BELLONA

EFFECTIVE USE OF RENEWABLES TO REDUCE EMISSIONS

IMPLICATIONS FOR HYDROGEN UNDER THE UK GOVERNMENT'S NEW TARGETS

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SUMMARY & MAIN MESSAGES

The UK Government recently doubled its 2030 targets for low carbon hydrogen production capacity, from 5GW to 10GW. At least half of this capacity is intended to be for making hydrogen by electrolysis, presently a small fraction of total production.

Low carbon hydrogen is likely to be required for a range of applications in a net-zero economy. For example, it is likely to be needed in iron and steel making, providing high temperature industrial heat, chemicals and probably for powering shipping. It is also likely to play an important role in balancing electricity systems.

Setting targets for low carbon hydrogen production capacity in 2030 recognises the value of building scale in production and transport over the remainder of this decade. Large scale green hydrogen relying on renewable electricity will likely become a major feature of the UK energy system during the 2030s. However, at present fossil fuelled generation remains an important component of the European power system, and while this remains the case there are some difficult trade-offs to consider.

It is not clear that the doubling of the target represents an appropriate deployment path. There will be extra emissions from producing hydrogen by electrolysis while the grid is not fully decarbonised. There does not appear to be any analysis published by the Government that shows how the benefits of increased production outweigh the damage from these extra emissions, or how the patterns of surplus renewables on the grid and export potential might affect this.

The extra emissions can arise because making hydrogen by electrolysis for heat in industry or buildings is an inefficient way of reducing emissions. When electricity generating plants fuelled by natural gas are running on the grid, displacing these with renewable electricity leads to much lower economy wide emissions than using the renewable electricity for making hydrogen.

This is because at present, additional electricity demand must almost always be met by fossil generation. Natural gas fuelled electricity generation is presently needed on the system in almost all hours of the year. In these circumstances, adding extra electricity demand by running electrolysers leads to increased generation from natural gas. Renewables generators will usually not be able to increase their output, because they will usually already be running at maximum outputs, as their running costs are very low.

This means that when electrolysers are running, the electricity they use will in practice be generated from natural gas. Electrolytic hydrogen manufacture thus creates additional emissions from making the electricity it requires at times when there is no surplus of renewables on the grid.

In these circumstances, for each MWh of available renewable electricity, the net emissions savings from making electrolytic hydrogen are 50-60 % less than simply replacing generation from natural gas with renewables. Electrolytic hydrogen is even less efficient when compared with using renewables to power efficient end use applications, such as heat pumps and electric vehicles.

Diverting electricity from decarbonising the grid to make electrolytic hydrogen could cause substantial additional emissions at the scale of production implied by the Government's new targets. 2.5GW of additional hydrogen production from electrolysers running in baseload, which creates a net increase in emissions of around 6.8mtpa.[1]

In this context the following become important:

- **Building renewables as rapidly as possible**,including the grids and interconnection needed to get the electricity to where it is needed. The UK's renewables targets are ambitious, and need to be met.

- **Phasing the deployment of electrolysers** up to the 2030 target, so it does not run too far ahead of grid decarbonisation, while encouraging continuing innovation. A careful balance needs to be kept between the extra emissions from making electrolytic hydrogen now, and the benefits this may bring in developing technology and scale for the longer term. This requires some investment now, but much more should follow as the grid fully decarbonises.

- **Developing, deploying and scaling low capital cost, flexible electrolysers that do not run baseload.** At the moment electrolysers have high capital costs, which leads to higher unit costs at low load factors. Furthermore, low load factor operation will in practice usually involve frequent switching on and off, to take advantage of periods of surplus renewables and low electricity prices. This raises technical challenges at present. Research and development to address these issues could enable the use of increasing amounts of surplus renewables available in off-peak hours in the future, while allowing renewables to displace fossil generation at other times. Such technologies are likely to have an important longer-term place on the system, so there will be strategic advantages to early development and deployment. Enabling this should be made explicit as part of the government's project selection process.

