Industrial Boilers

Study to develop cost and stock assumptions for options to enable or require hydrogen-ready industrial boilers

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December 2022

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1 Executive Summary

1.1 Objectives

This study aims to help the Department for Business, Energy and Industrial Strategy (BEIS) determine whether the government should intervene to enable or require hydrogen-ready industrial boiler equipment. It will do this based on information from existing literature along with qualitative and quantitative information from stakeholder engagement. The study draws on evidence gathered through BEIS' Call for Evidence (CfE) on hydrogen-ready industrial boilers. The assessment will advance the overall understanding of hydrogen-ready industrial boilers based on four outputs: definitions of hydrogen-readiness, comparisons of the cost and resource requirement to install and convert hydrogen-ready industrial boiler equipment, supply chain capacity for conversion to hydrogen, and estimates of the UK industrial boiler population.

1.2 Approach

Previous work on this subject and responses to the CfE were reviewed to identify evidence gaps. A question set was developed to cover the following outputs:

- Confirmation of the views of the industry on the definition of hydrogen-ready;
- Estimates of the costs of conventional and hydrogen-ready equipment, conversion of equipment to hydrogen-ready, and to firing hydrogen-only;
- Provide a greater understanding of the current supply chain capacity to achieve conversion to hydrogen-ready and firing 100% hydrogen;
- Estimates of the total UK industrial boiler stock.

Stakeholders were selected based on their responses to the CfE, along with additional stakeholders who would be able to help resolve evidence gaps. These stakeholders consisted of industrial boiler manufacturers, burner manufactures, end-users, boiler maintenance companies and trade associations. Interviews were completed with a limited number of stakeholders. Notes and data were recorded from the interviews and a copy of the technology sheet was sent to the manufacturers and maintenance companies for them to fill out further information. The data obtained was analysed in the further outputs.

An initial definition of hydrogen-ready was discussed with BEIS and this was presented to the stakeholders to confirm their views on the definition.

In order to gather data points, an initial technology sheet detailing Cost (£), Hours and Lifecycle (Years) broken down into equipment level (major industrial boiler sub-component e.g. burner system, boiler shell, fans and electrical control system) and site level (fixed fees i.e., labour, commissioning and contingency) across six scenarios. The scenarios were:

- new upfront conventional natural gas industrial boiler;
- new upfront hydrogen-ready industrial boiler;
- new upfront hydrogen-only industrial boiler;

- conversion of conventional industrial boiler to be hydrogen-ready;
- conversion of hydrogen-ready industrial boiler to hydrogen-only;
- conversion of conventional industrial boiler to hydrogen-only.

The technology sheet compared prices for industrial boiler outputs from 0.5 to 25 MW_{th} for shell and 25 to 500 MW_{th} for water tube boilers.

Based on the responses from the stakeholder engagement, a set of actions for the conversion and installation times was developed. Then based on average hours for an installer, the time taken and number of industrial boilers that could be converted or installed then converted was calculated. This was estimated for different scenarios to assess whether the boiler installation / maintenance supply chain had the capacity for this conversion. Also, the effect on the supply chain, of having industrial boilers that were already hydrogen-ready was analysed.

Previous work done in Hy4Heat "Work Package 6 Conversion of Industrial Heating Equipment to Hydrogen" was analysed to estimate the number of industrial boilers and the uncertainties in the number.[1] Various other sources were used to provide an estimate for the total UK boiler population with a capacity greater than 1 MW_{th}. This estimate was broken down into boilers used in industry and boilers that would be used for non-industrial purposes.

1.3 Results

1.3.1 Definition of hydrogen ready

The agreed definition of hydrogen-ready following discussions with stakeholders was:

'hydrogen-ready' should be defined as equipment that is optimally designed to run on 100% hydrogen but initially configured to run on natural gas. This equipment may require a minimum number of components to be changed at the point of switchover but will have been specifically developed to facilitate this process. The conversion will be carried out within a short period of time using the minimum necessary personnel and resources.

This definition determined the components that would need to be changed when moving from a conventional industrial boiler that uses natural gas to a hydrogen-ready industrial boiler and then to an industrial boiler firing hydrogen.

1.3.2 Cost outputs

Cost and resource data was obtained from stakeholders' current experience and estimated projections. This showed that there is high confidence in the data obtained for capacities of 0.5 MW_{th} up to 15 MW_{th}. The spread of boiler cost estimates increases at the higher capacities, above 15 MW_{th}. This is also the case for the upfront costs for hydrogen-ready and hydrogen-only industrial boilers with higher capacities. This is due to designs becoming more bespoke and capital cost is dependent on the options chosen.

[1] Element Energy and Jacobs. 2019. *Hy4Heat WP6: Conversion of Industrial Heating Equipment to Hydrogen.* (squarespace.com)

The primary sub-components that make up total equipment cost for an industrial boiler are the burner, boiler shell, fans, and electrical control system. The boiler shell and burner are the higher cost sub-components making up 62% and 20% respectively of the total boiler cost for conventional boilers and 60% and 25% respectively for upfront hydrogen-ready industrial boilers. Sub-components' cost make up of upfront conventional and upfront hydrogen-ready equipment are highlighted in Figure 1 and Figure 2.

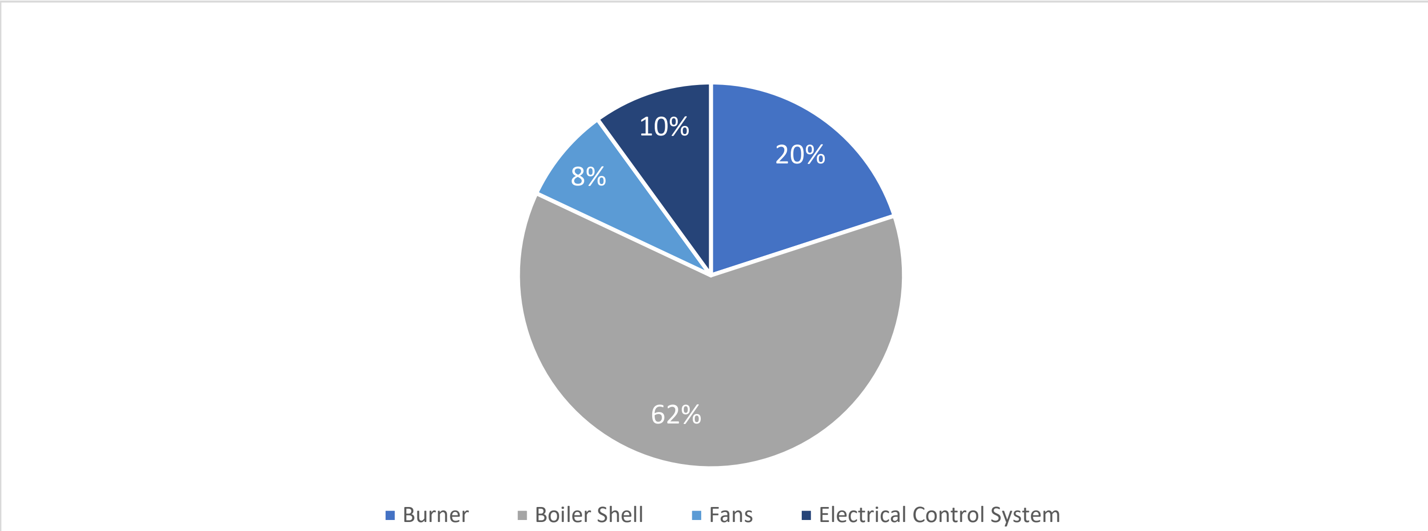

Figure 1: Sub-component cost make up of an overall upfront conventional industrial boiler

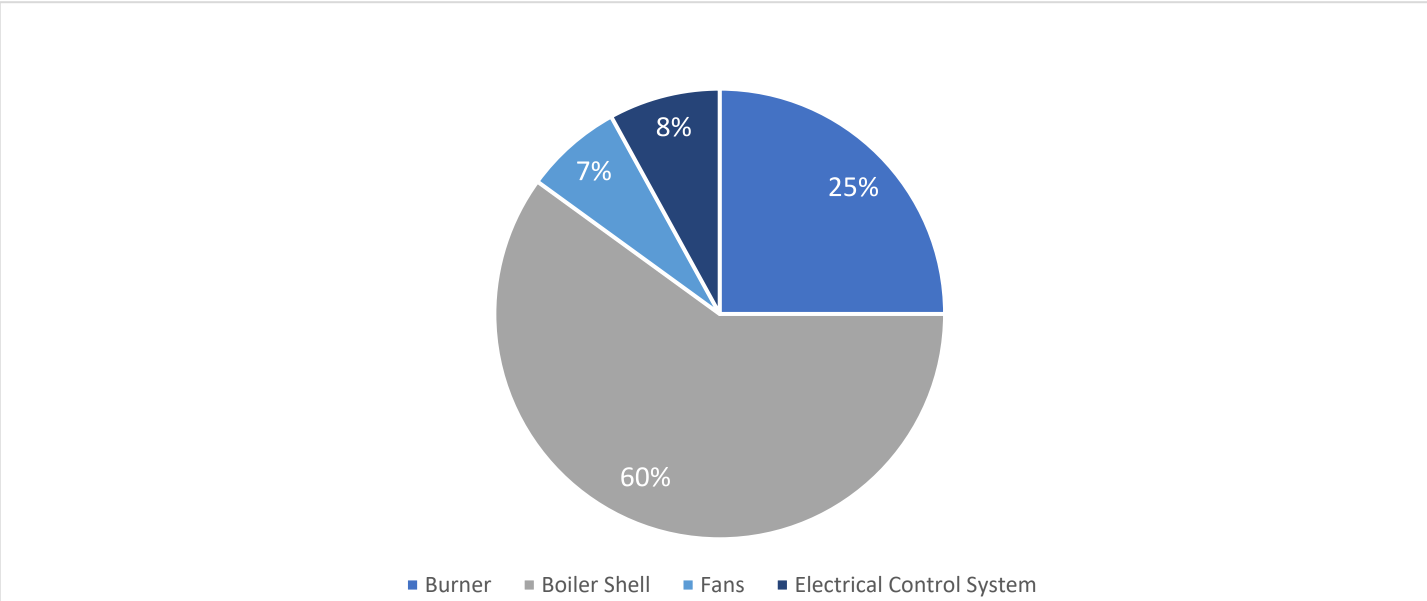

Figure 2: Sub-component cost make up of an overall upfront hydrogen-ready industrial boiler

Estimated cost of conversion pathways for a burner are presented in Table 1.

Table 1: Estimated cost of burner technology conversion pathways

Burner conversion pathway	Estimated increased cost
Upfront conventional to upfront hydrogen-only	~60%
Upfront conventional to upfront hydrogen-ready	~50%
Upfront hydrogen-ready to upfront hydrogen-only	~5%

Overall, the cost to manufacture an upfront hydrogen-ready industrial boiler was estimated to be 15% more than an upfront conventional natural gas industrial boiler, with the majority of cost increase coming from a burner suitable to fire hydrogen that produces low NOx emissions. Other cost increases would be from changes to the burner control system due to the different physical properties of hydrogen compared with natural gas.

The capital cost to manufacture and install hydrogen-only industrial boilers was estimated to increase by 22% when compared to upfront conventional natural gas industrial boiler and increase by 2-4% when compared to upfront hydrogen-ready boilers. The minimal increase from upfront hydrogen-ready industrial boilers is expected as the capital cost of major sub-components i.e., burner and electrical control system remain the same for both hydrogen-ready and hydrogen-only.

Higher capital costs were estimated for converting a conventional natural gas industrial to be hydrogen-only, compared with a new hydrogen-only industrial boiler. However, it was estimated that there would be a small (7-8%) reduction in installation or conversion hours through this single step conversion as opposed to double step conversion from conventional to hydrogen-ready and subsequently hydrogen-ready to hydrogen-only

As highlighted previously, the burner was the main cost difference between technologies. The costs to convert conventional burners to be hydrogen-ready are similar for boilers of sizes 0.5-1 MW_{th} and increase linearly up to 5 MW_{th}. The greatest difference is highlighted at higher capacities, 10-25 MW_{th}.

The cost to convert conventional natural gas equipment to be hydrogen-ready and conventional to hydrogen-only are approximately the same. This is because the capital costs of these conversion scenarios are dominated by the burner cost. Additionally, cost difference between hydrogen-ready and hydrogen-only is minimal and the increase is due to modifications required on the hydrogen-ready equipment to be suitable for hydrogen-only which include changes to the burner nozzle, addition of gas valve, re-programming of control system and replacement of the site gas meter. A breakdown of the differences in cost using a 5 MW_{th} boiler as a reference point is further highlighted in Figure 3, which compares costs of upfront boiler technologies and their respective in-situ conversion.

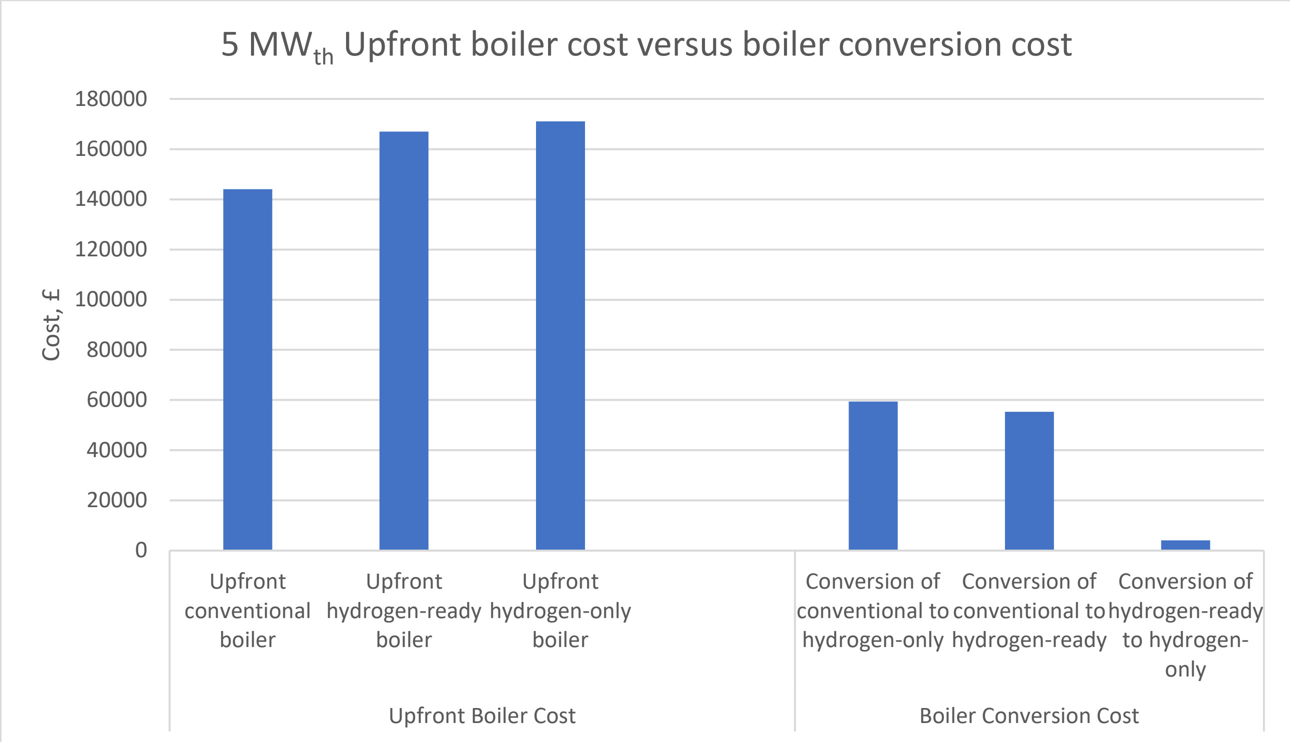

Figure 3: Cost comparison between upfront and conversion for a 5 MW$_{th}$ boiler

Further to the data presented in Figure 3, indicative cost scenario pathways for installation and conversion for a 5 MW$_{th}$ boiler are highlighted in Figure 4 and further estimated cost scenario pathways of other capacity boilers are indicated in Table 2. This suggests that when the installation and conversion costs of fuel switching to 100% hydrogen are considered, it is more cost-effective to install a hydrogen-ready boiler and convert to hydrogen-only than to install a natural gas boiler and subsequently convert it to hydrogen-ready and then to hydrogen-only. For a 5 MW$_{th}$ reference size boiler, Figure 4 indicates fuel switching to hydrogen using a hydrogen-ready boiler could achieve cost savings of around 15% when compared to fuel switching to hydrogen using conventional natural gas equipment. Cost savings are anticipated for single conversion pathways i.e., natural gas to hydrogen-only and hydrogen-ready to hydrogen-only, these are expected to be minimal, hence negligible. It should be noted that there will be other, site specific, costs of conversion and the costs in Figure 4 are for equipment costs only.

