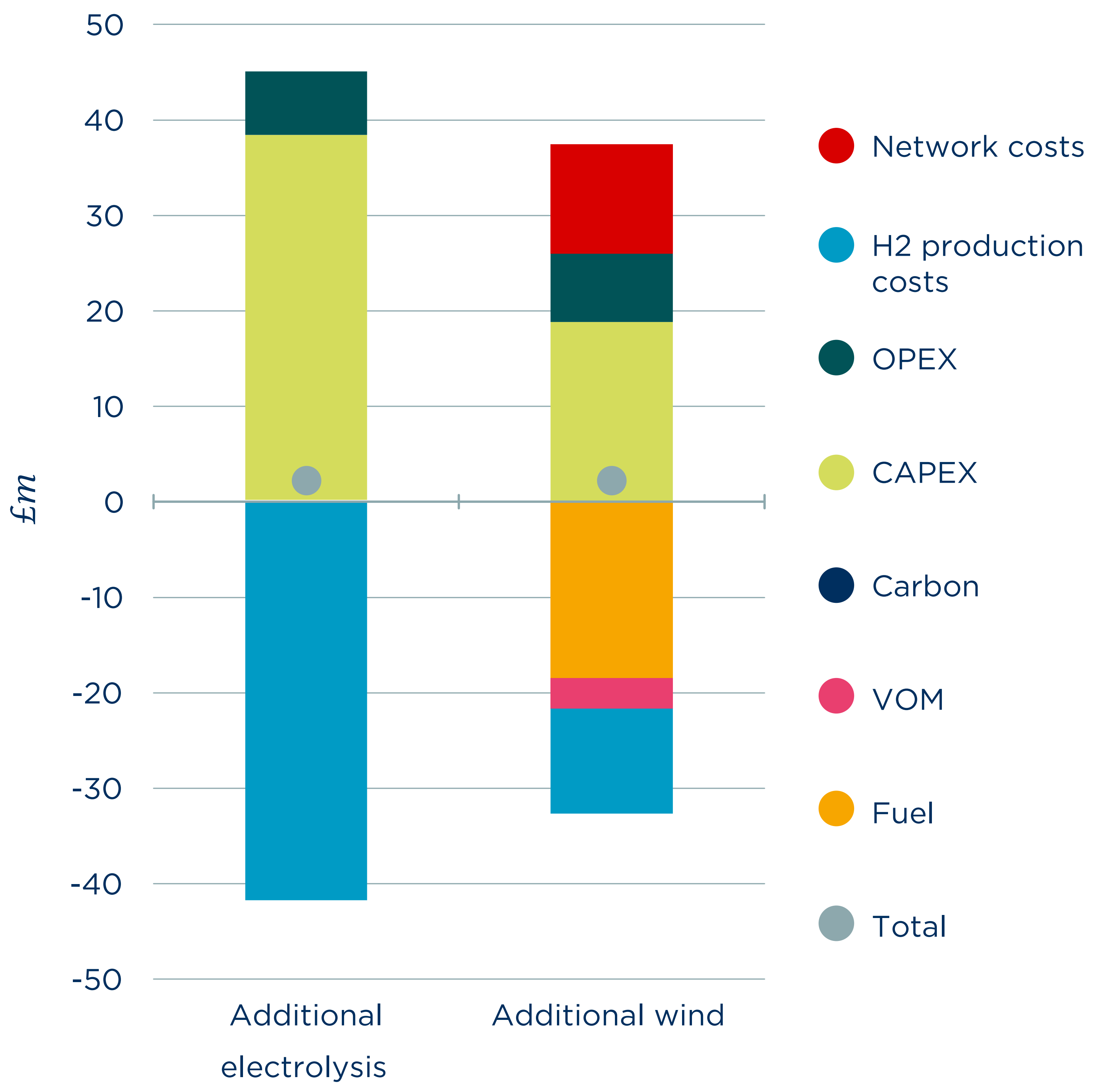
Interaction between electrolysers and renewable deployment

The system cost benefits of electrolyser deployment are based on using excess renewable generation to produce hydrogen and displacing blue hydrogen production such as SMR CCUS. The benefits will be larger when there is more renewable generation. On the other hand, deploying additional renewables will have the same benefit if there are under-utilised electrolysers on the system. Therefore, the system cost optimal deployment of electrolysers and renewables are closely related.

