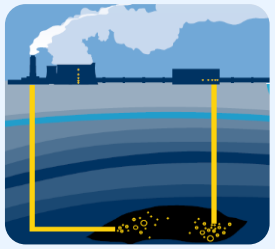








Hy4Heat WP6
Understanding industrial appliances

Industry Workshop

For BEIS & Hy4Heat

10th April 2019

elementenergy

JACOBS

CARDIFF UNIVERSITY

Emrah.Durusut@element-energy.co.uk
Ian.Moore@jacobs.com

Agenda

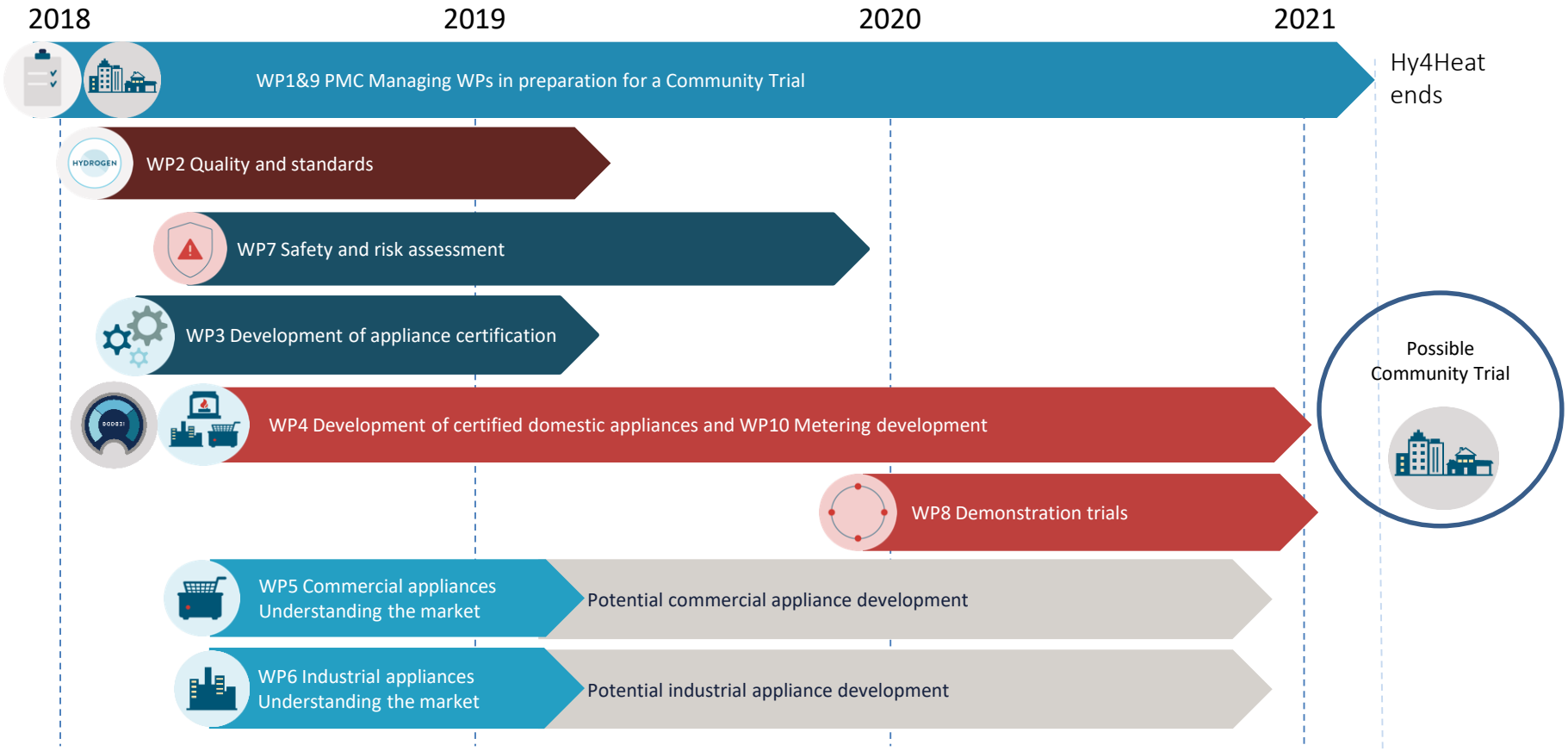
Agenda	Time
Arrival and lunch	12:30 - 13:20
Introduction and overview of Hy4Heat WP6	13:20 – 13:40
Element and Jacobs presentation of emerging findings a. Industrial appliances in the UK b. Feasibility and cost of hydrogen conversion c. UK-wide hydrogen conversion and timelines	13:40 – 14:35
Q&A	14:35 – 15:00
Coffee break	15:00 – 15:15
Discussion of hydrogen conversion challenges and enablers a. Short presentation on barriers and enablers b. Small group discussion around key questions c. Feedback to room and summary	15:15 – 16:30
Workshop close-out and AOB	16:30 – 17:00

Agenda

- Introduction
- Session 1: Hy4Heat WP6 key findings
- Q&A on findings
- Session 2 Next steps and discussion
- Workshop wrap-up
- Appendix

Overview of Hy4Heat programme

The Hy4Heat programme aims to demonstrate and de-risk the use of **hydrogen for heating** in GB homes and businesses, establishing if it is technically possible and safe to replace methane with hydrogen in buildings and gas appliances. This will enable the Government to determine whether to proceed to a community trial.



Overview of WP6: Understanding industrial appliances

elementenergy delivering in partnership with JACOBS Consultancy and CARDIFF UNIVERSITY

Project context and key objectives

- The aim of this study is to investigate issues relating to potential future conversion of industry **from natural gas to full hydrogen for heat**.
- Constraints to be analysed include those around **safety, functionality and cost** of hydrogen conversion and use in industry.
- The study will also document knowledge gaps and propose **necessary trials and appliance development work**.
- **Key outputs:** Comprehensive understanding of applications of H_2 for heat in industry, including costs, technical and commercial requirements, timeframes, barriers and opportunities.