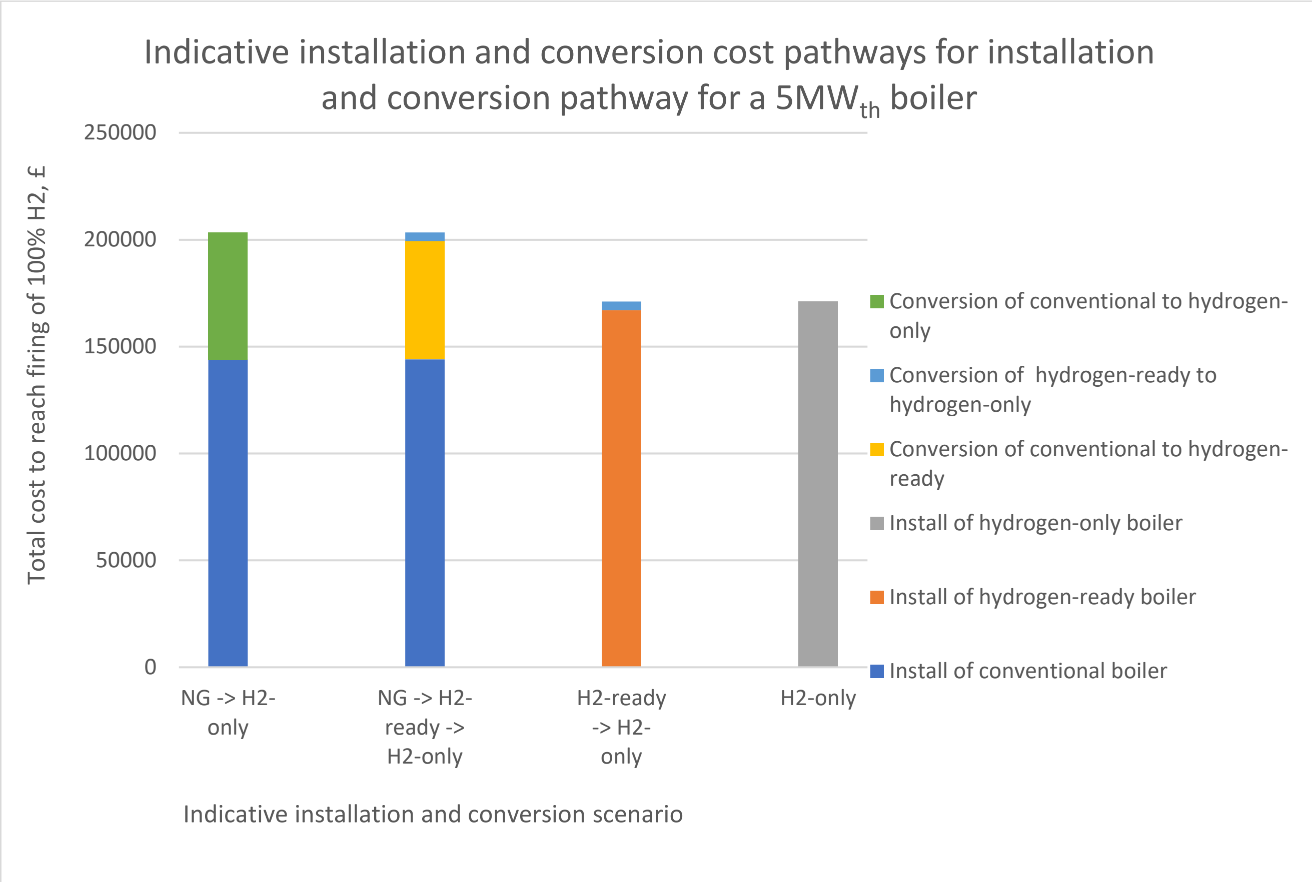

Figure 4: Cost comparison for installation and conversion pathways for a 5 MW_{th} boiler

Table 2: Indicative installation and conversion cost pathway for a 0.5, 1, 2, 10, 15, 20 and 25 MW_{th} boiler

Capacity (MW_{th})	Installation and Conversion pathway			
	NG -> H2-only	NG ->H2-ready -> H2-only	H2-ready -> H2-only	H2-only
0.5	£340,000 + £14,000 = **£54,000**	£40,000 + £12,000 + £1,000 = **£53,000**	£50,000 + £1,000 = **£51,000**	**£51,000**
1	£53,000 + £19,000 = **£72,000**	£53,000+ £17,000 + £2,000 = **£72,000**	£65,000 + £2,000 = **£67,000**	**£67,000**
2	£79,000 + £30,000 = **£109,000**	£79,000 + £26,000 + £4,000 = **£109,000**	£90,000 +£4,000 = **£94,000**	**£94,000**
5	£140,000 + £59,000 = **£199,000**	£140,000 + £55,000 + £4,000 = **£199,000**	£170,000 + £4,000 = **£174,000**	**£174,000**
10	£240,000 + £100,000 = **£340,000**	£240,000 + £95,000 + £5,000 = **£340,000**	£280,000 + £5,000 = **£285,000**	**£285,000**
15	£320,000 + £120,000 = **£440,000**	£320,000 + £110,000 + £10,000 = **£440,000**	£360,000 + £10,000 = **£370,000**	**£370,000**
20	£450,000 + £140,000 = **£590,000**	£450,000 + £130,000 + £10,000 = **£590,000**	£520,000 + £10,000 = **£530,000**	**£530,000**
25	£610,000 + £160,000 = **£770,000**	£610,000 + £143,000 + £17,000 = **£770,000**	£750,000 + £17,000 = **£767,000**	**£767,000**

1.3.3 Supply chain

Conversion and installation times were obtained from the stakeholder engagement data and analysis was conducted for an industrial boiler population of 2000 with each boiler having an average capacity of 2 MW_{th}. From this, the number of person years to convert new hydrogen-ready industrial boilers to fire 100% hydrogen was calculated. This was then compared with estimates of the numbers of qualified installation engineers. It was concluded that the supply chain was large enough to meet the increased demand for work with relatively small expansion. The stakeholders highlighted the fact that this would be dependent on the rate of roll-out of hydrogen.

As there are approximately 25,000 industrial / commercial Gas Safe engineers in the UK, the supply chain should not have trouble meeting the demand for additional resources. However, a variety of skills will be required and from the stakeholder engagement the biggest limitation identified was the number of commissioning engineers with experience with hydrogen projects. As more training would be required, it would take some time for the supply chain capacity to operate at this rate.

1.3.4 Boiler stock

To estimate the boiler stock, several data sources were reviewed. It was difficult to distinguish between different types of combustion equipment, so the totals also accounted for kilns and furnaces as well as boilers. From the stakeholder engagement, manufacturers provided estimates between 10,000 and 17,500 for the overall population of shell boilers sized greater than 1 MW_{th}. Sales data from manufacturers estimated that 450-500 shell boilers with outputs above 1MW_{th} are sold each year. If the average lifetime of an industrial boiler is 30-years this equates to a total population of 15,000 large scale boilers in the UK.

The Hy4Heat Work Package 6 report was the only source that provided an estimate for the total number of boilers in industry. Therefore, the number reported there (2000 industrial boilers) was adopted as the central estimate for the modelling. For a low and high estimate, it was assumed that the number of boilers in industry would be between 10% and 20% of the total shell boiler population, giving a low and high estimate of 1500 industrial boilers and 3000 industrial boilers respectively. The remaining shell boilers would be boilers that are not used in industry.

1.4 Conclusions and recommendations

The agreed definition of hydrogen-ready following discussions with stakeholders was: ‘hydrogen-ready’ should be defined as an equipment that is optimally designed to run on 100% hydrogen but initially configured to run on natural gas. This equipment may require a minimum number of components to be changed at the point of switchover but will have been specifically developed to facilitate this process. The conversion will be carried out within a short period of time using the minimum necessary personnel and resources.

The capital costs of conventional natural gas industrial boilers were supplied by several stakeholders and were generally in alignment, except at the largest capacities where the equipment becomes more bespoke, and the costs depend on the options chosen. There was a general consensus that a hydrogen-ready industrial boiler would cost up to 15% more than a conventional natural gas boiler.

The equipment cost for conversion of a conventional boiler to be hydrogen-ready and the costs of converting a hydrogen-ready industrial boiler to fire 100% hydrogen were more uncertain and dependent on the stakeholder’s perception of the equipment that would be involved at each stage. For a 5 MW_{th} reference size boiler, the study found that fuel switching to hydrogen using a hydrogen-ready boiler could achieve cost savings of around 15% when compared to fuel switching to hydrogen using conventional natural gas equipment. It should be noted that there will be other, site specific, costs of conversion and this cost saving covers equipment costs only.

The cost to both manufacture and install hydrogen-only industrial boilers are estimated to increase by 22% when compared to upfront conventional natural gas industrial boilers. The cost to both manufacture and install hydrogen-only industrial boilers is estimated to increase by 2-4% when compared to upfront hydrogen-ready industrial boilers. Cost savings are anticipated for single conversion pathways i.e., natural gas to hydrogen-only and hydrogen-ready to hydrogen-only, these are expected to be minimal, and within the errors in the estimates.

The figures presented are based on estimates in Q2 2022. Stakeholders tried to estimate costs based on Nth of a kind equipment. These are lower than “First Of A Kind” (FOAK) costs which reflect manufacturers’ development costs. Stakeholders predicted that as the hydrogen market further develops and demand for hydrogen equipment increases the costs presented in this study will reduce. There was an expectation that the capital costs of hydrogen-ready industrial boilers could reduce significantly but that they would still be 5 to 10% higher than conventional industrial boilers.

The time required to convert industrial boilers was compared to the size of the workforce carrying out this kind of work. Based on the number of industrial/commercial Gas Safe registered engineers, the supply chain should have the capacity to cope, however this may be affected by the limited number of commissioning engineers with hydrogen experience. Training would be required for the engineers, and this would mean that it would take time for the supply chain to adapt to the new requirements. Making all industrial boilers hydrogen-ready would reduce the number of personnel required for conversion to 100% hydrogen firing. This would increase the percentage of the boiler stock population that could be converted within a given timeframe and the reduced personnel required could help ease strain on the supply chain.

There was a large uncertainty regarding the industrial boiler stock population as there was a lack of data sources that were able to provide numbers solely for boilers. This was because the data sources did not distinguish between different types of combustion systems. The total number of shell boilers in the UK is estimated to be 15,000. The scenarios for the different number of industrial boilers are:

Scenario 1 (Below Expected) – 1,500 natural gas boilers in industry (1,050 steam boilers and 450 hot water boilers)

Scenario 2 (Expected Number) – 2,000 natural gas boilers in industry (1,400 steam boilers and 600 hot water boilers

Scenario 3 (Above Expected) – 3,000 natural gas boilers in industry (2,100 steam boilers and 900 hot water boilers).

The total cost to convert the UK industrial boiler stock to hydrogen-ready and hydrogen-only can be estimated with the use of the above scenarios. As detailed in section 5.1.5, the largest proportion of industrial boilers currently installed in the UK range between 1-2 MW_{th}. Assuming the cost to convert a conventional 2 MW_{th} boiler to hydrogen-ready and hydrogen-only, total cost figures are outlined in Table 3.

Table 3: Estimated total cost to convert U.K industrial boiler stock to hydrogen-ready and hydrogen-only

Scenario	Total cost to convert UK industrial boiler stock to hydrogen-ready	Total cost to convert UK industrial boiler stock to hydrogen-only
1 (1500 natural gas boilers)	£39,000,000	£45,000,000
2 (2000 natural gas boilers)	£52,000,000	£60,000,000
3 (3000 natural gas boilers)	£78,000,000	£89,500,000

The above figures are based on the total natural gas boilers presented in scenario 1, 2 and 3 and not split between shell and water-tube boilers. This is because it was highlighted in stakeholder engagement that market for water-tube boilers is declining and their use in industry is being replaced with alternative technologies, notably gas turbines and CHP plant. Total natural gas boiler stock across each scenario is also taken into consideration to account for conversion costs of larger boiler capacities which make up a small proportion of the total boiler stock.

1.4.1 Recommendations

- Boiler and burner manufacturers and end-users want to know when hydrogen will be readily available. A clear plan and timeline for the roll out of hydrogen, will give manufacturers confidence that there will be a market for hydrogen-ready and hydrogen appliances, and this will give end-users confidence in buying hydrogen-ready equipment.

- A clear definition for hydrogen-ready needs to be agreed for a boiler or burner such that there is no confusion from end-users who purchase the equipment as to what needs to be done to make the equipment fire 100% hydrogen.

- Government should encourage manufacturers to develop hydrogen-ready equipment and incentives for end-users to use hydrogen over natural gas will need to be introduced.

- Clarity is needed around the thresholds for NOx emissions that would be required to meet Medium Combustion Plant (MCP) regulations when burning hydrogen, as pollution from carbon dioxide emissions should not be replaced with pollution from high NOx emissions.

- The effectiveness of any changes to regulation would be dependent on the implementation date as some manufacturers might not be able to meet deadlines for 2025/2026 to only supply hydrogen-ready equipment as some manufacturers are still in the early stages of product development.

- There is a need for further evidence to determine the benefits of developing regulation to require boiler equipment to be hydrogen-ready and how this regulation might work in practice.

2 Nomenclature

BAU	Business as Usual
BEIS	Department for Business, Energy, and Industrial Strategy
CCC	Climate Change Committee
CH4	Methane
CHP	Combined Heat and Power
CO2	Carbon Dioxide
DEFRA	Department for Environment, Food and Rural Affairs
DSEAR	Dangerous Substances and Explosive Atmosphere Regulations
DUKES	Digest of UK Energy Statistics
FOAK	First of a Kind
GHG	Greenhouse Gas
H2	Hydrogen
TRL	Technology Readiness Level

3 Tables and Figures

3.1 List of figures

3.2 List of tables

4 Introduction

4.1 Background

In October 2021, the UK government published its net zero strategy which outlines steps to decarbonise the UK economy, with the end goal of reaching net zero carbon emissions by 2050[2]. This target accompanies the UK carbon budgets which act as interim targets for decarbonisation[3]. Low carbon hydrogen is regarded as an important means to achieving net zero[4]. Hydrogen is an especially useful energy vector where electrification is not feasible and other decarbonisation options are limited.

Following the UK Hydrogen Strategy, BEIS published a call for evidence (CfE) on 'hydrogen-ready' industrial boiler equipment. Hydrogen-ready boilers could enable industrial sites to take preparatory steps in line with natural replacement cycles for that equipment. This could allow faster and cheaper fuel switching, if and when hydrogen becomes available, than would otherwise be the case.

The CfE made clear that industrial boilers are a good test case to understand hydrogen readiness for other types of industrial process equipment. This is because of the higher TRL of hydrogen-firing for industrial boilers and the fact that they are used in a range of industrial sectors. It is notable that boiler conversion to hydrogen is not process specific, unlike burners in kilns or furnaces where the products of combustion are usually in contact with the product. This means that industrial boiler conversion should be more straightforward and can be applied across a range of industrial sectors.

The CfE asked for views on the following topics:

- How 'hydrogen-ready' for industrial boilers should be defined;
- If hydrogen-ready boiler equipment would enable cheaper and faster fuel switching;
- If government should take action to encourage hydrogen-ready industrial boilers;
- The role of the supply chain for boilers in supporting deployment of hydrogen-ready equipment and how best to maximise the economic opportunities for the UK.

Responses to the call highlighted a range of barriers and enablers to hydrogen conversion for industrial boilers, notably the definition of "hydrogen-ready" and the costs of conversion. This led to a need for further stakeholder engagement to fill gaps in knowledge to enable assessment the implications of converting industrial boilers to hydrogen-ready and ultimately to firing 100% hydrogen. This evidence would then enable the impacts of policies options to be assessed. In this report, the results of the engagement exercise are presented in terms of stakeholder opinions as well as costs and other quantitative information.

[2] net-zero-strategy-beis.pdf (publishing.service.gov.uk)
[3] Carbon Budgets - GOV.UK (www.gov.uk)
[4] UK Hydrogen Strategy (publishing.service.gov.uk)

4.2 Scope

This study aims to help determine whether the government should intervene to enable or require hydrogen-ready industrial boiler equipment. It will do this based on information from existing literature along with qualitative and quantitative information from stakeholder engagement. Technology sheets were developed to compare the cost and resource requirements to install and convert hydrogen-ready and hydrogen only industrial boiler equipment compared with installing and converting conventional natural gas equipment. Estimates for the population of UK industrial boilers were also developed.

