IEA Bioenergy Task 33

UK Country Report

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Authors:

Paula Blanco-Sanchez, Aston University

Dan Taylor, Aston University

Sam Cooper, University of Bath

Acknowledgements:

Neville Hargreaves, Velocys

Amna Bezanty, KEW Technology

Introduction

Biomass and waste gasification is a versatile technology that may play a key role in decarbonising the economy in the UK [1, 2] and internationally [3]. It provides a route for treating non-recyclable wastes, and for valorising biomass feedstocks including forest residues, waste wood, and lignocellulosic 2nd generation energy crops. The resulting syngas can be used for power and heat generation, further processed to produce bio-hydrogen, bio-methane and other synthetic fuels, or used as the basis for other chemicals.

Gasification systems can be operated with carbon capture. Depending on the configuration, this can be done effectively and with relatively minimal energy penalty. In this way, it is possible to achieve negative lifecycle greenhouse gas emissions. Because of this, gasification has gathered significant interest with increasing recognition of its potential use as a key component of applications such as bioenergy with carbon capture and storage (BECCS).

Within the International Energy Agency (IEA), the Task 33 focuses on the thermal gasification of biomass with the aim to promote the commercialisation of efficient, economical and environmentally preferable thermal biomass gasification processes. Within this framework, IEA undertook the task of collecting up-to-date information directly linked to this particular topic and for different countries across Europe. This report aims at providing a general review of the most relevant actors in the UK and linked to gasification.

The areas covered in this document include UK-biomass relevant reports and actions (2020-2021), a general overview of academic and research institutes working in gasification, and some case studies from companies using the gasification technology.

In the last year in the UK the Department for Business, Energy & Industrial Strategy (BEIS) has launched and led a number of UK-biomass relevant reports and actions. These include the UK Hydrogen strategy [4], a review and benchmarking report about advanced gasification technologies (AGTs) [5], the UK Biomass policy statement [1], and the UK biomass strategy [6]. There have also been some good examples of government funded programmes looking at promoting the commercial use of technologies including gasification. Some of these are briefly described in the present report.

Several research groups across the UK are currently engaged in gasification research at different levels. A good summary of the UK academic and research institutions has been previously reported in the Supergen report "*Bioenergy and waste gasification in the UK: Barriers and research needs*" [7]. However a brief summary is also included in this report.

From the commercial point of view, recent developments in the UK have focussed largely on waste treatment as these offer the potential for additional revenue. The commercial sites that are currently in operation, combust relatively unprocessed producer gas to raise steam for power generation. However, future developments are likely to target chemical energy vectors as these are more valuable and offer greater potential for GHG emissions reduction. In order to achieve this, the syngas needs to be improved. Two systems that achieve this are those in development by Advanced Biofuel Solutions Ltd and Kew Technology Ltd. Their systems are currently in the commercial demonstration phase. These take different approaches to the gas clean-up stage but both are effective.

Figure 1: Advanced Biofuels Solutions Ltd (ABSL) demonstrator site, Swindon.

Gasification Activities in the UK

Figure 2 illustrates that a wide range of commercial gasification facilities have been developed within the UK. This includes some sites that have subsequently closed, and some that are in different stages of development. The commercial conditions are challenging but also present attractive opportunities and so any list of sites currently operating would require regular revision to remain accurate.

All of these facilities (with the exception of the ARBRE project that was not completed) relate primarily to waste treatment - reflecting the commercial desirability of dealing with waste as well as supplying energy. As noted above, technical and commercial drivers have led to most designs being configured to combust relatively unprocessed syngas in order to generate electricity (and heat in some cases). However, the desirability of higher quality syngas and the more valuable products that can be derived from it is recognised and reflected in more recent developments (for example those highlighted in the case studies below).