Workshop objectives

- Summarise the aims of the study and the Hy4Heat programme
- Share the **emerging findings** in terms of industrial equipment and hydrogen conversion requirements
- Discuss the **challenges, knowledge gaps and demonstration programmes** required in each industrial sector
- Gain input and **feedback from industry** to inform the Hy4Heat programme going forward.

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Highest natural gas usage is in chemicals and food and drink, with significant CHP

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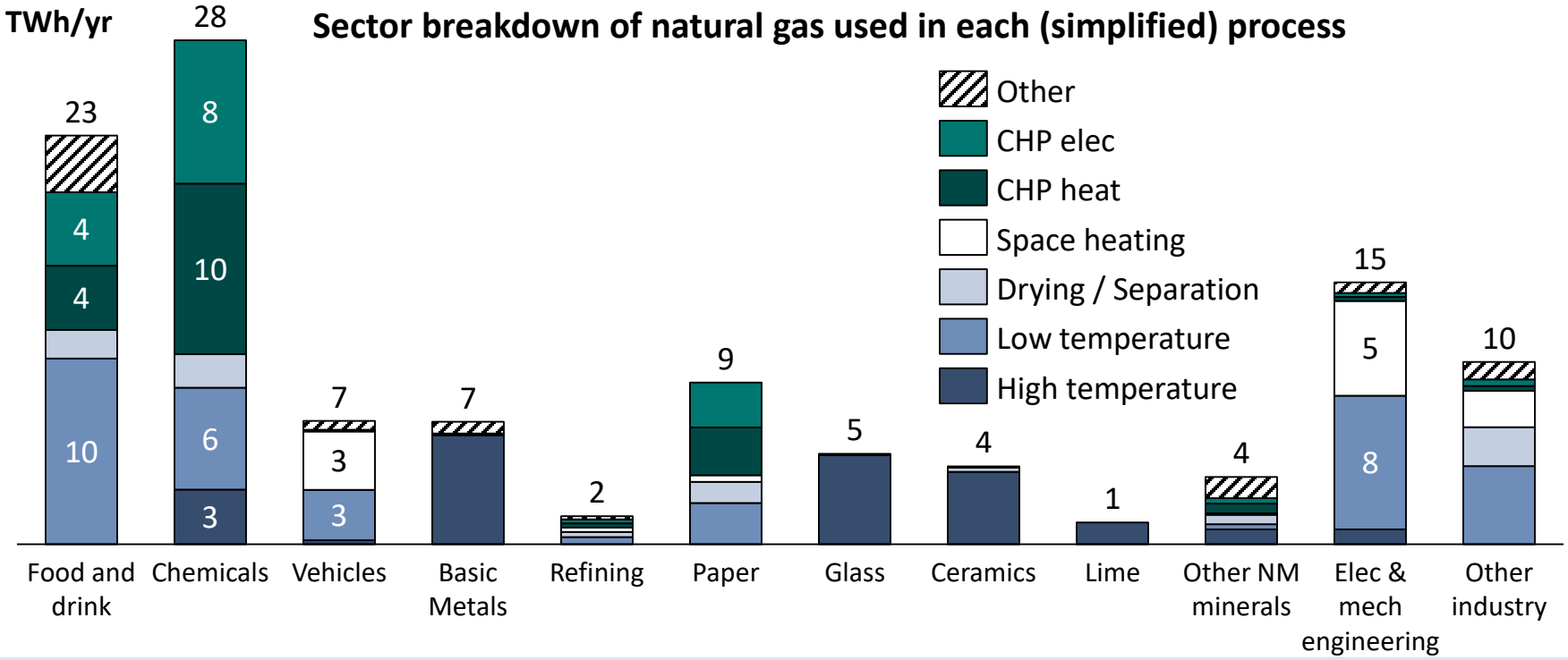
Breakdown of natural gas usage by industry sector and process shows scale of CHP

- Natural gas consumption profile different from total fossil fuel consumption (e.g. Cement).
- Some sectors have fewer sites, with high gas consumption at each (Paper, Glass, Refining), other sectors have more sites, each with low gas consumption (Elec and Mech. Eng.).
- CHP accounts for approx. 30% of total natural gas usage across industry*. Particularly important in the Chemicals, Food and Drink and Paper sectors.



Source: ECUK 2018 end process data; DUKES CHP data; Industrial fuel switching, Delta EE confidential data

**Original refining data includes oil and gas terminals and power plant so was considerably higher; scaled estimate*

Around 65 TWh/y of natural gas consumption is estimated to be included within the scope constraints for industrial conversion