4.2.1 Output 1: Definitions for hydrogen-readiness

The study recommends how hydrogen-readiness might best be defined for industrial boilers accounting for the subcomponents, resources and other onsite factors required for a hydrogen-ready boiler plant. At the outset, there were several ways hydrogen-readiness could be defined, with varying levels of cost/resource required at the point of installation and at the point of conversion to hydrogen. As part of the stakeholder engagement exercise, a consensus was developed on the definition. This required detailed definition of the equipment / components which would need to be changed to make an industrial boiler hydrogen ready, or to convert to firing 100% hydrogen. This detailed understanding then fed into the subsequent outputs discussed below.

4.2.2 Output 2: Technology sheets for hydrogen-ready and conventional industrial boilers

Based on the definition of hydrogen readiness for industrial boilers, the study developed technology sheets for the cost and resources to install hydrogen-ready plants and convert these to use hydrogen. The study also developed technology sheets for the cost and resources needed to install conventional equipment and to convert/replace these subcomponents to use hydrogen.

These technology sheets enable direct comparison of the costs and resources required to install and convert hydrogen-ready and conventional industrial boiler equipment. Costs are presented in £/MW and resources in skilled hours/MW. This also covers a range of different components and site level factors for both shell boilers and water tube boilers. (Shell boilers are used in industry for space heating and process energy use. Water tube boilers which generally have much higher capacity are used to produce higher temperature and pressure, superheated steam which is mainly used for industrial power generation.

The study also assessed whether there are other factors that would change the cost of installing and converting to hydrogen for either hydrogen-ready or conventional equipment. Factors included:

- Staff training;
- The impact of conversion on site infrastructure such as fuel piping and metering;
- Other site level factors such as achieving regulatory compliance, e.g., NOx emissions, compliance with explosive atmosphere regulations (DSEAR) etc.;
- The time and resources required for conversion and how the work can be scheduled to minimise disruption to equipment operation and loss of production;

- Loss of equipment efficiency. The impact of any reductions in efficiency is likely to be small. However, the recent volatility in energy prices make this very hard to quantify.

Datapoints were finalised through conversations with equipment manufacturers and other stakeholders. In developing these technology sheets, the study:

- Primarily considered conversion of natural gas industrial boilers for both hydrogen-ready and conventional equipment.
- Considered varying sizes of industrial boilers and different types of boilers including shell and water tube boilers.
- Considered whether assumptions would vary for boiler equipment deployed in different industrial sectors. For these considerations, the study considered the approaches taken for the Hy4Heat WP6 study.

4.2.3 Output 3: Research supply chain capacity for conversion to hydrogen

The study will help assess whether different options to require hydrogen-ready industrial boilers would enable sites using boilers to transition to hydrogen at a faster rate.

Based on industrial boiler lifetimes of between 15-25 years, the study used a baseline estimate that the existing supply chain services and maintains all boilers and replaces around 5% of industrial boilers per year. The capacity of the current supply chain to convert or replace equipment to use hydrogen could result in a need for recruitment and training. The study aimed to test whether sites having installed hydrogen-ready boilers would reduce the strain on the supply chain and enable it convert at a rate closer to the BAU service rate of 5%.

The study therefore provides evidence on:

- The capacity of the supply chain to replace industrial boilers with like-for-like equipment today, to inform the assumption that 5% of boiler stock can be replaced per annum.
- An assumption for the percentage of industrial boilers that the supply chain could convert/replace to hydrogen per annum, either from natural gas to hydrogen or from the defined hydrogen readiness developed in Output 1.
- Further evidence as to whether a requirement to be hydrogen-ready would help develop and expand a reliable and efficient supply chain for hydrogen boiler parts and services.

For this, the study used information provided by CfE respondents, in particular Section 4 focused on the supply chain. This evidence was supplemented with other sources, including interviews with stakeholders.

4.2.4 Output 4: UK industrial boiler stock population

This study will involve further research to provide estimations as to the stock population of shell boilers within the UK and the number of those boilers in industry.

Due to limitations in data availability, the work concentrated on industrial boilers with a capacity above 1 MW_{th}. Estimates of the number of boilers with capacities between 0.5 and 1 MW_{th} were also provided. The study considered and adapted the assumptions for the UK industrial boiler population developed in Hy4Heat WP6 stock model. This analysis was supplemented with other data sources such as data from the Environment Agency regarding site applications for the Medium Combustion Plant (MCP) regulation and Middle Layer Super Output area (MSOA) data. (Middle Layer Super Output Areas are aggregations of households used by government statisticians to collate data on a range of topics from health issues to energy use. MSOAs have an average population of 7500 residents or 4000 households.) Stakeholder understanding of the numbers of installed plant was also taken into account, to provide a range of estimates of stock population.

4.2.5 Output 5: Final report

The study resulted in this report setting out the methodology and findings on how hydrogen-ready should be defined and the cost and speed of installing and converting equipment to use hydrogen.

4.3 Study approach

A structured approach was established to determine key tasks and outputs within the study which aims at gathering and providing data to complete an impact assessment of options.

The flow diagram shown in Figure 5 represents the methodical approach to the study and link between tasks and outputs that ultimately drives the project findings.

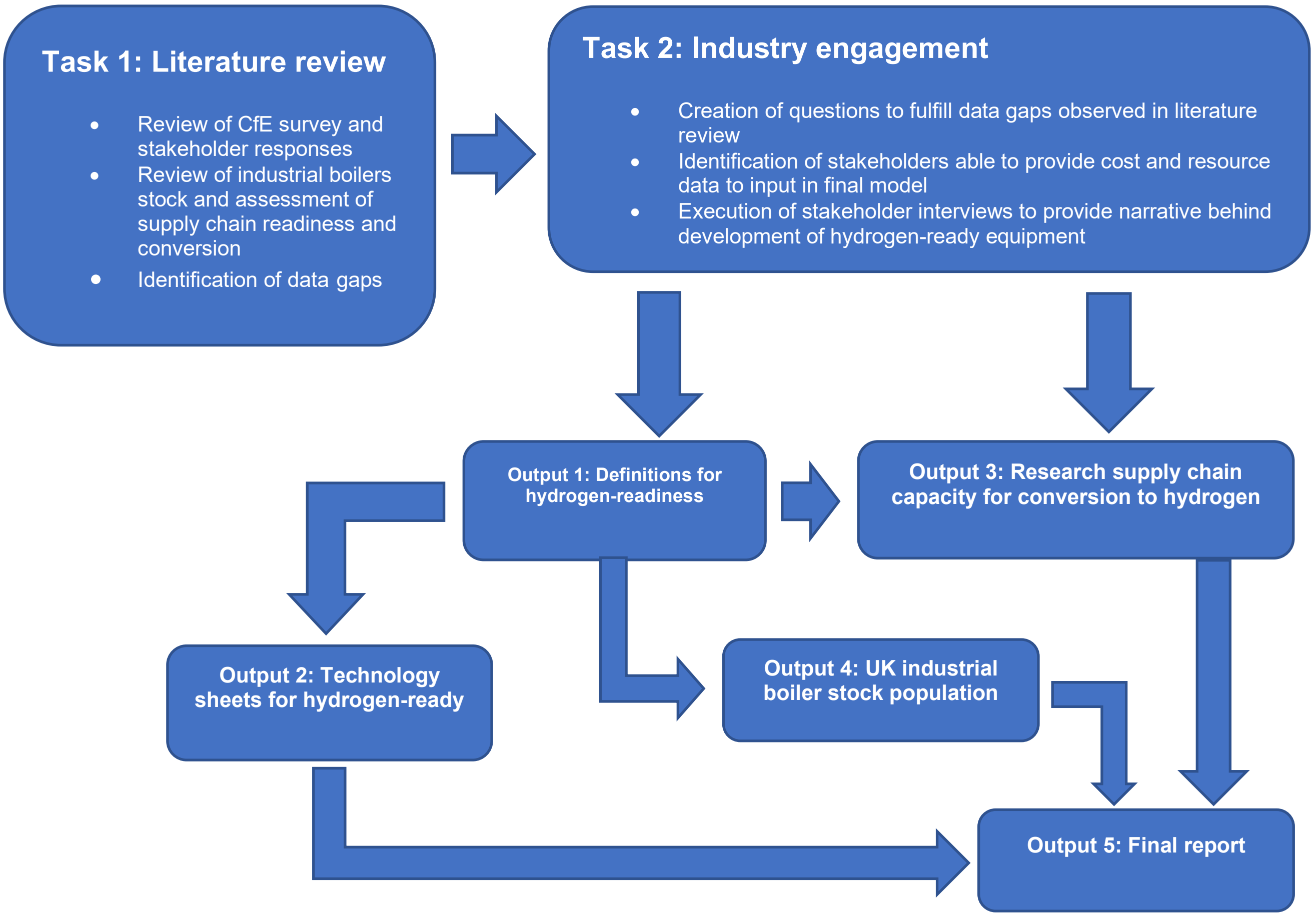

Figure 5: Diagram showing interlink between all project tasks

The methodology to obtain the most accurate data for equipment costs, supply chain capacity and industrial boiler stock population is dictated through a clear definition for “hydrogen-ready” as highlighted from the flow diagram shown in Figure 5. This approach was established to ensure that there would be an industry consensus as the definition for hydrogen-ready was expected to be interpreted differently based on the stakeholders approached, thus influencing their responses.

It was necessary to confirm the definition of hydrogen-ready first as it determines the data required for Outputs 2, 3 and 4. This provides better understanding of the hydrogen-ready requirements for the sub-components that make up an industrial boiler, which consequently affects the supply chain requirement as more or fewer personnel will be required to execute the necessary conversion as well as ensuring that there is sufficient expertise to carry this out.

The literature review and stakeholder engagement informed the main outputs from the study, i.e., technology costs, supply chain capacity, and industrial boiler stock estimation. These outputs can be used to examine the impacts of policy decisions for industrial boiler conversion.

As outlined in section 4.3.1, the literature review identified several data gaps following the CfE and already available publication behind industrial boiler equipment which remains unresolved with key data gaps being:

- Definition of hydrogen-ready
- Cost details surrounding industrial boiler sub-components and installation of equipment
- Supply chain timeline and requirement to prepare for hydrogen-ready regulation and support deployment at scale
- Total UK industrial boiler stock population with particular focus on population below 1 MW_{th}.

In addition to the data gaps, several considerations will also be required to achieve conversion, which include NOx emissions, explosive atmosphere regulations (DSEAR), accident regulations (COMAH), burner design, boiler age and site infrastructure that can only be resolved through appropriate engagement with relevant stakeholders and these will be the main focus of the industry engagement.

4.3.1 Literature review

The study was initiated by carrying out a literature review of the existing information available surrounding industrial boilers, with particular focus on the recently published call for evidence on hydrogen-ready industrial boiler equipment[5], and the Hy4Heat WP6 report[6].

The review of the responses received in the call for evidence highlighted potential data gaps for the study to focus on which enabled planning of the industry engagement approach with particular emphasis on the selection of stakeholders and development of question set for this study’s engagement. Data gaps include:

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[5] Enabling or requiring hydrogen-ready industrial boiler equipment: call for evidence (publishing.service.gov.uk)

[6] Element Energy and Jacobs. 2019. *Hy4Heat WP6:* Conversion of Industrial Heating Equipment to Hydrogen (squarespace.com)

- No standardised definition for ‘hydrogen-ready’.
- Details of boiler equipment sub-components readiness suitable for hydrogen.
- Requirements and restrictions to achieve conversion.
- Timeline and requirements for suppliers to prepare for hydrogen-ready regulation and support deployment of hydrogen-ready industrial boiler equipment at scale.
- UK industrial boiler stock population with capacity lower than 1 MW_{th}.

The Hy4Heat WP6 report estimated the current industrial boiler stock and broke this down by capacity. Identification of data gaps following literature review concluded that there is a need to explore these gaps with industry stakeholders in order to fulfil data inputs for BEIS’ model.

Industrial Boilers: Barriers and enablers to hydrogen-ready industrial boilers

When assessing the suitability of converting to or installing hydrogen-ready industrial boilers, the following barriers and enablers should be considered by industry stakeholders and policymakers. These barriers and enablers encompass both general comments concerning hydrogen equipment and specific comments concerning hydrogen-ready industrial boilers.

For hydrogen boilers in general, there are a few burner manufacturers to supply burners that are fit for firing on hydrogen

The relevant stakeholders may have to consider the following factors.

- **Industry knowledge.** There is a relative lack of industry knowledge relating to decarbonisation options. A lack of understanding of hydrogen’s technical barriers, opportunities, and requirement undermines the efforts to switch to hydrogen as it acts as a barrier for industrial sites to engage with fuel-switching initiatives. The Hy4Heat report recommends disseminating information about decarbonisation options through workshops and sharing the results of relevant reports with industry stakeholders.
- **Competitiveness - domestic.** Policymakers must ensure that there is an equitable plan for hydrogen transition across different parts of the United Kingdom which would switch to hydrogen at different times. Consequently, capital investment and the price of carbon and fuel should be considered when designing policies.
- **Competitiveness - international**. Policymakers must consider the trade-offs of hydrogen switching policies with international competitiveness, such as the imposition of carbon emissions allowances and taxes; if the policies are too stringent, this could risk carbon leakage of firms as they offshore their operations to countries with more lenient policies. This would both harm the UK economy and undermine the overall efforts of carbon emissions reduction. The Hy4Heat report suggests potentially subsidising the cost of the hydrogen as an interim solution.
- **NOx emissions.** There is potential that hydrogen combustion for industrial processes will increase NOx levels; due to the higher flame temperature compared with natural gas. Further independent information is required on this issue, though industrial burner manufacturers report that low NOx burner designs have been produced and are available. Another way to mitigate this issue, as with the problem of the lower convective heat transfer, would be to use FGR. However, this is not considered further in this report, which assumes FGR would be unnecessary to meet permitting requirements for industrial boilers. The Hy4Heat WP6 report recommended

standardisation and collaboration with the Environment Agency over permitting requirements for NOx emissions and mentions the potential need for emissions monitoring to show compliance with the MCP regulations for NOx limits.

- **Explosive Atmosphere Regulations (DSEAR).** Solutions to this barrier should be judged on a site-by-site basis. Any affected equipment and workstations may need to be moved or replaced.
- **Accident regulations (COMAH).** Solutions to this barrier should be judged on a site-by-site basis. The Hy4Heat report suggests that this may only affect a small number of sites. Changes required include re-permitting or reduced storage. It should be noted that COMAH regulations only apply to sites which store more than 5 tonnes of hydrogen. It is unlikely that industrial sites would require storage of more than 5 tonnes of hydrogen, and the costs of such storage would be high. If the source of hydrogen is local generation, then some storage is likely to be necessary. The costs of compliance with COMAH would encourage sites to keep storage capacity below 5 tonne if this was operationally possible.
- **Training.** Despite being minor, costs of training (both monetary and time) will end up being incurred. Resources are required and it is suggested that a warning of mandatory training is provided. Training for hydrogen activities is currently available which entails the workers being trained on the risks related to hydrogen along with providing training on the procedures; this training should be completed before anyone works with hydrogen.
- **Original Equipment Manufacturer (OEM) supply chain.** To facilitate effective and efficient switching to hydrogen, there needs to be sufficient capacity and expertise within the OEM supply chain to implement this; if the hydrogen switching happens with a faster roll-out, the urgency to advance capacity and expertise is inevitably higher. Furthermore, some of the OEM supply chain is based internationally (e.g., some burner manufacturers have facilities in Europe). This creates a potential barrier if there is insufficient demand for global suppliers to be incentivised to produce their components. For OEM supply chain components based in the UK, the Hy4Heat report suggests undertaking R&D or testing of 100% hydrogen equipment.
- **Burner design.** The Hy4Heat WP6 report suggested that despite the technical challenges, if it is possible for an industrial boiler to have two sets of nozzles (for natural gas and hydrogen), this could significantly limit conversion costs. However, this is likely to be a more expensive option than producing a hydrogen ready burner which would need minimal components to be replaced on conversion to hydrogen firing, and this is the route that the burner manufacturers have been following.
- **Time required for conversion.** Regarding downtime for conversion, this affects the revenue generated and creates uncertainty; these affect sites with only one boiler most severely as they are unable to share the load with other boilers. As noted above, it is unusual for site to rely on only one boiler, most sites have multiple units installed. TheHy4Heat WP6 report suggested that it is expected that sites would align hydrogen conversion with maintenance schedules and planned shutdowns.
- **Other components of site infrastructure.** It is possible that components within existing industrial sites may not be compatible with hydrogen, therefore would require replacing. This includes electrical equipment, distribution pipework, emissions reduction equipment, and flame detection equipment. The Hy4Heat WP6 report suggested that further work was required to fully understand these implications.