Looking at 2050 under our optimal electrolyser deployment pathway (where we assume 26.6GW of electrolysers in 2050), we examine this relationship more closely. In this year, we consider two alternatives for increasing hydrogen production: **building more electrolyser capacity** or **building more offshore wind**.

For the next 1GW of electrolyser capacity added in 2050, we found that to achieve the same increase in hydrogen production, you would need to build 190MW of offshore wind. The chart here shows the system cost impacts of these two alternatives. Since the system cost impact is close to 0, the levels of deployment for electrolysers and offshore wind optimise system costs against this wider market background.

System cost change



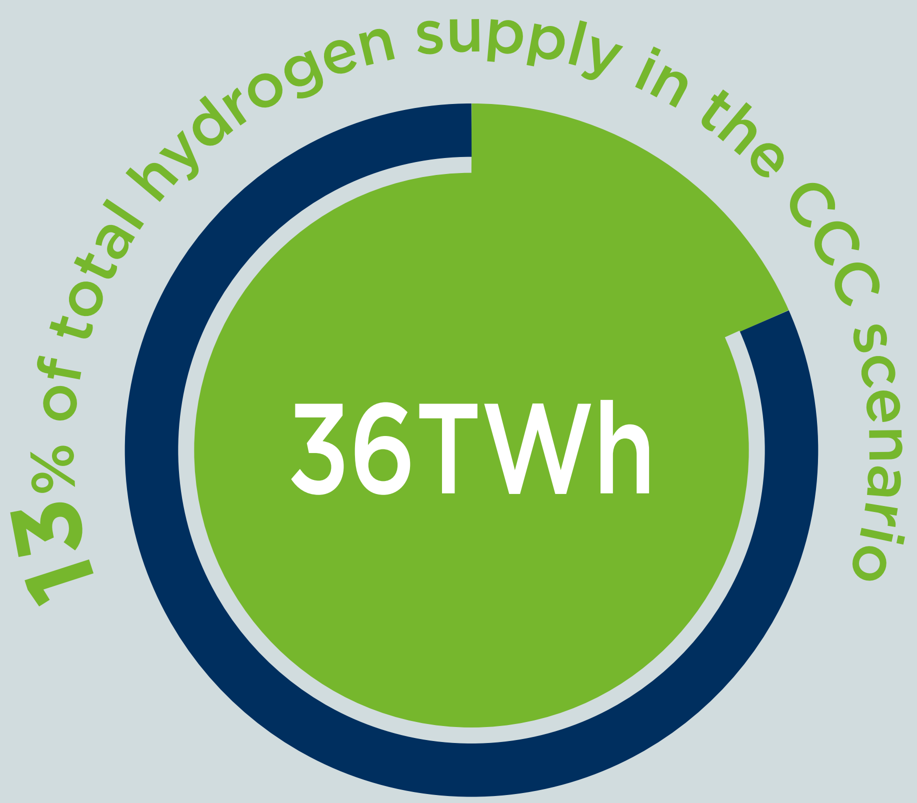
This suggests that there is a place for significant investment in electrolysis and that it can be used as a preferable alternative to building additional renewables. However, achieving the optimal pathway will require detailed understanding of the interaction between deployment of renewables and green hydrogen production.

Demand for hydrogen

The Climate Change Committee (CCC) estimates that up to **270TWh** of low carbon hydrogen could be needed in its 'Further Ambition' by 2050. Analysis by BEIS on Carbon Budget 6 (CB6) suggests demand for hydrogen could be anywhere from **250TWh – 460TWh** by 2050.

While overall hydrogen demand is forecast to outstrip green hydrogen production in the future there is a bigger challenge in developing the first markets for this hydrogen. These are likely to be fragmented to start with, with variable levels of demand, which is why support mechanisms will be required to offer investors comfort to deploy green hydrogen projects.

This means there will always be demand for green hydrogen as the scenario used for this report produces just over 36TWh of green hydrogen or 13% of total hydrogen supply in the CCC scenario or between 8% and 14% for the BEIS analysis.



Hydrogen support mechanisms

Our analysis shows that the role for green hydrogen is closely linked to the deployment of renewables in the power system and the wider scenario for decarbonisation. Under some scenarios there is a place for significant investment in electrolysis and it can be used as a preferable alternative to building additional renewables. In addition, there are use cases where low carbon hydrogen production may be required for decarbonisation. **By 2050 we see that some decarbonisation scenarios would benefit from 26GW of electrolyser deployment.** The total amount of investment in electrolysers needed to reach 26GW would be £13bn. There would be additional benefit if these electrolysers were built in locations where renewable energy is currently curtailed, such as Scotland.