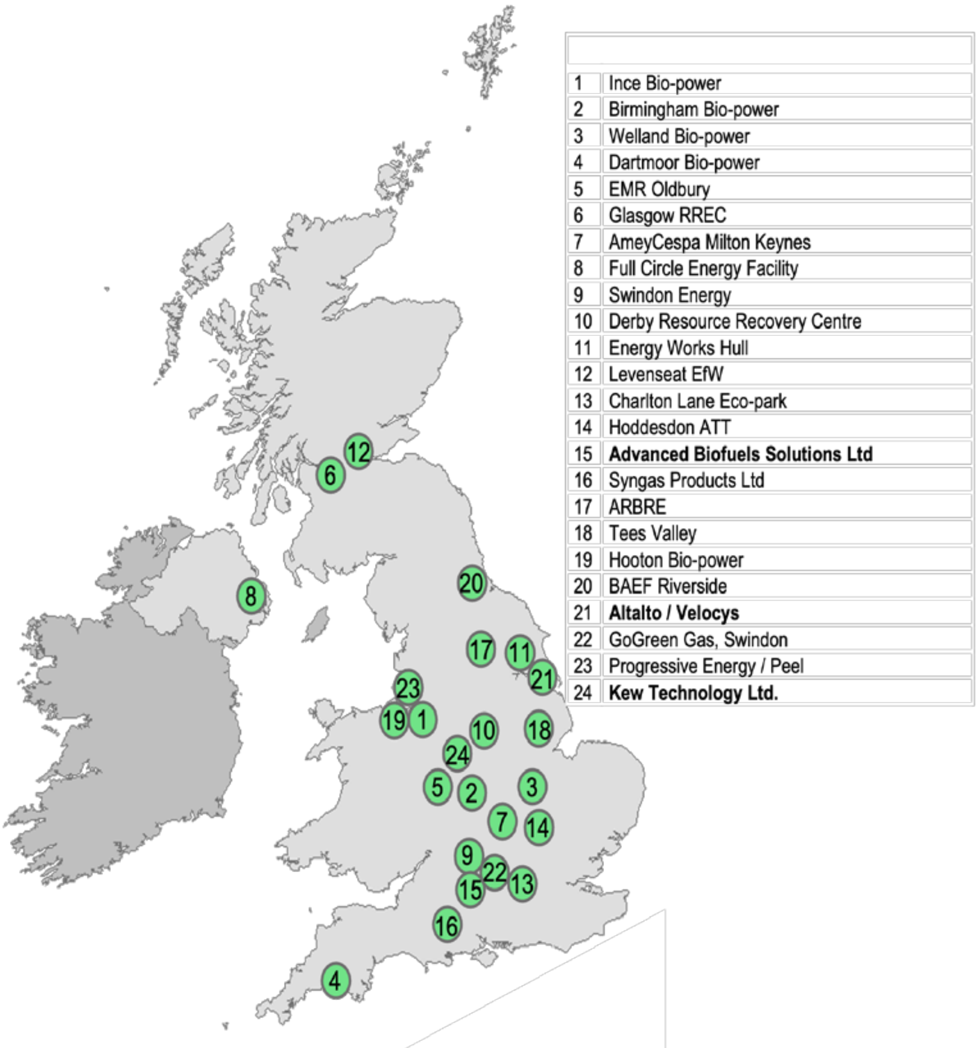

Figure 2. Sites with relevance to UK commercial gasification development

Research Activities

The Supergen report "*Bioenergy and waste gasification in the UK: Barriers and research needs*" published in 2019 [7], provided a summary of relevant institutions undertaking gasification research in the UK. **Figure 3** shows that there are at least 17 academic Institutions undertaking gasification research in the UK.

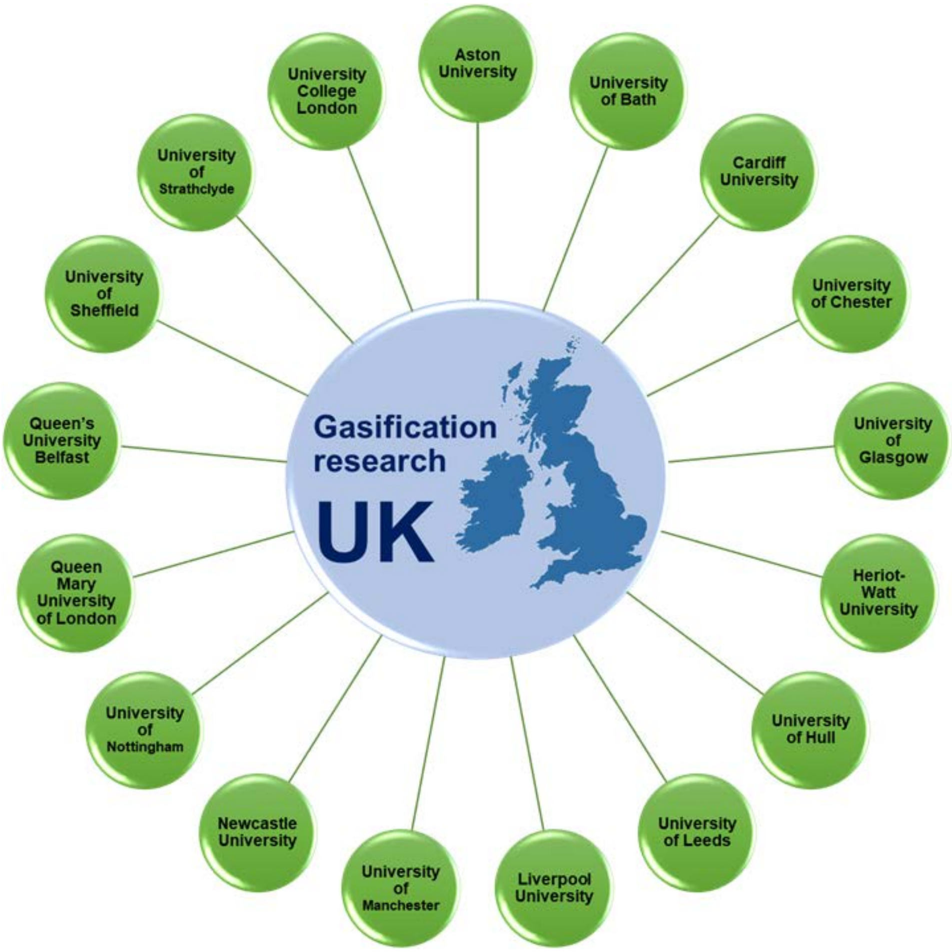

Figure 3. UK academic institutions undertaking research in gasification

A brief summary of the key activities from the Universities in **Figure 3**, including their main research topics, approaches (modelling or experimental), as well as details on their experimental equipment are provided in **Table 1**.