- **Boiler age.** Along with the factors discussed above, industry stakeholders' engagement in regard to fuel-switching equipment may be influenced by the stage of their boilers' life. Given the uncertainty around when hydrogen will become readily available, industry stakeholders may be discouraged from investing in the conversion of their boiler to be hydrogen-ready.
- **Public perception.** Public perception is an important factor in fuel switching due to the engagement that large industrial sites have with the community which consequently allows for public pressure to influence decisions relating to decarbonisation, emissions, and sustainability

Costs

Currently, there is no publicly available data on estimations of conversion and installation costs for hydrogen-ready industrial boilers. As the next-best alternative, the Hy4Heat report outlined the approximate proportions of the different costs; the costs mainly comprise capital expenditure (CAPEX) and fuel costs, while fixed & variable operating costs (other than fuel costs) account for a small proportion of the overall cost. Furthermore, the report provides indications of how hydrogen conversion would affect these components.

The Hy4Heat report provides estimations for CAPEX costs for converting from solely natural gas to hydrogen for 1 MW_{th} and 10 MW_{th} industrial boilers across different sectors. The estimations show a trend that the CAPEX costs experience economies of scale as the capacity of the industrial boiler increases.

Hydrogen as a fuel source has significant issues in terms of its cost and availability relative to natural gas. To address the issue, sites are attempting to investigate and implement ways to reduce fuel consumption and increase energy efficiency as a means of reducing fuel costs. Other variable costs include nitrogen for purging, distribution pipework, and directly involved labour which would need hydrogen-specific training. These additional requirements will marginally increase costs compared to natural gas.

Fixed costs for hydrogen include maintenance, spare parts, labour, and overheads. Fixed operating costs were estimated to be 15-20% higher for hydrogen fired boilers compared to natural gas. This is because of the increased cost in technical, and environment, health, and safety requirements involved in the use of hydrogen. Comments from stakeholders in the current work suggested that fixed costs were likely to reduce over time to a similar level to current fixed costs with natural gas fired boilers. These cost reductions would be dependent on the market for hydrogen fired boilers developing and increasing in size.

Stock population

In the Hy4Heat report, it was estimated that there were 2000 industrial boilers[7] of which the majority were considered as 'hydrogen-ready defined as "dual-fired equipment which can fire both hydrogen and natural gas; this contrasts with the concept of converting industrial boilers to fire solely on hydrogen.

However, these findings contain a number of scope limits which this report has sought to expand on: the industrial boiler stock population was calculated based on connections to the <7 bar network and the scope of the calculations excluded boilers below 1 MW_{th}, which

[7] WP6 Understanding Industrial Appliances Report (squarespace.com)

account for most of the UK boiler stock. Also, the definition of ‘hydrogen-ready’ is not standardised and a variety of definitions for the term exist.

4.3.2 Industry engagement

The study was initiated by assessing available data surrounding industrial boilers with particular focus on the responses received from the “Enabling or requiring hydrogen-ready industrial boiler equipment Call for evidence” and the Hy4Heat report “Work Package 6 Conversion of Industrial Heating Equipment to Hydrogen”.

A set of questions was developed which aimed to fill knowledge gaps from the previous work. The questions were targeted to:

- confirm the views of the industry in relation to defining hydrogen-readiness,
- estimate costs in relation to conventional and hydrogen-ready equipment, conversion of equipment to hydrogen-ready and to firing hydrogen-only,
- provide greater understanding of the current supply chain capacity to achieve conversion to hydrogen-ready and hydrogen firing, and
- estimate the total UK industrial boiler stock.

Stakeholders who were able to provide information were contacted and interviewed. The interviews were in-depth and lasted for up to two hours. Where respondents’ views differed, these were supplemented by follow up discussions by email and further interviews.

Various stakeholders from the industry were consulted. These included:

- Boiler manufacturers - 6 interviews.
- Burner manufacturers - 2 interviews.
- End users - 2 interviews.
- Boiler maintenance and servicing company - 1 interview.

Although this was a relatively small group of interviewees, they were representative of the industry, particularly those who were beginning to develop policies for conversion to hydrogen.

A set of questions was produced which would provide qualitative and quantitative data and would cover all the outputs.

Interviews were arranged and the question set was used to guide the discussion. The technology data sheet was sent to the boiler and burner manufacturers so that they could fill it out based on the scenarios being considered in this study:

Upfront conventional equipment: Cost of a natural gas industrial boiler and resource required to install in a pre-existing boiler house with no modification to the existing gas supply, steam or hot water delivery system, or fluing and chimney arrangements.

Upfront hydrogen-ready equipment: Cost of a hydrogen-ready industrial boiler and resource required to install in a pre-existing boiler house with no modification to the existing gas supply. This boiler will run on natural gas.

Conversion of conventional equipment to hydrogen-ready: Cost and resource required to convert a natural gas industrial boiler to be hydrogen-ready. This includes complete installation and conversion of a new hydrogen-ready burner, modification to electrical control system and installation of a flame detection system that is suitable for hydrogen.

Conversion of hydrogen-ready Equipment to hydrogen only: Cost and resource required to convert a hydrogen-ready industrial boiler to fire 100% hydrogen. This includes changes to the burner (e.g., nozzle size and modifications to gas train), adjustment of injection arrangements, addition of control valves that are suitable for hydrogen and re-configuring of the control settings.

Two additional scenarios were introduced later in this study to allow further cost comparisons. These are defined as:

Upfront hydrogen only equipment: Cost of a hydrogen-only industrial boiler and resource required to install in a pre-existing boiler house with modification to the existing gas supply. This boiler will run on hydrogen.

Conversion of conventional equipment to hydrogen only: Cost and resource required to convert a natural gas industrial boiler to become hydrogen-only. This includes complete installation of a new hydrogen-ready burner with adapted nozzle size and modification to the gas train, modification to electrical control system with re-configuration of control settings, installation of a flame detection system that is suitable for hydrogen, and addition of control valves suitable for hydrogen.

4.3.3 Definition of hydrogen-readiness and fuel switching pathways

The purpose of this output was to provide a definition of hydrogen-ready for industrial boilers which would account for the subcomponents, resources and other onsite factors required for the boiler plant to be hydrogen-ready. This definition would then be presented in the stakeholder engagement and account for their views on the definition.

It was observed that there was a very wide range of stakeholder knowledge regarding hydrogen, hydrogen conversion, and the definition of “hydrogen ready”. Final cost and resource outputs of the study to identify the requirements to install and convert hydrogen-ready industrial boiler equipment compared to installing and converting conventional natural gas equipment were dependent on the definition of hydrogen-ready.

Following discussions with BEIS and the stakeholder interviews, the following definition of ‘hydrogen-ready’ was developed:

‘hydrogen-ready’ should be defined as equipment that is optimally designed to run on 100% hydrogen but initially configured to run on natural gas. This equipment may require a minimum number of components to be changed at the point of switchover but will have been specifically developed to facilitate this process. The components to be changed are defined below. The conversion will be carried out within a short period of time using the minimum necessary personnel and resources. The implications of adopting this definition are summarised below:

- **Making a conventional natural gas industrial boiler hydrogen-ready:** This would mainly involve replacing the burner with a burner that can easily (and quickly) be adapted to fire 100% hydrogen. This would include a low NOx natural gas burner and flame management system with provision for a one-time change to hydrogen.

- **Conversion of a hydrogen-ready industrial boiler to fire 100% hydrogen:** This would include changing burner nozzles, new gas valve, reprogramming controls, changing the site gas meter. The equipment costs would be similar whether the boiler was a new hydrogen-ready unit, or a natural gas boiler converted to be hydrogen-ready.
- **Installation of a new industrial boiler fired on 100% hydrogen:** In this option, the equipment required would be the same as both categories above, i.e. a low NOx gas burner with hydrogen nozzles, flame management system, new gas valve, reprogramming controls, changing the site gas meter. There would be a reduction in the labour requirements as some of the work would be carried out at the boiler maker's factory rather than on-site.

The detailed assumptions are set out below:

- The cost and workload estimates were based on installing equipment in an existing boiler house, with existing site infrastructure.
- In all cases it is assumed that NOx emission limits could be met using a low NOx burner, and that there would be no need to install Flue Gas Recirculation equipment to meet these limits.
- The change to firing 100% hydrogen is seen as a one-off event. Once the site has a hydrogen supply and the switch to firing hydrogen is made, changing back to natural gas would be unlikely due to costs.
- It is also assumed that the existing site gas pipework would be repurposed to carry hydrogen. Standard practice for installation of new burner equipment would be to pressure test the pipework to verify that the leak rate was within acceptable limits. It is assumed that this procedure would be followed when repurposing to hydrogen. The only changes to site infrastructure would be the installation of a new gas meter (required by the increased volumetric flow of hydrogen compared to natural gas). Boiler steam or water connections would be re-used, and the existing fluing and chimney arrangements would also be reused.
- Most stakeholders considered the use of 'Dual Fuel' burners (natural gas / hydrogen) to be unnecessary. Dual fuel burners have been installed on some natural gas/light oil boilers where the boiler can be seamlessly changed from one fuel to the other.

It was notable from the stakeholder interviews that there was enthusiasm for conversion to hydrogen. Boiler and burner manufacturers saw the use of hydrogen as a business opportunity and a way of future proofing their products. Boiler operators saw it as one way of enabling them to reduce CO2 emissions and help with the transition to net zero. All stakeholders believed the timetable for hydrogen roll-out was crucially important. Investment decisions were reliant on an understanding of the timing of hydrogen being available in particular geographical areas or at particular industrial installations. All the stakeholders emphasised the importance of a plan or road map which would detail the speed of roll-out of hydrogen. This would remove uncertainty from boiler operators' future plans for investment. It was expected that the hydrogen roll-out road map would be provided by the government.

5 Industrial boiler stock population

The purpose of this section is to develop assumptions for the industrial boiler stock within the UK. This builds on the work done previously in Hy4Heat Work Package 6 and provides additional scenarios based on research from different sources including discussions with manufacturers from the stakeholder engagement. The proportion of industrial boilers for process heat is estimated along with the boilers that are used for non-industrial purposes such as space heating for office blocks or sterilisation for hospitals.

From discussions with stakeholders including boiler or burner manufacturers and other equipment suppliers, it was apparent that there is little recorded information on where industrial boilers are used once they are sold. Information from stakeholders and other sources such as the Environment Agency including MCP regulation data, indicate that historically there has been a lack of detail recorded on the final use. Therefore, it is challenging to differentiate between different types of combustion equipment e.g., boilers and kilns, the fuel used, and the numbers of combustion appliances installed on a site, where a capacity is provided. Although boiler manufacturers hold historical sales information, this is of limited use in determining the total installed boiler stock due to the data available. The split between boilers installed at industrial sites compared with those in commercial, retail, educational, and healthcare settings is even more imprecise as the stakeholders do not differentiate their data in this way. Distinguishing between a steam boiler on an industrial site owned by an industrial manufacturing company and one owned and operated by a 3rd party (i.e., a commercial operation) is difficult without surveying sites or extensive stakeholder engagement which would be beyond the scope of this project.

The total number of industrial boilers installed has a large uncertainty as the only data available resides in other reports such as the Hy4Heat Work Package 6 Conversion of Industrial Heating Equipment to Hydrogen Report which only refers to a proportion of the estimated industrial boiler stock.

Discussions with stakeholders further reinforced the limitations on total industrial boiler stock population as the only accessible data were annual sales figures from boiler manufacturers. This does not give a true representation of the total population due to sales figures only being collated by capacity, not by end use. However, this information was a useful cross check and enabled estimates of the boiler stock developed.

Due to these limitations, the approach taken is to estimate the installed stock numbers for the UK, and then determine the industrial boiler stock.

Data on the total UK boiler stock population with a capacity greater than 0.5MW_{th} is gathered from several sources:

- Defra impact assessment on the introduction of the Medium Combustion Plant Regulation (MCP), this covers boilers with a rated thermal input of 1 MW_{th} to 50 MW_{th} (net)[8];
- Data from the Environment Agency on boilers installed in specific industrial sectors, notably chemicals, paper, and food and drink;

[8] DEFRA, Medium Combustion Plant Directive Impact Assessment (2016) (Available here)

- Information from stakeholders on the split between numbers and types of boilers of different capacities;
- Middle Layer Super Output Area (MSOA) data, which shows the natural gas usage of sites connected to the gas distribution network. These data were filtered for users with a supply equivalent to around 500kW and above.

The estimated total boiler stock was then filtered to determine the boilers installed in industry. This exercise was informed by:

- Information from the Hy4Heat WP6 report on conversion of industrial heating equipment to hydrogen;
- Information from stakeholders on the split between numbers and types of boilers of different capacities.

5.1 Defra MCP regulation impact assessment

For the MCP regulation, an impact assessment was commissioned by DEFRA, which provided an estimate of the numbers of sites that would fall under the regulation and the overall site capacity range. As of 2011, the impact assessment estimated there would be a total of 9930 working plants, 4891 standby plants and 8940 back up plants in England and Wales. Working plant was defined as those operating on average more than 500 hours per year. Stand-by plant was plant installed alongside working plant to provide for additional demand at peak times or in case of shut down of the main working plant and operating fewer than 500 hours per year. Back-up plant was plant installed to provide emergency electricity generation in times of interruption to supply of mains grid electricity, operating rarely and normally much less than 500 hours per year.

However, based on lack of information at the time of the report, plant numbers and the number of different types of combustion plant had to be estimated. This 2011 estimate was created using the number of MCP currently operating in England and Wales with associated capacity, sectoral distribution, average operating hours, and emissions. National fuel consumption data, average plant size and working hours per sector were used to estimate plant numbers for each type of fuel. This estimation is shown below in Figure 6.

Source	Number	Total Capacity (MWth)	Fuel consumption (PJ)	SO2 emissions (t)	NOX emissions (t)	PM emissions (t)
Working plants	**9,930**	31,102	370	31,123	38,950	5,813
Standby	**4,891**	15,319	9	818	1,023	153
Backup	**8,940**	21,233	2	723	1,550	194

Figure 6: Estimation of number of sites from DEFRA Impact Assessment

An estimate for 2030 was provided in the Defra impact assessment using European Commission sector data, National Atmospheric Emissions Inventory (NAEI) data and Capacity Market auction results. NAEI and European Commission data was used to split plants into capacities and by fuel type. Capacity Market auctions were used to sense check results for 2014 and 2015, where the majority of these are assumed to have capacities between 1-5 MW_{th}. From this, the number of boilers installed in England and Wales for 2030 was estimated at 12079; this is shown below in Figure 7.

Capacity	Turbines	Engines	Boilers	Total	Share of total	Proportion of MCPs that are directly associated to an IED installation	Number of IED associated plants
1-5 MW	41	21,397	10,965	32,402	95%	5%	1,620
5-20 MW	57	485	1,101	1,643	5%	10%	164
20-50 MW	2	2	13	17	<1%	40%	7
Total	100	21,884	12,079	34,062			**1,791**

Figure 7: Estimation of number of boilers greater than 1 MW_{th} in 2030 from DEFRA Impact Assessment

However, this estimate is for 2030 and only accounts for England and Wales and not for Scotland and Northern Ireland.

5.2 Environment Agency data

Following discussions with the Environment Agency, MCP application data was provided, however this could only identify whether combustion was used and not the use of the heat produced by combustion. Therefore, based on this data, sites with boilers could not be distinguished from sites with kilns or furnaces. Any thermal capacity from the MCP accounts for the total site rather than individual combustion units. Also, no specific information relating to capacity was obtainable from the data.

5.3 Results from stakeholder engagement

Discussions with stakeholders during the engagement process further emphasised the lack of certainty as to where boilers are installed, as none of the manufacturers could provide data on how many boilers were sold to industry and how many went to non-industrial use. However, an estimation of a range was provided from the stakeholder interviews, and this was that the overall population for shell boilers in all sectors was between 10,000 and 17,500.

From discussions with boiler manufacturers, an average industrial boiler lifetime of the 30 years is used for this analysis. Initially a 20-year lifetime had been derived from the 5% BAU rate. However, it was pointed out that many legacy boilers are maintained and kept running for 40-50 years. As it is more economically viable to maintain an older boiler than replace it with a new boiler. This is more common for the higher capacity boilers where the capital costs of the installing a new boiler is higher. Although lower capacity shell boilers e.g., 1 MW_{th} or less can have expected lifetimes as low as 15 years. Therefore 30 years has been taken as average to account for the larger capacity shell boilers.

Based on sales figures from manufacturers, an estimated 450-500 boilers (1 MW_{th} to 15 MW_{th}) are sold each year within the UK, which over a 30-year boiler lifetime, would suggest that between 13,500 and 15,000 boilers would be running before they needed to be replaced. Therefore, an estimation of approximately 15,000 for the total 1 MW_{th} to 15 MW_{th} boiler population is proposed.