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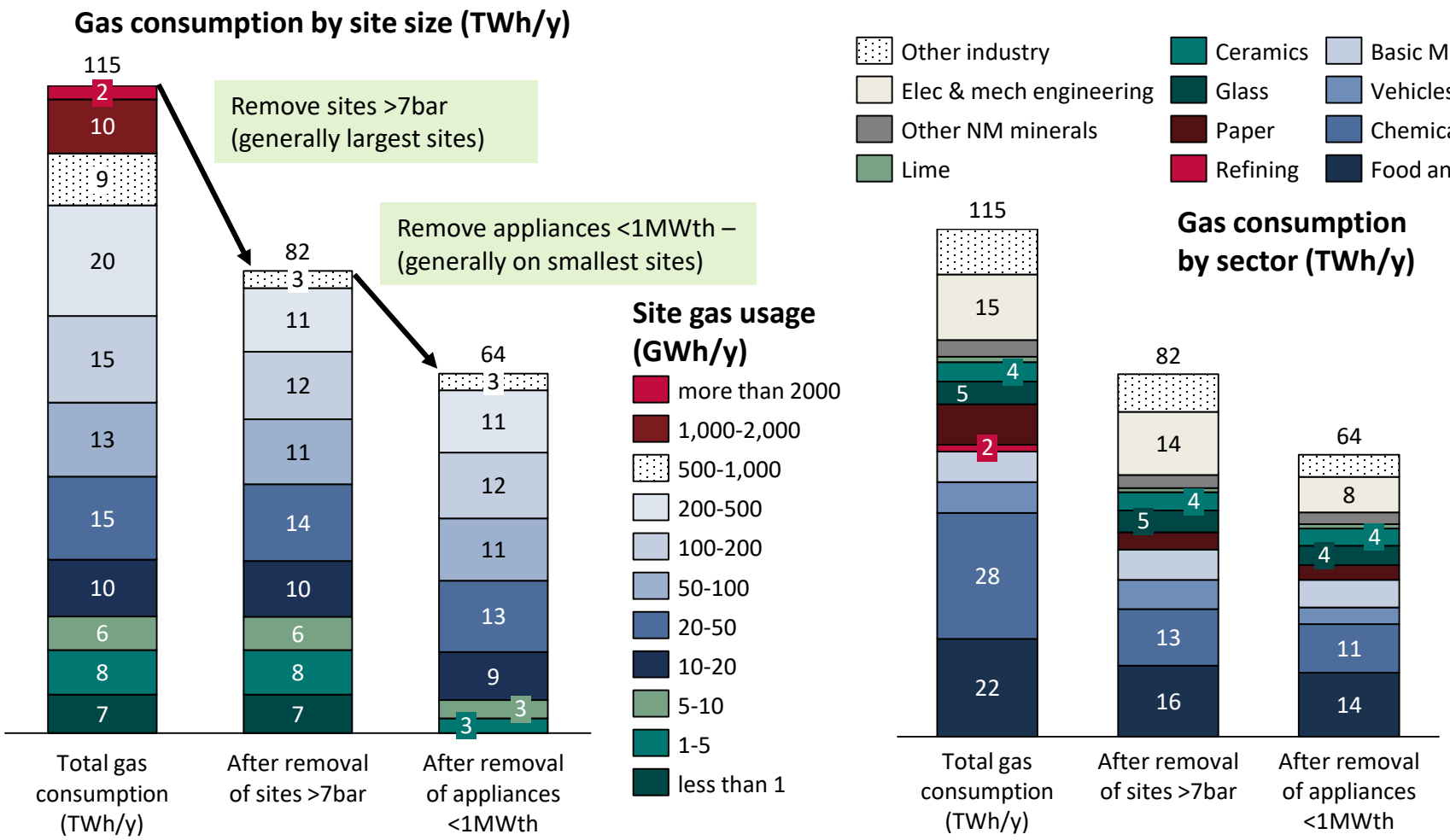
The two scope constraints are applied to focus on relevant sites (<7bar) and appliances (>1MWth)



Source: Cadent and SGN data, calculation from the above assumptions.

Boilers are the most numerous and highest total capacity, though a significant range of direct fired appliances exists

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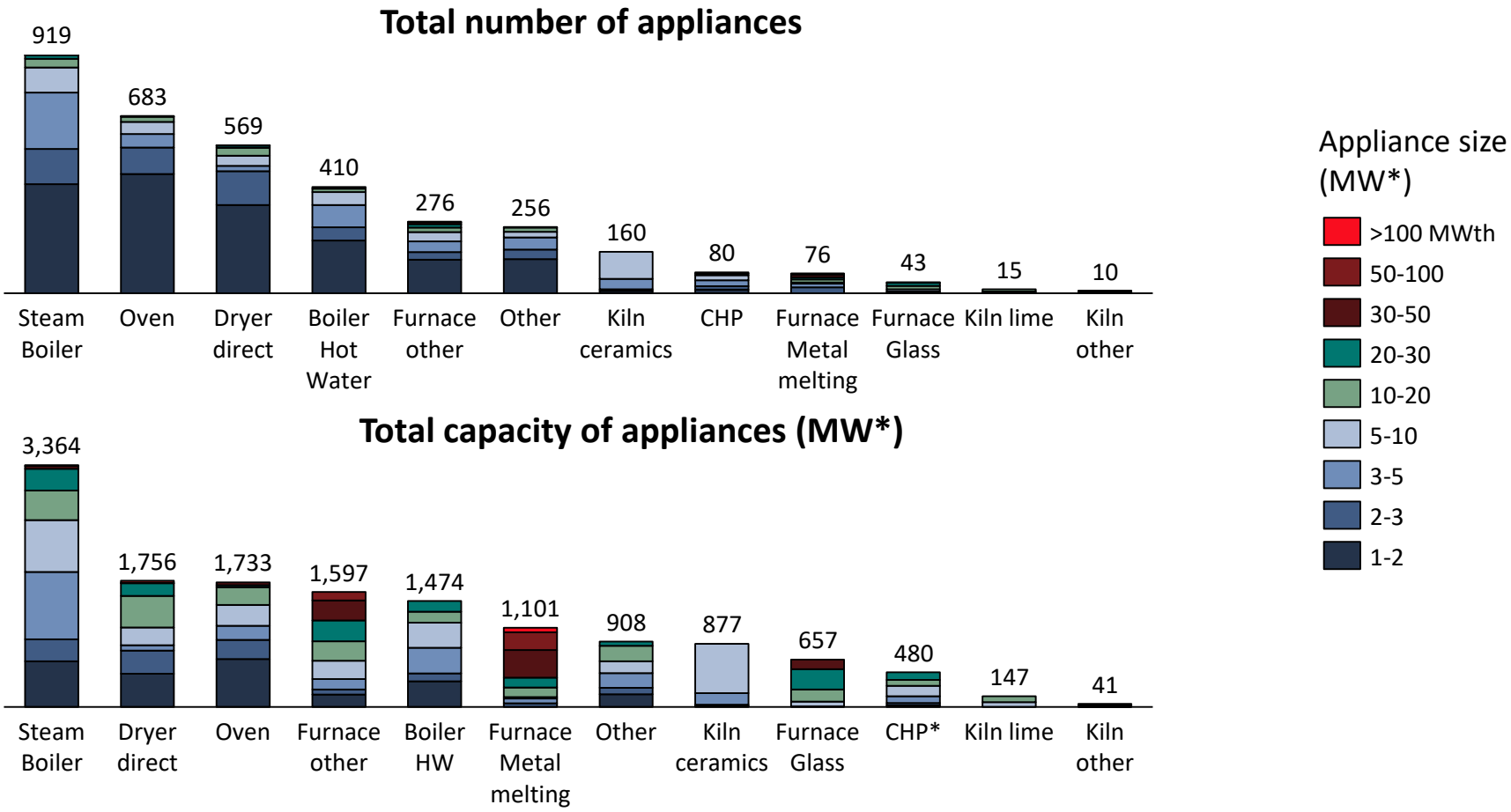
Draft outputs as to the total number of each appliance type in the UK shown below