Table 1. Summary of gasification research activities and equipment details per Institution

Institution	*Activities linked to gasification*
Aston University	Modelling (TEA/LCA); development of catalysts (i.e. tar cracking). **Facilities:** 1MW fluidised bed gasifier, analytic equipment.
University of Bath	Modelling (TEA/LCA).
Cardiff University	1-D and 2-D CFD modelling (reactor conditions and fuel characteristics). **Facilities:** 1-2 kW experimental rig.
University of Chester	Syngas quality & tar content. **Facilities:** Two 25kW downdraft gasifiers and analytical equipment.
University of Glasgow	Real-time control of gasifiers. **Facilities:** Lab-scale downdraft and fluidised bed gasifiers. TEA and environmental assessments.
Heriot-Watt University	Reaction kinetics and catalysts development; co-firing biomass-coal.
University of Hull	Biomass pretreatment; product analysis and upgrading. Reactor optimization. **Facilities:** Two lab-scale (1-3g/s) gasifiers with extensive TGA and other analytical gas, liquids and char monitoring capability.
University of Leeds	Catalytic and non/catalytic plasma syngas for syngas cleaning. **Facilities:** Lab-scale fixed-bed and fluidised bed reactors.
Liverpool University	Catalytic plasma syngas for syngas cleaning.
University of Manchester	Large scale gasifier design; off-design operation at lower output levels; gasification integration and assessment, with application to agricultural residues.
Newcastle University	Catalytic plasma syngas for syngas cleaning; process Intensification.
University of Nottingham	Novel approaches for syngas cleaning; carbon capture. Research on biomass governance issues. **Facilities:** 10kW prototype downdraft gasifier.
Queen Mary University of London	Physicochemical modelling of biogas combustion, with application to gasification. Modelling reactor performance (syngas composition and gasifier performance).
Queen's University Belfast	Operation of gasifiers: development of catalysts, the use of varied feedstocks and integration with carbon capture technologies.
University of Sheffield	Effect of reactor conditions and feedstocks on the characteristics of the gasifier outputs and syngas. Numerical simulation based on kinetics and CFD; Carbon capture; H&S, risk management and feedstock storage. **Facilities:** co-flow pyrolysis unit, FBG and fixed bed gasifiers, and a 2m entrained flow gasifier
University of Strathclyde	Modelling the effect of particle size on the gasification products and ash generation. Reactor design and process upgrading.
University College London	Feedstock and gasifier variations affect gasification products. Plasma for tar reforming and ash stabilisation; LCA. **Facilities:** small-scale FBG rig (equipped with analytical facilities such as X-ray and thermal imaging); bench-top plasma assisted gasification.

Table 1, provides an overview of the variety of research topics linked to biomass gasification ranging from lab scale up to pilot plant experimental facilities and a good combination with modelling approaches looking at the overall process optimisation. An example of the 1MW fluidised bed gasifier in place at Aston University in Birmingham, is shown in **Figure 4**.

Figure 4. 1MW fluidised bed gasifier at the Energy & Bioproducts Research Institute (EBRI), Aston University.

Relevant UK funding & reports

In the last year (2020-2021), the Department for Business, Energy & Industrial Strategy: BEIS; has published a series of reports and carried out some actions directly linked to UK-biomass gasification. There have also been funding programmes looking at technology development and application, including gasification and these come from UK-funding bodies such as the UK Research and Innovation (UKRI).

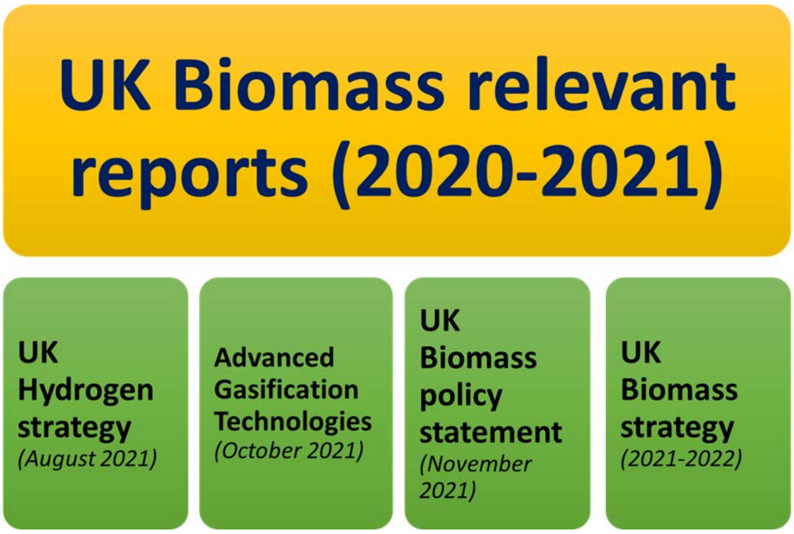

Figure 5. UK biomass relevant reports (2020-21)

UK-biomass gasification reports and strategy

UK Hydrogen strategy (Department for Business, Energy & Industrial Strategy: BEIS, August 2021) [4]

The development of a low carbon hydrogen sector in the UK is a key plank of the government's plan to build back better with a cleaner, greener energy system.