5.4 Middle Layer Super Output Area Data

Another potential method was to work out the number of sites based on the non-domestic gas consumption by MSOA data. This provides both mean and median consumption per gas meter and the number of meters. This could then be filtered down into consumptions over 500 kW_{th} and assuming that each site would have one gas meter this would indicate the number of sites. The majority of these sites using 500 kW_{th} or above would be using the gas to fire a gas boiler. Each site is likely to have several boilers. However, this data is not able to distinguish between types of combustion equipment similarly to the MCP data.

More data has been requested from BEIS statistical department; this data would provide a better estimation for the number of boilers under 1 MW_{th}. However, there is an increasing trend where sites with capacities less than 1 MW_{th}, have multiple cascade boilers e.g., a 500 kW_{th} site capacity would have ten 50 kW_{th} cascade boilers in a cascade. This would allow for greater downturn, as each cascade boiler has a turndown of 33% and only certain numbers of boilers would need to be run to achieve the desired output. As these cascade boilers would have a lower capacity, domestic boilers could be used instead of shell boilers as the installation and maintenance would be easier. It is noted that domestic boilers have a shorter lifespan of 10-15 years.

5.5 Number of boilers installed in UK industry

From previous work done in Hy4Heat Work Package 6, an estimation of the total number of boilers in industry was produced. The estimates were based on data from several sources, including DUKES, the National Atmospheric Emissions Inventory, and gas use data. This report estimated that there were approximately 1400 steam boilers and approximately 600 hot water boilers giving a total of approximately 2000 boilers in industry with capacities greater than 1 MW_{th}. Figure 8 below shows the distribution of industrial steam and hot water boilers by capacity.

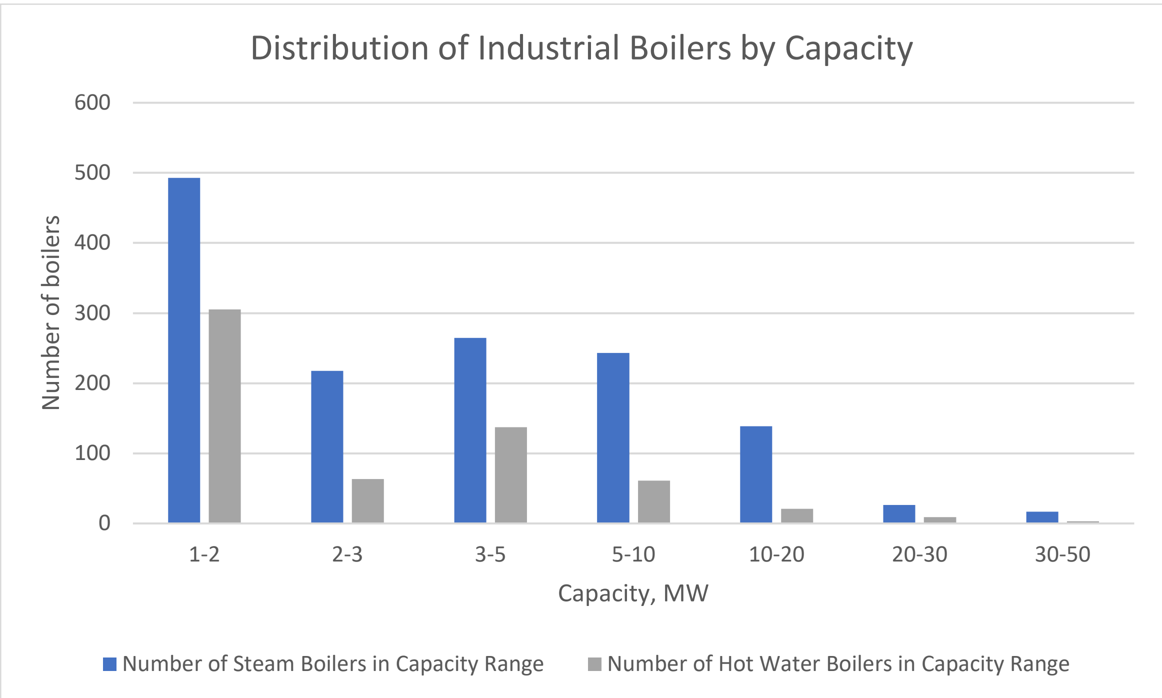

Figure 8: Distribution of industrial boilers by capacity in terms of numbers

The same information is presented in Figure 9 as percentages of installed industrial boilers by capacity.

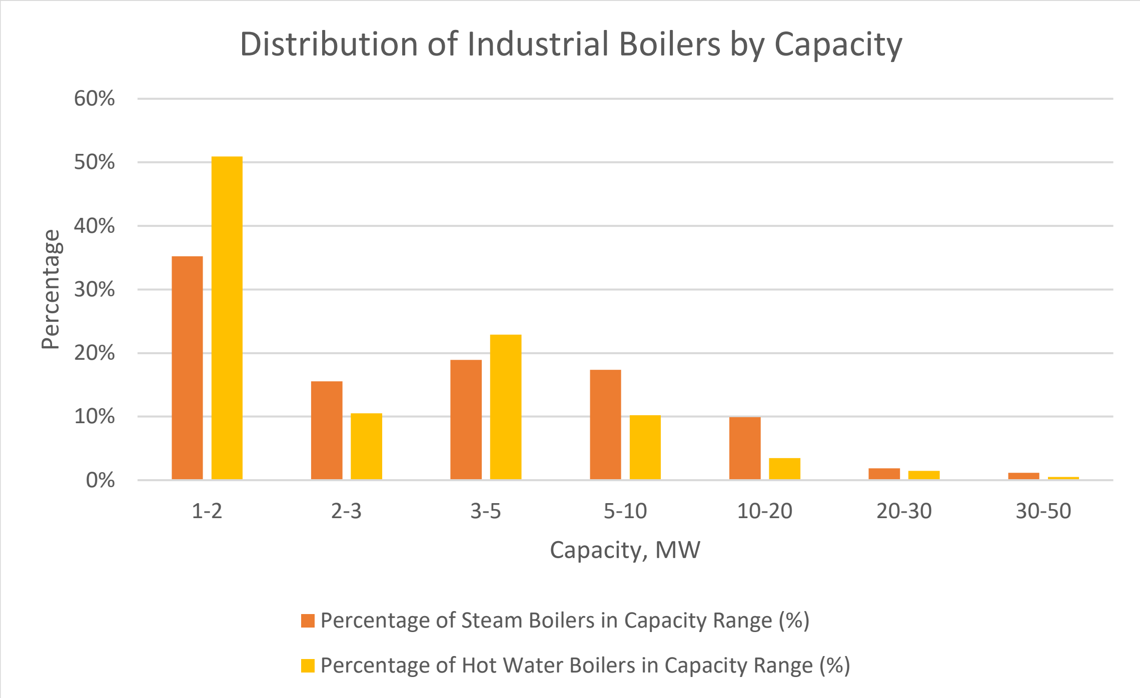

Figure 9: Distribution of industrial boilers by capacity in terms of percentages

It can be seen that hot water boilers tend to be in the lower capacity ranges, whilst steam boilers are more evenly distributed over the capacity range.

Industry knowledge and stakeholder interviews indicate that most of the boilers greater than 0.5 MW_{th} would have smaller capacities (between 500 kW_{th} and 1 MW_{th}) and that most of these smaller boilers would be installed in commercial or retail scenarios. To provide a low and high estimate for the scenarios, it was estimated that the number of industrial boilers would be between 10% and 20% of the total shell boiler population. This provides an estimate of a minimum of 1500 and a maximum of 3000 boilers installed in industry. The 2000 boilers estimated in the Hy4Heat Work Package 6 was the only source of information found within this research that provides an estimate for the total number of shell boilers within industry and it fit into the range based on the 15,000 total shell boilers from the stakeholder engagement. This has been selected as the central estimate based on the findings from this research. However, due to the uncertainties in the split between steam and hot water boilers, the same ratio as provided by Hy4Heat Work Package 6 will be used, 70% steam boilers and 30% hot water boilers.

The uncertainties in the estimates of total boiler stock and boilers installed in industry mean that it is difficult to provide well evidenced data on the numbers of industrial boilers installed. Therefore, a scenario-based approach is recommended to enable BEIS to model the costs of changing to hydrogen-ready boilers. Based on the information obtained, we propose that three scenarios should be modelled by the BEIS team:

Scenario 1 (Below Expected) - 1500 natural gas boilers in industry (1050 steam boilers and 450 hot water boilers)

Scenario 2 (Expected Number) – 2000 natural gas boilers in industry (1400 steam boilers and 600 hot water boilers

Scenario 3 (Above Expected) – 3000 natural gas boilers in industry (2100 steam boilers and 900 hot water boilers)

For the minimum, central estimate, and maximum number of industrial shell boilers, the proportion of shell boilers that are not used in industry for tasks such as heating office blocks or heating and sterilisation in hospitals has been calculated as the rest of the estimated 15,000 total shell boilers in the UK. The number of shell boilers used in industry and not in industry for each of the 3 scenarios are shown in Table 4.

Table 4: Estimated number of shell boilers used in industry and not in industry for three different scenarios

Location of Shell Boilers	Scenario 1	Scenario 2	Scenario 3
Estimated number of shell boilers used in industry	1500	2000	3000
Estimated number of Shell Boilers not used in industry	13500	13000	12000

6 Cost of adopting pathways

6.1 Technology sheet overview

This section aims to develop the costs and resources required to install conventional natural gas, hydrogen-ready and hydrogen-only boiler equipment. It also includes the cost and resources to convert these technologies to use hydrogen, with focus on the conversion from conventional to hydrogen-ready, conventional to hydrogen-only and hydrogen-ready to hydrogen-only. The scenarios defined in section 4.3.2 were developed from the data provided by stakeholders.

Data for the cost and resources to install and convert were used to enable direct comparison between the different scenarios, and was broken down into:

- Central Cost Estimate (£): Best cost estimate determined from average of Low and High-cost data obtained from stakeholders;

- **Confidence Rating (%):** Percentage deviation between High and Low-cost data range obtained from stakeholders which assesses the credibility of obtained data;

- Cost (£/MW): Central cost to install or convert boiler equipment per MW;

- Installation or Conversion (Hours): Hours required to install or convert boiler equipment;

- Installation Cost (£): Cost to install or convert boiler equipment as a function of hours based on a £40/h rate based on SPON's Mechanical and Electrical Services Price Book, 2021 [9];

- Total Installed Cost (£): Total cost including Central Cost Estimate (£) and Installation Cost (£).

- Installation or Conversion (Hours/MW): Hours required to install or convert boiler equipment per MW;

- Lifecycle (years): Lifecycle range of boiler equipment across all scenarios.

The technology sheet included boiler capacities from 0.5 to 25 MW_{th} for shell and 25 to 500 MW_{th} for water tube boilers. It is to be noted that the minimum capacity for water tube boilers is 25 MW_{th} and it was observed from stakeholder engagement that the water tube boiler market is progressively declining hence limited data was available to carry out cost comparisons.

The technology sheet was distributed with stakeholders and data obtained from this engagement was based on current product offerings, including capacities outlined in technology sheet i.e., 1 MW_{th}, 2 MW_{th}, 10 MW_{th}, etc. Not all stakeholders were able to provide a complete set of information; burner manufacturers concentrated on burner costs and installation requirements. It was necessary to follow up with stakeholders to ensure that the figures provided were on a similar basis following the definition outlined in section 4.3.3.

A range of costs was reported by stakeholders for the same reference points, therefore Low and High-cost ranges were introduced to determine the spread of costs. The spread of data

[9] AECOM, SPON's Mechanical and Electrical Services Price Book, 2021.

points was illustrated by a RAG rating system which is defined by the following set of parameters:

Table 5: Red Amber Green (RAG) Rating Parameters

RAG Rating Level	Definition
High	Average between single figures obtained from stakeholders and/or deviation between stakeholders' data in the range of 0-20%.
Medium	Average between single figures obtained from stakeholders and extrapolation to fill in data gap and/or deviation between stakeholders' data in the range of 21-50%.
Low	Large range between stakeholders' data and/or multiple use of extrapolated data to fill in gaps and/or deviation between stakeholders' data >51%.

The central cost estimate was an average of the cost estimates supplied by stakeholders a further cost function obtained from SPON's Mechanical and Electrical Services Price Book 2022.

The cost estimates presented in sub-sections 6.2 and 6.3 highlight costs for upfront conventional, hydrogen-ready and hydrogen-only boilers. The costs of conversion of conventional equipment to hydrogen-ready and hydrogen-only were also estimated, but stakeholders were less confident in these estimates as the demand for this equipment was low as the market is less well developed.

Equipment and installation costs for natural gas boilers were well known by the stakeholders and prices from different manufacturers were generally similar. There was consensus that equipment cost would be around 15% higher to make the boiler hydrogen-ready. Stakeholder interviews highlighted that several shell boiler and burner manufacturers have already developed hydrogen-ready equipment whilst others are currently carrying out research and development particularly on burner technology. As a result, data returned by stakeholders have some limitations as cost differences were noted. This is not surprising given the current availability of hydrogen. As the market for hydrogen-ready or hydrogen firing boilers is currently very small, there is little incentive for manufacturers to develop hydrogen products. Some burner manufacturers have developed hydrogen burners and offer them for sale. Nearly all of these are sold to the petrochemical industry, notably in USA. UK domestic sales of these burners were not reported.

Interviews with stakeholders highlighted that the water-tube industrial boiler market is declining and their use in industry is being replaced with alternative technologies, notably gas turbines and CHP plant. As a result, there is limited data on costs to install and manufacture conventional water tube boilers, with even greater uncertainty on the conversion to hydrogen-ready and 100% hydrogen firing.

Data received from stakeholders' view of current market and future projections highlight that the cost to manufacture an upfront hydrogen-only boiler is estimated to be similar to manufacture of an upfront hydrogen-ready boiler. The cost difference between hydrogen-ready and hydrogen-only is minimal and the increase is due to modifications required on the hydrogen-ready equipment to be suitable for hydrogen-only which include changes to the burner nozzle, addition of gas valve, re-programming of control system and replacement of the site gas meter. Hydrogen-ready and hydrogen-only boilers would have the same lifetime as a conventional boiler of the same capacity. No components within a hydrogen-ready boiler would be damaged by hydrogen and all components in a conventional boiler would be assessed and made suitable for hydrogen when converting the boiler to become hydrogen-ready.

Costing information for upfront hydrogen-ready boilers is for a Nth of a kind boiler, based on costing information from Q2 of 2022. These are lower than the costs for First Of A Kind (FOAK) boilers, which reflect the manufacturers' development costs. However, these costs are expected to decrease once hydrogen is readily available and the demand for hydrogen increases. There was an expectation from stakeholders that the capital costs for hydrogen-ready industrial boiler equipment could reduce significantly but that they would still be 5 to 10% higher than for conventional boiler equipment.

The general inflation and large increases in energy prices post the Ukraine war (and the initial commissioning of this report) are rendering costs difficult to predict. This is compounded by difficulty in getting stake holders to be specific on whether the prices they quote are FOAK or Nth Of A Kind. There are probably less than 100 forced draft hydrogen burners in the whole country (including those used on refineries) and most OEMs will include large FOAK contingencies. This explains the wide range of prices given.

6.2 Upfront conventional natural gas, hydrogen-ready and hydrogen-only equipment

As expected, the costs to manufacture and install a conventional boiler increased with increased capacity. Figure 10 highlights comparisons between the central cost estimate and Low/High-cost range show that there is high confidence in the data obtained for capacities up to 15 MW_{th}. The spread of boiler costs increases at the higher capacities i.e., higher than 15 MW_{th}. The same trend is observed in Figure 11 for upfront hydrogen-ready and hydrogen-only boilers with higher capacities as these boilers become more bespoke and the capital cost is dependent on the extra options chosen. These options generally related to control and monitoring equipment. For example, more sophisticated (and expensive) control systems will allow longer periods of unattended operation which will reduce staff costs.

The capital costs outlined in Figure 10 and Figure 11 include both equipment level and site level costs. As previously defined, "equipment level" refers to CAPEX to manufacture a boiler through its major boiler sub-components i.e., burner system, boiler shell, fans and electrical control system and "site level" refers to CAPEX to install the boiler i.e., removal, labour, commissioning, and contingency.