- Showing **natural gas consuming appliances >1MWth**, connected to **<7bar gas** network.



** CHP is in MWe. MWe is more commonly used for CHP, and if in MWth/(MWe + MWth) would be approx. 3.5-4.5x the capacity*

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No ‘show-stopping’ technical barriers were identified. Gas Engines may need replacement rather than conversion.

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Suggested approaches to overcoming identified technical barriers

	Potential Barriers	Sensitive Sectors*	Enablers
Technical	Heat Transfer – Convection vs Radiative	Glass, Ceramics and Lime	Further experimental investigation on heat transfer balance in glass furnaces and kilns.
	NOx emissions	All	Flue gas recirculation, steam addition and post-combustion treatment (SNCR & SCR) can be used. Further work on low NOx burners may also reduce emissions.
	H_2 Burner Manufacturers	All except chemical and refinery examples	Further research and development by burner manufacturers. This requires a future commercial market
	H_2 Burner Materials	All	No new action – materials currently exist and have been used
	Flue Gas Moisture Content	Ceramics, Food and Drink, Vehicles, Lime	Specific product demonstration trials required within relevant sectors
	Gas Engine Conversion	Sites with gas engines	Period of research and development, small/large scale trials. Potential appliance replacement.
	Piping and fittings	All	No new action – materials and standards currently exist.

*Sectors that have particular concerns around conversion impact and uncertainties

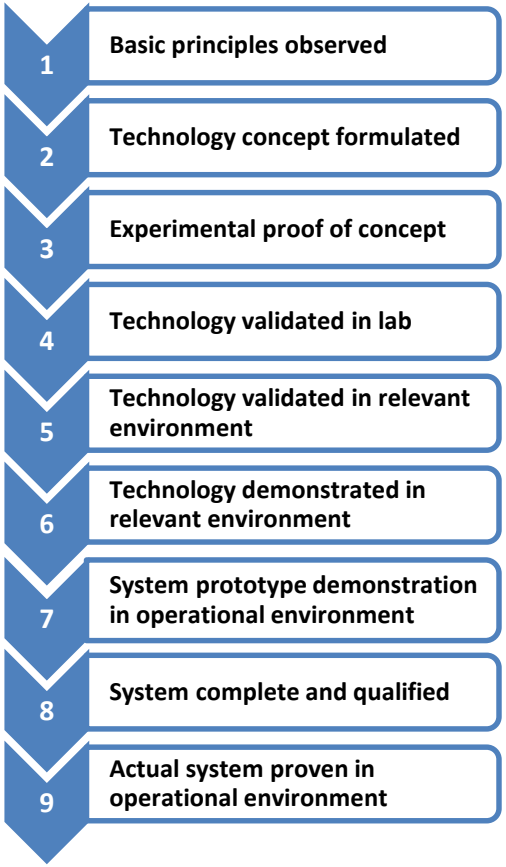
Boilers and Gas Turbines have high TRLs, hydrogen direct fired appliances are less developed

Technology Readiness Level

- Based on initial discussions with technology vendors, it is technically possible to convert many appliances to hydrogen, but there are few examples of commercial implementation.
- The key component in all cases is the **burner technology and design** – this drives appliance design.
- Boiler, dryer, furnace manufacturers can adapt appliances, dependent on the burner design and end use application

Appliance Type	Hydrogen TRL	Comment
Boiler	7 (30 MW)	Commercially available
Kiln	4	Require demonstration
Furnace	5	Require demonstration
Oven / Dryer	4	Require demonstration
Gas Turbine	8	Emissions concerns
Glass Furnace	4	Heat transfer mechanism concerns

EU H2020 TRL Definition



While OEM guarantees are a key piece of evidence, many organisations want demonstration, some on specifically their site

Industry View on demonstration

- The appropriateness of multiple demonstrations for similar technologies will be dependent on any specific difference in application of similar technologies within different sectors.
- Many sites are led by advice from the Original Equipment Manufacturers (OEMs)
- In some cases, industry may not need specific site demonstration and will rely on guarantees provided by vendors that hydrogen equipment will not adversely impact operations.

Level of Evidence required

- **Minimum level of evidence:** Guarantee from OEM that conversion would not adversely impact operations.
- **Medium level of evidence:** System demonstration of appliance for the **specific industrial application**, either at a collaborative location, such as a catapult, or at a willing site with space or redundant facilities.
- **High level of evidence:** Where a sector wide demonstration is not acceptable to a specific site and the site wants an **individual demonstration** of the technology.

Collaborative and site demonstration trials are in progress, such as Glass Futures (2023) and the Industrial Fuel Switching Study Phases 2 and 3 (planned completion March 2021)

Demonstration Trials Required to achieve TRL 9

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Number of Demonstration Trials Required to reach TRL 9 and associated CAPEX

- Costs below are based on converting an existing site with redundant facilities capable of supporting trials. **OPEX or Civil Works not accounted for here**.
- Trial scales based on understanding of range of appliance sizes within industry. In most cases demonstration trials will support 10-20x larger scale commercial implementation.

