KEW TECHNOLOGY

Modular Approach to Decarbonisation of Energy for Glass:

"MADE for Glass"

An innovative industrial decarbonisation solution
DESNZ Industrial Fuel Switching Phase I Report

Department for Energy Security & Net Zero

NSG GROUP

PILKINGTON

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Executive Summary

DESNZ Industrial Fuel Switching Programme overview

The Department for Energy Security and Net Zero (DESNZ) is actively working on several grant-funded programs to support the UK's goal of achieving Net Zero by 2050. These programs focus on low carbon feasibility and demonstration, covering hydrogen production, bioenergy supply chain development, and greenhouse gas (GHG) reduction technology.

DESNZ is committed to helping UK industries decarbonize, not only to protect the environment but also to safeguard skilled jobs against global competition. One such initiative, the Industrial Fuel Switching (IFS) program, aims to develop low carbon energy solutions for UK industries, enabling a smooth transition to sustainable and carbon-neutral alternatives.

Addressing energy use in the industrial sector is critical as it accounts for the largest portion of GHG emissions. By taking urgent action in this area, the UK can make significant progress towards achieving its 2050 Net Zero objectives. Together, we can build a sustainable and greener future for our country.

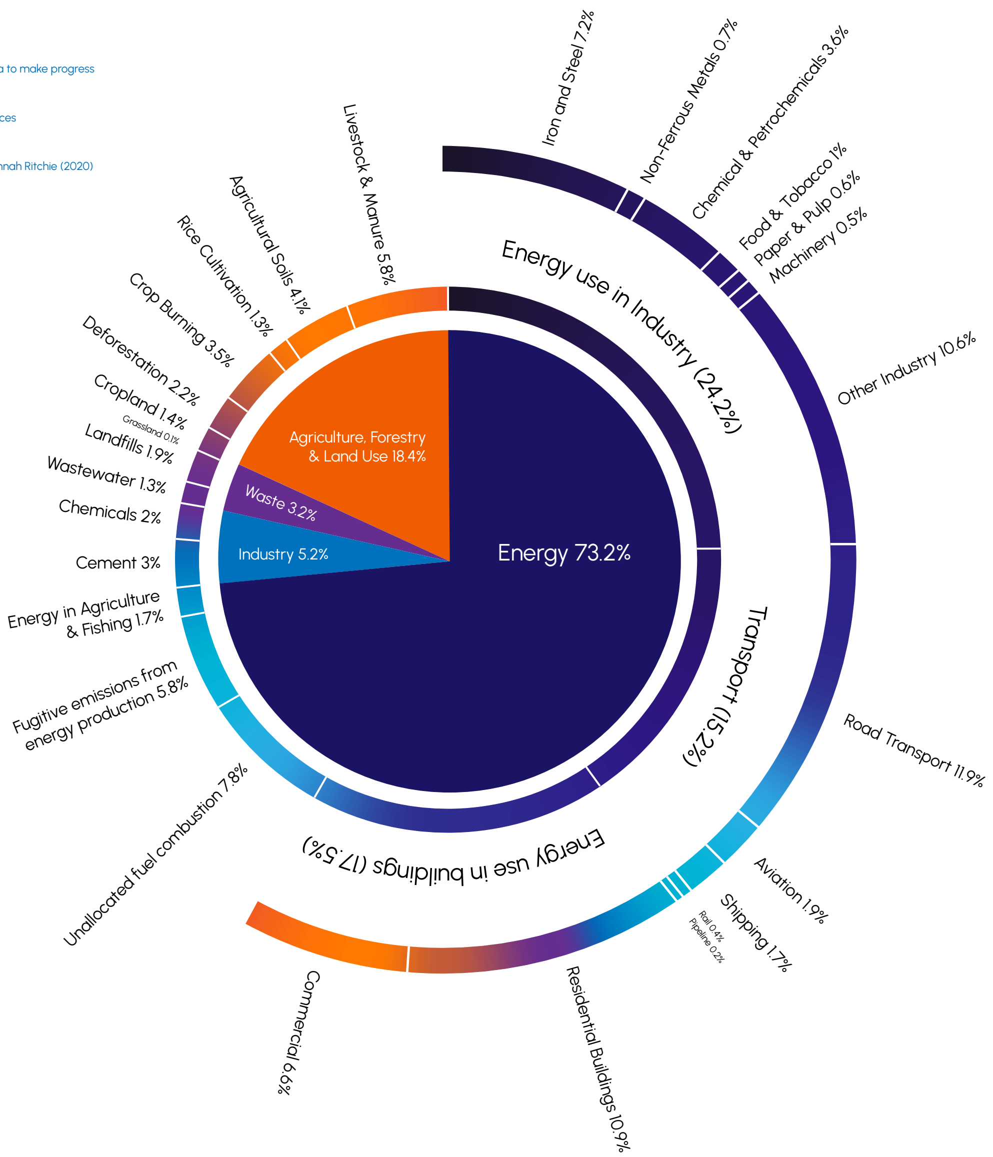
Global greenhouse gas emissions by sector

Figure 1

This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO_2eq.

OurWorldinData.org – Research and data to make progress against the world's largest problems.

Source: Climate Watch, the World Resources Institute (2020).



DESNZ' fuel switching initiative has been divided into three areas of focus: hydrogen, electrification and biomass/waste solutions. There are developmental challenges in all three areas which are being investigated under the IFS program. Development is being funded in energy generation, energy transport, materials manufacture as well as process electrification and switching from natural gas to biomass, and derived syngas

MADE for Glass project background

KEW Technology (KEW), together with the NSG Group, has been in discussion regarding potential waste and low-grade biomass derived energy solutions to decarbonise the glass manufacturing process using a modular deployment of KEW's proven advanced gasification process, a form of Advanced Conversion Technology (ACT).

This modular approach to the decarbonisation of energy for glass manufacturing (MADE for Glass) should pave the way not only for the decarbonisation of the UK glass industry, but also develop techniques and integration solutions which can be deployed more widely across other industrial sectors such as pulp and paper, steel, nickel refineries, cement, and chemicals.

The glass industry faces specific challenges as the float furnace process cannot be electrified because a flame is needed to impart important characteristics into the final product. While conversion to hydrogen is technically possible, as has been demonstrated at Pilkington United Kingdom Limited, part of the NSG Group, Greengate Works site already, this does not provide a viable permanent fuel switching solution today as the volume of hydrogen required, c.1.5 tonnes per hour, could only be delivered by pipe and no such network exists now or will exist in the short to medium term. Until such a pipe network were to exist, the only way in which glass manufacturing could switch to a low carbon fuel is for low carbon fuel to be manufactured at site from biomass or a biogenic rich feedstocks such as waste and low-grade biomass.

KEW's decarbonisation solution: clean syngas replacement of natural gas

KEW has proposed two different modular industrial fuel switching solutions for two of the NSG Group's UK glass manufacturing plants. Both solutions involve the advanced gasification of waste or biomass in KEW's modular plants to create a hydrogen-rich syngas. This syngas will be used to replace, either partially or wholly, the use of natural gas. This will provide significant decarbonisation benefits, providing financial stability through predictable and lower energy costs all without impacting product quality. KEW's industrial fuel switching solution includes the following key features:

- A pressurised advanced gasification unit, a form of Advanced Conversion Technology (ACT), which can utilise a wide variety of non-recyclable waste and low-grade biomass feedstocks processes by unique application of pressure, a fluidised bed gasification system, and a proprietary downstream synthesis gas (syngas) reformation process
- Carbon capture ready syngas with consistent composition and quality. KEW's proprietary process, the Equilibrium Approach Reformer (EAR), produces a consistent, clean, hydrogen-rich composition of syngas free of any hydrocarbons (tar) and contaminants to enable stable performance parameters, low-cost operations, and reliable syngas offtake ready for use in existing industrial processes with minimal equipment changes required. The lack of tar-free syngas and composition consistency and quality has been the traditional 'Achilles heel' of other precursor ACT technologies

- A unique modular approach for the waste-to-energy and biofuels sector enabling early adopters to overcome the current risk and challenges of large-scale, bespoke project solutions by offering repeat proven units while allowing for the subsequent installation of additional modules in a flexible, rapid deployment approach. KEW's modular solution, aided through the application of pressure, provides c.8 times the capacity of equivalent-sized atmospheric units thus enabling commercially viable projects in very compact footprints for the decentralised industrial market that is not well served by a large-scale centralised production and supply model. The modularity also enables installations across the whole of the UK local to feedstock supply; in dispersed sites or, in the future, near carbon capture and storage (CCS) pipelines
- Existing, operational advanced gasification plant at commercial scale, with unique support from the Energy Technologies Institute (ETI), KEW has constructed, commissioned and is now operating the Sustainable Energy Centre (SEC). This existing operational plant limits the technology development risk incurred with developing an industrial fuel switching solution to only the incremental risk in the syngas integration, not the whole end-to-end process
- Advanced gasification for industrial fuel switching has strong sustainability and ESG credentials as it utilizes renewable waste/biomass, reduces GHG emissions, promotes the circular economy, enhances local energy production and social impact, and aligns with regulations while fostering innovation

Developing the integration solution: focus of the Phase I feasibility

KEW's core focus in Phase I of the Industrial Fuel Switching Programme was to assess the technical and commercial feasibility of the proposed integration solution, to provide a strong foundation for the subsequent detailed engineering, development, and demonstration of the preferred site in Phase II. For this Phase 1 assessment, KEW focused on two NSG Group sites:

1. **Pilkington UK's Greengate Works, St Helens – float glass manufacture, requiring direct fire solution**
2. **NGF, St Helens – glass cord reinforced drive belt manufacture, requiring indirect fire solution**

Our key areas of focus were:

- Baseline solution: Analysing the energy demand of both sites, nature of that demand in terms of KEW modules and therefore the space required onsite for the syngas modules
- Determining optimum layouts for the positioning of syngas modules, utility connections, feedstock stores, vehicle movements, and the piping of the syngas to where natural gas is currently being used
- Determining the maximum fuel switching possible for the direct fire solution: looking at indirect firing for one facility and direct firing in the float glass furnace at the other facility, which included undertaking natural gas/syngas mix flame trials to assess characteristics such as temperature, flame length, luminosity, burn rates and other factors

- Analysing the business case for commercial deployment of the modular product and comparison with the current and forecast energy and carbon tax costs
- Analysing sustainability benefits of the NSG Group switching from natural gas to syngas

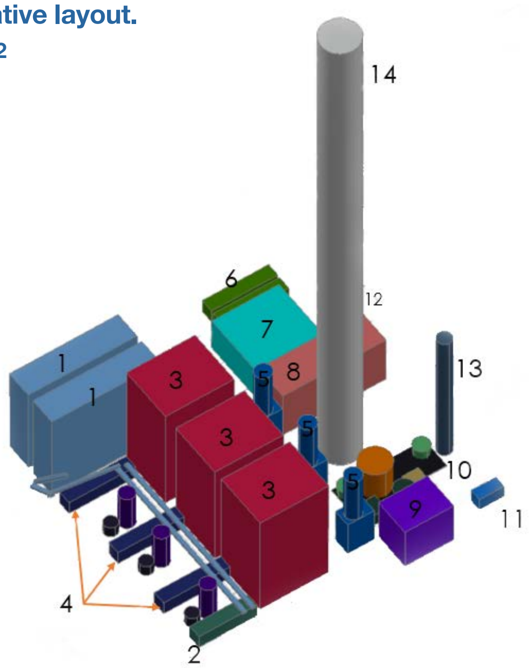
Core conclusions of the Phase I feasibility