In the strategy it is emphasised that low carbon hydrogen has a critical role to play in the transition to net zero, by helping to bring down emissions in vital UK industrial sectors and providing flexible energy for power, heat and transport. There are five main topics covered in this strategy including:

1.Low carbon hydrogen
2.Scaling up the hydrogen economy
3.Economic benefits for the UK
4.International leadership
5.Track progress

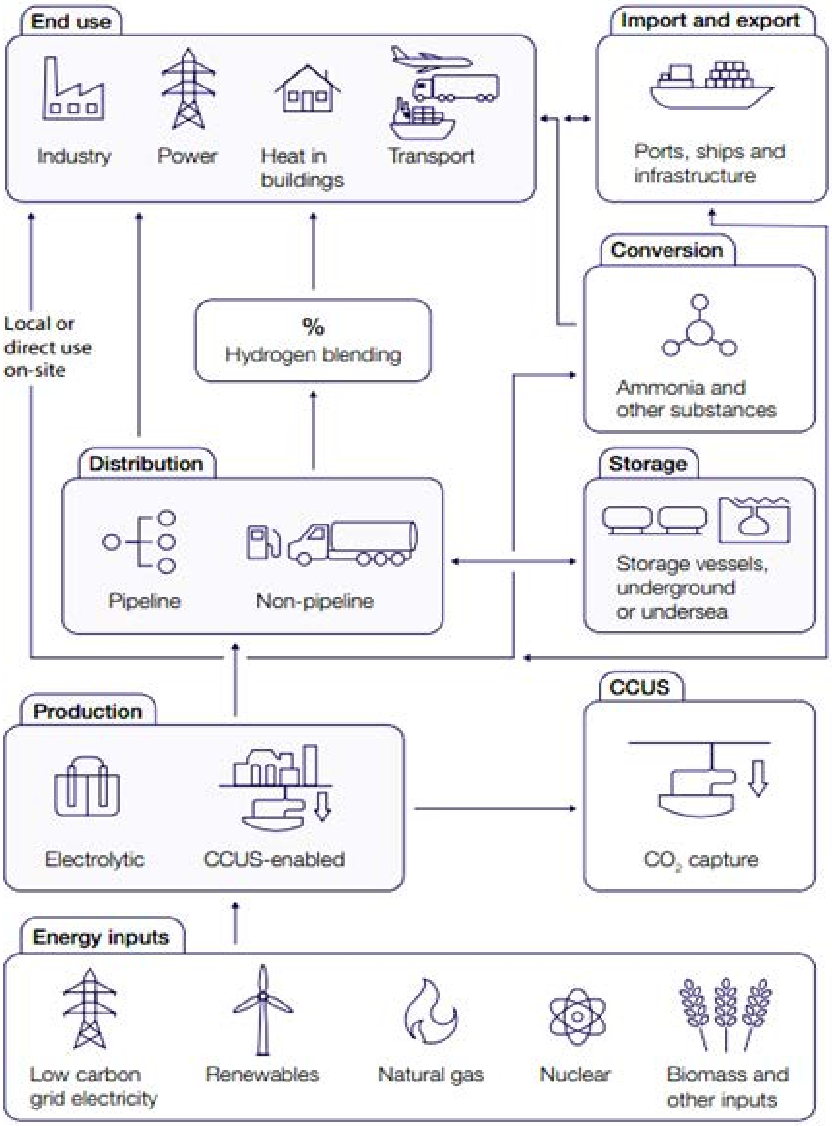

Figure 6. The Hydrogen value chain [4]]

Advanced Gasification Technologies (AGTs): Review and Benchmarking (BEIS, October 2021) [5]

The advanced gasification technologies (AGTs) covered in this document included: thermal conversion technologies (gasification or pyrolysis) for conversion of biomass or waste into aviation fuels, diesel, hydrogen, methane & other hydrocarbons.

The main goal of the document is to understand the current development status of AGTs and to inform future policy direction and innovation spending in relation to this class of technologies. The topics covered included:

1.Current status of AGTs
2.Opportunities & barriers
3.Techno-economic analysis and product cost benchmarking
4.Development pathway

This report reviewed diverse AGTs, a list of those are shown in **Figure 7**.