Appliance Group	Sensitive Sectors*	No. Small Trials (Size)	No. Large Trials (Size)	Rationale	Total Estimated Conversion CAPEX
Boilers:	N/A	2 (1 MW)	2 (5MW)	Wide range of appliances in industry.	£1.5 million
Furnace:	Chemicals & Metals	1 (0.5 MW)	2 (10 MW)	Mostly large furnaces	£3.1 million
Glass Furnace:	Glass	0	1 (15 MW)	Use mothballed site	£1.8 million
Lime Kiln:	Lime	0	1 (5 MW)	Appliances 3-20 MW range	£0.9 million
Kiln:	Ceramics, Glass	2 (1 MW)	1 (5 MW)	Wide range of appliances in industry. High temp (ceramics) and lower temp Lehr kilns.	£1.9 million
Oven:	F&D, Vehicles	4 (0.5 MW)	2 (5 MW)	Appliances in <1-20 MW range. Impact of flue gas moisture content on product.	£3.0 million
Direct Dryer:	F&D, Paper, Ceramics,	3 (0.5 MW)	2 (5 MW)	Appliances in <1-30 MW range. Impact of flue gas moisture content on product.	£2.7 million

- **Costs presented here based on using existing site with redundant facilities to convert**
- **Total fuel costs to run these demos at industrial load factors approx. £35 million per annum****

*Sectors that have specific concerns around conversion impact

** H_2 price of 7.6 p/kWh assumed.

Appliances broken down into components, to resolve components which need conversion with 100% H_2 fuel.

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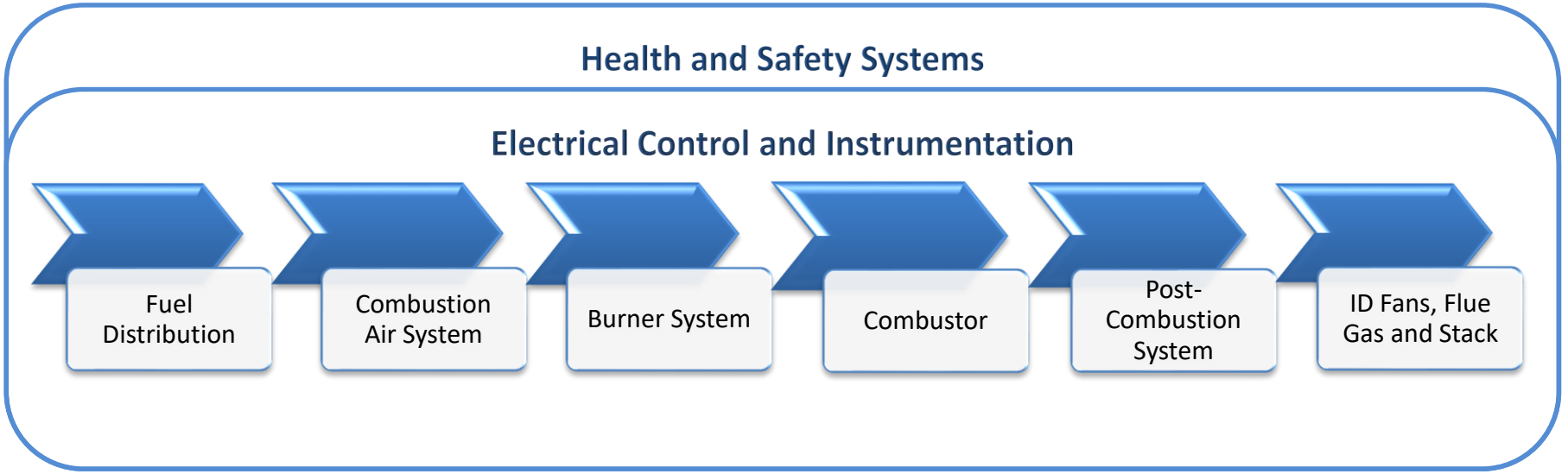
Component Breakdown for Conversion and Cost Estimation



Questions to Consider

- Requirement to convert each module?
- Conversion cost for modules requiring conversion
- Low Technology Readiness Level?

Cost of Conversion Caveat

- The cost of conversion provided is for a **typical** appliance or site within each sector and serves as a ballpark cost for guidance. **Specific sites may vary drastically from this determination.**