Summary of the integration Phase I feasibility justifying progression to Phase II demonstration

- A complementary technology solution: KEW's development of its industrial fuel switching solution has been designed in a way that enables it to be deployed across many industries, either alone or in conjunction with other technologies. The modular nature of the solution facilitates its deployment into a wider range of industrial settings as the energy balance can be better achieved and the end-energy vector can be selected to match the industrial user's requirements
- Demonstration ready: the existence of the SEC, as a proven commercial scale demonstrator of the advanced gasification technology, significantly reduces the commercial and financial risks of installing and developing industrial fuel switching solutions to the energy integration
- Overall, the industrial fuel switching solution proposed here is founded on the principle of converting the maximum possible energy contained in a wide-range of biomass and waste sources into a low carbon or carbon-free energy vector. This offers a strong opportunity for decarbonisation of UK industry now. The technology exists and its deliverability does not rely on future CCS or new hydrogen grid construction

Preferred site option for Phase II: Overview of Pilkington UK's Greengate Works integration /solution

Indicative layout.
Figure 2



1. Fuel reception/storage
2. Day fuel bin (1-of)
3. XTE modular unit (3-of)
4. MCC/LER (3-of)
5. Char/ash silo (3-of)
6. Control Room/office
7. Water island
8. Oxygen and nitrogen packages
9. Cooling water package
10. Syngas cleaning and wastewater treatment plant
11. HV/MV building
12. IA/CA packages
13. Flare
14. Existing Greengate Works UK6 stack

Pilkington UK's Greengate Works was chosen as the preferred site due to its higher complexity and the need for further innovation, setting it apart from the other site option. The core scope of the Phase I feasibility (to be demonstrated at commercial scale in Phase II) is to install KEW modular advanced gasification units at the NSG Group facility, process waste and biomass feedstocks into a hydrogen rich syngas and use that syngas as a replacement fuel to reduce NSG Group's current reliance on natural gas. The Phase II deployment will only involve the installation of 1 module due to the IFS grant program financial limitations. However, as KEW's solution is modular, additional syngas modules can be installed after the end of the Phase II project, (to displace a higher volume of natural gas) following successful integration demonstration. The proposed integration solution is designed to fit within a limited space, including feedstock store, confirming its deployability within industrial premises across the UK.

The successful demonstration of the integrated syngas modules will increase the TRL of the technology to TRL 8 and trigger the commercialisation of the integration solution from the end of the Phase II project in early 2025.

A low-cost decarbonisation solution

Following a technical feasibility study for the two-site option, KEW's Phase I commercial and financial assessment concluded:

- KEW's fuel switching solution can be deployed at a lower cost to industry than long run natural gas prices, let alone the current very high pricepoint
- Indicative financial modelling in Phase I is based on zero government incentives, which provides a compelling 'value for money' proposition for policy makers and tax payers

Other benefits of the MADE for Glass project and of supporting KEW's modular ACT as a key pathway for decarbonising UK industry

- Effective utilisation of the valuable waste and biomass: KEW's process utilises waste or low-grade biomass as a feedstock, which is a renewable and recycled carbon energy source. By efficiently converting these materials into clean syngas, it reduces the reliance on finite fossil fuels and contributes to a more sustainable energy mix, as well as supporting waste reduction and promoting the circular economy. The solution transforms waste into valuable energy, reducing landfill and incineration of waste and promoting resource efficiency
- GHG reduction: this fuel switching solution produces syngas with lower carbon intensity, significantly reducing GHG emissions compared to traditional fossil fuel-based processes. This contributes to mitigating climate change and achieving environmental goals
- Pathway to net negative: as carbon capture, usage, and storage (CCUS) becomes widely available, KEW's modular solution can be retrofitted with a carbon capture module to achieve a net negative energy output

- De-risked scale-up: at the core of KEW's strategy is standardised factory-build modular construction which enables strong ongoing cost-reductions enabling wide-spread deployment. The modules can be installed and commissioned at host industrial sites in short timescales with minimal disruption and risk, making use of locally available feedstock
- Regulatory compliance and reporting: this industrial fuel switching solution aligns with stringent environmental regulations and reporting standards. It demonstrates a commitment to ESG principles

Wider macro impacts: environmental and social benefits

- Improving the competitiveness of UK industry will be achieved through the deployment of affordable, low carbon fuel switching solutions. Customers are increasingly demanding "low carbon" products and industrial companies who are unable to deliver this will begin to lose market share and/or come under price pressure
- Protecting UK manufacturing jobs will be an outcome of industrial fuel switching as it will assist in retaining manufacturing jobs in the UK
- KEW's proposed geographically distributed deployment model provides value to all areas of the UK economy, particularly those areas which will not be connected to CCS infrastructure or a hydrogen grid for many years. Without access to viable low carbon energy, it is likely that manufacturing jobs would gravitate to the CCS clusters (or abroad) before any hydrogen grid was complete thus impacting adversely on the Levelling Up agenda as regional imbalances would be reinforced
- Further addressing the residual waste headroom: Further growth in waste treatment infrastructure required to close the residual waste headroom is likely to be driven by decentralised projects with a smaller annual waste catchment, rather than larger waste requirement projects. Investors acting rationally will become uncomfortable funding larger plants as they are likely to tip regional residual waste headrooms into deficits, resulting in a decline in gate fees as seen across continental Europe
- Positive social impact: Advanced gasification can create local job opportunities and stimulate economic growth in communities where the technology is deployed. It contributes to sustainable development and enhances social well-being
- Technology advancement: Investing in advanced gasification demonstrates a commitment to adopting innovative and cleaner technologies. It showcases a proactive approach to sustainability and positions the UK as a leader in the industry's transition to low-carbon alternatives

Phase II Demonstration proposed outcome: a commercial-scale integration demonstration

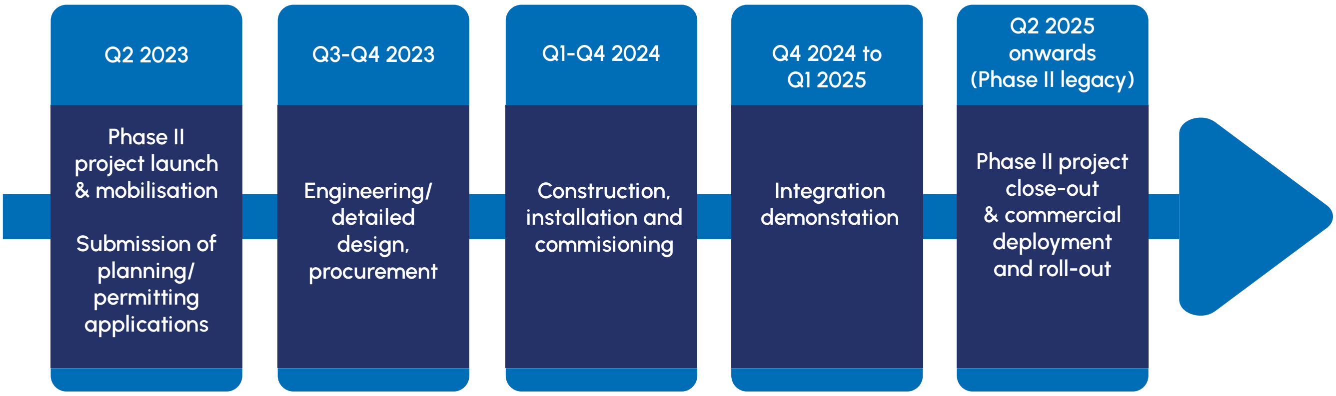
The Phase II demonstration will deliver a full-scale industrial fuel switching solution from waste/biomass to syngas to deployment at Pilkington UK's Greengate Works float glass furnace, resulting in the replacement of a proportion of existing natural gas usage. The demonstration will build on the existing commercial scale equipment at KEW's Sustainable Energy Centre to demonstrate the innovation of the industrial integration solution and its performance at an industrial facility.

Building on the key insights from Phase I, the proposed demonstration will have the following objectives:

1. **Technical: detailed design and installation of the integrated fuel switching system and a series of tests followed by continuous operation of the end-to-end low carbon energy supply solution**
2. **Commercial: to validate the economic case for industrial fuel switching comprising an assessment of operating costs, feedstock costs/income, impact on UK ETS obligations, etc**

These objectives are intended to integrate based on the indicative timeline shown in Figure 3 and summarised in more detail in Section 3.

Figure 3 **MADE for Glass timeline**



The demonstration will draw upon KEW's existing operational advanced gasification plant, with a new module being constructed and installed at the Pilkington UK's Greengate Works site. This will ensure the supply of syngas is sufficient to enable the extended period of continuous running to be achieved. This is important to demonstrate the feasibility of fuel switching without impacting ultimate output product quality.

Industrial decarbonisation commercial deployment pathway

The industrial decarbonisation commercial deployment pathway will build on the successful demonstration of the integration of KEW's modular technology at a major UK industrial site. The roll-out will focus on the deployment of modules across UK energy-intensive industry reliant on fossil fuels such as natural gas. This is part of a pathway of a range of solutions to take initial decarbonisation measures now utilising technology that can be upgraded in several years' time to provide further decarbonisation benefits as CCUS opportunities become widely available throughout the UK.

Direct firing syngas industrial fuel switching solutions are inherently more risky than indirect firing solutions as the use of the syngas forms a key part the manufacturing process. Upon the successful conclusion of the demonstration phase project at NSG Group's Pilkington UK Greengate Works, KEW will have access to the empirical data to show that a syngas solution can be delivered safely at acceptable cost and provide significant reductions in a customer's carbon footprint. The ability to reference operational direct firing will also act to support indirect firing decarbonisation opportunities as the technical challenges are less.

The attractiveness of low carbon, fixed price, lower cost, secure energy supply has already triggered significant interest from UK industry, but the technology is only starting to commercialise and is currently at early adoption with NSG Group being a pioneering early adopter for energy-intensive industry. KEW, by being able to provide a compact footprint, decentralised, standardised but flexible solution, will be able to engage with a significant proportion of UK industry to enable decarbonisation to be accelerated. This wider deployment planning will commence during Phase II to maximise the opportunity provided by the Industrial Fuel Switching Program.

Once there is a technology reference, the attractiveness of KEW's sustainable energy solution to the investment community will also be significantly enhanced. This ability to access third party finance will remove one of the remaining impediments to quick roll out and also enable UK industry to retain their scarce investment capital for core investment projects, product development, and energy efficiency measures.