Advanced Biofuel Solutions Ltd.
Enerkem Inc.
Kew Techs.
GoBiGas
Standard Gas
PowerHouse Energy
LanzaTech
Velocys
Sumitomo Foster
Alphaco
ThermoChem Recovery
ReOil

Figure 7. List of AGTs reviewed

UK Biomass Policy Statement (BEIS, November 2021) [1]

The UK Government provides in this report a strategic view on the role of biomass across the economy in different timelines: short (2020s), medium (by 2035), and long-term (by 2050) timelines. It addressed the key policy aims for biomass use across the economy, including the electricity, heat, transport and industry sectors.

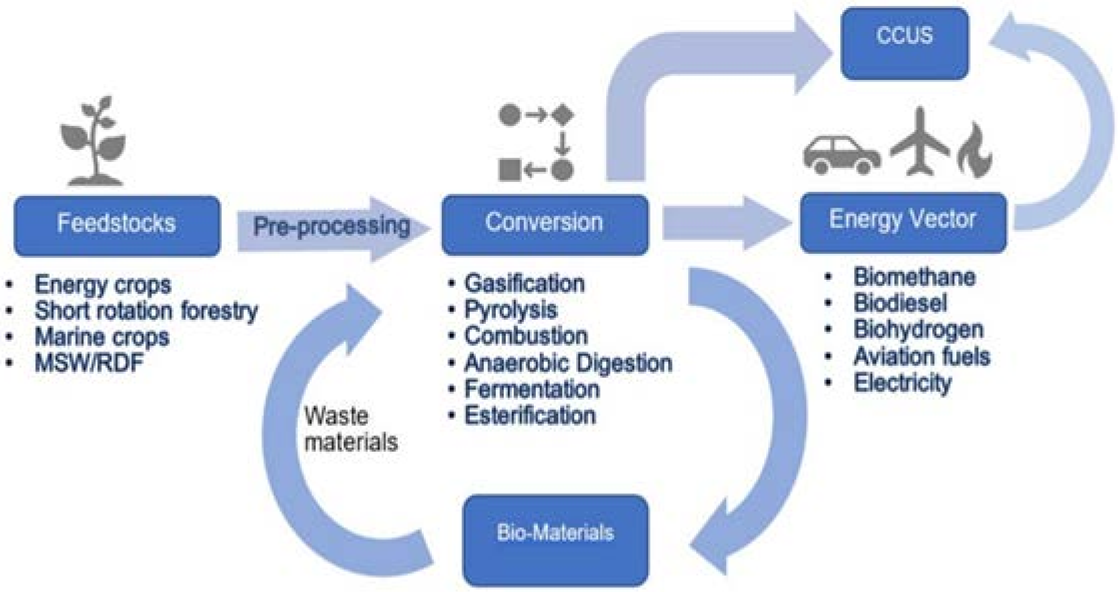

Figure 8. Potential routes for biomass processing and use [1]

The key principles included:
• Compliance with sustainability criteria and waste hierarchy principles;

• Contribution to carbon budgets and net zero considering feedstock availability, life-cycle greenhouse gas emissions, and cost-benefits;
• Biomass to be used with carbon capture utilisation or storage where feasible.

An the priority areas:
• Sustainable aviation fuel and hydrogen production (decarbonise relevant sectors)
• Bioenergy with Carbon Capture and Storage: BECCS (deliver negative emissions and support energy security).

UK Biomass strategy (BEIS, 2022) [6]

BEIS is planning to publish a new UK Biomass strategy in 2022 including carbon capture recommendations. They are currently analysing the feedback provided by stakeholders through a call for evidence "*The role of biomass in achieving net zero*". Evidence was collected from a series of round table discussions.

This consultation ran from April until June 2021; and the UK Biomass Strategy is expected to be published in 2022. For this, relevant actors including the Supergen bioenergy hub, have contributed with information about bioenergy with carbon capture and storage (BECCS).

The key areas to be addressed in this report will be:
1. Supply - how much biomass can we assume the UK will have access to?
2. End use of biomass – how should we use biomass to reach net zero?
3. Sustainability and Accounting for Emissions – (i) how can we strengthen our sustainability criteria and (ii) how can we improve the way we account for biomass emissions?
4. Innovation - what technological or systems developments do we need to see?

Funding programmes

UK Greenhouse Gas Removal Demonstrator (GGR-D) programme

This forms part of the interdisciplinary £31.5 million Strategic Priority Fund (SPF) Wave 2 Greenhouse Gas Removal Demonstrators Programme. It aims to assess sustainable routes for large-scale removal of greenhouse gases from the atmosphere, allowing the UK to take a major step towards achieving net-zero emissions, and placing the UK in a leading position to benefit from the £400 billion future global market in greenhouse gas removal.

It is looking at funding five multidisciplinary research projects with nature based solutions (peatlands, enhanced rock weathering, biochar, large-scale tree planting, rapid scale-up of perennial bioenergy crops).

