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BioSNG Pilot Plant

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Background

Bio-Substitute Natural Gas (BioSNG) addresses the issue of decarbonising heat which, accounts for 50% of all final energy use in the UK. It also offers an alternative route for gas supply - one that is greener and affordable which could help to provide an improved and more secure energy future.

National Grid is working with specialist companies Advanced Plasma Power, Progressive Energy and Carbotech to develop new technology to convert municipal waste into a valuable and long-term energy resource. At the heart of the approach is an innovative project designed to convert waste to BioSNG, which can be used in the gas network. The project is in receipt of multi-million pound innovation grant funding from both UK energy regulator Ofgem's Network Innovation Competition and from the European BioEnergy Securing the Future ERANET programme.[1]

Using BioSNG would greatly expand the supply of renewable gas over and above existing solutions such as anaerobic digestion (AD). Previously unused waste products diverted from landfill and other biomass material can act as the feedstock for gas generation.

The technology is being showcased at a new pilot process plant being built at Advanced Plasma Power's headquarters in Swindon. The test facility is designed to show the potential of BioSNG from both a technical and commercial perspective - and will move the technology from concept to reality. It will demonstrate the potential for communities to access locally generated renewable gas, using waste that would be sent to landfill.

By demonstrating technical feasibility, and showing that this approach can contribute to generating the volumes of pipeline-quality gas required to sustain the nation's energy requirements, the project partners believe that such plants can serve regional needs across the country. Such a plant network could make a telling contribution to the future reliability of gas supplies at an affordable cost and with minimal environmental impact.

The approach could help solve an issue facing governments, energy suppliers, policy makers and consumer groups across the world: how to produce low carbon energy in a sustainable way through the development of advanced technology that is commercially viable, affordable, and acceptable to the energy-consuming public.

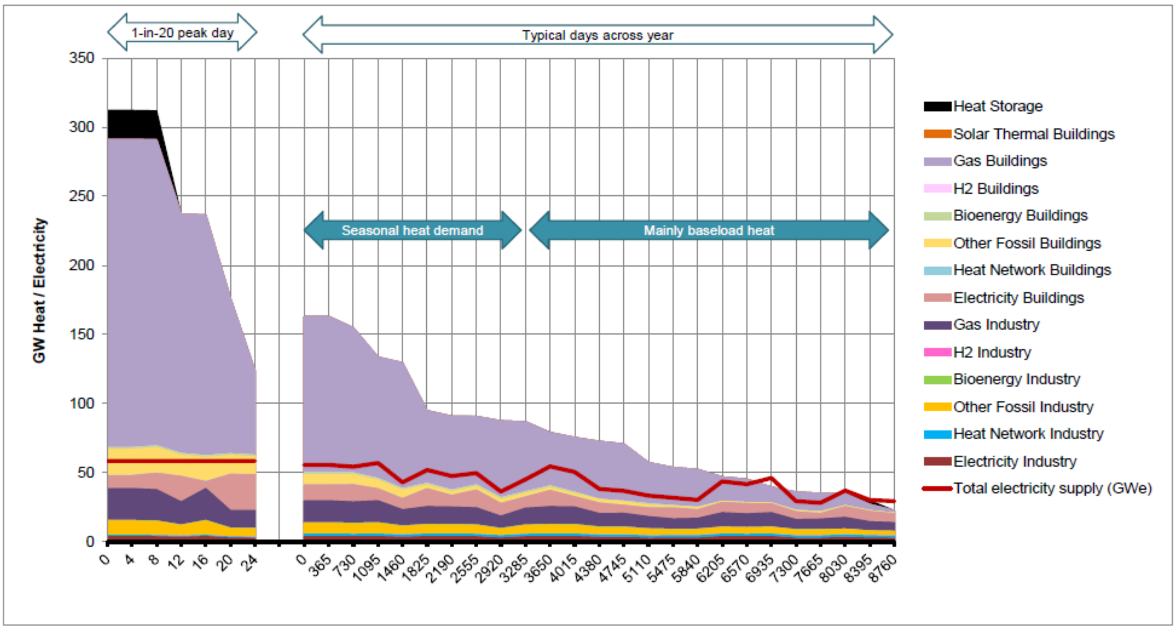
[1] The BioEnergy Securing the Future (BESTF) ERANET programme is a consortium of 8 EU member States and Associated Countries to provide funding to collaborative and innovative bioenergy demonstration projects. For more information see: http://eranetbestf.net/

The environmental benefits will include contributing to the acceleration of a low carbon economy, the decarbonisation of heat, and a marked reduction of waste volumes going to landfill. The economic benefits include new investment opportunities which will provide affordable energy for consumers, and the possibility of increased local control over waste processing linked to green energy generation.