1. Industrial Fuel Switching: a decarbonisation solution enforcing a circular economy

1.1 The opportunity: at the heart of two parallel market ®evolutions

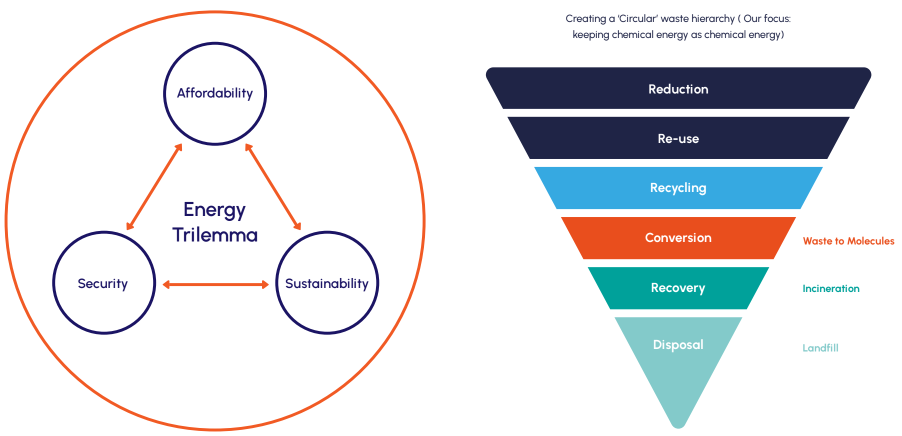


Figure 4

1.1.1 The problem

A technology gap exists for small and medium scale decentralised technology solutions which could be used to provide a more flexible and local solution to facilitate industrial decarbonisation through fuel switching. This technology gap was identified by the Energy Technologies Institute around 2012 and resulted in a development programme which provided strong support to KEW's technology development.

The benefits of supporting small to medium scale ACT, and in KEW's case with modular scalability, is the ability to efficiently convert, at flexible scales (e.g. 20ktpa to 200ktpa of waste) a wide range of both residual waste and/or biomass directly into a range of high-value energy vectors.

In addition to this, the UK and global market, have seen many failed larger-scale ACT projects, where either (i) waste types, (ii) residue outputs, (iii) and more typically the failure to deal with the resultant long-chain hydrocarbons (tar) within the syngas stream. This has led to many projects failing with significant investment and confidence in the technology lost. Ultimately, these failed ACT technologies had sought to accelerate from lab-scale demonstration to full scale commercial operations, without sufficient investment being made in the R&D scale-up cycle that is critical to bridge the technology scale up element of the technology readiness curve.

1.1.2 How KEW's technology solution addresses the problem

KEW's mission is to simultaneously tackle two of the most significant global environmental issues – providing low or negative carbon sustainable energy through the effective conversion of waste and/or biomass in a true circular economy framework. Decarbonisation is the biggest challenge of the current century, with circular economy becoming the dominant issue from a resource preservation and allocation perspective.

KEW's process enables the high-efficiency valorisation of non-recyclable waste and biomass feedstocks through high-pressure conversion into high-value energy products such as a replacement for natural gas and advanced molecules such as hydrogen, rDME, rMethanol, aviation fuel, etc). The syngas produced comprises significant but stable proportions of H_2 and CO, providing confidence to industrial users regarding the predictability of performance of the syngas necessary to support its integration into a critical manufacturing process.

KEW's key technology USP is operating the advanced gasification process under pressure, with a patented syngas reformation step, which enables the cracking of the longer hydrocarbons and removal of impurities which otherwise creates challenges with solids and tar build up – one of the biggest challenges in the gasification space. Additionally, the use of pressure is a strategic design characteristic which gives rise to the significant benefits of economised scale and costs enabling KEW's unique strategy: to apply its technology into embedded industrial processes and deploy its technology immediately while allowing a gradual commercial ramp-up of larger advanced sustainable fuels production facilities with leading energy corporate strategic partners.

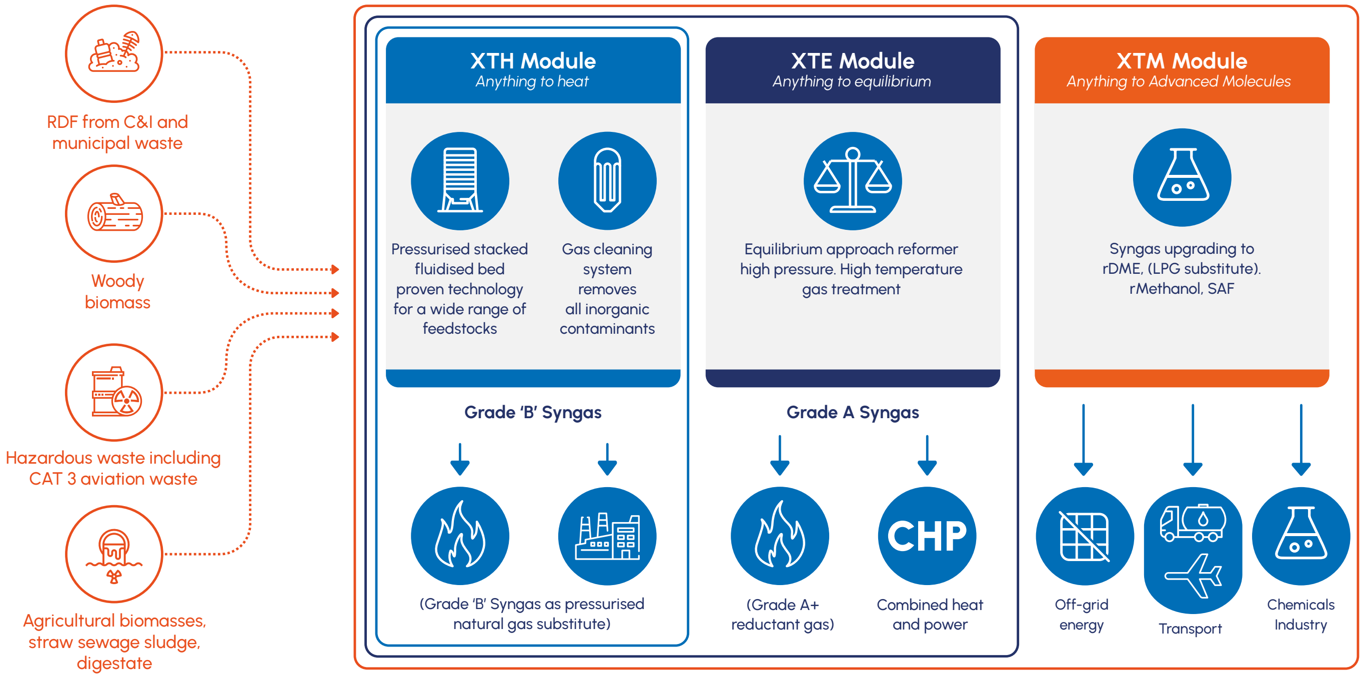
KEW's modular, high-pressure system is capable of processing a wider basket of waste and biomass feedstocks. Uniquely, the system can effectively process low-grade biomass such as sewage sludge, AD digestate, and waste 'fines'. This effective solution for low grade waste feedstocks diverts commercial and industrial waste material from landfill, generating an economic saving as well as providing an environmental benefit.

The modular high-pressure design combined with the processing of low-grade feedstocks drives a compelling economic proposition. Equally, our modular technology and consistent syngas composition provides a unique stepping-stone towards high value energy vectors such as hydrogen, rMethanol, aviation fuel, and LPG alternatives.

From an emissions perspective, the solution is fundamentally low carbon, significantly reducing the emissions associated with the applications which they fuel. Moreover, the KEW solution is inherently carbon capture ready; enabled for pre-combustion capture. This is much more cost effective than attempting post combustion capture and KEW's plants produce pressurised CO_2 reducing cost for capture and utilisation or sequestration.

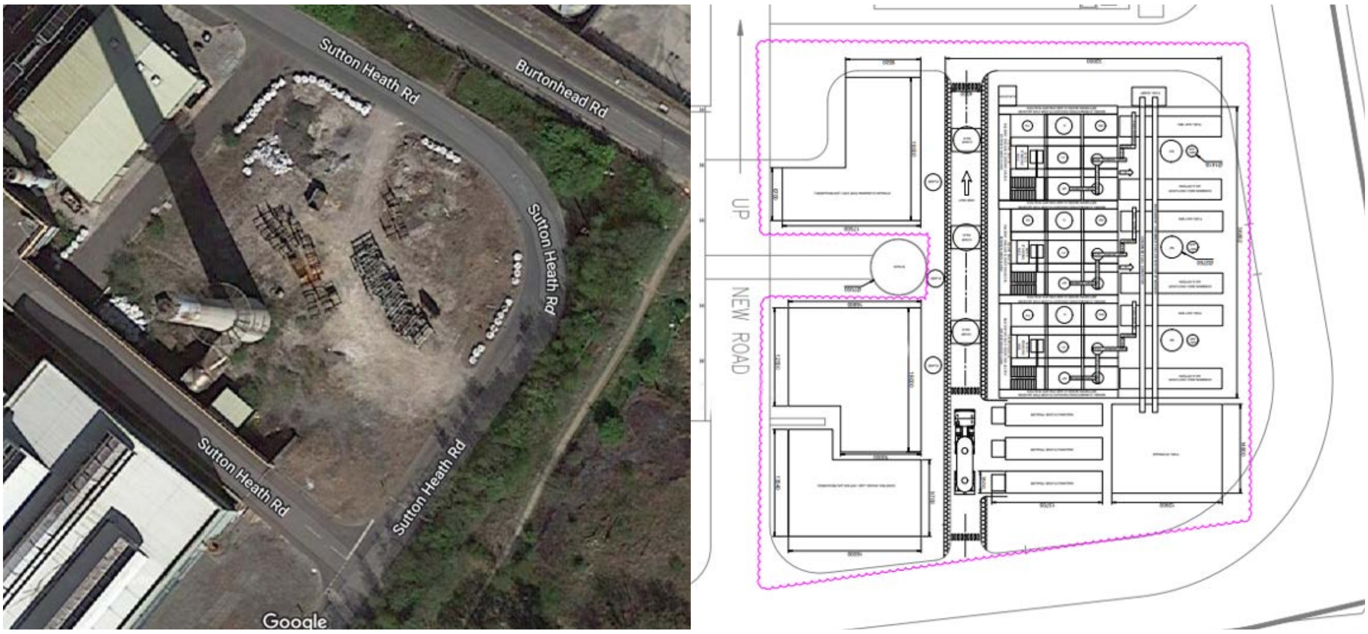
KEW's modular technology is ideally suited to industrial co-location as it can process a wide variety of waste and biomass resources and efficiently convert them into a wide variety of useful energy vectors, as shown below.