Case Studies

In order to gauge the progress of industrial gasification projects being developed, built, or operational within the UK we reached out to over 24 individual sites, of which 2 returned the information below in the form of 2 case studies. The first is a collaboration between Velocys and British Airways which aims to be Europe's first waste to sustainable aviation fuel plant, and the second is KEW Technology's decentralised modular system and full-scale demonstrator plant.

Velocys (Neville Hargreaves)

Altalto Immingham Waste to Sustainable Aviation Fuel Project

- Plan to build what could be Europe's first waste-to-SAF plant
- 500,000 tonnes of residual waste saved from incineration or landfill per year
- Enough fuel to power over 1,000 transatlantic flights with net-negative carbon emissions
- Over 300,000 tonnes of CO_2 saved per year
- Collaboration between Velocys and British Airways
- Uses Velocys proprietary Fischer-Tropsch technology combined with TRI gasifier and other demonstrated technologies

Site

The plant is to be built on a 78-acre site (**Figure 9**) near the major cargo port of Immingham, North East Lincolnshire. It is in an industrial area with easy access by road and rail, and a target for industrial development in the Local Plan. Planning consent was granted in June 2020. A model of the completed plant is also shown in **Figure 10**.

Figure 9. Altalto Immingham site

Figure 10. A model of the completed plant

Feedstock

The Altalto plant will take residual Municipal Solid Waste or Commercial and Industrial Waste, unsuitable for recycling and otherwise destined for landfill or incineration. The flexible nature of the process ensures that it is robust to the variations in composition that are typical of waste.

Process and technology

The Altalto project combines demonstrated technologies in a first-of-a-kind plant that could be Europe's first waste-to-SAF (Sustainable Aviation Fuel) plant.

The process is shown in **Figure 11**, and a brief description is as follows. Incoming waste is conditioned for gasification using a series of physical processes such as sorting, shredding and drying. The conditioned material is then fed into the gasifier to generate synthesis gas (syngas). Gasification technology is provided by Thermochem Recovery International (TRI). The raw syngas coming from the gasifier then passes through a Partial Oxidation process supplied by Arvos, mainly to convert remaining organics (tars), followed by a syngas clean-up process supplied by Air Liquide. This step adjusts the hydrogen to carbon monoxide ratio of the syngas to that required for Fischer Tropsch synthesis, and at the same time produces a side-stream of carbon dioxide ready for sequestration; this makes a major contribution to the carbon savings and allows the production of net negative emission fuels. The syngas clean-up step also removes contaminants such as sulphur and chlorine for safe disposal.

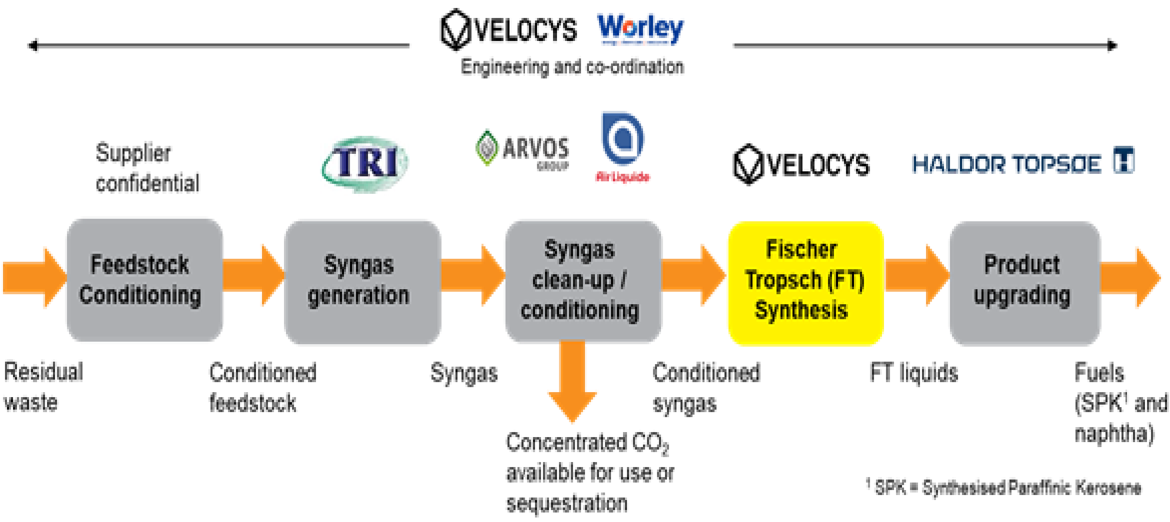

Figure 11. Process and technology licensors

The clean syngas undergoes Fischer-Tropsch synthesis using Velocys' proprietary reactor and catalyst technology, making a range of hydrocarbons which are then upgraded in a final hydrocracking, isomerisation and separation step to make fuels (**Figure 12**).

Figure 12. Velocys Fischer Tropsch reactor (above) and the finished product, SPK (right)

Products and carbon savings

The plant will produce SAF in the form of Synthesised Paraffinic Kerosene, SPK, meeting ASTM D7566 Annex A1; this is approved for worldwide use in aviation at up to 50% and can be used without any change to engines or fuelling infrastructure. The plant will also produce naphtha for blending into petrol. Total fuel production is approximately 50,000 tonnes per year. When combined with Carbon Capture and Storage (CCS), the fuel will deliver carbon savings of around 150%.