Aim

The UK has committed to an 80% reduction on 1990 Greenhouse Gas (GHG) levels by 2050. To date the focus has been on decarbonising electricity supply, yet heat demand makes up almost 50% of final energy use. Whilst there are multiple potential pathways for decarbonisation of electricity, the options for low carbon heat are more limited and challenging. The production of renewable gas has the potential to deliver significant quantities of renewable heat directly to consumers, without replacing millions of consumer appliances or requiring significant investment in energy delivery systems.

The key issue in supplying heat energy is the highly variable nature of heat demand, as can be seen by heat demand curves shown below.



Peak and seasonal heat demand in the UK is extremely variable, with the peak capacity load on a daily basis being over five times the lowest day, and the peak capacity hour being over ten times the lowest hour. Currently gas dominates the heat supply curve in the UK with 83% of its buildings heated by gas, typically using efficient modern gas boilers.

The possible electrification of heat delivery through the widespread roll out of electric heat pumps is limited by the ability to build sufficient low carbon generation to meet peak demand, the amount of reinforcement required on the electricity transmission and distribution systems, and the need for a mass replacement of end user appliances. It is neither practical nor cost-effective to meet the peak demand solely through electrification of heat.

Similarly, decarbonisation of heat by means of biomass boilers or district heating is likely to be limited to specific local applications with favourable characteristics (typically off gas grid and high density housing respectively).

Conversely, the delivery of renewable gas manufactured from biogenic sources using a gas network which is ideally suited to transmitting and distributing such variable levels of energy offers the prospect for best value to consumers.

Methods

Biomethane derived from anaerobic digestion is already being upgraded and injected into the UK gas grid. However, factors such as feedstock availability and the need for an environmentally friendly use for the digestate produced by AD are expected to constrain maximum output, potentially to around 40TWh/a (12% of current annual domestic gas demand).

Following extensive feasibility work National Grid, along with its partners have identified that the production of BioSNG has the potential to provide substantial volumes of biomethane required to provide low carbon cost-effective gas and therefore heat to customers via the existing gas networks and existing customer appliances.

BioSNG is produced using thermal processes. The dry biomass, or biomass-rich waste is gasified to produce a bio-rich synthesis gas. This intermediary product is similar to fossil derived town's gas, used in the network until the 1970's, and is predominantly a mixture of carbon monoxide and hydrogen. However, recognising the need for a fungible fuel which can be used in consumers' appliances with no modifications, this gas is purified, upgraded and converted to a methane-rich substitute natural gas using catalysis. Following final polishing this is suitable for injection into the grid. This provides a low carbon heat solution to customers.

This ability to process other more abundant sources of biogenic feedstock including residual black bag & commercial wastes (more than 98% of the UK's potential biogenic resource is found in waste products - [Gill et al, Biomass Task Force Report, 2005]) has the potential to significantly increase the availability of renewable gas by ~100TWh (30% of current domestic demand). This waste still has a high biogenic content (>60%) and through thermal gasification and methanation could produce BioSNG which is pipeline quality, low carbon and cost competitive with other renewable energy sources.

The Pilot facility being developed in this project builds on extensive work carried out by the project partners, specifically a feasibility study sponsored by National Grid, Centrica and the North East Process Industries Cluster (NEPIC) [Progressive Energy 2010] and an extensive design and development programme sponsored by Ofgem's Innovation Funding Incentive. This process of stage-gated project development has provided a process design concept and confidence in its commerciality gained through economic modelling of a full-scale plant, together with sustainability credentials and pre-FEED and detailed design of the pilot plant.

Overview of Project

The objective of this project is to construct a pilot plant that will demonstrate the techno-economic feasibility of the transformation of a waste-derived syngas into a pipeline quality substitute natural gas.

It will test and demonstrate this by taking a waste derived syngas from Advanced Plasma Power's Gasplasma® pilot facility, located at Swindon and upgrading it through a dedicated conversion and clean-up plant to a pipeline quality (UK Gas Safety (Measurement) Regulations (GSMR) specification) gas.