Figure 5



1.2 The industrial decarbonisation opportunity

Figure 6



KEW's proposed industrial decarbonisation solution involves co-locating KEW modules on industrial sites and integrating the energy vector produced into the industrial customer's existing energy system. Given KEW's compact syngas modules, there are significant opportunities for deployment across UK industry. In the MADE for Glass project, KEW and NSG Group have been assessing a fuel switching solution for their Pilkington UK Greengate Works site in St Helens. The picture above identifies the proposed site, currently brownfield land, which is proposed to be used in a Phase 2 Demonstration project. The graphic also highlights a further deployment benefit of KEW's modular system in that the major plant can be placed in a range of physical configurations to best utilise the available space. In this case, the layout has been designed to fit around an existing chimney.

Waste in refuse-derived fuel (RDF) form or waste wood will be converted into a hydrogen-rich syngas, which will then be piped across to the glass furnace, blended upto 30% with natural gas (necessary to maintain the product quality), and then the gaseous mixture will be fired into the glass furnace.

The flexibility of KEW's solution gives confidence about the wider applicability of its use across the UK economy as a way of enabling industry to decarbonise through fuel switching from natural gas to biomass-based alternatives.

1.3 A glass industry decarbonisation solution: KEW's proposition

KEW's commercial and technical solution provides a strong decarbonisation solution while also enabling a glass manufacturer to both fix and reduce its energy costs. Fixing energy costs is possible because of the switch away from fossil fuels to a waste derived syngas where the waste is supplied under a long term, fixed price contract. Given limited variability in other costs, the overall energy costs can be fixed over the long term to achieve required investor returns or payback periods. The energy cost reduction comes through a combination of income for processing wastes and significant reductions in a company's obligations under the UK Emissions Trading Scheme (UK ETS).

The solution would achieve these aims through co-locating KEW syngas modules at the glass manufacturer's site to produce a waste or biomass derived syngas which could be used as a low carbon alternative for natural gas without impacting product quality. The number of units which could be located at an industrial site will be dependent upon both the available space and the energy requirements.

Each modular advanced gasification unit:

- Consumes around c.20,000 tonnes of feedstocks per year
- Produces c. 5-7 MWth energy output as syngas

The core underlying advanced gasification technology is already commissioned and in operation at KEW's Sustainable Energy Centre (SEC) in Wednesbury near Birmingham, UK. KEW has assessed the installation and integration possibilities at two separate sites which are part of the NSG Group.

The first, at NSG Group's Pilkington UK Greengate Works site, required the syngas to be mixed with natural gas and then co-fired in the float glass furnace. Due to the need to maintain flame quality and characteristics, the project included an assessment of the greatest syngas proportion which could be used without impacting glass production.

The second, at the NSG Group's NGF Europe site, required the firing of the syngas in a burner to create steam. With the second solution being indirect firing into a burner, there were no technical limits to the proportion of switch over and a 100% switch over to syngas was considered.

The key to the successful integration of KEW's module and the waste/biomass derived syngas is maintaining the flame properties given the different characteristics of the syngas as compared with natural gas. The image below shows the flame within the float glass furnace.

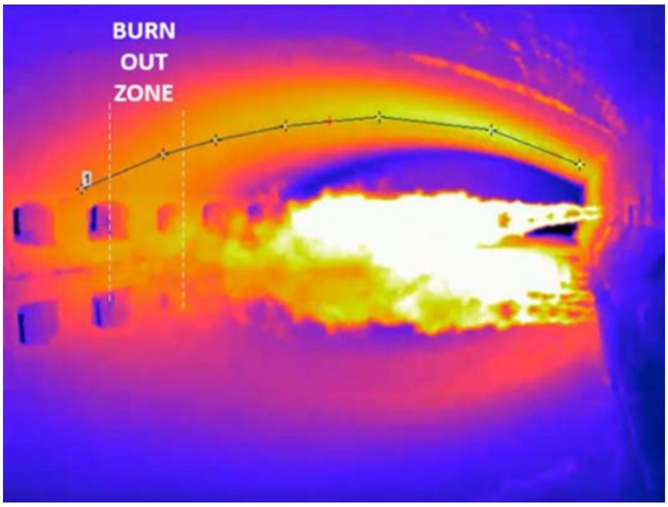
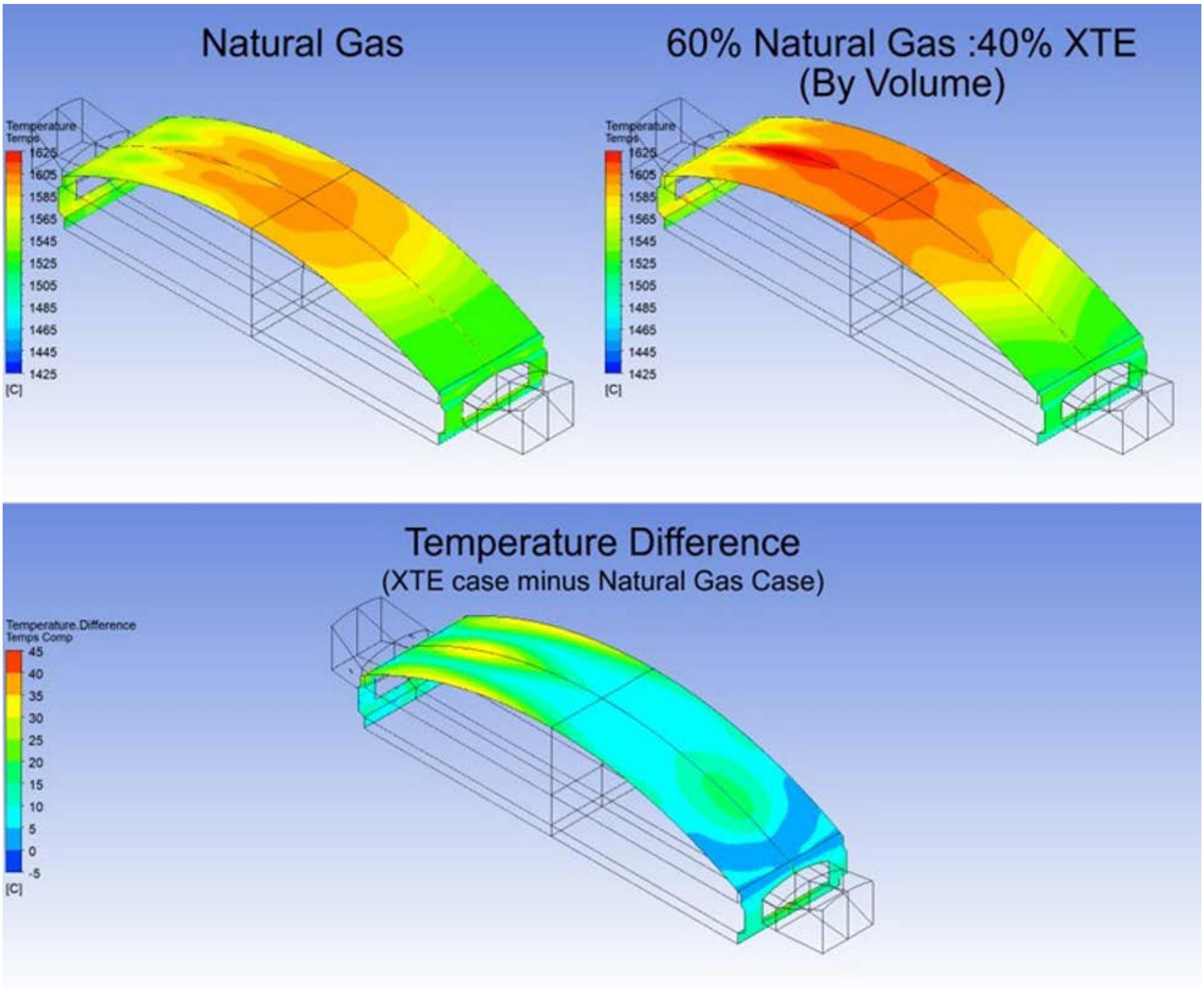


Figure 7

KEW designed and manufactured a syngas flame test rig so that it could test the flame properties at various syngas percentages. This would identify the maximum decarbonisation possible. The flame properties assessed included flame length, absolute temperature, change in temperature across the flame length, and luminosity. From these measurements, it was possible to determine the maximum fuel switching. The test results were confirmed with detailed CFD modelling.

Figure 8



2. Benefits of the industrial decarbonisation solution

2.1 Commercial benefits

2.1.1 A low-cost, fixed price secure energy supply industrial energy solution

Recent global events have highlighted the exposure the UK industry has to global events and the affordability and security of energy. The MADE for Glass project assessed the technical and economic solutions available to switch heavy industry from fossil fuel to low carbon energy. Not only would this switch reduce industry's carbon footprint but would reduce their energy costs and, as importantly, move them onto a predictable price base from a secure local energy supply.

The costs of switching are predominantly incurred in the installation and integration of the syngas modules. Once installed, the ongoing costs are relatively small and, if waste is used as a feedstock, provide additional income.

The project feedstock would be sourced under a long-term fixed price contract. Operating costs of the modules would also be fixed and predictable being mainly labour. This fixed, low-cost base will enable industry to budget more accurately their energy costs which, in turn, would enable them to signal better to markets the prices for their products.

2.1.2 Pathway to achieving a low-cost industrial solution

KEW's financial assessment (see Figures 9 and 10), has considered installations at each site. Different technical solutions were developed reflecting the differing energy volume requirements and syngas quality. The solutions were:

For the Greengate site:

- Install 3 of KEW's XTE ("Anything to Equilibrium") syngas modules to provide the tar-free hydrogen-rich gas necessary for direct firing
- 3 modules represented the maximum possible switch from natural gas to syngas without impacting flame quality
- 3 modules were also the maximum number of modules which could be installed on the available space

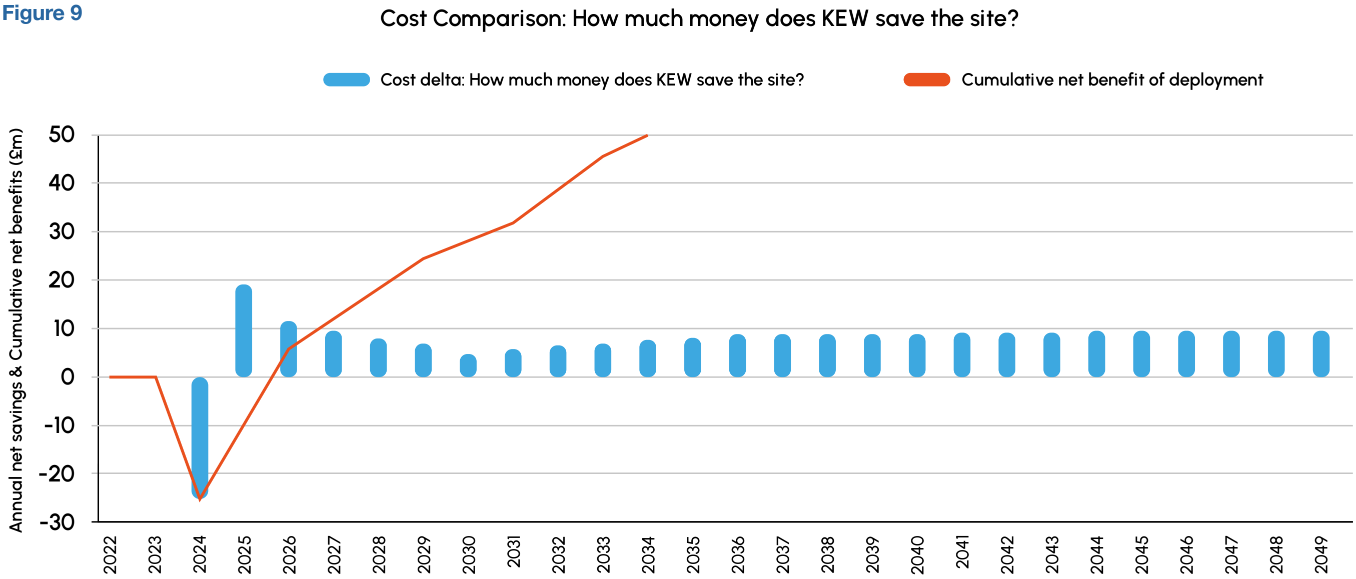
For the NGFE site:

- Install 1 of KEW's XTH ("Anything to Heat") syngas modules for indirect firing in a burner
- 1 module would provide 100% of the energy required at NGFE
- 1 module was also the maximum number of modules which could be installed on the available space

The modularity and flexibility of KEW's solution enables bespoke fuel switching solutions to be developed to reflect the particular energy type, volume requirements, and available space of industrial customers. The costs used in the financial assessment represent current pricing information for KEW modules and additional equipment. While KEW expects cost savings in respect of its modules as these are deployed more widely, those savings have not been included.