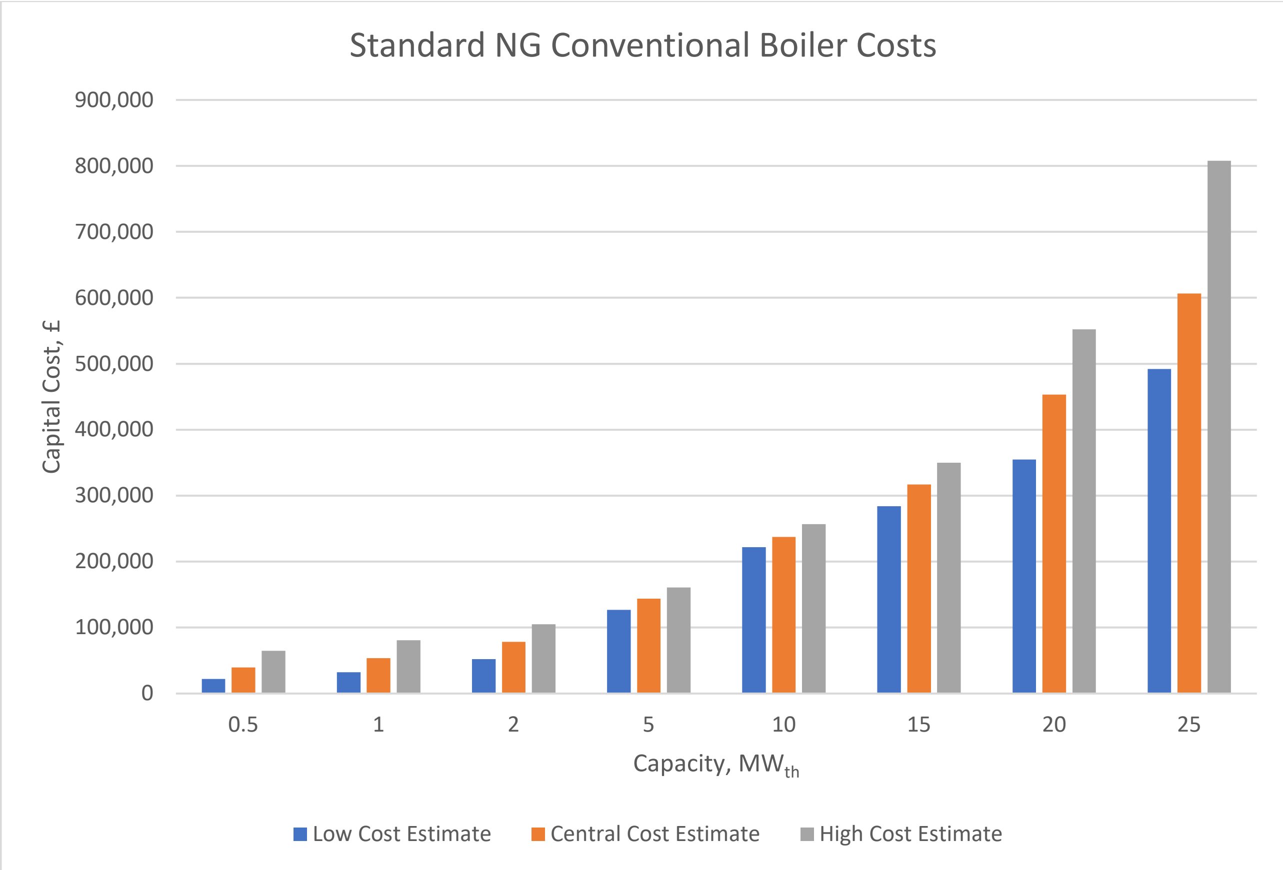

Figure 10: Central, low and high-cost estimate to manufacture and install conventional natural gas industrial boilers

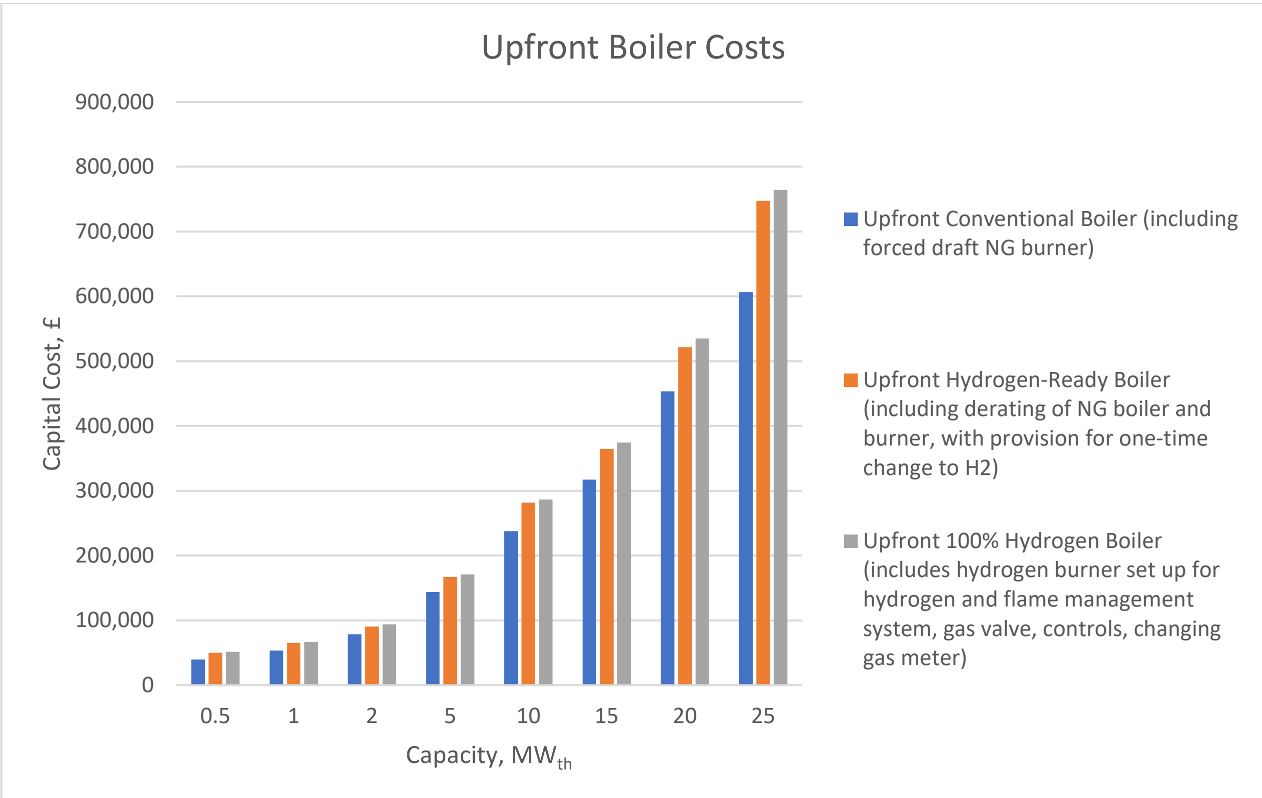

Figure 11: Central cost estimate of upfront conventional natural gas, hydrogen-ready and hydrogen-only boilers

The primary sub-components considered to make up total equipment level cost are the burner, boiler shell, fans, and electrical control system. The boiler shell and burner are the higher cost sub-components making up 62% and 20% respectively of the total boiler cost for conventional industrial boilers and 60% and 25% respectively for upfront hydrogen-ready boilers. The estimated percentage costs are derived from averages based on component cost build-ups obtained from stakeholders who supplied data used in Figure 12.

Interviews with boiler manufacturers highlighted that the boiler shell has the longest lifetime of approximately 30-40 years whilst other sub-components (burner, fans, and electrical control system) range in average between 15-20 years. This is expected as sub-components such as the burner, fans and electrical control system are mechanical and electrical components. It is to be noted that these components also undergo routine maintenance checks as per recommendations of manufacturers which can lead to longer lifetimes.

It is observed from stakeholders' data that the greatest sub-component cost difference across technologies is the burner. The cost differences are shown below:

- upfront conventional and upfront hydrogen-ready burners – ~50%.
- upfront conventional and upfront hydrogen-only burners – ~60%.
- upfront hydrogen-ready and upfront hydrogen-only burners – ~5%.

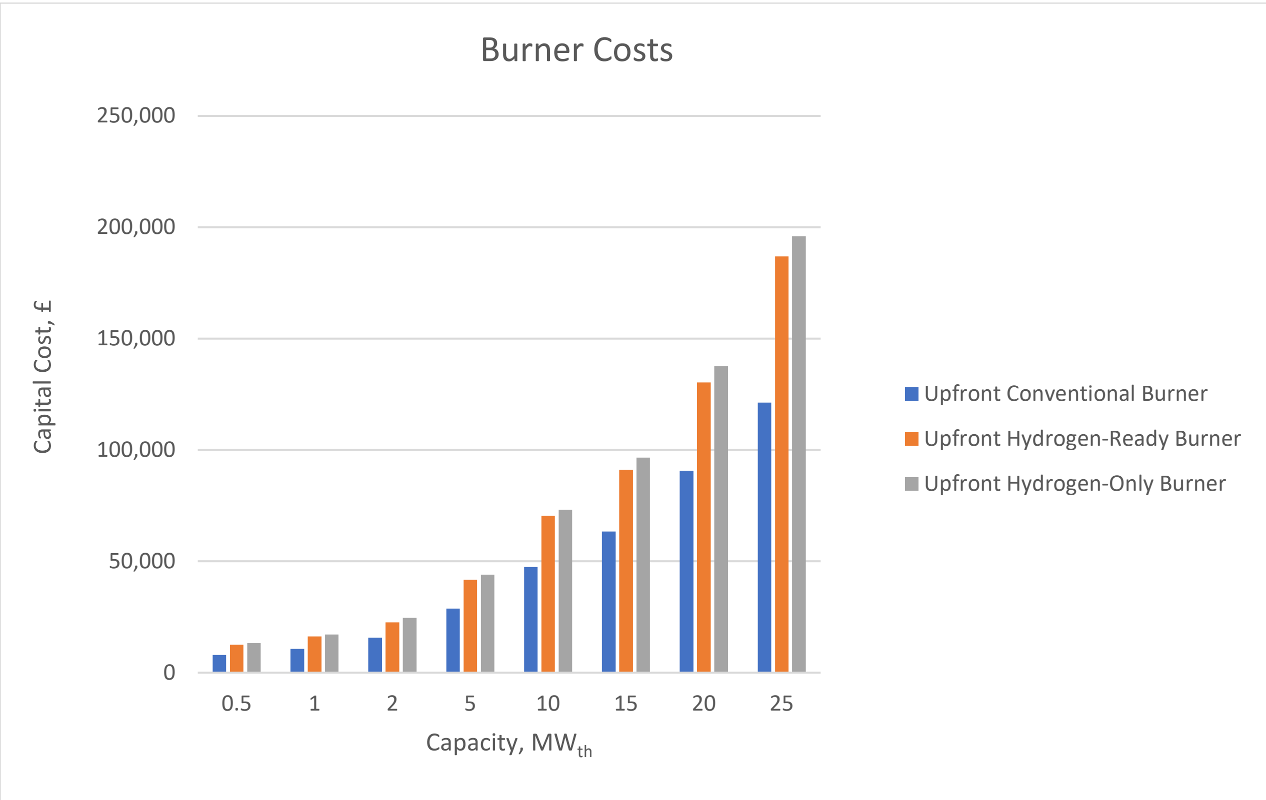

Figure 12: Burner costs for upfront conventional, hydrogen-ready and hydrogen-only burners

The major cost difference between upfront conventional and hydrogen-ready burners is a result of the complete change of the flame detection system from infrared or flame ionization to ultraviolet (UV). This is necessary as hydrogen combustion produces low infrared radiation and flame ionization is weak.

The stakeholders expected that some site level distribution pipework changes would be required. However, other work suggests that this would not be necessary, and that pipework could be repurposed to hydrogen so long as gas tightness testing was carried out[10]. Pipework costs will be very site dependent and affected by the location of fuel supply connections (natural gas or hydrogen) as well as the future availability of hydrogen at site which dictates the overall pipework network structure. On very large industrial sites, costs of installing new pipework could be substantial. Stakeholders were not prepared to offer estimates of these costs as they were so site specific. The costs presented here assume that existing site pipework would be repurposed to hydrogen.

The boiler capacities used throughout this report are based on the energy output of the equipment with typical efficiencies and steam or hot water temperatures and pressures.

Figure 10 shows that upfront natural gas boiler costs were consistent for boilers up to 15 MW_{th}. For boilers with higher capacities, there was a greater spread of capital costs reported by the stakeholders. The central capital cost estimates for upfront conventional natural gas, hydrogen-ready, and hydrogen-only boilers are shown in Figure 11. This shows that the cost to manufacture an upfront hydrogen-ready boiler is 15% more than an upfront conventional natural gas boiler. The majority of the cost increase came from a low NOx burner suitable to fire hydrogen.

From the figures above, it can be seen that the capital costs of boilers show an almost linear relationship with boiler capacity. This is unsurprising as a large proportion of the cost of a boiler is in the work required to build the boiler shell. This will increase linearly with the capacity. The costs of equipment for conversion do not show this linear trend but tend to level out at the higher boiler capacities, see section 6.3.

Furthermore, the capital cost to manufacture and install hydrogen-only industrial boilers is estimated to increase by 22% when compared to upfront conventional natural gas boiler and increase by 2-4% when compared to upfront hydrogen-ready boilers. The minimal increase from upfront hydrogen-ready boilers is expected as the capital cost of major sub-components i.e., burner and electrical control system remains the same for both hydrogen-ready and hydrogen-only. The increase in cost derives from setting up the burner and flame management system to fire hydrogen, addition of a new gas valve and change of gas meter.

6.3 Conversion of conventional natural gas equipment to hydrogen-ready and hydrogen-only

Stakeholder data highlights the significant cost in converting conventional natural gas equipment to hydrogen-ready across all capacities as the majority of the cost derives from complete replacement of the burner.

Figure 13 compares the cost of converting conventional natural gas equipment to hydrogen-ready and the premium between an upfront hydrogen-ready and natural gas boiler to enable assessment of cost conversion efficiency. This highlights that conversion of natural gas equipment to hydrogen-ready on site is not cost efficient compared to the cost of an upfront hydrogen-ready boiler.

[10] Steer Energy Hy4Heat WP7 Lot 1 Variation Plant room testing

The cost difference between an upfront natural gas and hydrogen-ready boiler is estimated to be lower than conversion of equivalent conventional equipment to hydrogen-ready, for example cost of conversion for a 5 MW_{th} boiler is estimated to be £55,000 whilst the premium for upfront hydrogen-ready boiler is estimated to be £23,000. The same can be highlighted across all capacities with greater cost differences observed at higher capacities i.e., > 10 MW_{th} as seen in Figure 13., It is therefore more cost-effective to install a hydrogen-ready industrial boiler than to install a natural gas industrial boiler and subsequently convert it to hydrogen-ready. However, this is complicated by three further considerations:

1. If a site has installed a natural gas boiler it is likely that the conversion to hydrogen-ready and then to be able to use 100% hydrogen would happen in a single step, reducing costs. This would entail incurring the capital costs of both steps at that time.
2. There is a risk that the site never converts to hydrogen and this would entail a sunk cost for sites that chose to install hydrogen ready boilers rather than conventional equipment.
3. At higher capacities, 25 MW_{th} and upwards, boiler equipment tends to become bespoke as a result of additionalities requested by end-users, therefore higher costs are expected for upfront equipment leading to a higher premium at these capacities.

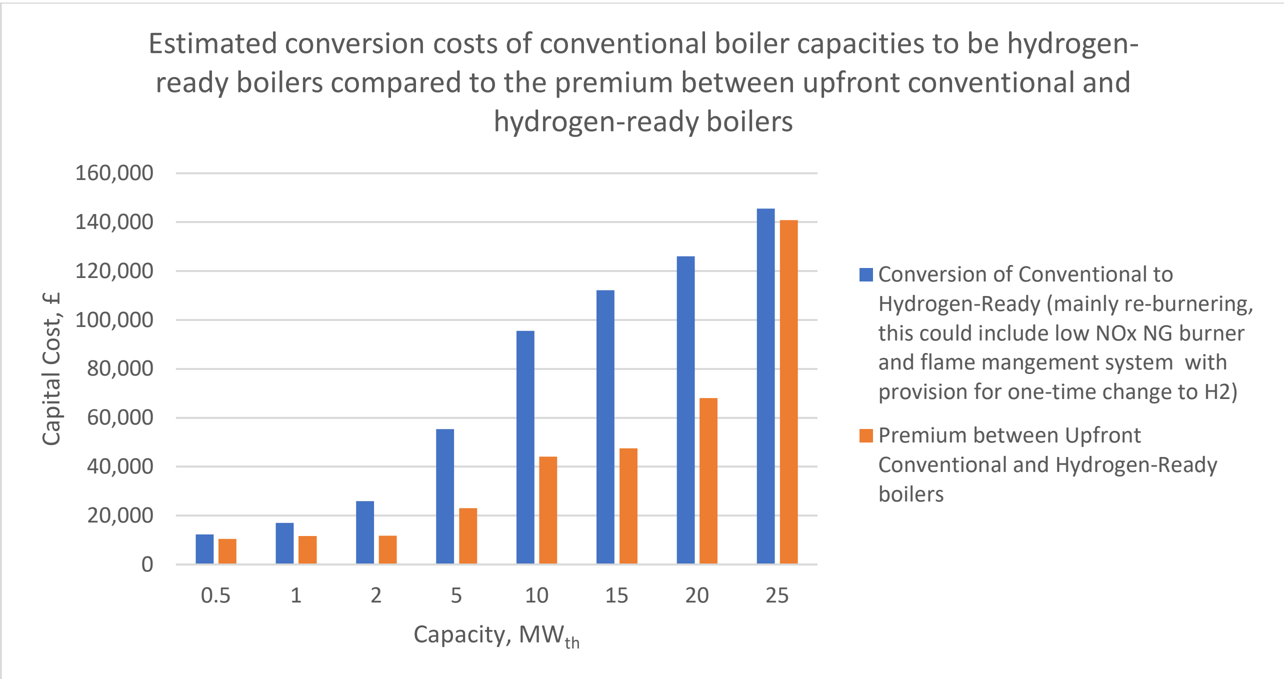

Figure 13: Comparison between conversion cost of conventional to hydrogen-ready boilers and premium between upfront conventional and hydrogen-ready boilers

Figure 14 highlights the cost of conversion of conventional equipment to hydrogen-ready and hydrogen-only. It is observed that the cost to convert hydrogen-ready equipment to hydrogen-only is minimal as activities required for this conversion do not require high-priced equipment changes; these will be modifications to burner nozzles, addition of a new gas valve, re-programming of the control system and replacement of the site gas meter. A new site gas meter would almost certainly be required as the volumetric flowrate of hydrogen would be around 3 times the flowrate of natural gas to deliver the same energy.