Conversion costs differ with appliance types, size and sector

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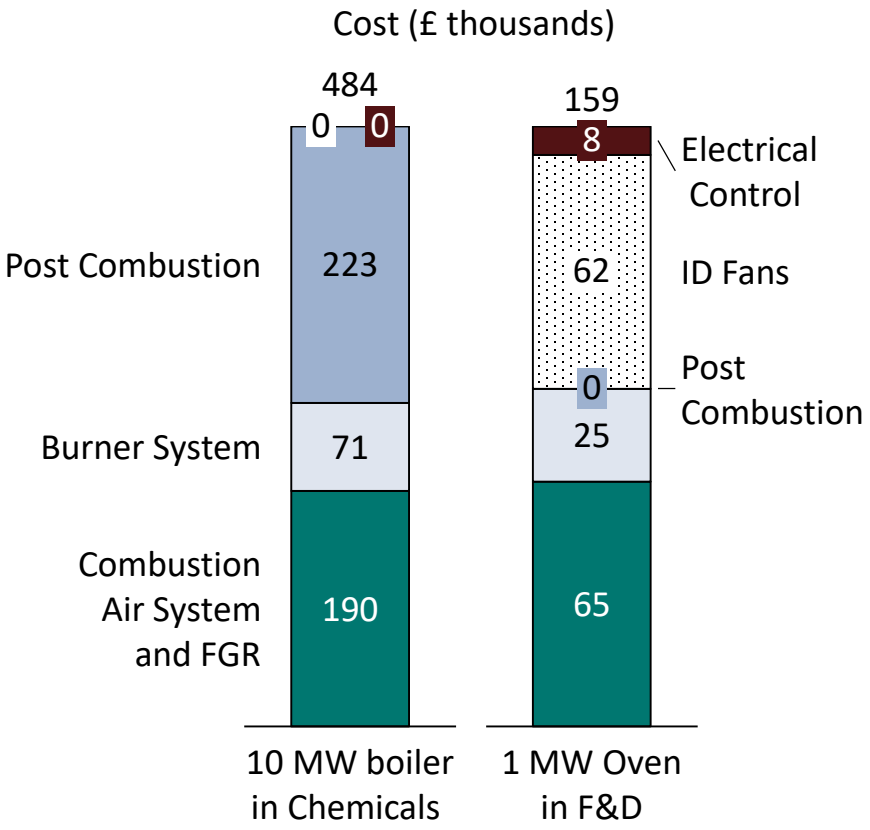
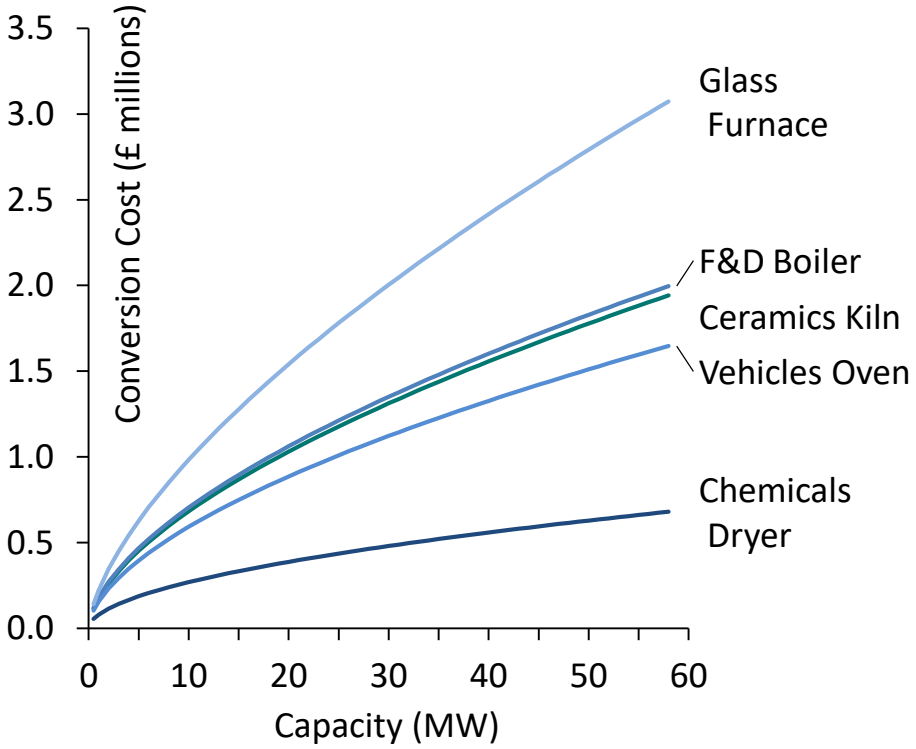
Subcomponent Costs - examples



Appliance Cost Curves - examples



Site level costs – Transmission Pipework (≈£30-60k) and minimum engineering cost (≈£30-60k)

Costs presented here do not include: Civil Works, OPEX, EHS Permitting

Conversion Costs for some Example Appliances

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Example appliance conversion CAPEX*

Sector	Example Equipment	Appliance Conversion CAPEX (£ millions)*
Food and Drink	5 MW Steam Boiler	0.45
Food and Drink	1 MW Oven	0.15
Chemicals	10 MW Steam Boiler	0.64
Chemicals	10 MW Furnace	0.84
Vehicles	2 MW Oven	0.21
Basic Metals	20 MW Furnace	1.11
Paper	5 MW Steam Boiler	0.49
Glass	20 MW Glass Furnace	1.21
Ceramics	2 MW Kiln	0.24
Lime	10 MW Lime Kiln	0.52
Other NM Minerals	10 MW Rotary Dryer	0.43
Elec and Mech Engineering	1.5 MW Hot Water Boiler	0.22

*Does not include site level fuel distribution costs, costs of demonstration programmes, permitting, OPEX or other costs.

There may be a significant impact from OPEX and Hidden Costs

Operational Expenditure

- **Variable costs (fuel and non-fuel):**
  - (Fuel – out of scope)
  - Consumables (increased N_2 for purging)
- **Fixed costs (maintenance and labour):**
  - "Replacement Asset Value" (RAV) approach
  - Considers the equivalent cost of replacing the full asset including all engineering, management, material, licensor and construction costs.

Other potential costs	Approx. Impact (per Site)
Variable OPEX (non-fuel)	50% increase
Fixed OPEX	15% increase
Possible re-permitting	£75k-100k / site
COMAH (very few sites)	£100k / site

Overview of Possible Hidden Costs to Convert

- Hidden costs associated with site appliance conversion not considered part of cost estimate:
  - Feasibility studies
  - Early demonstration of conversion
  - Operational and commercial impact of extra shutdown required for conversion
  - Re-certification with respective authorities might be required
  - Acquiring new warranties for existing equipment when converted to hydrogen firing
  - Increased insurance premiums related to higher risk

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The overall UK conversion cost is estimated to be ≈£2 billion. Sectors with a large number of small sites/appliances dominate.