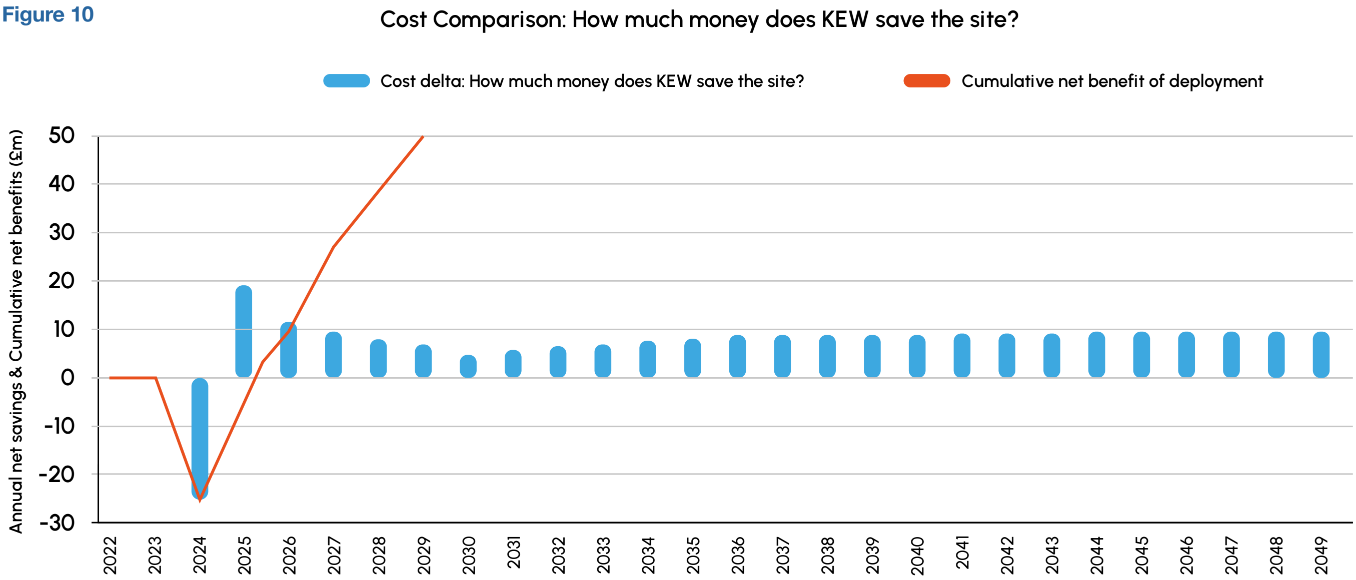
2.1.3 Indicative financial benefits

Figure 9



Indicative financial results from switching to waste

Figure 10



Indicative financial results from switching to waste wood

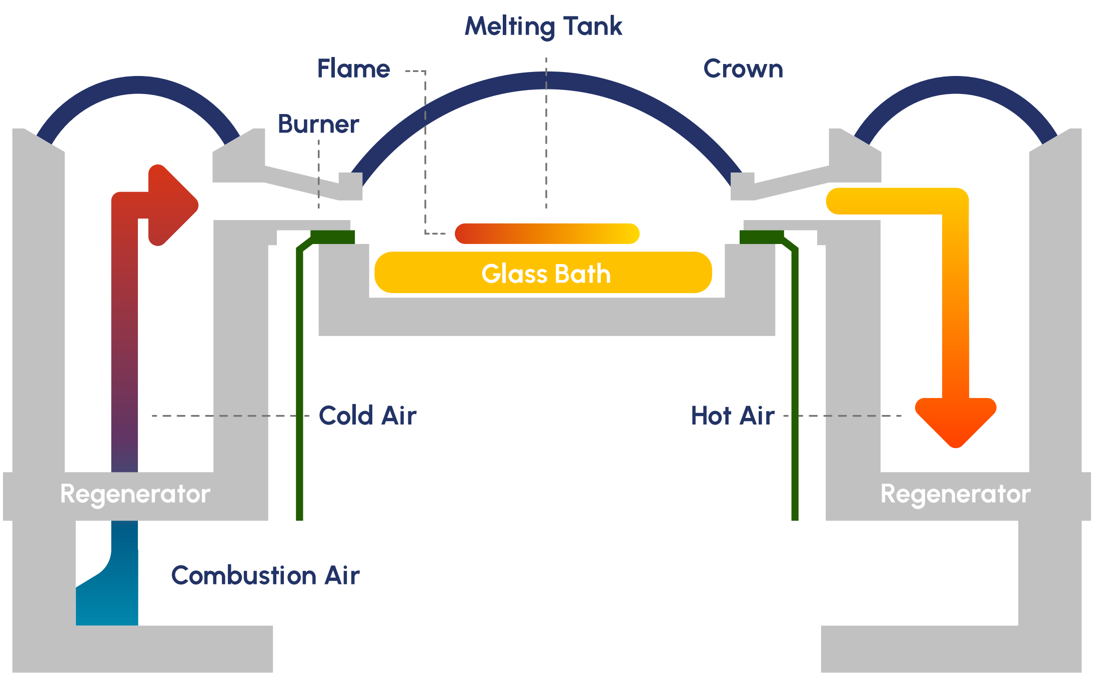
Assumption	Explanation
Feedstock	In Phase 1, KEW compared the economics of waste in RDF form and waste wood. The blue bars above show the difference in financial performance when using KEW's module to supply low carbon syngas to replace natural gas at the Greengate site. The upper chart shows the financial impact of switching to waste wood derived syngas with the lower chart showing the switch to RDF. Switching to RDF provides a better financial return, but a lower decarbonisation benefit given that only a proportion of RDF would be biogenic (DEFRA default is 45%). The choice of feedstock does not impact the quality or quantity of energy produced by each module.
UK ETS Impact	Greengate: The Greengate site falls within the UK ETS given its very large energy use. This means that for each tonne of biogenic CO_2 emitted at the site, there is a reduction in its financial obligations under this scheme. This financial benefit from decarbonisation helps offset the additional costs of using waste wood as compared with using RDF as the biogenic content of waste wood is higher. NGFE: The NGFE site does not currently fall within the UK ETS so there is no additional financial benefit of securing the greater decarbonisation benefit from using waste wood as opposed to using RDF.

2.2 Technical benefits

2.2.1 Direct syngas firing replacing natural gas

The MADE for Glass project considered two technical integration solutions to address the different glass manufacturing processes. Plate glass, used for windows, containers, etc, is made at NSG's Greengate site through a float furnace which uses very large quantities of energy in the form of flames across the top of the molten materials (see below).

Figure 11



In order to ensure that the syngas could be used as a valid replacement for the natural gas, it was necessary to assess the syngas flame characteristics and to determine the maximum energy switch over which could be achieved without risking product quality. The MADE for Glass project included syngas flame trials in which the temperature and other key characteristics of the syngas flame were tested. This test data formed the basis of CFD analysis which confirmed the suitability of upto 30% switch-over to syngas. To ensure there was no contamination in the combustion from soot or other materials, KEW's proposed technology solution was to use 3 modules of its XTE (Anything to Equilibrium) reformed syngas modular solutions.

A further complication in the development of a viable technical solution is that combustion gas is injected alternately from each side of the float furnace and there is a short period during the switch over when no gas is combusted. KEW's advanced gasification technology produces syngas on a constant basis but a solution was devised to enable an interruption in the use of the syngas to be managed without impacting on the gasification process or the combustion process.

2.2.2 Indirect syngas use

The second solution assessed in the MADE for Glass project was in respect of an indirect heat requirement. The NSG Group has a second facility in St Helens, NGFE, which manufactures specialist glass cord products (used in products such as car timing belts, tyres, woven fabrics and industrial brushes). This second plant has a far smaller energy requirement than NSG's Greengate plant. With an indirect firing solution, the syngas does not need to be reformed and can be taken straight from KEW's XTH (Anything to Heat) module and be combusted in a burner.

2.2.3 Pathway to Net Zero

The MADE for Glass project has demonstrated the technical feasibility of both direct and indirect firing solutions as a way for decarbonising UK heavy industry, improving the UK's environmental credentials and protecting jobs. This initial step to using syngas is an important technology stage in the pathway to Net Zero. As GHG removal technology is developed further, permanent CO_2 utilisation and sequestration solutions are also developed. KEW modules producing non-reformed or reformed syngas could be retrofitted and upgraded to produce hydrogen from biomass. This would reduce emissions to the point where they would be considered negative emissions, thus offsetting those emissions which can't be avoided.

2.3 Achieving wider impact: environmental and social benefits

2.3.1 Environmental benefits

There are multiple environmental benefits identified during Phase I as a result of the deployment of the industrial decarbonisation solution. An element of the MADE for Glass project was an independent assessment of the GHG reduction from switching from natural gas to biomass derived syngas. This analysis assessed both RDF and waste wood as feedstocks. A range of scenarios were assessed covering both sites and both feedstocks. The annual GHG reductions achieved ranged from **c. 20ktpa to 100ktpa CO_2 savings** (source: NNFCC independent GHG assessment). Importantly, these carbon reductions were achieved without any allowance for carbon capture.

Whilst the GHG reduction assessment was undertaken in respect of both RDF and waste wood, KEW's flexible advanced gasification modules would also be able to use other biogenic rich materials including low grade biomass and sewage sludge. The supply chains for both these potential feedstocks need further development before they can be considered viable in an industrial setting. Once that stage has been reached, it would be possible to incorporate these feedstocks into the feedstock mix enabling potential greater CO_2 savings.