Under medium and high CAPEX assumptions electrolyser units may find it difficult to create sufficient returns to cover CAPEX and OPEX costs. However, they may be required to enable the Net Zero transition in which case they would require support. The building of additional electrolysers is not the only technology that could undermine electrolyser revenue. Other flexible technologies such as energy storage (batteries, pumped storage or other technologies) and interconnectors will also either store excess renewable power or export it to other countries.

BEIS's consultation on a business model for low carbon hydrogen[9] sets out the advantages and disadvantages of revenue support under producer-led or end user models. BEIS's preferred option is to go with a producer-led model which can work across a range of different production technologies and end use sectors. BEIS consider this is the most effective approach to provide reasonable surety of returns for investors and achieve their strategic objectives. The main reasons for this is that a producer-led model is less complex and faster to implement, largely due to fewer counterparties being involved. A producer-led model also has the benefit of providing investors with more certainty over future revenue, allowing larger projects which can create hydrogen for multiple sectors to attract finance.

This consultation also sets out three price support options for a production-led model. These include a **fixed price**, **fixed premium** and **variable premium** option. BEIS favours the variable premium option (which is similar to Contracts for Difference (CfD) used for low carbon electricity) but notes that selection to the reference price will be important to the effectiveness of this mechanism. It is clear that early projects will require support, as green hydrogen developers will need to factor in the additional complexity of the interaction between the hydrogen price and the load factor it can expect to achieve.

9 Consultation on a business model for low carbon hydrogen: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011469/Consultation_on_a_business_model_for_low_carbon_hydrogen.pdf

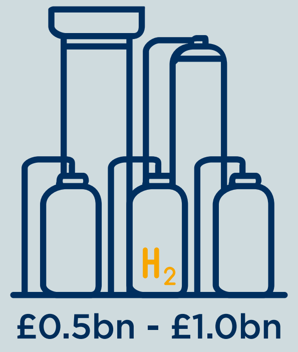
Conclusions

We have shown that the production of green hydrogen can provide system benefits by **utilising excess renewable generation, reducing system costs** as well as **offsetting the production of blue hydrogen**. However, the optimal rate of deployment depends on the rollout of renewable generation. This requires whole system modelling of the power market which captures the interaction of electrolysers with generators, storage and other forms of demand.

There is a need for the Government to provide support to early green hydrogen projects to speed up the rollout of this technology. This is due to:

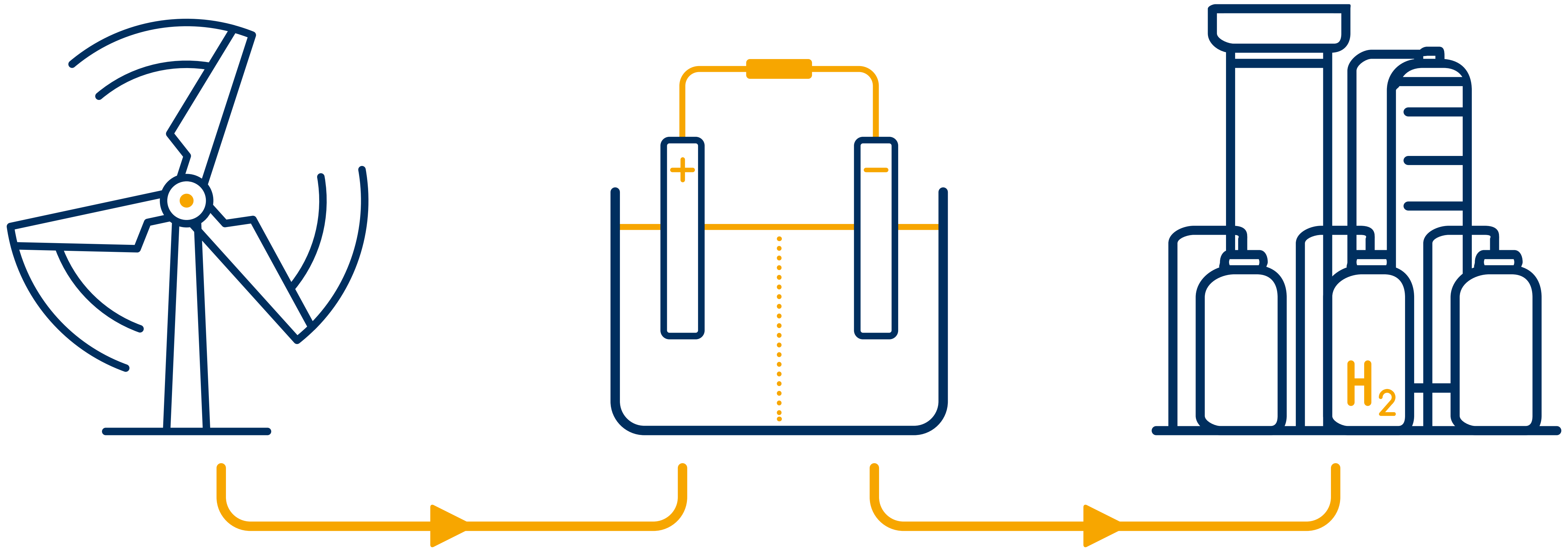
Revenue uncertainty: Revenue from electrolysers is uncertain, a revenue stabilisation mechanism will reduce the cost of capital for these projects.