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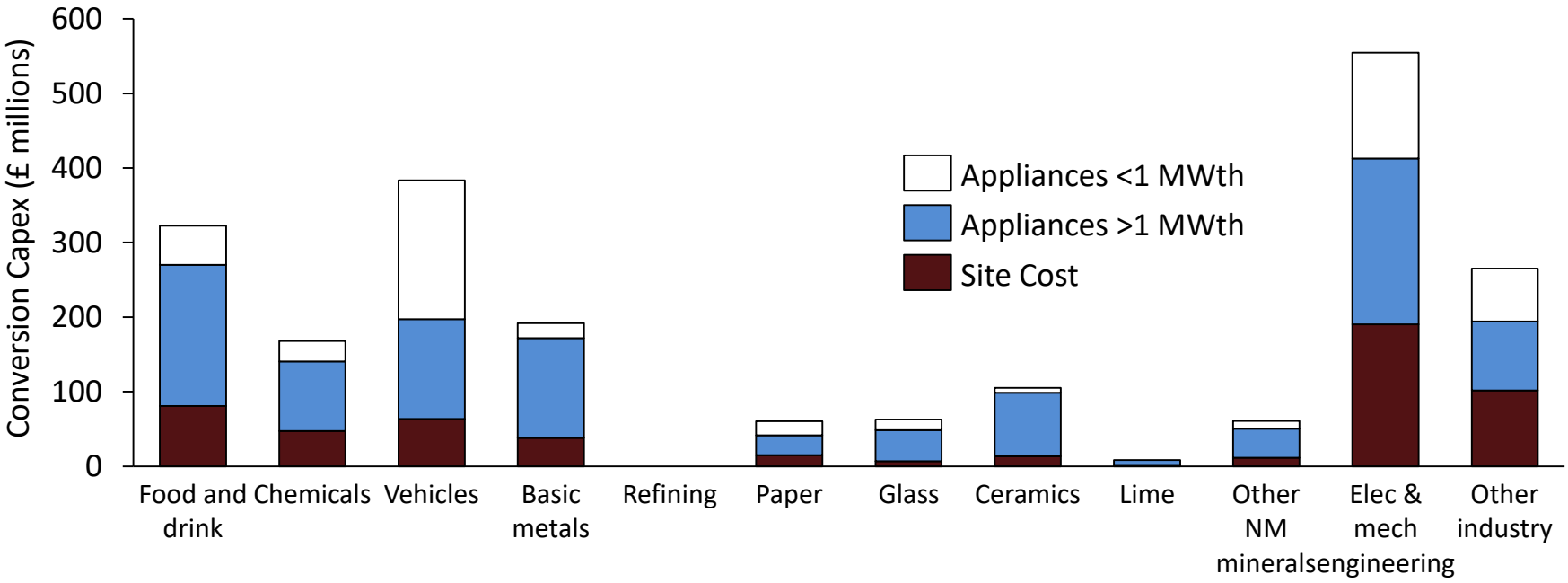
UK wide conversion CAPEX*

- Appliances <1MWth on industrial sites will need to be converted or replaced (e.g. Lehr Kilns).
- Electrical and Mechanical engineering (and Vehicles) has large cost due to many small sites and appliances, little CHP (not costed) and few sites on >7 bar network.



Overall UK wide industrial conversion CAPEX is estimated to be £2.2 billion, including £0.6 billion for appliances <1MWth.*

*CHP, sites <1 GWh/y and >7 bar not costed. Does not include costs of demonstration programmes, permitting, OPEX or other hidden costs.

Technology Development Timeline

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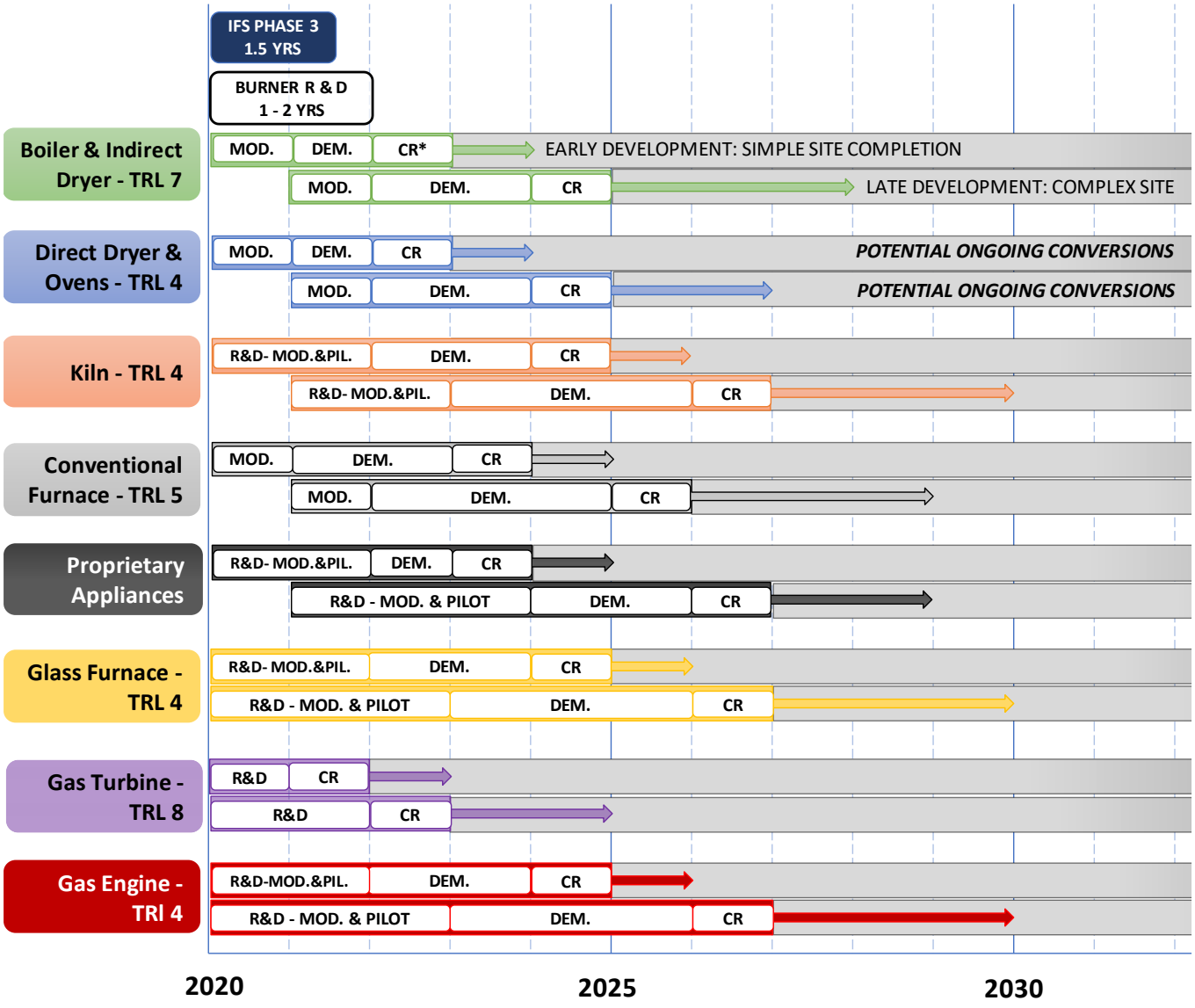