In addition to decarbonising the UK industry, KEW's syngas modules also produce a carbon-rich char and carbon black as a by-product and this can be used in fertilizers and soil improvement products. There is also the ability to incorporate the char into building products which would provide a permanent carbon sequestration solution.

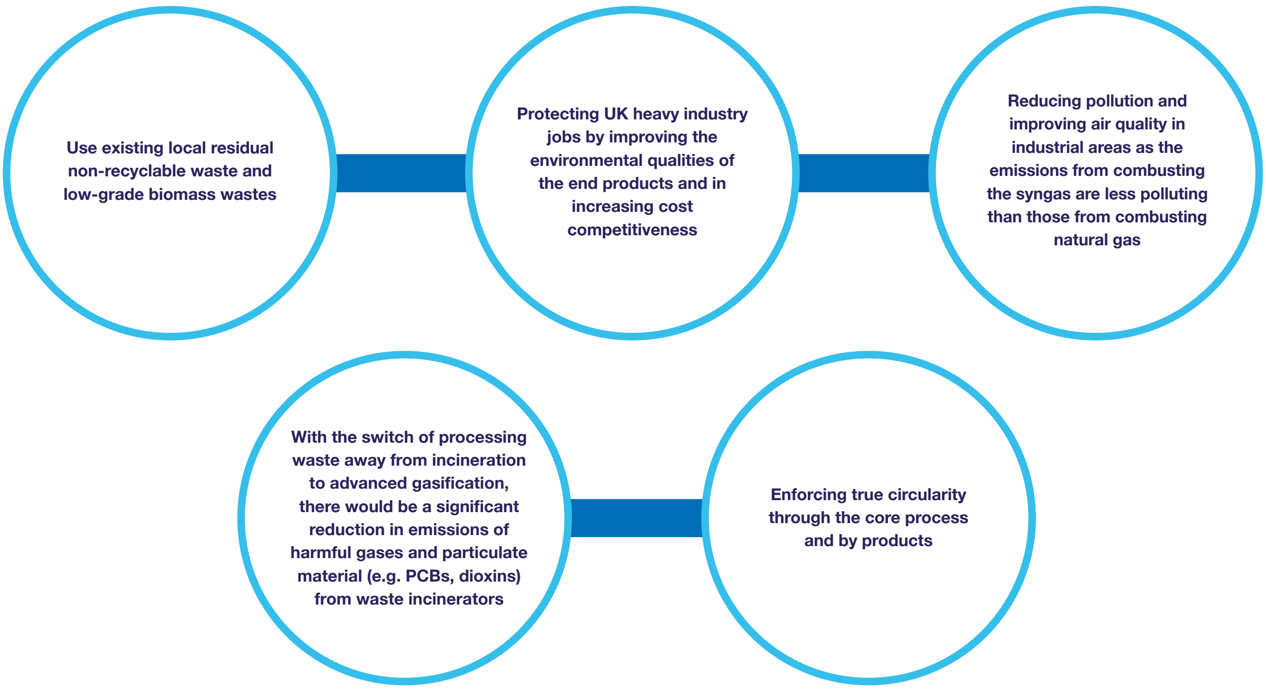
Conversion to KEW's syngas represents an initial decarbonisation step towards Net Zero. As CO_2 sequestration projects reach operational status, it will be possible to retrofit carbon capture modules to the KEW syngas modules resulting in an even greater carbon saving of >100% CO_2 reduction.

2.3.2 Social value benefits

Progress was made during Phase I of the project to better understand the impact of social value benefits when deploying the proposed industrial fuel switching technology. This social impact can be seen across several sectors as well as supply chains.

As the decarbonisation solution is applicable throughout UK industry due to its modular nature, its social value can be described as a fivefold benefit solution.

Figure 12



The level of impact of these varies according to the location of the industrial plant.

2.3.3 Wider drivers supporting KEW's pathway to a low-cost industrial energy solution

2.3.3.1 Energy market drivers

Recent global events have highlighted how unpredictable energy costs can be and how dependent energy supply is on a limited number of countries. The UK industry is facing a critical time in surviving the significant cost pressures impacting their cost base and energy security. This is in addition to the environmental pressures to decarbonise their products and production processes. For those industrial energy users who fall within the UK ETS, they also face a financial pressure to decarbonise.

The government has had to step in to cap unit energy costs for UK industry to maintain financial viability and protect jobs. Therefore, the UK industry needs to identify energy solutions which ideally, can address both the financial imperative and the decarbonisation pressures.

KEW's flexible solution can address the energy affordability, sustainability, and security challenges. Furthermore, as the operating cost base of the ACT solution can be fixed through long term contractual arrangements, this solution also addresses the price volatility risk inherent in gas markets. Greater certainty in long run energy costs will provide a significant advantage to the UK industry.

2.3.3.2 Drivers enabled through KEW's feedstock flexibility

The waste (in RDF form) and waste wood scenarios comparison in the analysis outlined above is necessary as they present comparable energy replacement impact but different decarbonisation benefits. The feedstock flexibility of KEW's technology is fundamental to this, as homogenous 'wood' input is not required and waste (e.g. refuse derived fuel) can also be consumed with gate-fees providing additional income to offset the lower UK ETS savings.

The government is developing a range of biomass-based business models to decarbonise the UK economy. Many of these rely on access to biomass or biogenic-rich feedstocks such as waste. For these decarbonisation solutions to be able to achieve their maximum potential, it will require significant increases in the volume of available biomass. Where technologies have little feedstock flexibility, they will be at risk of becoming a stranded asset or come under financial pressures if they have to compete for a narrow range of biomass feedstocks. KEW's flexible process can successfully convert a wide range of biogenic-rich materials into a low carbon syngas to replace natural gas. This feedstock flexibility will enable projects to change feedstock where there is too much competition for a narrow range of product.

In Phase II, KEW would demonstrate the use of both mixed waste and waste wood. Other biomass sources, such as energy crops, will be assessed as their supply chains are developed and they become viable and reliable alternatives.

2.4 Achieving rapid scale-up: modularity benefits

At the core of KEW's strategy is a standardised factory-build modular construction approach. This provides a scaled supply chain of compact modules, capable of being assembled at end user industrial sites via transportable frames in shorter construction periods than incinerators. This enables ongoing cost reductions as experienced with wind turbines, low construction risk, and projects viable at smaller scale so they can consume feedstock from a local catchment area and provide energy where required.

KEW's industrial decarbonisation solution is based on the same modular platform approach whereby the three main process systems are divided up and each provide either syngas for indirect firing, heat and steam, or reformed syngas for direct firing.

The modules can be arranged according to the energy needs of the client. This allows for a standardised but versatile product offering applicability across industry to help it adapt to a rapidly evolving energy market with bolt-on modules for future capital investment and a transition to a net-negative carbon footprint. This modular approach allows for standardisation of the technology; avoiding the need for re-engineering and can be easily replicated with minimal cost, time, and risk.

2.5 Wider benefits: alignment with emerging policy and macro drivers

The conversion of waste and biomass into low-carbon energy for utilisation by industry is an essential step in the UK's pathway to Net Zero. Electricity generation has been decarbonised significantly over the past decade and continues to move towards a Net Zero position. The conversion of industry away from fossil fuel, where electrification is not possible at an economic cost, now needs to benefit from the same focus. The government is supporting many initiatives in decarbonising the UK, whether through carbon capture or supporting low carbon fuels and chemicals, but needs to foster the development of solutions which can decarbonise heavy industry
A summary of the key wider benefits:

- **Sustainability:** Advanced gasification supports renewable energy adoption, contributing to carbon reduction targets and sustainability goals set by emerging policies. Reducing industry's carbon footprint will also aid its competitive position internationally and help to protect UK manufacturing jobs
- **Decarbonization:** It helps industries transition to low-carbon alternatives, aligning with global efforts to combat climate change and reducing their carbon footprint. Transitioning industry from fossil fuel to waste and/or biomass derived energy will produce significant GHG benefits
- **Circular economy:** By utilizing waste and biomass as feedstock, gasification promotes a circular economy and resource efficiency, in line with circular economy policies. Small scale, flexible solutions like the MADE for Glass project can provide on-site local production of low carbon industrial energy from local feedstock supply
- **Resource diversification:** Advanced gasification offers diverse feedstock options, aligning with policies supporting resource diversification, and reducing reliance on fossil fuels

- **Energy efficiency:** Advanced gasification optimizes energy use, supporting energy efficiency targets set by regulatory policies
- **Energy security:** On-site energy production from local feedstocks enhances energy security, aligning with policies promoting energy independence and resilience
- **Regulatory compliance:** Adoption of advanced gasification aligns with emerging environmental regulations, ensuring compliance and avoiding potential penalties
- **Economic competitiveness:** It improves competitiveness by showcasing commitment to sustainability, in line with increasing investor and customer focus on ESG considerations
- **Innovation leadership:** Advanced gasification is a key area of innovation due to its feedstock flexibility and useful product production. Early adopters strongly align with policies encouraging technology innovation and lead in sustainable practices
- **Job creation:** Supporting sustainable technology aligns with policies aimed at fostering green job creation and promoting economic growth in the renewable energy sector

3. Potential outcome of Industrial Fuel Switching Phase II

3.1 Summary of Phase I findings leading into Phase II

The Phase I findings of the techno-economic feasibility study of the Industrial Fuel Switching Program demonstrate both a technically deliverable solution and an economically viable solution.
The proposed solutions could:

- Convert a wide variety of non-recyclable waste and low-grade biomass feedstocks into a valuable low-carbon energy alternative for UK industrial users
- Reduce industries' reliance on natural gas
- Provide options to future proof the solution with an ability to upgrade to hydrogen providing even greater environmental benefits
- Provide energy cost certainty and cost savings to UK industry

3.2 Phase II objectives

The high-level aim of the Phase II Demonstration project will be to install one of KEW's modular gasification units at NSG's Greengate plant, commission and prove the successful and continuous operation of the technology with the ability to integrate the syngas as a replacement for natural gas without impacting on product quality. This installation, testing, and operation would increase the TRL of the combined decarbonisation solution to TRL8 and enable commercial exploitation of the solution.