Process modelling, engineering design and empirical work on catalyst performance has been undertaken by the consortium partners during the last two years and is being embodied in the pilot plant. The construction and operation of this plant, together with associated test programme, will demonstrate the way in which waste-derived syngas can be transformed into pipeline quality gas. Beyond the initial proof of concept, the test programme also plans to explore the operational envelope of the technologies employed in order to identify the key optimisation parameters for the overall performance of the system. These activities will inform the design and economic viability of subsequent commercial plants that could significantly increase the potential of renewable gas in the UK as discussed above.

The project will take approximately 3 years, split into 3 phases: build, commission and test programme. The project commenced on 1st April 2014 and the expected completion date is 31st March 2017.

Pathway to deliver the solution

Conversion of coal-derived syngas to methane is in commercial operation globally, as are examples of waste gasification for the purpose of producing power. However, the end-to-end process of waste feedstock through catalytic methanation and refining to pipeline quality gas has not been demonstrated before anywhere in the world. The commercial attributes of a such a project are such that the process optimisation parameters are significantly different from conventional applications of methanation; (a) the product specification is for GSMR quality gas, not pure methane which is typically required as a chemical feedstock in large scale coal facilities, (b) the smaller scale demands simpler once-through processes operating at lower pressures, (c) capital cost at moderate scale is a key requirement of success, (d) process optimisation is not simply waste-gas efficiency, but importantly integration of servicing internal heat and electricity demands. The previous work has developed a process based on these attributes.

In order for projects to come to the market, technology demonstration is required. Without demonstrating the techno-economic feasibility through a pilot project it is very unlikely that commercial projects would reach fruition and hence the potential benefits to the UK from increased availability of GB sourced renewable gas would not be realised. Therefore, through the demonstration and dissemination of knowledge from this project it is envisaged future commercial projects will be developed.

Technical Description: Proposed Pilot Plant

The proposed pilot plant is based upon APP's existing Gasplasma® process for the production of syngas, which has been extensively demonstrated at its Swindon facility, which is an advanced conversion technology (ACT) that has been developed to achieve best available technology (BAT) status. The core of the Gasplasma® process comprises a fluidizing bed gasifier which converts solid feedstock to a crude syngas, followed by a plasma converter that efficiently cracks the tars entrained in the crude syngas, to produce syngas of sufficient quality to fuel an efficient turbo-charged gas engine.

The detailed process design has been developed from a conceptual design and defines the process flow scheme, mass and energy balance and layout for the BioSNG pilot plant at the APP Swindon facility, where the existing Gasplasma® plant will be used to supply the syngas derived from waste as a feedstock for the SNG process. This existing facility will be used intermittently to fill a high-pressure syngas store that will have capacity to run the BioSNG pilot plant for a sustained period.

The "engine quality" syngas produced by the Gasplasma® facility is well understood from its operational history. In the proposed pilot plant this syngas will undergo further gas cleaning prior to compression and high-pressure storage. Thereafter the hydrogen:carbon monoxide ratio of the syngas will be adjusted to the stoichiometric 3:1 composition required for methane production by means of a conventional catalytic water-gas shift reaction prior to methanation. A number of methanator design configurations have already been evaluated by the consortium, the principal challenges being the paucity of literature for the low pressure / high molar concentration conditions required in this application, coupled with the large heat release that is a feature of the catalytic methanation reaction. To reduce the uncertainty in reactor design, test runs on representative syngas samples have been undertaken by a catalysis specialist research laboratory in the UK, to provide empirical data to inform the design of the methanation reactor. In addition to this precaution the design incorporates provisions to evaluate a number of reactor configurations and a variety of catalyst bed geometries during the testing period.

In the transformation of syngas to SNG, approximately half the carbon in the feedstock will be converted to carbon dioxide which in turn must be separated from the product stream emerging from the methanation reactor. The design work has identified pressure swing absorption as the preferred technique for this. In order to minimise the parasitic power demand the process is designed for operation at a moderate pressure, with SNG compression to gas network injection pressure undertaken only on the final SNG product at the end of the process.

Throughout the experimental phase of the project, data will be generated to prove the durability and efficient performance of all the component unit operations working in combination. The technical, economic and ecological performance of the final process will be determined utilising life cycle assessment (LCA) and whole life costing (WLC) for the integrated system. Rigorous performance tests will be conducted to attest to the low emissions of the system, cost effectiveness and efficiency compared to established alternatives.

This project is truly innovative by considering feedstocks, scale and product gas.