- **Using hydrogen where it reduces emissions most or is most valuable.** A tonne of hydrogen in iron and steel making, replacing use of a blast furnace, results in greater emissions reductions than using a tonne of hydrogen for industrial or building heating. In other cases, hydrogen may be the most practical or lowest cost route to decarbonisation. Furthermore, some projects may form part of wider clusters of decarbonisation, reinforcing and benefitting from those efforts.

- Making a **greater proportion of blue hydrogen** (that is hydrogen from reformers with CCS) in the short to medium term. The Government's policy is for half of capacity to be electrolytic.[2] However, if blue hydrogen capacity runs at higher load factors than electrolysers this may imply more than half of total TWhs of low carbon hydrogen are blue hydrogen. Blue hydrogen will of course need to meet the low carbon hydrogen standard, which will require high capture rates for CCS and low emissions from natural gas production and transport, including methane emissions.

1 Calculated as the increases in emissions from manufacture minus emissions savings from using the low carbon hydrogen to displace natural gas.

2 The target is for: "doubling our ambition to up to 10GW of low carbon hydrogen production capacity by 2030, subject to affordability and value for money, with at least half of this coming from electrolytic hydrogen". https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy. The qualification of "up to" and the other conditions stated mean that the commitment is not a firm guarantee to build this much.

INTRODUCTION

In April 2022 the UK Government announced a doubling of its target for low carbon hydrogen production capacity by 2030, from up to 5GW to up to 10GW. At least half the total is intended to be electrolytic. The amount of hydrogen produced and the electricity required for 5GW of electrolytic hydrogen running at different load factors is shown in the table.

Table 1 : Energy from 5GW of production capacity at different load factors

	2000 hours (23%) (seasonal and peak)	4000 hours (46%) (midload)	8000 Hours (91%) (baseload)
Hydrogen produced (TWh HHV)	10	20	40
Electricity required (TWh)	14	29	57

Note: Efficiency of electrolysis is assumed to be 70% LHV.

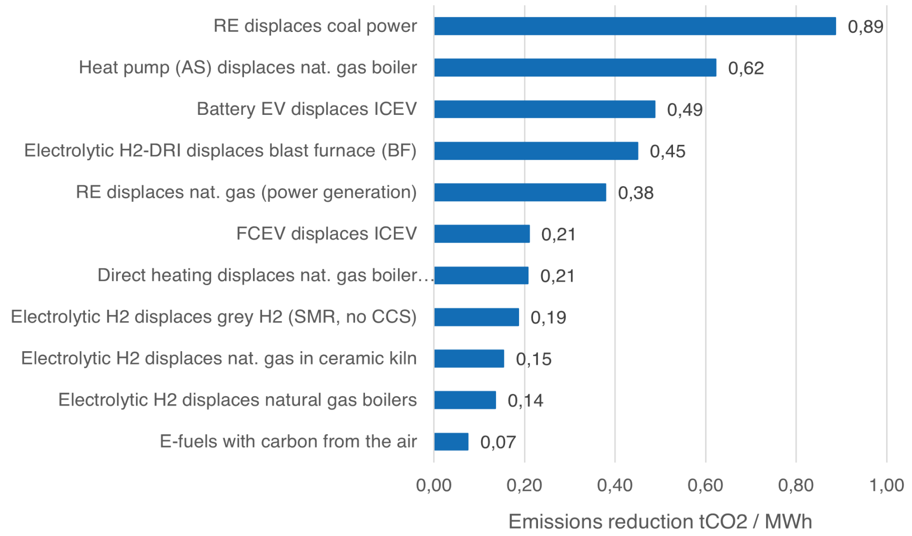
The targets recognise the value of building scale in hydrogen production. However, they pose challenges for reducing emissions, because making hydrogen by electrolysis to provide low carbon heat in industry and buildings or many other applications is not the most efficient use of scarce renewable electricity.[3] This briefing paper considers these challenges, and potential ways forward.

3 The total amount of low carbon power on the system, including nuclear, will in practice be relevant. However, the amount of nuclear on the system is largely pre-determined over the period under review here, due to lead times for project development and construction.