The parties to the MADE for Glass project had to consider the relative development and future wider deployment requirements when making the selection between the two Phase I projects.
The decision to move forward with the more complex integration situation were:

- Within the NSG Group globally, and the glass industry more generally, there are more float furnaces than the type installed at NGFE. This therefore offered greater deployment potential as the integration technology developed at Greengate could be deployed in more locations worldwide, unlocking greater carbon reductions too
- In a full commercial deployment project, there would be three KEW modules installed at Greengate, thus providing a far greater decarbonisation benefit than the one module which could be installed at NGFE
- With Greengate being direct firing, the integration risks are greater and it was considered less likely that a commercial entity would take the investment risk on new technology, particularly at a time when cash flow is under pressure due to very high natural gas prices
- It was considered more likely that more industrial users would take comfort from a successful demonstration of a more complex direct firing solution than an indirect firing solution, which will increase the proven solution's attractiveness both to other glass manufacturers as well as the rest of the UK's heavy industrial base

The Phase II project technical and operational objectives include:

- Build and demonstrate the integrated industrial fuel switching solution by integrating the syngas produced by the KEW module into the glass furnace, resolving the current uncertainties surrounding:
    - CAPEX
    - OPEX
    - Performance
    - Feedstock flexibility
    - Product quality
    - ETS reductions achieved
    - The design and build will then be followed by a series of tests followed by continuous operation over an extended period

The targeted key outcomes of the Phase II project are:

- Proven integrated system for the deployment of syngas in a direct firing industrial energy solution
- Successful demonstration of strong GHG reduction capability
- Defined and sustainable economic proposition
- Dissemination of key findings to wider stakeholder groups in order to further develop and deliver industrial decarbonisation solutions to progress the UK towards its Net Zero targets
- Provide a platform for commercially led projects, through removal of key roadblocks and risks around integration into a 24/7 operation, feedstock supply, financing, offtake, insurance, and project delivery
- Assess the ability to expand the initial fuel switching solution from one module to three modules
- Assess the ability to retrofit carbon capture modules to further improve the environmental benefits derived from industrial fuel switching

3.3 Phase II demonstration facility; NSG Group's Pilkington UK Greengate Works, St Helens

KEW's technology is already being demonstrated at the Sustainability Energy Centre (SEC) in Birmingham, UK. The full-scale commercial flagship facility, co-funded by the Energy Technologies Institute (ETI), converts c.20,000tpa of mixed biomass and waste-based feedstocks into a high-quality syngas vector.

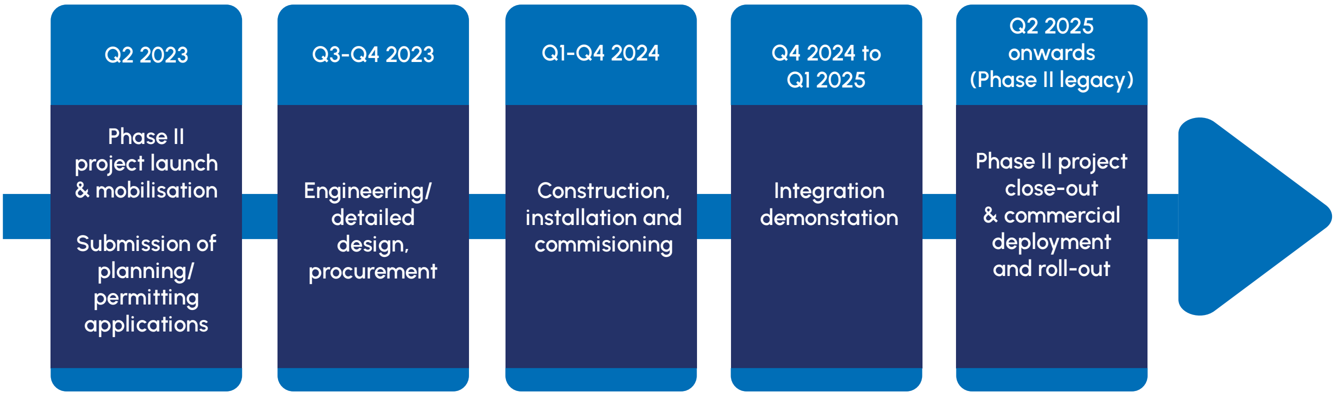
The existing production of consistent quality syngas provides a sound, risk mitigated technical basis on which to base the Phase II deployment of a module in an industrial setting.

The existing production of consistent quality syngas provides a sound, risk mitigated technical basis on which to base the Phase II deployment of a module in an industrial setting.
An available parcel of brownfield land has been identified within the Greengate site on which the demonstrator unit can be situated.

The Phase II demonstration project would comprise the installation of a renewable energy testing facility including site preparation, installation of utility packages, installation of pipework connections from the renewable energy testing facility to the glass furnace, and blending of the syngas supply into the natural gas supply, and the rental of a KEW module for the duration of the Phase II project.

3.4 Phase II timeline

Figure 13



4. Industrial decarbonisation commercial deployment pathway

4.1 Overcoming the challenges to industrial decarbonisation deployment

In order to meet the Paris Agreement goals, all major governments must take wide ranging action across the following major energy and carbon-intensive sectors to achieve their Net Zero ambitions: industry, energy, transport, and buildings. Although each sector has very different requirements, the common consensus is that low-carbon biomass-derived energy vectors can play a very significant role in achieving meaningful and sustainable decarbonisation to help achieve a world beyond fossil fuels.

Industry is widely spread throughout the UK with varying energy needs, both in terms of quantity and how it is used. An adaptable, flexible solution to decarbonise industry through fuel switching has been identified and can be delivered through KEW's modular gasification system. This adaptable system also has the benefit of being upgraded in due course to supply low carbon hydrogen once there are economically viable and accessible CO_2 sequestration solutions available nationwide. KEW's modular solution can also provide decarbonisation and fuel switching opportunities to the UK's off-grid industry that is unlikely ever to be connected to a hydrogen supply grid. Decarbonisation of industry can, and should, start now with technologies that are adaptable and future-proof, with the ability to be upgraded to provide hydrogen in the future.

The main challenges that require addressing in order to enable the deep decarbonisation of industry are:

- Ensuring sufficient access to biomass and biomass-rich waste streams for feedstock in what will become a more competitive market, particularly where other energy sectors using biomass feedstock benefit from low-carbon energy support
- Obtaining greater clarity on the structure of the UK Emissions Trading Scheme (ETS) and how this will change over the next decade
- Access to capital to cover the upfront investment costs at a point in time when industry is coming under significant financial pressure

4.2 The need for a balanced solution portfolio; applying the lessons of renewable electricity

Recent experience of decarbonising the UK electricity sector highlights the importance and benefits of ensuring a diversity of technology solutions is developed to achieve strategic outcomes. This is particularly true in the context of low carbon energy for industry where industrial energy takes many forms and there is a wide range of user energy requirements. Waiting for a switch over to the mass use of green hydrogen will delay the UK's trajectory to Net Zero and risks placing UK industry at a competitive disadvantage as it will not be able to offer low-carbon products for some year to come.

Short to medium term solutions must therefore include dispersed/decentralised low carbon energy production co-located on industrial user sites. This must commence as quickly as practical on a technological and commercial pathway to decarbonisation across many fronts.

KEW believes that without equal access to affordable, small scale, modularised low carbon energy, the UK economy risks becoming 'two-speed' with the first areas connected to CCUS pipelines advancing faster at the expense of other, mainly inland areas. This would be counter to government's Levelling Up agenda.

4.3 Modularity overcoming market barriers

One of the obvious challenges with smaller modular projects is the ability to achieve the required level of scale that is needed to support the government's decarbonisation agenda in the UK. All projects have a degree of complexity whether large or small, potentially creating an argument to support a focus on large scale projects. However, KEW's modular approach to decentralised projects can quickly achieve large scale deployment by circumventing many of the problems traditionally associated with larger scale 'first of a kind' energy projects. With modularity, there is a greater ability to re-use knowledge and design integration solutions as the issues are more similar. Having assessed the issues and challenges of direct firing of syngas in the glass sector, KEW is better placed to assess the direct firing of syngas at, for example, steel manufacturing plants as there will be considerable overlap in issues and solutions.

4.3.1 Achieving supply chain scale through modularisation

Factory assembled equipment on skids or in containers has become increasingly the preferred approach in many areas of industry where there is a sufficient volume demand for a specific item to justify the upfront investment in the manufacturing, tooling and production line.

KEW modular plants will avoid re-engineering existing processes with standardised modules which can be easily replicated with minimal cost, time, and risk. This has been achieved by breaking out the core processes into their respective areas and optimising their design.

This enables production at scale as the modular units can be manufactured using lean techniques with supply chain bottlenecks mitigated. This would, in parallel, create a significant prospect for UK green technology leadership and the resultant green collar employment opportunity.

Standardisation of manufacturing will also facilitate greater levels of contractual performance which will facilitate the rapid progression to full scope EPC (see section 4.3.2.3 below) and the increasing availability of performance-based insurance products that are also key in enabling infrastructure funding availability and risk reduction for industrial fuel-switching businesses.

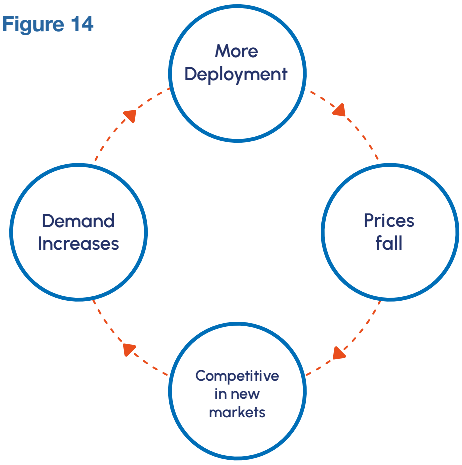
4.3.2 Reducing levelised cost of production through modularisation

There is historical evidence indicating that there are significant reductions per unit production when there are new technologies deployed commercially through repeatable modular delivery. This is a result of the 'virtuous circle', where increased deployment leads to manufacturing gains, reducing prices and opening new markets which drives sales, as shown graphically in Figure 14. These unit cost reductions have been clearly seen in the renewable electricity sector where solar and wind power capex costs have tumbled with widespread installation of repeatable modular solutions.
In parallel with the reduced CAPEX, there has been a reduced need for taxpayer or energy user subsidies to the point where both solar and wind can now be delivered subsidy free.