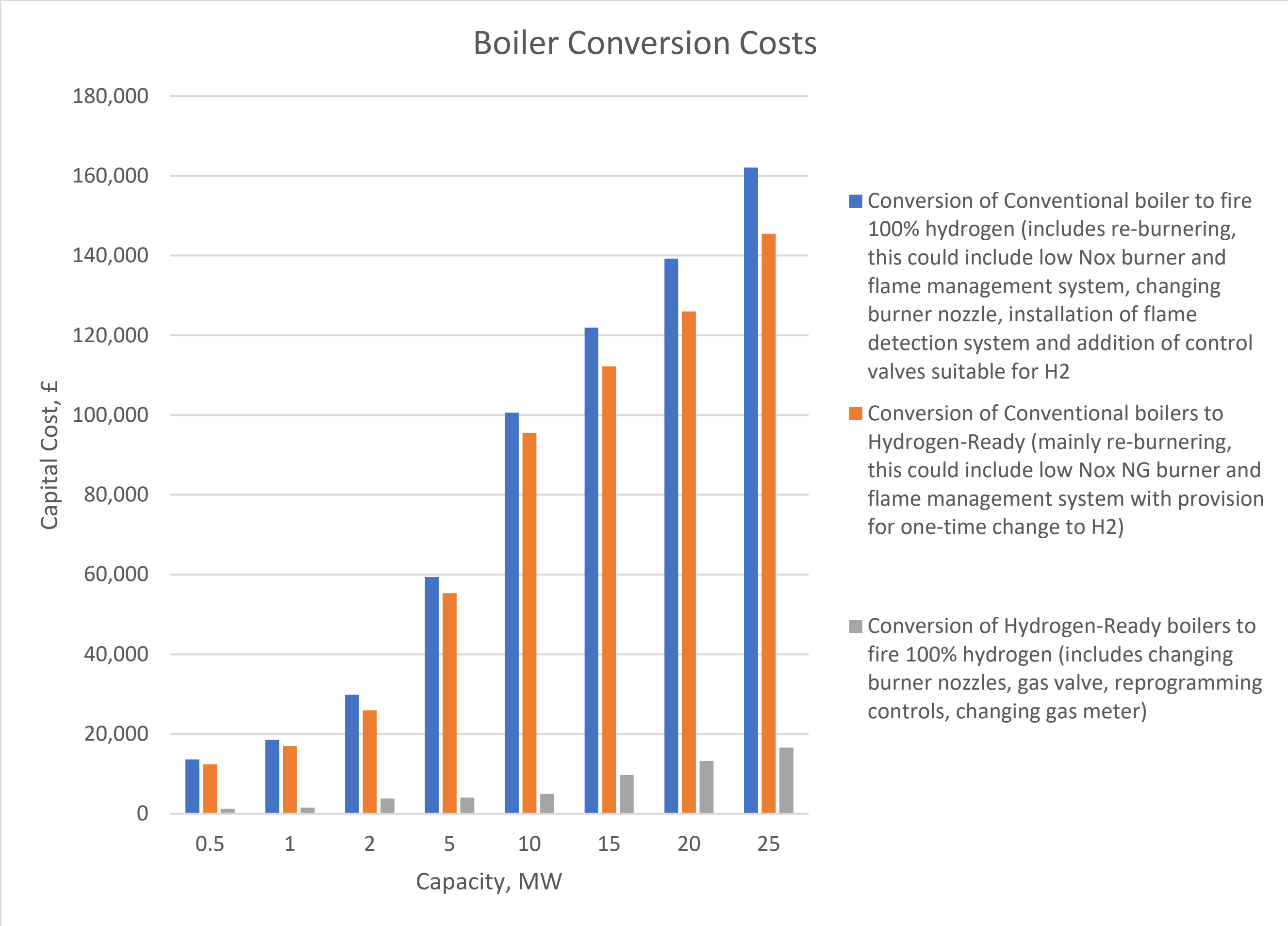

Figure 14: Cost estimate to convert conventional to hydrogen-ready and hydrogen-ready to hydrogen-only boiler

Higher capital costs were estimated for converting a conventional natural gas industrial to be hydrogen-only, compared with a new hydrogen-only industrial boiler. However, it was estimated that there would be a small (7-8%) reduction in installation or conversion hours through this single step conversion as opposed to double step conversion from conventional to hydrogen-ready and subsequently hydrogen-ready to hydrogen-only.

The capital costs of single or double step conversion to hydrogen firing therefore are very similar, so the small reduction in conversion time required does not have a large impact on overall conversion costs.

The burner cost is the main cost difference indicator across all boiler capacities. Figure 15 compares the cost of replacing a burner from conventional to hydrogen-only, conventional to hydrogen-ready and hydrogen-ready to hydrogen-only equipment.

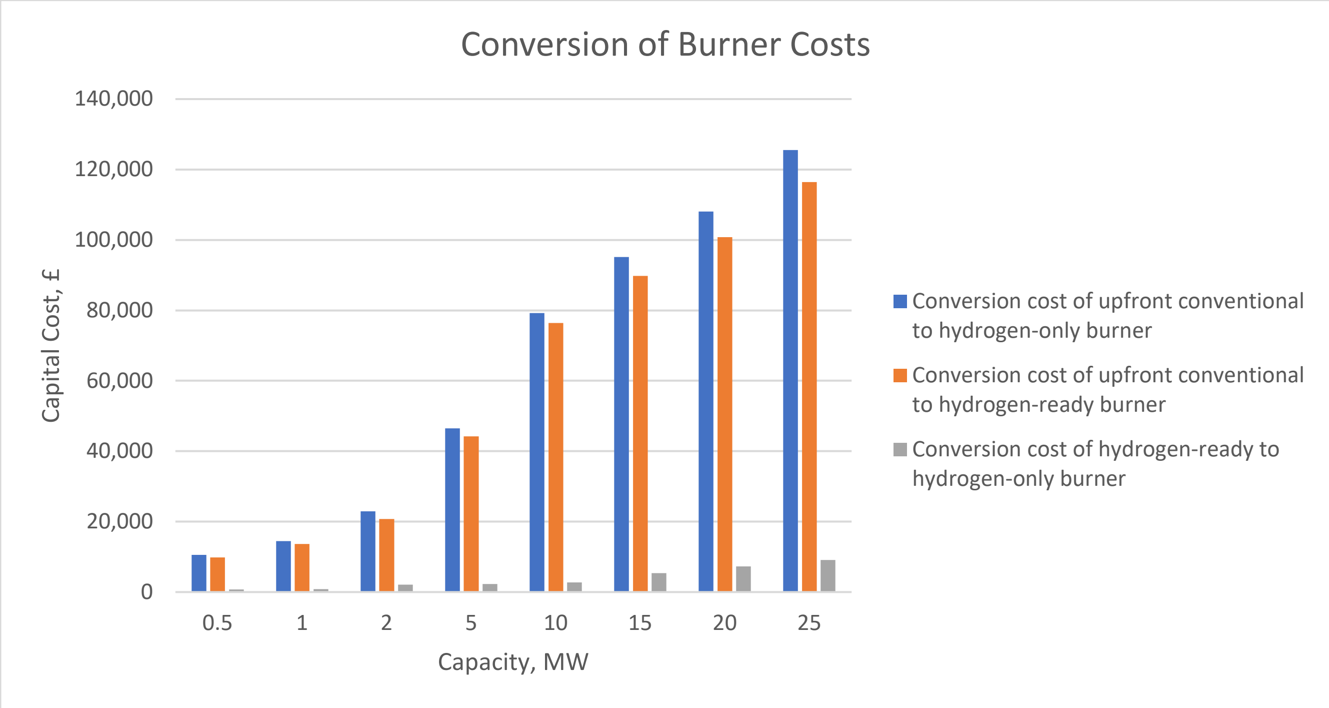

Figure 15: Cost conversion of burners for upfront conventional, hydrogen-ready and hydrogen-only burners

It is observed that the cost to convert a conventional burner to hydrogen-ready is similar between 0.5-1 MW_{th} and increases linearly up to 5 MW_{th}. The greatest difference is seen at higher capacities i.e., 10-25 MW_{th}. It was highlighted in the interviews with boiler and burner manufacturers that higher site demands are likely to be met by multiple boilers instead of a single boiler.

7 Supply chain implications

In this section, capacity of the supply chain to manufacture and install hydrogen ready and hydrogen firing boilers is assessed. If the lifetime of a boiler is around 20 years, then the replacement rate is 5%, i.e., 5% of the boiler stock will be replaced each year. This is considered to be the “Business As Usual” (BAU) rate. Estimates of the time required to install or convert boilers were made, based on responses from the stakeholder engagement. The stakeholders suggested that boiler lifetimes were likely to be longer than 20 years, up to 30 years. However, some boiler components such as burners and control systems may be subject to shorter replacement times of around 10 to 15 years. Therefore, subsequent analysis was based on the more conservative estimate of a 20 year boiler replacement cycle. The impact of installing boilers which are hydrogen ready was assessed.

7.1 Parameters for the analysis of supply chain capacity

The central estimate for the number of industrial boilers in the boiler stock population was 2000. Based on the boiler stock estimate, the median steam boiler output fell within 2-3 MW_{th} and the median for hot water boilers fell within the 1-2 MW_{th} range. Therefore, an average capacity of 2 MW_{th} was chosen.

The time required to install a 2 MW_{th} natural gas boiler was estimated to be around 340 hours. This represents the time to install a new natural gas boiler in an existing boiler house. This was from the stakeholder data for a 2 MW_{th} boiler.

Stakeholders suggested that the time required to install a hydrogen-ready industrial boiler in an existing boiler house would be slightly longer at around 360 hours. There is no time allowance for installation of FGR equipment which the study assumed would not be necessary, see section 4.3.1.1. These estimates do not include the time required to decommission and remove the existing boiler. However, this time is expected to be small compared with the time to install and commission the new boiler.

Stakeholders estimated the time to convert a natural gas industrial boiler to hydrogen-ready to be 75 hours. This represents the average conversion time for a natural gas boiler to become hydrogen-ready from the stakeholder data for a 2 MW_{th} boiler. The process would mainly involve re-burning, this could include installing a low NOx natural gas burner and flame management system with provision for a one-time change to fire hydrogen.

The time to convert a hydrogen-ready industrial boiler to fire 100% hydrogen was estimated as 35 hours. This is based on the stakeholder data for a 2 MW_{th} boiler. This would include changing burner nozzles, gas valve, reprogramming controls, and changing the site gas meter.

Stakeholders estimated that the time required to convert an equivalent conventional natural gas boiler to fire 100% hydrogen would be 110 hours. Cost savings are anticipated for single conversion pathways i.e., natural gas to hydrogen-only and hydrogen-ready to hydrogen-only, these savings are expected to be minimal, hence negligible.

The time worked by an installer per year was estimated as 1800 hours. This was calculated assuming that each person works 8 hours a day and 225 days each year.

The cost to employ installation staff was estimated at £40/h. The average wage was taken from SPON'S Mechanical and Electrical Services Price Book 2021[11] (the hourly wage for both an electrical technician (electrician) and a foreman for a heating, ventilation, and air conditioning engineer (installation engineer)). These costs were then adjusted to reflect the additional factors for cost of employment.

7.2 Analysis of the supply chain capacity

Boiler and burner manufacturers were confident that there was capacity within the industry to increase production of hydrogen-ready or hydrogen firing equipment. However, the required increase in production would be dependent on the rate of roll out of hydrogen across the country. Their production rates would be governed by the demand for hydrogen-ready or hydrogen firing equipment.

The capacity of the installation and maintenance sector to accommodate the additional work which would be required to install or convert boilers to be hydrogen ready or hydrogen firing is also dependent on the speed of roll-out. Based on the boiler stock central estimate of 15,000 total boilers from section 5.1.3 and the BAU rate of 5%, the staff employed installing new boilers (with an average capacity of 2 MW_{th}) amounts to around 140 person years. This is not the total size of the workforce, there will be many more staff carrying out boiler maintenance, inspection, and refurbishment work.

Table 6: Time required to install or convert boilers

	Hours	Person years	
	1 boiler (2 MWth)	**BAU rate (5%)**	**All 2000 industrial boilers**
Time to install a natural gas boiler	340	19	378
Time to install a hydrogen-ready boiler	360	20	400
Time to convert a natural gas boiler to be hydrogen-ready	75	4	83
Time to convert a hydrogen-ready boiler to fire hydrogen	35	2	39
Time to install a natural gas boiler and convert to firing hydrogen	450	25	500
Time to install a boiler firing hydrogen	395	22	439

Table 6 suggests that there would be a slight increase in the time requirements to install hydrogen ready boilers at the BAU rate, compared with installing natural gas industrial boilers. It also shows that conversion to hydrogen-ready and then to firing hydrogen would require a further increase in labour. However, compared to the number of person years to complete the

[11] AECOM, SPON's Mechanical and Electrical Services Price Book, 2021.

BAU installations these increases are small. It should be noted that these figures are based on stakeholder estimates of time required and that there is considerable uncertainty in them.

Table 7: Percentage of the industrial boiler stock that could be converted based on the additional person years available

Person Years Available for converting Natural Gas boilers to fire 100% Hydrogen	Total number of Natural Gas boilers that can be converted to fire 100% Hydrogen	Percentage of Boiler Stock Population that could be converted if 0% of the boiler population was hydrogen-ready i.e., all boilers are Natural Gas	Total Number of hydrogen Ready-Boilers that can be converted to fire 100% hydrogen	Percentage of Boiler Stock Population that could be converted if 100% of the boiler population is Hydrogen-Ready
10	160	8%	510	26%
20	330	16%	1030	51%
50	820	41%	2600	100%
100	1650	82%	5100	100%
200	3300	100%	10300	100%

Table 7 shows the total number of natural gas industrial boilers and hydrogen-ready boilers that could be converted to fire 100% hydrogen along with the percentage of the boiler stock that would be converted. If all industrial boilers were hydrogen-ready, an additional 50 person years would mean that they could be converted to fire 100% hydrogen. Conversely, if none of the industrial boilers were hydrogen-ready only 41% of the boiler stock could be converted. This indicates that making industrial boilers hydrogen-ready would ease any strain on the supply chain and that fewer person years would be required to completely convert all the 2000 boilers to fire 100% hydrogen. This table only estimates conversion time of boiler equipment and does not account for boiler installation time, or wider factors to prepare a site to use switch to hydrogen.

Discussions were held with the Gas Safe Register to gain information on the numbers of installers who are registered, and the proportion of these who are qualified to install industrial / commercial boiler equipment. Information from the Gas Safe Register suggests that there are over 120,000 registered gas installers in the UK. Of these, approximately 25,000 are industrial/commercial registered engineers. The number of engineers will fluctuate over time, as the qualifications need to be renewed every five years, and some engineers only renew their industrial registration depending on their workload in this sector. It is recognised that the number of industrial registered engineers who are working on large boiler replacement projects will be fewer than the total pool available. However, these are the people who would carry out the conversion work to make industrial boilers hydrogen-ready or to fire 100% hydrogen. This large pool of engineers would suggest that the supply chain has significant capacity and that there is unlikely to be a problem in meeting the relatively low time requirement for conversion of industrial boilers to use hydrogen. However, as training would be required for these engineers, it would take some time for the supply chain capacity to operate at this rate.