1 DIFFERENCES IN EMISSIONS REDUCTIONS FROM USING RENEWABLES IN DIFFERENT APPLICATIONS

Different uses of a MWh of renewable electricity lead to different amounts of total emissions reduction. Lower total emissions will be achieved, other things being equal, by focussing on using renewable electricity where it reduces emissions the most. Chart 1 shows the number of tonnes by which a MWh of renewables reduces emissions in different applications.[4]

Chart 1: Emissions savings from using 1MWh of renewable electricity for various applications



FCEV: Fuel Cell Electric Vehicle, EV: Electric Vehicle, ICEV: internal Combustion Engine Vehicle RE: Renewable Electricity, DRI: Direct Reduced Iron

Source: Bellona analysis.[5] The use of renewables will usually focus on electricity but in some cases may include a component of renewable heat.

The following applications generate the largest reduction:

- Highly efficient end use applications of renewable electricity, such as heat pumps and electric

4 Central estimates are shown. There is clearly significant variation around each of these values. Estimates depend, for example, on efficiency of a fossil fuelled power plants, or the emissions from the petrol or diesel car that is being displaced by an EV. And there may be changes over time as technologies improve, although some of these technologies are limited by the fundamentals of their processes. Nevertheless, the broad picture is likely to remain approximately similar.

5 The UK's Climate Change Committee (CCC) has produced similar estimates to those presented here, though covering a somewhat smaller range of options. See https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Electricity-generation.pdf, figure M5.4. The relative performance of the options and the approximate savings are similar in the two sets of analyses. However the analysis in this briefing indicates somewhat less abatement per MWh in many of the cases, which appears to reflect more cautious assumptions.

vehicles.
- Using hydrogen from renewable electricity for direct reduction of iron (DRI) to replace blast furnaces in iron and steel manufacture, partly because it is displacing coal.
- Directly replacing natural gas in power generation. Coal will be eliminated from power generation in the UK by 2025, but some UK renewables may displace coal plants elsewhere if exported, so coal in power generation is included on the chart.

Other applications of renewables are less effective in reducing emissions. Making hydrogen by electrolysis for industrial heat, use in boilers, or blending with the natural gas grid all result in lower emissions reductions from each MWh of low carbon power. Reductions are around 50% to 60% lower than displacing gas in power generation. Using hydrogen for fuel cell vehicles also leads to less effective emissions reductions. Least effective of any of these approaches is the manufacture of e-fuels, where electrolytic hydrogen is combined with CO_2 to make liquid hydrocarbons using renewable electricity.

The size of emissions reductions per MWh is, of course, not the only consideration when choosing between options. Other factors include costs, the availability of alternative ways of reducing emissions, and the need for early stage deployment of technologies that will be required at scale in future. Nevertheless, this perspective is a useful complement to looking at cost per tonne of abatement, usually summarised in a marginal abatement cost (MAC) curve.

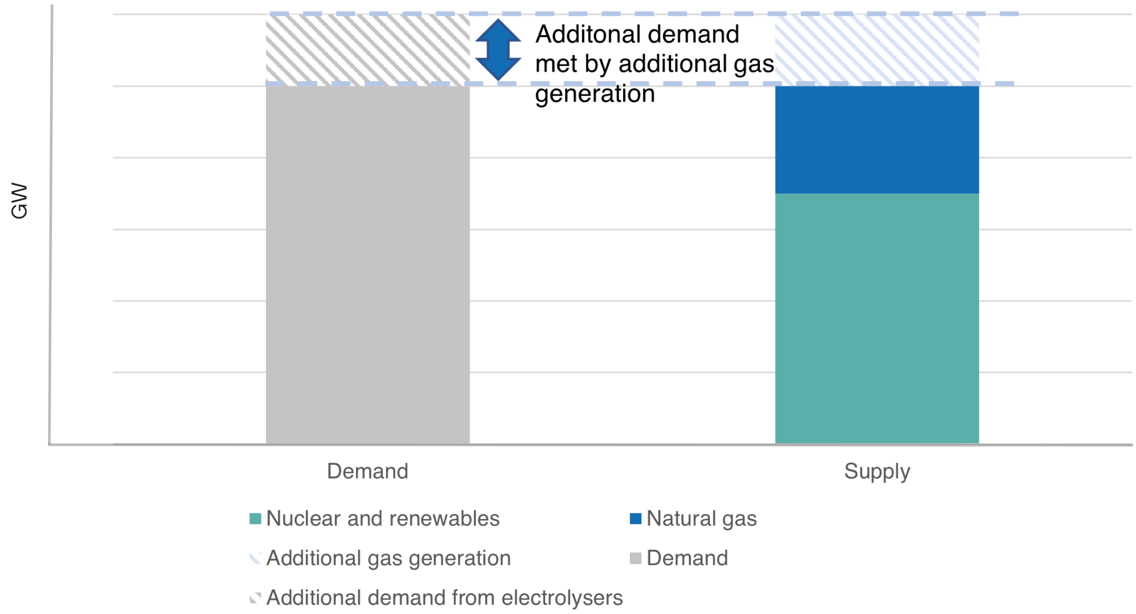
1.2 Implications when there is a choice between further grid decarbonisation and making hydrogen by electrolysis