Capturing positive externalities: These projects will require support to monetise the system cost benefits provided. Without this support, market revenue is not high enough to cover costs.



Contractual payments to producers and regulatory returns models could be designed to deliver low carbon hydrogen production in the 2020s. **The level of support required for these early projects would be between £0.5bn and £1.0bn over the lifetime of these assets.**

Hydrogen will be a valuable resource in the future and it's clear that demand is likely to outstrip green hydrogen production alone. Hydrogen generation from blue hydrogen will be needed to meet demand at times when storage is depleted or when green hydrogen is not economic to produce due to low renewable generation.



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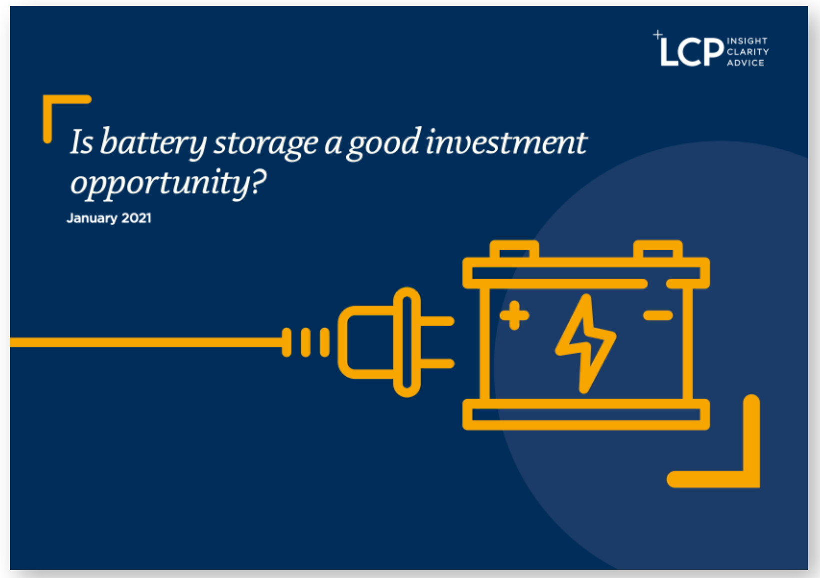