Timeline is focused purely on **technology development**, rather than policy and commercial factors.

Key:

IFS Industrial fuel switching

MOD. modelling

PIL. Pilot scale

DEM. System demonstration at scale

CR Commercial readiness

Overall Conclusions

Appliances in UK Industry

- Around **4000 large scale (>1MWth) industrial natural gas heating appliances** in UK industry
- **Boilers** are the most common appliance type, with wide range of sector specific direct fired appliances such as furnaces, kilns and ovens.
- Large number of <1 MWth appliances on industrial sites will also need to be converted, however a significant proportion are packaged in nature.

Feasibility and timelines of conversion

- Hydrogen conversion is technically **feasible**, with some trials already ongoing, and only certain components need **retrofitting**
- Key technical challenges being addressed – **NO_x, Heat Transfer, Flue Gas Moisture Content**
- Technology Development Timelines are **3-10 years, with earliest conversions possible from ≈2024**. After this point sites and appliances could be converted, dependent on fuel availability, policy and commercial factors.

UK wide Hydrogen Conversion Cost

- CAPEX for UK wide conversion of industry estimated to be **£2-3 billion**, including appliance conversion and site level pipework.
- Economies of scale cause 'cost skew' towards industries with smaller sites / many appliances
- Cost of conversion is sector, appliance and site dependent

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Q&A and discussion on emerging findings

We are happy to accept any questions on the material presented and would also appreciate input on the topics below

Questions for discussion:

- Do the UK equipment stock model outputs align with your expectations?
- Do the modification requirements and costs align with your expectations?
- Are there any key challenges to hydrogen conversion that you would like to highlight?
- Do you have any comments on the technology development timelines?

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Introduction to Session 2

Focus and aims

- **The focus on this session is the challenges to be overcome and the enablers / demonstrations that are required**. Aims include:
  - Additional input into challenges you foresee
  - Understand what level of evidence would be required and how this may be obtained (e.g. through demonstration programmes).

Plan

1. Brief presentation (5 mins) of key barriers which equipment demonstrations and the roll-out method need to address
2. Table group discussion on challenges and enablers / demonstrations (35 mins)
3. Each group will summarise key points from their conversations to feed back to the room for discussion (30 mins)

Demonstrations need to show appliance operation and overcome key technical and EHS barriers.

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Policy from government and fuel supply is required to address economic barriers

	Potential Barriers	Sensitive Sectors*	Enablers
Technical	Heat Transfer – Convection vs Radiative	Glass, Ceramics and Lime	Further experimental investigation on heat transfer balance in glass furnaces and lime kilns
	NO_x emissions	All	Flue gas recirculation, steam addition and post-combustion treatment can be used. Further work on low NOx burners may also reduce emissions.
	H_2 Burner Manufacturers	All except chemical & refinery examples	Further research and development by burner manufacturers. This requires a future commercial market
	H_2 Burner Materials	All	No new action – materials currently exist and have been used
	Flue Gas Moisture Content	Ceramics, Food & Drink, Vehicles, Lime	Specific product demonstration trials required within relevant sectors
	Gas Engine Conversion	Sites with gas engines	Period of research and development, small/large scale trials. Appliance replacement.
	Piping and fittings	All	No new action – materials and standards currently exist.
EHS	DSEAR cost and space impact	All	Solution on a site by site basis – move or replace affected equipment and workstations
	COMAH risk	All	Solution on a site by site basis. Only a small number of sites may be affected. Re-permitting or reduced storage
	Re-permitting	All	New environmental permitting required for converted equipment.
Other	Staff Training	All	No new action; training on H2 appliances available with sufficient warning.
	Hidden Costs	All	Site by site basis
Economics	**Energy Costs**	All	Potential subsidies, incentives, reduced hydrogen costs as a result of capital investment
	Conversion Outage	All	Fund costs. Early warning of conversion (~10 years) so companies can plan.
	Return on invested capital	All	Fund costs. Early warning of conversion (~10 years) so companies can plan.

*Sectors that have specific concerns around conversion impact and uncertainties

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Workshop session 2 – group discussion

Topic 1: Barriers and opportunities associated with hydrogen conversion

- Additional challenges or barriers your organisation would like to highlight?
- What other opportunities are associated with hydrogen conversion for your industry?
- How far in advance do you need to be warned by government for a network switch to hydrogen?

Topic 2: required level of evidence / demonstration programmes

- What level of trials and demonstration programmes would be required in your sector / equipment?
- How would you envisage these happening and would you be interested in participating?
- What might be the costs associated with the demonstration programmes in your sector / equipment?
- What timeframes would you expect these to be completed over?
- What other enablers would be required?

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Workshop wrap-up

Project next steps

- Collate and review the input from this workshop
- Finalise the cost modelling work and recommendations around timelines for demonstration
- Report to be drafted in coming weeks and published in a couple of months

Wider workstreams

- Wider Hy4Heat programme: other applications, H_2 quality and safety, demonstration
- Initiatives such as HyNet, H21, HyDeploy (blending 20%)
- Industrial Fuel Switching Phases 2 and 3 (overall £20 million in funding)

Thank you