At present, additional electricity demand will almost always be met by fossil generation. Natural gas fuelled electricity generation is presently needed on the system in almost all hours of the year. In these circumstances, adding extra electricity demand by running electrolysers leads to increased generation from natural gas. Renewables generators will usually not be able to increase their output, because they will typically already be running at maximum outputs, as their running costs are very low.

This means that when electrolysers are running, the electricity they use will in practice be generated from natural gas. Electrolytic hydrogen manufacture thus creates additional emissions from making the electricity it requires. This is illustrated in the Figure 1 below.

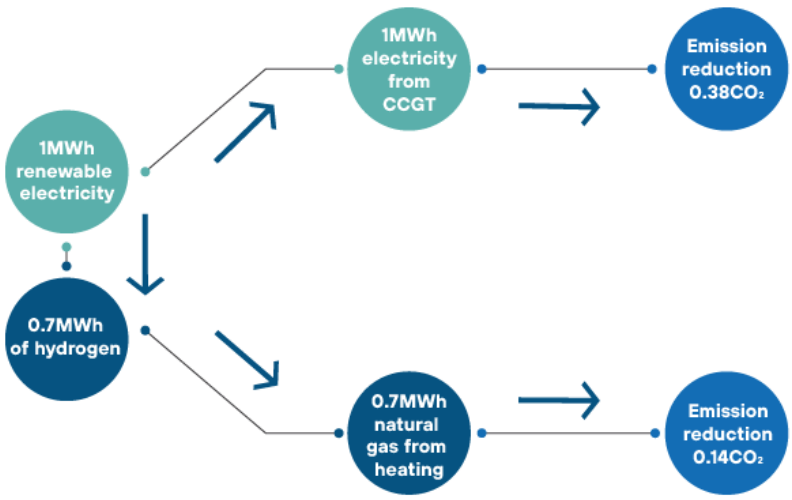
The extra emissions from electrolytic hydrogen are potentially large. 5GW hydrogen production from electrolysers running in baseload results in emissions of about 21mtCO_2 each year.

Figure 1: Additional electricity demand is met by additional generation from natural gas



Instead, as extra renewables become available they can be used to continue reducing fossil generation. This will lead to lower economy wide emissions than making hydrogen to displace natural gas in heating or other applications. The chart above shows that using a MWh of electricity to displace remaining gas power from the system will reduce emissions by 0.38 tCO_2, compared with a reduction of 0.14-0.21 tCO_2 from making and burning hydrogen to provide heat for buildings and industry. For each MWh of extra renewable power, continuing to decarbonise the power sector thus leads to double or more of the emissions reduction from using hydrogen from electrolysis.This is illustrated in Figure 2.

Figure 2: Making hydrogen by electrolysis results in less reduction in emissions than continuing to decarbonise the grid



Scale and co-benefits of emissions saving

The extra emissions from making electrolytic hydrogen are potentially large at the scale of production capacity specified in the Government's targets. 2.5GW hydrogen production from electrolysers running on baseload results in additional net emissions of about 6mtCO2 each year.