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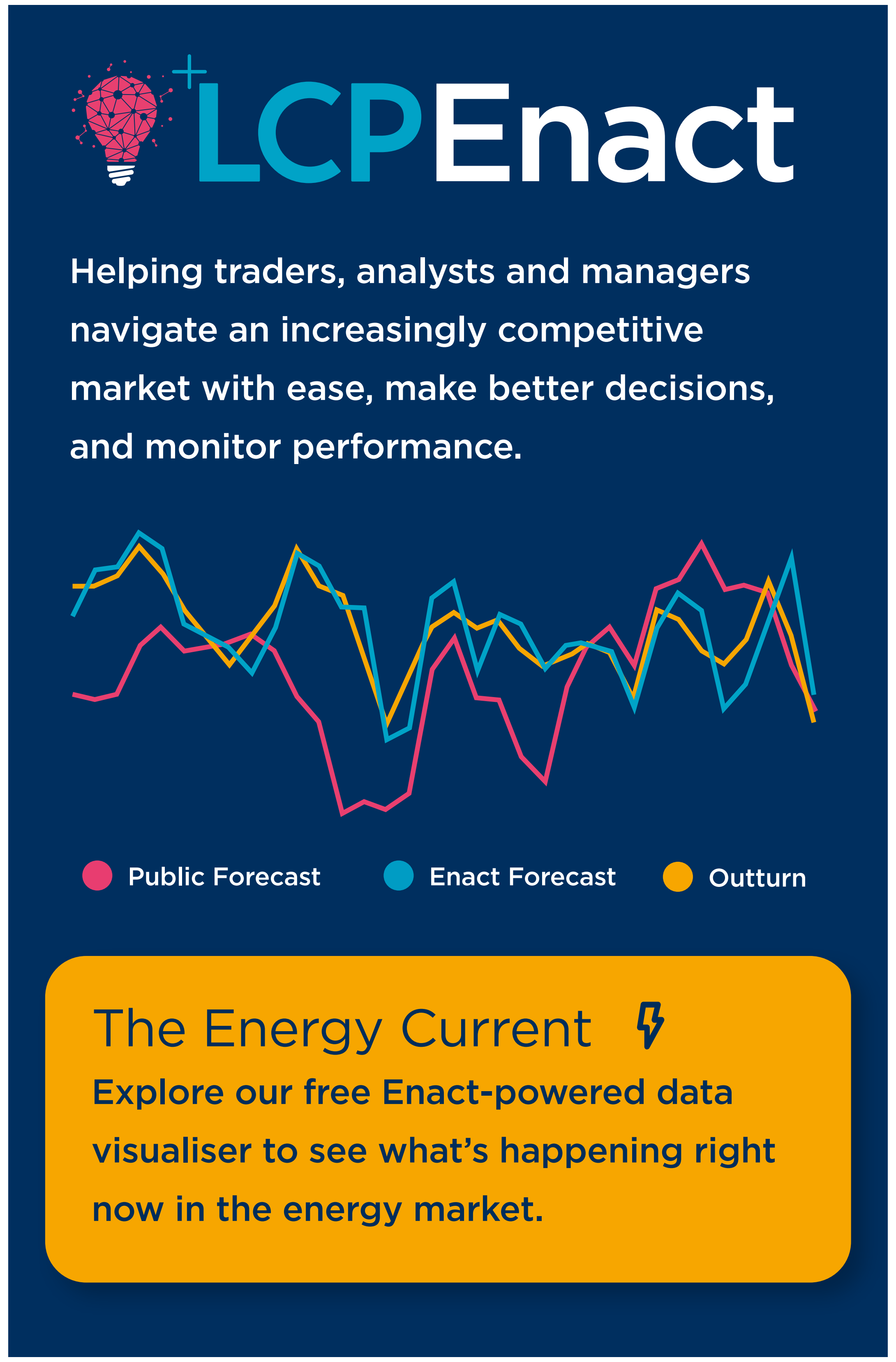

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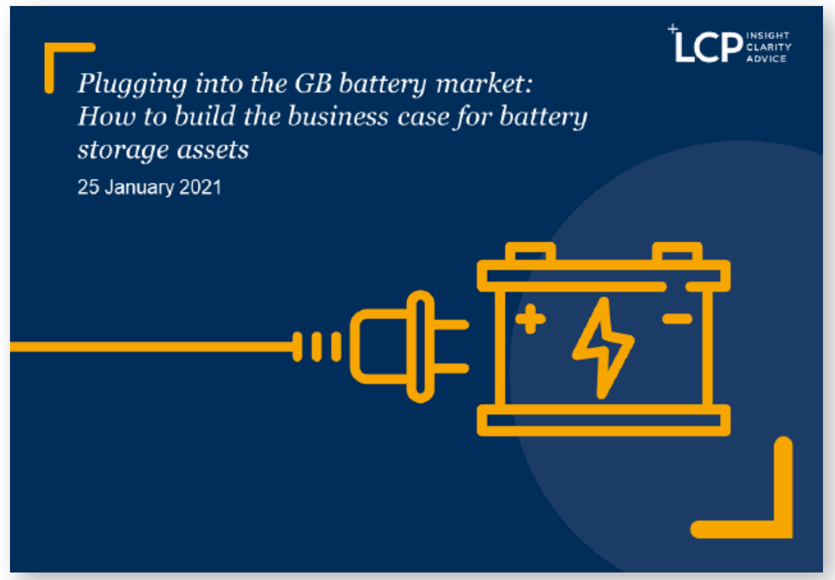

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