Conversion of coal to methane via catalytic methanation is practiced internationally at 3000MWth scale, for example at the Dakota synfuels plant in the USA, as well as other large scale, coal fuelled facilities in China, primarily for the ultimate production of ammonia. The objective here, however is to provide renewable and low carbon sources of substitute natural gas, that is the system must be designed to use biomass rich feedstock rather than coal. Given the nature of waste arisings, BioSNG must be able to be produced commercially at a smaller scale than this, in 50-200MWth scale units.

This therefore represents a significant innovative developmental challenge; delivering technically and commercially viable methanation of syngas derived from waste-derived biomass. This must be able to accommodate the different set of contaminants arising from waste gasification, be able to be deployed at much lower scale than conventional methanation facilities and deliver an output product which meets GSMR requirements (which is different from the production of pure methane for chemicals applications).

The only BioSNG projects under development in the world are from pure biomass feedstocks, specifically a small scale research facility at Gussing and a larger biomass fuelled plant under construction in Gothenburg. As is shown graphically below, the UK is very different from Sweden and the most abundant and cost effective sources of biomass come from waste streams and not forestry; the most cost effective solution for the UK gas consumer is one which can process biomass-rich wastes.

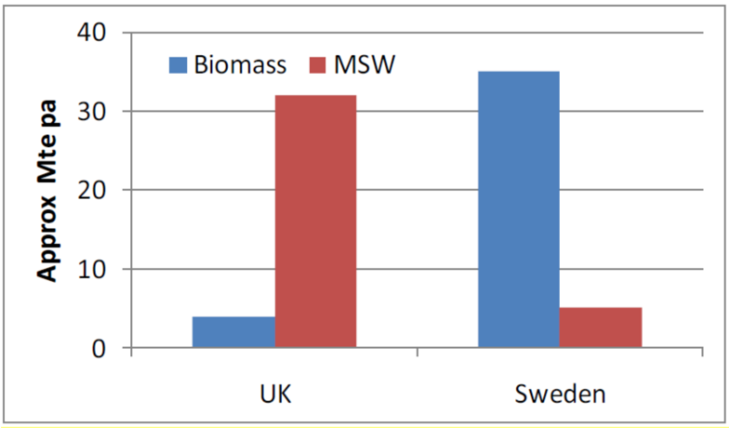


Figure 2.1

Through the work undertaken previously by the partners a process design has been developed specifically designed to meet the requirements of waste-derived syngas, moderate scale and to meet GSMR requirements.

This provides the platform for deployment of cost effective, low carbon heat delivery to the UK gas consumer

Design of the Trial: Programme

The purpose of this programme is to: (a) demonstrate technically that waste-derived syngas can be converted to grid quality gas using a design appropriate for commercial scale operation (b) optimise the process operational parameters (c) confirm the final process is commercially viable, and provide tangible demonstration to the low carbon investment community and other stakeholders.

The steps involved are: (a) procure and build Pilot SNG facility, (b) connect to syngas source and commission, (c) extensive technical test programme, (d) review and refine commercial project specification, design and ecological attributes (e) showcase the proposed solution as part of a knowledge transfer programme. Items (c-e) are not expected to be sequential; but to be undertaken in parallel.

Procure and build Pilot facility as specified in the detailed design

Previous work by the consortium has resulted in a well-developed detailed design and specification for the facility. More recently the team has completed the procurement process for the major components of the pilot plant. The equipment has now been delivered to site and individual components have been commissioned.

Connect to APP's existing gasifier and commission the plant

The project programme envisages completion of the end-to-end commissioning process later in summer 2015, comprising control interface testing, cold and hot commissioning.

An extensive, staged technical test programme

The test programme has been carefully constructed to provide both early confirmation of feasibility, to underpin commercial development of full scale project, whilst also providing deep technical evaluation of the process to allow optimisation of a detailed robust process design. This is outlined in more detail below. Early data is to be provided within 6-9 months, whilst the overall programme is 18 months. Specifically, the programme is designed to understand and confirm:

- The impact on plant design and product quality of a variety of syngas compositions, feedstocks and a range of operational conditions as well as the associated carbon accounting. These early tests will underpin the commercial assumptions required to expedite the development of a full-scale facility. This programme is planned to provide the necessary information within 6-9 months of completion of commissioning.