The lower emissions when renewables displace natural gas generation are due to lower total gas use relative to making electrolytic hydrogen. Consequently, focusing renewables on displacing gas in the power sector has potential co-benefits for security of energy supply.

1.3 Requiring additionality for renewables does not significantly affect this picture

In the absence of defined renewable electrolytic hydrogen targets, "Additional" renewables could be used for other purposes than making electrolytic hydrogen. Funds used to build renewables should be used for more effective abatement than hydrogen production. Indeed funding will often come from the same ultimate source; consumers or government funds. And, once built, any renewables can be switched to other applications.

In rare cases of renewables stranded by grid constraints it will usually be cheaper to resolve the constraint. In any case there will usually not be a viable alternative such as hydrogen production locally. This is because hydrogen demand is usually close to centres of population and industry with good electricity interconnection, and if production is far from these centres transport of the hydrogen will usually be more difficult and expensive than transporting the electricity.

This would not apply if production were supported by the market price of the low carbon hydrogen alone, without policy support (other than a carbon price) for either the electricity or the hydrogen. In this case the market would create extra funding for renewables and more could be built. However, this seems likely to remain a long term prospect only. Electrolytic hydrogen manufacture will continue to require policy support for many years.

The value of additionality criteria

While defining a need for renewables to be additional does not directly affect relative emissions, it nevertheless has some benefits. These include focusing the attention of hydrogen developers on the sources of their energy. Specifying geographical and temporal correlation may focus efforts on securing the right kind of power contract. Indeed it may be a useful step in establishing a traded market for green power contracts. Consequently, additionality requirements can form a useful part of a coherent policy package.

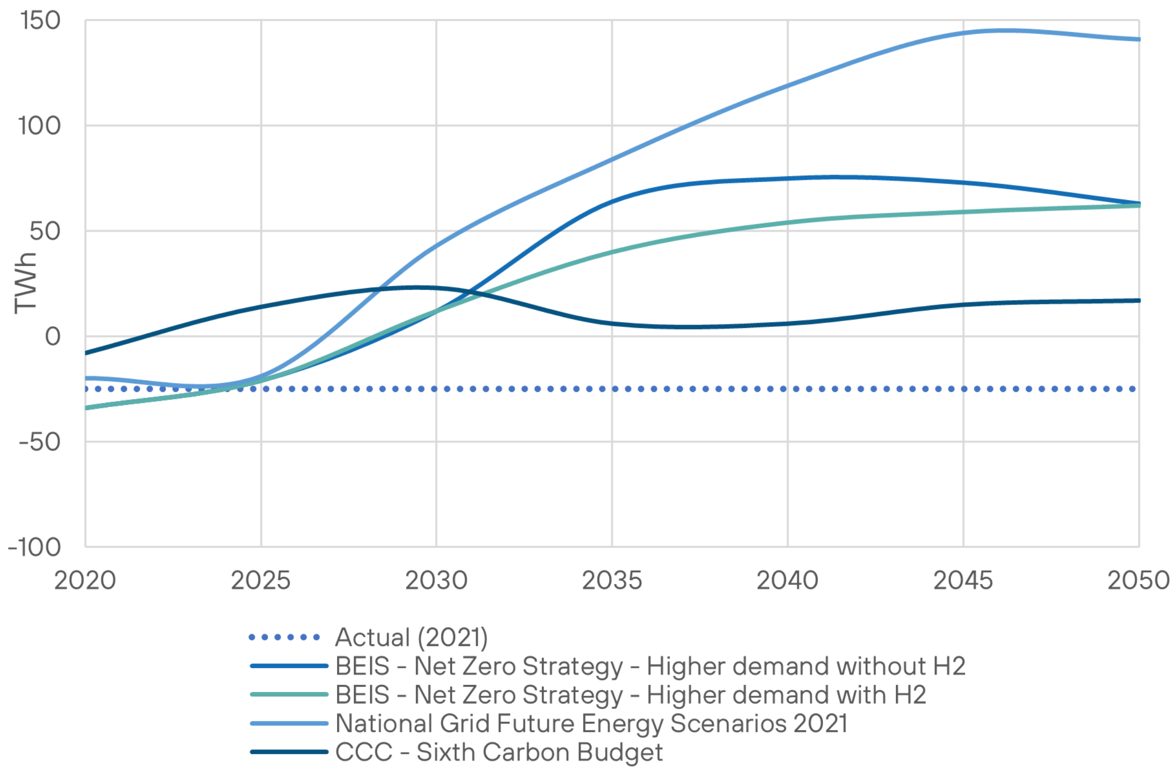
2 THE AVAILABILITY OF RENEWABLE ELECTRICIT