Progress and plans

The Altalto project has completed pre-FEED engineering and been granted planning consent. The project is largely FEED-ready, pending clarification of SAF policy by the UK Government. Subject to financing, the plant is expected to be producing SAF by 2026. Further plants in the UK and overseas are expected to follow to meet the substantial need for SAF; for example, EU mandated SAF demand by 2030 is 5%, expected to be equivalent to 3 million tonnes. This technology offers a route from abundant waste feedstocks, with no indirect land use change, and is therefore expected to contribute to aviation decarbonisation worldwide.

KEW Technology (Amna Bezanty)

Company

KEW Technology is a UK-based sustainable energy solutions company. The company has developed an Advanced Thermal Conversion (ATC) technology based on gasification, that efficiently converts non-recyclable resources and low-grade biomass into a wide-range of sustainable energy vectors, such as hydrogen, power, heat and advanced fuels for a zero carbon future. KEW was initially founded with the vision of developing products that allow two global challenges, waste disposal, and sustainable energy supply, to be tackled simultaneously. KEW's vision is a future of energy and resource utilisation through smart, circular economies that integrate energy supply and users in local networks enabling optimisation of energy conversion and utilisation. KEW deploys its technology into developed projects, helping industrial corporations to achieve their net-zero ambitions in harder to decarbonise areas such as industrial gases and fuels.

Technology

KEW's gasifier system can use solid waste feedstocks and biomass, and convert them into high-value energy products such as advanced fuels (hydrogen, jet fuel, diesel), heat as well as power through compact, modular efficient plants.

The key innovation in KEW's system is operating the gasification system (and specifically a gas reformation step) under pressure. This cracks longer hydrocarbons and removes impurities which otherwise create challenges with solids and tar build up - one of the biggest challenges in the gasification space.

The flexibility of the platform allows it to service two parallel markets:

- **Decentralised, embedded waste to energy solutions**: The compact nature and ultra-low emissions make it well suited for integration into industrial and commercial premises, converting locally generated wastes into heat, power, and renewable industrial fuels for on-site consumption.
- **Advanced biofuels production:** The syngas is suitable for producing advanced biofuels such as hydrogen, aviation fuel, DME and diesel.

The technology is configured to facilitate combination with CCS, enabling *negative* carbon potential while providing end-product flexibility.

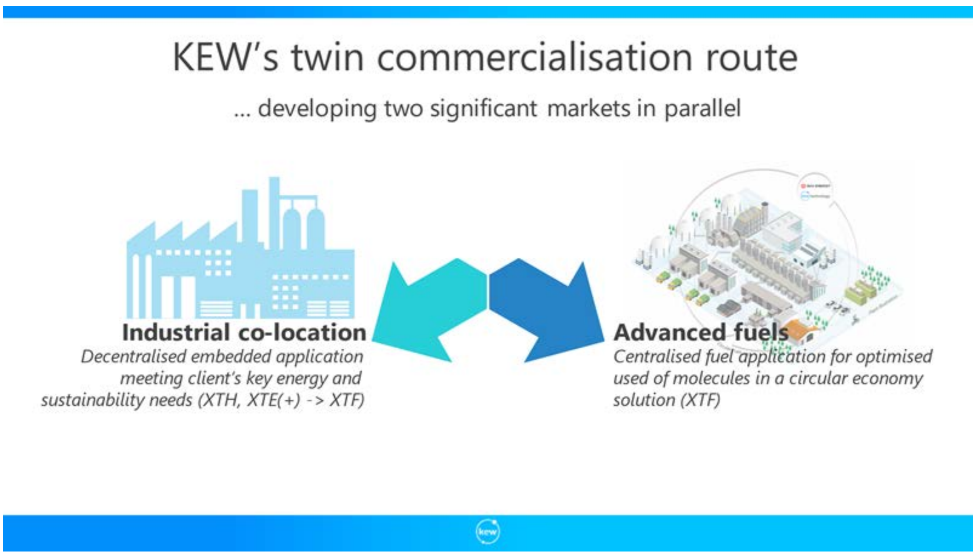

Figure 13. Kew Technology markets

Modular Solution

KEW's pressurised operating envelope enables compact plant design (>1/8th the physical size of non-pressurised technologies) with high process efficiency and reliability. The pressurised operation lends the technology to a modular, factory built architecture. This allows efficient project execution and delivery as well as excellent project economics that benefit from the use of standardised, serial, lean production methods that cut costs and increase revenue.

This modular approach also enables the technology to be embedded into projects that are shorter term and allow immediate technology deployment while allowing a gradual commercial ramp-up of larger biofuels production facilities with leading strategic partners.

The platform has three variants: XTH (Anything to Heat), XTE (Anything to Electricity) and XTF (Anything to Fuels) which allows various end-product vectors depending on the application.