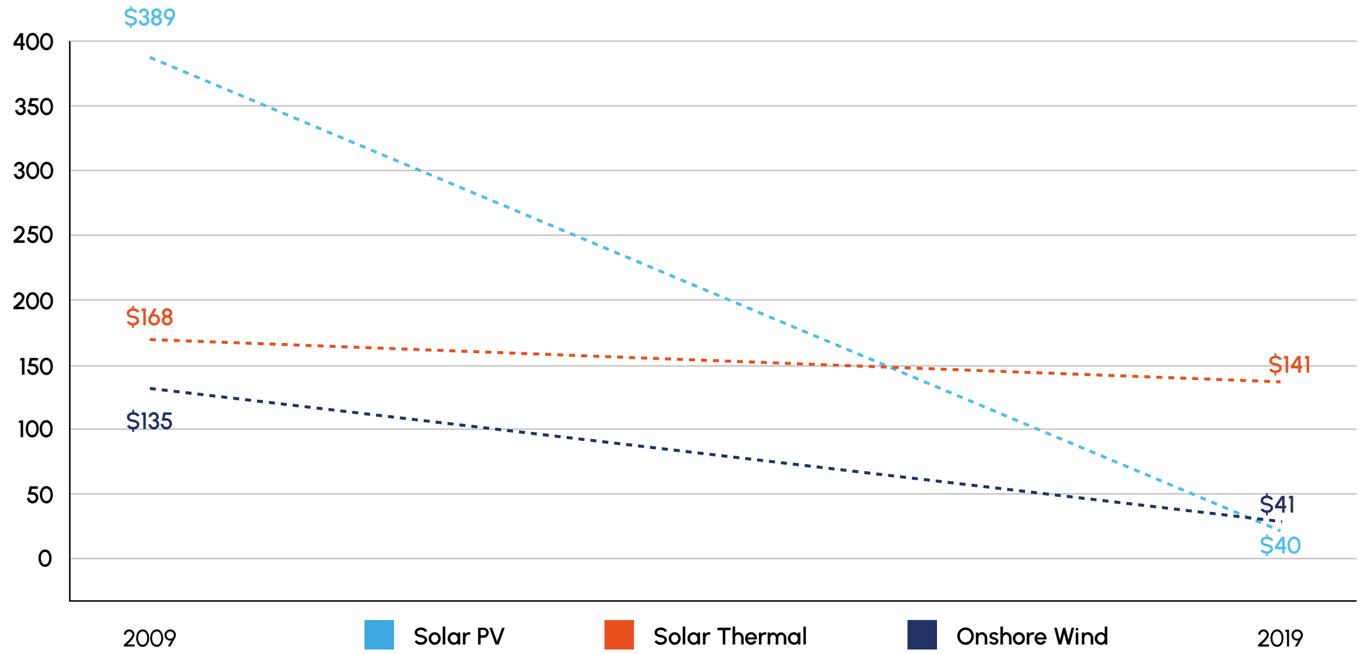
KEW anticipates that the same experience will be seen with the deployment of its modular industrial fuel switching system. Initially, this will be deployed with early-adopters keen to lead their industry towards Net Zero. This initial deployment will drive unit uptake and, therefore, cost reductions. As the fuel switching technology becomes more widely taken up, the cost reductions derived from these deployments will benefit and enhance the economics of further deployment of the same underlying advanced gasification technology whether in industry, fuels, or in H_2 BECCS solutions.

Virtuous Circle

Figure 14



KEW has made projections for the potential cost savings and would also point to historic precedent from other renewable sectors to support these projections. As detailed below, the cost reductions which will be achieved depend on the rate of deployment of KEW's technology. Historic comparators are shown in the Figure 15.



Comparison of the cost reduction of renewables over the last decade, correlated with the quantity of unit systems produced[1]

The reduction in costs over 10 years are most striking for solar PV, with a reduction of 89%. Substantial reductions were also seen for onshore wind, reducing 70% with solar thermal experiencing only a 16% reduction.

The cost reductions experienced are correlated not with time, but with the deployment of identical or quasi-identical units with a consistent % reduction in costs for each doubling of the number of units in service. This constant cost reduction relationship was first identified in 1936 by Theodore Paul Wright and has been called Wright's Law. Initially it was identified in the aerospace sector, but empirical data has held it to be accurate across a wide range of sectors not just aerospace but also automotive parts, aluminium, DNA sequencing and, most importantly, renewables.

1.Our World in Data (2021) - Why do renewables become so cheap so fast? https://ourworldindata.org/cheap-renewables-growth

The implications of Wright's Law, the empirical data and the constant cost reductions means that the best way to achieve value for money for the UK economy in the decarbonisation of industry through fuel switching is to encourage the deployment of as many of KEW's ACT modules as possible to maximise the per unit cost savings. Wright's Law also implies that greater product cost savings, and therefore industrial energy cost savings, can be achieved through the deployment of many smaller units than a few very large projects. By its very nature, the UK industry is geographically dispersed and cannot easily be serviced with low carbon energy from large, central plants without significant investment in new energy transportation infrastructure, such as a hydrogen grid.

At some point, this new hydrogen supply model will service well-established industrial clusters but will not be viable for the remaining industry (c.40%) that is located outside of the main industrial hubs. Equally, a significant proportion of this UK industry is in its current location for historical reasons, and many have been on the same site for a long period of time, meaning a likely inertia against relocation. Therefore, in these situations a low-carbon energy must be produced at the industrial site.

With a small, flexible, modular system such as KEWs, the rate of deployment can be significant as they can be located in a wide range of industrial settings, can process a range of feedstocks, produce a range of low-carbon energy products, and the required investment quantum means that investment and funding decisions can be made quickly. All deployments of KEW's modules, whether in a specific industrial fuel switching setting or more fuels, H_2 BECCS or other setting, will assist in achieving capex cost savings.

This comparison in cost reduction performance between small flexible projects and large inflexible projects can be seen from the graph above. Solar thermal installations, the equivalent of very large, centralised energy solutions, require significant investment and can only be deployed at a large scale to be viable and require significant industrial energy offtake to be economic, thus, limiting location choice. Onshore wind and solar PV, the equivalent of KEW's modular solution, can be located virtually anywhere at much lower investment cost as neither has these limitations. Consequently, they have been deployed in far greater numbers and have experienced far greater per unit output cost savings.

KEW's modular solution, exhibiting more closely the characteristics of solar PV and wind, will therefore experience greater cost reductions than for larger, bespoke "mega"-projects and provide better value for money for UK industry by requiring smaller subsidies (if any) and the existence of any such subsidy regime for a shorter period of time.

4.3.2.1 Enabling access to finance through modularisation

The economically viable route to achieving practical low-risk commercialisation of the CO_2 capture technology lies in a step-by-step approach in which techno-commercial barriers are tackled incrementally to lower the risks for financial investors (and minimise costs that are required to be supported/funded by government). Commoditising an infrastructure asset class enables progressively more and cheaper funding into projects, achieving scale, and driving down reliance on government support/subsidies.

Ultimately, KEW believes that starting small and building to scale through repeatable modular deployment not scaling individual unit size is the sensible, proven and low risk approach to commercialisation of innovative and emerging technologies. This approach overcomes the most critical challenges that always block commercialisation through a strategy of rapid scaling; especially the challenge of funding large scale First of a Kind (FOAK) projects.

Following a phased, modular approach provides a viable way of achieving commercialisation and deployment of innovative and emerging technologies much sooner. This inevitable large-scale deployment can only be achieved economically when funders are comfortable with the real risk vs. return of the asset class. This can only be done gradually through the initial phased infrastructure roll-out of smaller, less capital intensive and less technically complex projects. Focusing on large scale projects with unproven technologies and market commercials will necessitate an over-reliance on larger and longer term government incentives, which will not benefit from the commoditisation of the asset class as demonstrated above for smaller modular based technologies such as KEWs.

KEW's modular solution provides the answer in that it can be deployed initially in a larger number of smaller projects with limited subsidy requirements to create investor confidence, operating track record and stimulate supply chain savings which will then benefit the future larger deployments involving larger numbers of KEW modules to address the larger scale requirements.

4.3.2.2 Overcoming challenges to funding industrial decarbonisation projects

The recent examples of this sector (gasification) trying to achieve immediate large-scale of operations provide very painful evidence that jumping to large scale is not the correct path. The financial investor community are aware of these high-profile (and expensive) failures, as are the relevant supply chain (specifically EPC), who will be very unwilling to offer the level of full EPC wraps required to achieve the underlying value for money debt/equity funding for large scale projects.

KEW's phased modular approach can overcome these traditional investor barriers to enable true scale of infrastructure to be realised.

4.3.2.3 EPC buy-In

Outsourcing technology risk from projects via an investment grade full scope EPC wrap is a key 'non-negotiable' funder requirement for any project. In terms of ACT and industrial fuel switching deployment, given the above mentioned high-profile large scale-gasification project failures and challenges, the EPC community will be very apprehensive of wrapping large scale infrastructure, given the likely requirement from the funding community for a Right to Reject (RTR).

The risk of the RTR clause for large scale gasification projects is material and will dissuade most/ all from participating in any EPC tenders, regardless of the potential EPC margin they could achieve given the downside risk.

Clearly, in the beginning, a smaller modularised project approach is the only way of securing a bankable EPC wrap in the short term as the RTR clause is less material (given the smaller CAPEX size) relative to the enhanced margin that could be earned from initial project deployment. It is also easier for an EPC to due diligence and get comfortable with the risks surrounding the delivery of an existing full commercial scale gasification process than one which has yet to be developed, designed, or built. Industrial fuel switching projects bring additional complexity and risk as the syngas produced is being integrated into an industrial process.

Delivery of small scale well-developed opportunities, such as those made possible by the BEIS Industrial Fuel Switching Program, will significantly reduce the perceived risks of industrial fuel switching integration risks and lead to faster and wider deployment.

4.3.2.4 Obtaining feedstock contracts

Feedstock is the other critical funder issue alongside EPC. In order to deliver industrial fuel switching, the projects must be able to access a viable and contractually secure source of biomass or biomass-rich feedstock. Environmental focus on the harmful emissions released in incineration continues to gather pace and there is also greater focus now on the inefficiencies of the incineration process and the relatively small amounts of low carbon energy which is available – more so once carbon capture equipment becomes a requirement. With these growing pressures on incineration, it is anticipated that additional biomass rich RDF will become available as a feedstock to support industrial fuel switching and industrial decarbonisation.

KEW believes that local waste processing solutions are most appropriate for a low-carbon energy solution as it reduces transport emissions too. The integration solutions developed in the MADE for Glass project provides a local waste processing solution and an industrial decarbonisation solution. Further, with the flexibility of KEW's modular solution, if feedstock markets dynamics change, there is the ability to change the feedstock blend and incorporate waste wood, sewage sludge, AD digestate, low grade bioenergy crops, etc. into the supply chain to continue the supply of low carbon energy to industry.

The flexible technology demonstrated by KEW's modular solution allows industrial energy users to have feedstock supply chains structured to fit their specific requirements and local market conditions.

4.4 Achieving value for money

For any industrial decarbonisation and fuel switching solution to be capable of being deployed widely across the UK economy, it must be affordable and provide value for money for the industrial energy users. Smaller solutions represent a less complex and less risky investment decision for industrial customers and for third party investors. Value for money also encompasses an assessment of financial risk and business risk.

Any industrial fuel switching creates a business risk for the host industrial client, particularly those where the energy use is direct (such as at Pilkington UK's Greengate Works), as they need to ensure that the fuel switch does not impact on product quality. A modular approach provides the best solution for this as the fuel switch over can be undertaken in phases as performance is demonstrated. The downside risk is limited to a single module – which can be removed and reused elsewhere if required. Where an industrial decarbonisation energy system is designed to match exactly 100% of the industrial users' energy demands, the switch over would be a very risky fail or work. This creates too high a business risk and would be unlikely to be pursued.

The incremental investment possible with a modular industrial fuel switching solution reduces business and financial risk to the level where it should be acceptable, thus leading to greater take up within the market and greater decarbonisation of industry.

Smaller and incremental projects should be able to deploy quickly, enabling fuel switching to be phased and module deployment to ramp up, which in turn will drive down supply chain costs and reduce investor return requirements. Again, mirroring the recent learnings of the renewable electricity sector, rapid commoditisation of the asset class enables the rapid reduction in the levelized cost of low carbon energy.