The Government does not appear to have published a detailed analysis of the timing and extent of surplus renewables on the grid. However, by the 2030s it seems clear that there will be an increasing number of hours when the supply of renewables on the GB grid exceeds total demand, creating a surplus.

These surplus renewables will be available for export. The amount of interconnection between the GB system and others has increased greatly in recent years, with continuing expansion expected. National Grid expects interconnector capacity to be around 20GW by 2030, with new and existing links to France, Germany, Belgium and the Netherlands.[6] Chart 2 shows the amount of exports under scenarios by National Grid[7], BEIS and the Climate Change Committee. They mostly show exports to be much higher in the 2030s than now. The difference in projected exports may reflect a number of factors, including amount of electricity storage assumed to be available.

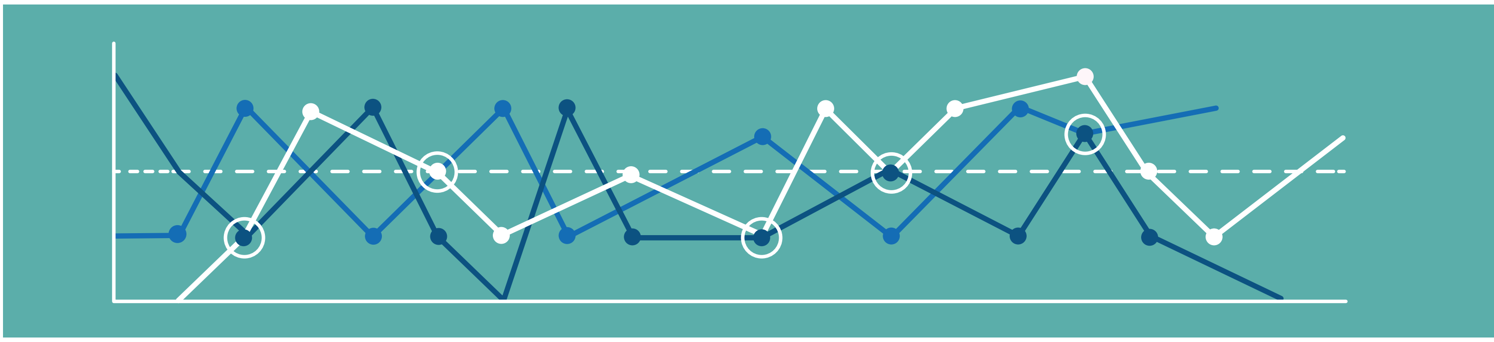
Exports of renewables from the GB grid are expected to mainly displace fossil generation elsewhere in Europe in the short to medium term, with consequent emissions reductions.

Chart 2: Net exports from the GB grid



6 https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents and ofgem.gov.uk/energy-policy-and-regulation/policy-and-regulatory-programmes/interconnectors

7 https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/documents



Electricity prices are likely to act as a strong signal of when fossil fuel generation will be displaced. When fossil fuel generation is running at the margin, electricity prices will likely be higher, due to the costs of both fuel and carbon emissions. Exports will tend to be more profitable at such times. Electrolysers will tend to be less profitable. In contrast, when renewables are at the margin in Europe prices will likely be lower and incentives for exports greatly reduced.

If exported electricity displaces fossil fuel generation, this will reduce total emissions more than diverting it to electrolytic hydrogen production, in a similar way to when the GB grid is short of low carbon power.