The plants qualify as "End of Waste" infrastructure, facilitating embedded installation.

Commercial demonstrator

KEW has developed a full commercial-scale demonstrator. In a sector with a high requirement for proven technology, KEW is one of the few technologies globally that has a fully deployed platform at its Sustainable Energy Centre (SEC) site in Wednesbury, UK. The site acts as a centre of excellence for technology and product development and proving, operator training and the development of novel, ground-breaking associated technologies such as carbon capture.

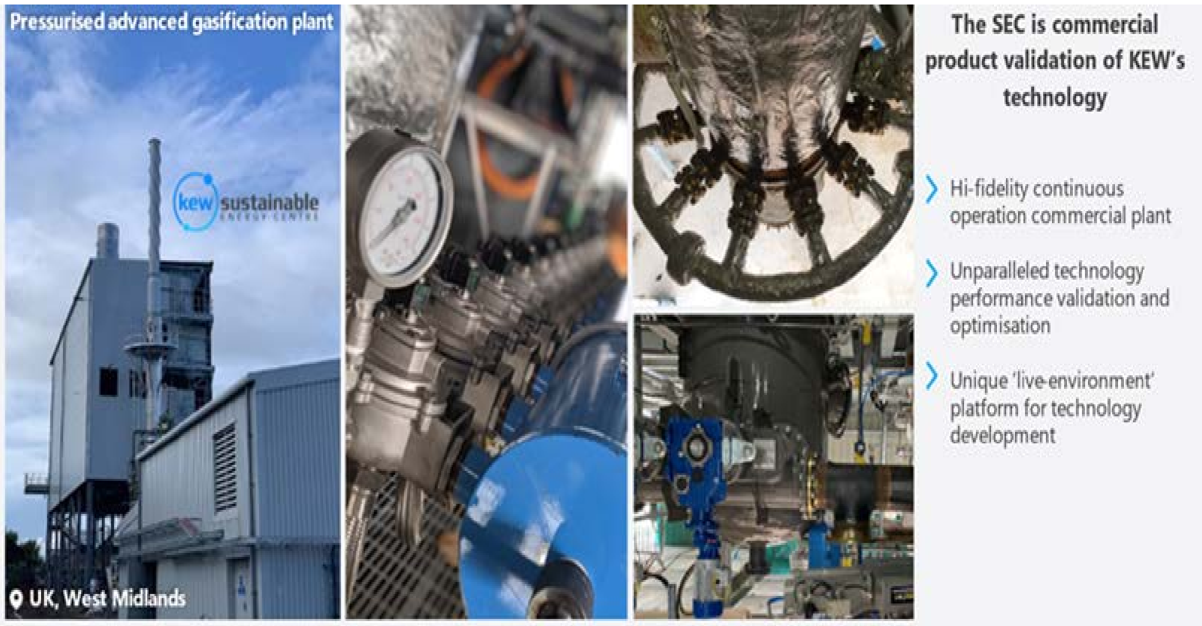

Figure 14. Kew Commercial scale demonstrator built in the UK

Partnership with Energy Technologies Institute

The technology and therefore the company have both benefited from involvement and support from the Energy Technologies Institute (ETI). The ETI was established to research low carbon energy system planning and technology development to address critical UK energy and climate change targets. It was a Public-Private Partnership (PPP) made up of the UK Government (BEIS), and top global energy players such as BP, Shell, Rolls-Royce, Caterpillar, EDF and E.On.

The benefits of supporting small scale Advanced Conversion Technology (ACT) was the ability to thermally convert a wide range of both residual waste and/or biomass directly into a range of high-value energy vectors, rather than just electricity and occasionally heat, which were the outputs from the incumbents. The UK market had seen many failed ACT projects, where either waste types, residue outputs, and more typically the failure to deal with the resultant long-chain hydrocarbons (tar), captured within the syngas stream had seen many projects fall and significant investment and confidence in the technology lost.

One of the key challenges was to research and identify the technology gap for small scale decentralised technology solutions (in the <10MWe scale) as the UK is heavily reliant upon less efficient, very large mass-burn Incineration, to convert waste into energy.

As a consequence, the ETI developed and opened a competition to explore and discover innovative ATC technologies. The competition received 97 separate applications, and KEW were one of three selected to carry out 12 months of funded and very detailed Due Diligence. Following this vigorous & robust process, KEW were selected to receive the full development funding from the ETI.

Conclusions

This short report aimed at providing an overview of the current scenarios and challenges around biomass gasification in the UK. This included recent advances in the academic, government and industrial sectors. There are still several barriers to commercial success of gasification such as those reported by the Supergen Bioenergy Hub in 2019 [7].

It is clear that there are certain areas where further research is needed in order to face common challenges in waste gasification in the UK. These challenges are a result from constrained available finance, non-technical barriers and technical difficulties.

The UK as a country is making efforts in the academic, government and industrial sectors in order to address these challenges and most importantly, link them to the country's strategy to achieve Net Zero by 2050.

References

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