7.2.1 Supply chain: information from the stakeholder engagement

The stakeholder interviews suggested that the skills required to convert a conventional natural gas industrial boiler to hydrogen-ready or to convert to firing 100% hydrogen include:

- Mechanical fitters for burner installation, burner nozzle conversion, and gas pipework modifications, including installation of the new gas train, gas valve, and site gas meter.
- Electricians / instrument technicians for installation of boiler controls and flame management systems.
- Combustion engineers for setting up and commissioning the boiler when converting to fire 100% hydrogen.

Some of the people involved are multi-skilled and can cover all the tasks required for conversion. There was a consensus among stakeholders that there may be a skills shortage surrounding combustion engineers capable of setting up industrial boiler able to fire hydrogen. Their technical knowledge is based on natural gas or fuel oil firing, rather than hydrogen. The techniques and measurements required to commission a natural gas or oil boiler rely on the carbon dioxide / carbon monoxide (CO2/CO) ratio. As the hydrogen fuel contains no carbon, the commissioning process will need to be based on flue gas oxygen measurements. This will be unfamiliar to the majority of commissioning engineers. This can be addressed by training and requirements are currently being developed by BEIS and Energy & Utility Skills[12]. It is likely that the boiler makers would develop in-house training programmes to supplement the training which will be offered by traditional providers such as further education colleges and commercial training organisations.

The estimates of time required to install or convert boilers were derived from information provided by the stakeholders.

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[12] Energy & Utility Skills - https://www.euskills.co.uk/

8 Conclusions and recommendations

8.1 Conclusions

A definition of “hydrogen-ready” for industrial boilers has been developed. This definition was generally accepted by the stakeholders. Although there were some differences of opinions on the work that would need to be carried out to make an industrial boiler hydrogen-ready and conversion to fire 100% hydrogen, these were minor, e.g. whether to upgrade the burner flame management system when making the boiler hydrogen ready or when converting to fire 100% hydrogen.

Capital cost estimates have been developed for a range of options:

- New conventional natural gas industrial boiler.
- New hydrogen-ready natural gas industrial boiler.
- Conversion of a conventional industrial natural gas boiler to make it hydrogen-ready.
- Conversion of a hydrogen-ready industrial boiler to firing 100% hydrogen.
- Conversion of a conventional natural gas industrial boiler to firing 100% hydrogen.
- New industrial boiler firing 100% hydrogen.

The capital costs for industrial boilers show an almost linear relationship with boiler capacity. This is unsurprising as a large proportion of the cost of a boiler is in the work required to build the boiler shell, which will increase linearly with the capacity. The costs of equipment for conversion do not show this linear trend as the costs of burner control equipment are likely to be independent of boiler size.

The capital costs of conventional natural gas industrial boilers were supplied by several stakeholders and were generally in alignment, except at the largest capacities where the equipment becomes more bespoke, and the costs depend on the options chosen. There was a general consensus that a hydrogen-ready industrial boiler would cost up to 15% more than a conventional natural gas boiler. The equipment cost for conversion of a conventional boiler to be hydrogen-ready and the costs of converting a hydrogen-ready industrial boiler to fire 100% hydrogen were more uncertain and dependent on the stakeholder’s perception of the equipment that would be involved at each stage. For a 5 MW_{th} reference size boiler, the study found that fuel switching to hydrogen using a hydrogen-ready boiler could achieve cost savings of around 15% when compared to fuel switching to hydrogen using conventional natural gas equipment. It should be noted that there will be other, site specific, costs of conversion and this cost saving covers equipment costs only.

Installation and conversion costs have been developed for the options above. The uncertainties associated with these costs mirror the equipment cost uncertainties. The costs of installing a natural gas industrial boiler were well known, the costs of conversion to hydrogen ready or hydrogen firing less so. Therefore, there is good confidence in the costs of replacement of a natural gas industrial boiler like for like, but less confidence in the costs of conversion to hydrogen ready and to firing 100% hydrogen.

Estimates of the boiler stock population have been made, both for all boilers sized greater than 1 MW_{th} and for those installed at industrial sites. These stock population numbers have a relatively large uncertainty associated with them as data sources were limited, and there was difficulty in differentiating between the total boiler stock and the stock segmented by end use (industrial, commercial, hospitals, etc.). Central estimates were:

- installed UK boiler stock sized greater than 1 MW_{th}, 15,000 units.
- installed industrial boiler stock, 2,000 units.

The supply chain capacity was analysed based on the average time taken for installation and for conversion. There is a large pool of engineers who are qualified to install or convert large scale industrial or commercial boilers. This suggests that the supply chain has significant capacity and that there is unlikely to be a problem in meeting the relatively low time requirement for conversion of industrial boilers. The supply chain appears to have the capacity to deal with this, however this may be limited by the lack of commissioning engineers with experience with hydrogen. It is less time and resource intensive to convent a hydrogen-ready industrial boiler to fire hydrogen than to convert a natural gas industrial boiler to fire hydrogen. So, on the one hand, a high proportion of hydrogen-ready boilers could ease the pressure on the supply chain at the point of conversion. However, when taken in the context of the number of engineers, it appears unlikely that there will be significant restriction at this point in the supply chain. It is unlikely therefore that deploying hydrogen-ready industrial boilers would give a material benefit for the speed at which industrial boilers can fuel switch to hydrogen.

The purchase of new or re-purposing of boiler houses to hydrogen is relatively straightforward and there are a range of suppliers of both the shell boiler and the burner. Large boiler houses fitted with water tube boilers are all bespoke designs. The additional capital costs for firing hydrogen are difficult to predict but are likely to be less than 15% above natural gas only costs. Some of the operators of such sites see no feasible alternative to low-carbon hydrogen and find themselves in a difficult position when trying to decarbonise.

Assuming small to medium industries continue to purchase such boilers, there is enthusiasm from users to install hydrogen-ready equipment if they can be confident of the date when hydrogen might arrive. Given such enthusiasm and the relatively modest cost (in mass production), regulatory support for hydrogen ready might well be appropriate. However, this would be dependent on a clear timetable for hydrogen roll out which will determine the size of the market for hydrogen-ready or hydrogen only boilers.

If there is no clarity on the size of the market, justification to require hydrogen-ready status for industrial boilers alone appears difficult. It may be more appropriate to include other sectors and other technologies (e.g. CHP plant) and require all of these to also be hydrogen-ready. There is no evidence of the large number of existing industrial gas boilers being located in clusters, except for the largest boilers. It appears that industrial boilers are fairly widespread across the country.

8.2 Recommendations

8.2.1 Recommendations from the authors

Considering the large uncertainty associated with data obtained from stakeholders as highlighted in the report, the authors have reviewed these against the project outputs.

The impact of CHP gas engines on any requirement for future hydrogen readiness should be considered carefully. This transition (i.e., from boilers to CHP) has already occurred on the largest plants and, anecdotally, this is moving to smaller sites. This area should be investigated as CHP was beyond the scope of this report.

Data has been sought from the BEIS DUKES team on the numbers of sites by annual gas usage. Nearly all gas not burnt in CHP is combusted using forced draft burners; the cost of these is relatively independent of end use (i.e., whether the burner is heating a kiln, air heater or boiler). It should be possible to investigate the option of requiring all new gas forced draft burners to be hydrogen-ready. This could present a simpler regulatory approach than only requiring industrial boilers to be hydrogen ready. However, this is complicated by the fact that burners on kilns and furnaces are relatively bespoke and the whole furnace or kiln may need redesign to ensure that product is heated correctly. This would need to be considered on a process-by-process basis. CHP and unusual/unique burner systems could be exempted from this.

The BEIS statistical data on the geographical spread of industrial boilers should be analysed. If boilers are spread uniformly across the country, this could influence the scope of any policy changes. For example, it may be the case that requiring all industrial boilers to be hydrogen-ready would not be beneficial if some boilers are unlikely to receive a hydrogen supply in the near term.

8.2.2 Recommendations from the stakeholder engagement

Manufacturers and end-users need to know when hydrogen will be readily available. This will help companies that are making decisions about their decarbonisation strategies which will affect their decarbonisation targets e.g., end-users are already making decisions about buying boilers that they plan to use beyond the 2050 deadline. A plan and timeline for the rollout of hydrogen could give manufacturers confidence that there will be a market for hydrogen-ready and hydrogen firing appliances, and this could give end-users confidence in buying hydrogen-ready equipment.

The definition for what constitutes a hydrogen-ready boiler developed here could be publicised to help reduce confusion from end-users who purchase the equipment as to what needs to be done to make the equipment fire 100% hydrogen.

Government should encourage manufacturers to develop hydrogen-ready industrial equipment and incentives for end-users to use hydrogen in place of natural gas will need to be introduced.

Clarity is needed around the NOx emissions that would be required to meet MCP regulations, as pollution from carbon dioxide emissions should not be replaced with pollution from high NOx emissions.

The effectiveness of any changes to regulation would be dependent on the implementation date as not all manufacturers might be able to meet deadlines for 2025/2026 to only supply hydrogen-ready equipment as some manufacturers are still in the early stages of development.

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10 Appendix

10.1 Industry engagement

Stakeholder contacted	Role	Did they participate in the stakeholder engagement	Method of engagement
Babcock Wanson	Boiler Manufacturer	Yes	Interview
Bosch Thermotechnology	Boiler Manufacturer	Yes	Interview
British Sugar	End User	Yes	Interview
Byworth Boilers	Boiler Manufacturer	Yes	Interview
Cochran	Boiler Manufacturer	Yes	Interview
Combustion Engineering Association	Trade Association	Yes	Informal call
Dunphy Combustion	Burner Manufacturer	Yes	Interview
Groupe Atlantic	Boiler Manufacturer	Yes	Interview
Hoval	Boiler Manufacturer	Yes	Interview
ICOM	Trade Association	Yes	Informal call
Limpsfield	Burner Manufacturer	Yes	Interview
McQuillan Boiler Services	Boiler Maintenance Company	Yes	Interview
Palm Paper	End User	Yes	Interview
Spirax Sarco	Steam Handling Equipment Supplier	Yes	Informal call

10.2 Stakeholder engagement question set

Hydrogen Ready Definition

1. Do you agree that ‘hydrogen-ready’ should be defined as an equipment that is optimally designed to run on 100% hydrogen but initially configured to run on natural gas? This equipment may require a minimum number of components to be changed at the point of switchover but will have been specifically developed to facilitate this process. The conversion will be carried out within a short period of time using the minimum necessary personnel and resources.

a. Are most existing shell and water tube boilers capable of conversion to hydrogen?

b. Could shell and water tube boilers be designed to be ’hydrogen-ready’? In line with the definition above, this would be equipment not just only capable of hydrogen conversion by optimally designed for conversion. Is this possible today? If not, what would you expect the timescale be to develop such a product?

2. Would it be feasible to develop a standard/certification that manufacturers could follow to manufacture of H2-ready boilers and its subcomponents? Please provide details.

Technology Sheet

3. We would like to develop assumptions for the following scenarios set out in the technology sheet provided. These scenarios describe different ways to fuel switch a boiler to hydrogen:

a. Natural gas boiler that converts to hydrogen

b. H2-ready boiler that converts to hydrogen

c. Hydrogen boiler

d. Dual fuel boiler

This would be for equipment sized at the following thermal capacities:

Shell boilers: 0.5MW, 1 MW, 2MW, 5MW, 10MW, 15MW, 20MW and 25 MW

Water tube boiler: 25MW, 50 MW, 100MW, 150MW, 200MW, 250MW, 300MW, 350MW, 400MW, 450MW and 500MW

4. Please confirm the subcomponents listed in the technology sheet are those that would have a material impact on the costs of fuel switching to hydrogen.

5. For each scenario, please provide costs and the resources/time to purchase and install boiler equipment at the listed capacities.

6. For scenarios [3a] and [3b], please provide costs and the resources/time to convert boiler equipment from natural gas to hydrogen.

Additional Technology Questions

7. Would there be substantial downtime costs associated with fuel switch to hydrogen? If yes, how would these differ under different scenarios?

8. Would on-site pipework need to be adapted to become H2-ready? If so, how often would this need to be replaced and what is the expected cost?
9. Do you have any views or evidence for whether all electrical components would need to be ATEX rated? Could you please provide an estimate of costs for conversion of these components for both conventional natural gas boilers and new H2-ready boilers?
10. Would any additional equipment on site need to be ATEX rated after the conversion to hydrogen and what would the costs be?
11. What would the NOx emissions from a conventional natural gas boiler and a new H2-ready boiler be?

a. If they do not meet the MCP regulations, what emissions control would be required?

b. What would be the costs to convert either a natural gas or h2-ready boiler to meet these emissions controls?

12. Would there be a difference in energy efficiency levels for the four scenarios listed at question 3? For 3a and 3b please indicate energy efficiency when running on natural gas and once converted to hydrogen.
13. Are there any other factors to consider that would substantially impact the costs and resources to convert to hydrogen under these four scenarios, for instance, costs associated with training or insurance?

Supply Chain Capacity

14. Do you agree that the proportion of boiler stock that can currently be replaced or refurbished each year is 5% of the total stock? If not, what proportion of boilers would you estimate the supply chain can replace or refurbish each year?
15. Without policy support, we think that the current supply chain could convert fewer boilers to hydrogen than the proportion that undergo natural gas replacement / refurbishment each year (i.e. 5% per annum). Do you agree? If so, what proportion of natural gas boilers could be converted to hydrogen each year?
16. If the UK boiler stock was increasingly hydrogen-ready to what extent would this help the supply chain convert a greater proportion of natural gas to hydrogen each year? For instance, if 10% of UK boilers were h2-ready boilers, what proportion of natural gas boilers could the supply chain convert to hydrogen each year?
17. If UK boilers were not hydrogen-ready, but there was demand for hydrogen conversion, how quickly could the supply chain expand capacity to meet that demand What would be the limiting factors to supply chain growth? What would help the supply chain to grow?

Stock Population

18. Could you please provide annual UK sales figures of your shell boilers that are 0.5MW, 1 MW, 2MW, 5MW, 10MW, 15MW, 20MW and 25 MW. Please base figures on averages from the last five years of sales.
19. Could you please provide annual UK sales figures for water tube boilers that are between 25MW, 50 MW, 100MW, 150MW, 200MW, 250MW, 300MW, 350MW, 400MW,

450MW and 500MW? Please base figures on averages from the last five years of sales.

20. What would you estimate as the installed stock today for natural gas boilers in the UK at these capacities e.g., based on maintenance, servicing or permitting?
21. Do you anticipate that future UK sales of these types of boilers will remain stable compared to previous years, or do you anticipate significant changes to uptake over the next 10 years? For instance, do you think that large water tube boilers will be displaced by gas turbine CHP?
22. What proportion of these shell and water tube boilers are used for:

a. industrial process heat
b. commercial space heating, such as in airports, hospitals, and heat networks

23. What are the operating lifetimes of the boilers in both operating hours and years (years, if they are not being operated 24/7)? Are any of the boilers retired before the end of their operating lifetime? If so, after how long are they typically retired?

Please note questions 24 to 30 were only asked during interviews with end-users.

Existing Operations

24. Do you currently consume large quantities of natural gas? If you have multiple sites, does this vary from site to site across the UK?

    Would you be prepared to share the locations and annual total/peak gas consumptions for these going forward. These would be confidential, but would enable BEIS to investigate the potential availability of hydrogen in these areas?

25. What type of combustion system do you currently use for this natural gas on these sites?

- Shell boilers
- Water tube boilers
- Gas turbine/IC engine and waste heat boilers (i.e. CHP)
- Again, does this vary from site to site?

26. What is the pressure tier of your current NG supply to your sites i.e., national transmission (~70barg), local transmission (~20barg) or local distribution (<7barg)?
27. Does the combustion of gas continue to play a part in your current future energy plans and if not, how might you replace this energy e.g., by burning more waste materials? If you plan to continue to burn gas, how will you best use it?

Interest in hydrogen

28. As part of a UK decarbonisation plan it might be that low carbon hydrogen (i.e., green or blue rather than grey) is made available to replace natural gas, would this hydrogen be of interest to you?
29. Manufacturers of domestic boilers have said that they can readily supply hydrogen-ready boilers (which a Gas Safe registered installer can change over in <1hr). Part of

this study is to confirm (or otherwise) the availability of hydrogen ready industrial combustion plant; this will include shell boilers, possibly water tube boilers and possibly CHP.

If this hydrogen ready equipment were available, might you purchase it? If it were modestly more expensive, would you pay a premium?

Upcoming Regulatory Changes

30. Will your current gas combustion equipment pass the up-coming NOx legislation under the MCP? Will you have to re-burner? Would you be interested in low NOx hydrogen ready burners?

This publication is available from: https://www.gov.uk/government/consultations/enabling-or-requiring-hydrogen-ready-industrial-boiler-equipment-call-for-evidence
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