However these reductions will take place outside the UK and so will not contribute to the UK meeting its carbon budgets. Diverting surplus low carbon electricity from exports to make electrolytic hydrogen in the UK will likely lead to higher global emissions, but lower emissions in the UK while fossil fuel plants remain at the margin in the wider European market.

If surplus electricity is not exported, for example because there is adequate supply of low carbon power elsewhere in Europe, the load factors of electrolysers will likely tend to increase over time.This is because the number of hours during which there is a surplus of renewables will increase.

3 THE IMPLICATIONS OF THE DOUBLING OF THE TARGET FOR HYDROGEN

The context described here implies the UK Government's increased target for low carbon hydrogen production raises challenges, because of the risk of increasing emissions by running electrolysers while there is no surplus of renewables. This challenge can be managed in several ways.

Building out renewables as quickly as possible

Building renewables as rapidly as possible, including the grids and interconnection needed to get the electricity to where it is needed, minimises the time for which the grid needs generations from natural gas. The UK's renewables targets are ambitious, and need to be met.

Phasing Deployment

Growth of capacity to 2030 and beyond should be phased such that electrolyser capacity does not run too far ahead of grid decarbonisation, while encouraging continuing innovation. A careful balance needs to be kept between the extra emissions from making electrolytic hydrogen now, and the benefits this may bring in developing technology and scale for the longer term. This requires some investment now, but much more should follow as the grid fully decarbonises. There may be further short term supply chain constraints, due to the relatively small amount of electrolytic hydrogen to date, that affect the optimal balance.

Types of electrolyser built

Research, development and deployment of flexible, low capital cost electrolysers should be a priority. They are likely to be needed to maximise the value from periods of surplus electricity, while not running when fossil fuel plants are running on the grid. Prices are likely to provide a strong signal for such operation anyway, with higher prices while fossil plants are at the margin making electrolyser operation less profitable.

This could help meet the Government's energy security strategy's stated goal of: "*By efficiently using our surplus renewable power to make hydrogen, we will reduce electricity system costs"* [8] Such technologies are likely to have an important longer-term place on the system, so there will be strategic advantages to early deployment.

Low capital costs are necessary because electrolysers will run for only a minority of hours, so will have less output from which to recover their capital costs. Flexible operation is necessary because of the need to switch on and off, depending on electricity prices and whether the grid is in surplus.

Optimising operation in this way would provide capacity (GW), while not producing additional hydrogen (TWh) at times where renewables are scarce. The benefits of such flexible capacity are

8 https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy

likely to continue in a decarbonised system. Enabling this should be made explicit as part of the government's project selection process for projects.

Focusing on more effective uses of hydrogen

- **Using hydrogen where it reduces emissions more than when used for heating.** For example, a tonne of hydrogen in iron and steel making replacing blast furnaces reduces emissions by more than a tonne used for industrial or building heating (see above). It also produces greater reductions than displacing natural gas from the grid.
- **Applications where other decarbonisation options are not available.** There may be advantages to prioritising these over other uses of hydrogen. For example, it may be useful in developing new technologies that will be needed to achieve net zero.
- **Wider economic objective.** There may be an imperative to develop production and applications for hydrogen that form a part of wider objectives. For example, it may form part of low carbon development, including proposed "SuperPlaces" for decarbonsing industry.

These approaches may overlap. For example, low carbon steel making with hydrogen may be an effective use of renewables, one of few available decarbonisation options, and form part of a wider low carbon industry cluster.

The role of blue hydrogen

Additional production may be of "blue" hydrogen made from natural gas in a reformer (SMR or ATR) with CCS. Blue hydrogen uses comparatively little electricity, and, if necessary, low carbon electricity generation with gas plus CCS can be included in project design. However blue hydrogen projects will need to be robust to the increasing amounts of electricity available to make green hydrogen over the lifetime of a project.

Such projects, if developed in the next few years, may help build scale for hydrogen networks and markets. However, they will need to demonstrate that they conform with the Low Carbon Hydrogen Standard.