- Further investigations into the technical and commercial effectiveness of the syngas cleaning, converting and upgrading techniques specified in the process design and alternatives that may be identified through the planned optimisation programme:

    a. Mapping of the performance envelope of the key process operations to provide a basis for value engineering to reduce unit SNG production cost.

    b. Evaluation of the performance of alternative catalyst types with respect to longevity, reactor design configurations, cost effectiveness, and product slate.

    c. Investigation into the effects on plant design and product quality of a variety of syngas compositions and a range of operational conditions of temperature and pressure.

- Further investigations into the technical and commercial effectiveness of the syngas cleaning techniques specified in the Stage 2 process design and alternatives that may be identified. Confirmation of the optimal techniques for removal of CO_2 from the product stream to produce Carbon Capture and Storage-ready CO_2 for transportation and sequestration.

- Investigations into control of the gas quality to ensure reliable delivery of pipeline quality gas e.g. Wobbe Index, nitrogen, hydrogen content etc.

- Refinement of the overall process control system for safe and reliable operation.

Review and refine commercial project specification, design and attributes

Using the confirmatory data from the initial 6-9 months of the test programme, the commercial and sustainability attributes of a full scale facility will be reviewed. This is designed to confirm the economic profile of such a project which will underpin commercial development activities for the first project, which can then be progressed in parallel. This compresses the lead time to deployment and the realisation of value to the UK consumer.

Showcase the proposed solution as part of a knowledge transfer programme

The partners are committed to a knowledge sharing programme. The purpose of this programme is to maximise the value to the UK consumer by facilitating deployment of BioSNG. This is best achieved through communication of the benefits offered by BioSNG developments as well as the results from this project. The audience of such a programme is:

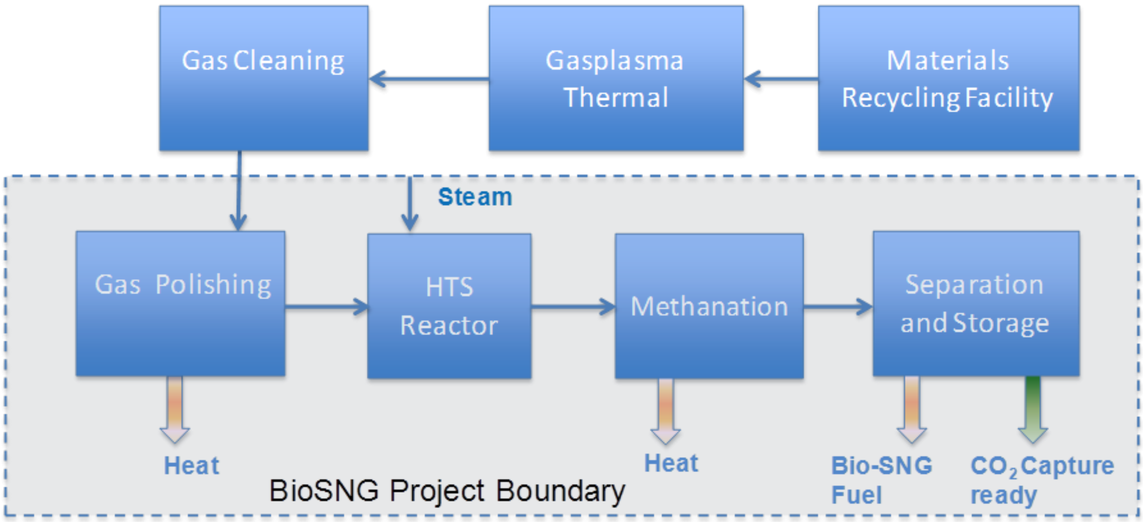
- Policymakers. Deployment of renewable technologies requires an appropriate policy environment. This project aims to provide early tangible demonstration of the opportunity offered by this approach. The current policy environment is conducive to the development considered; show-casing progress demonstrates progress towards low carbon heat outcomes and the confidence to ensure the policy environment endures.

- Other network owners, gas suppliers, local authorities and project developers. The consortium will welcome commercial entities to witness operation of the technology. Understanding of the potential of the technology assists in providing a supportive environment for local connections and commercial pull from gas off-takers. In order to maximise the benefit to the UK consumer it is expected that the technology may be used in conjunction with other gasification technologies and to be applied by other developers. This maximises the speed and scope of roll out.

- Customers. The showcase is designed to inspire consumers, communicating the carbon benefits of converting waste arisings from their own local area to low carbon renewable gas being delivered through their local gas distribution network.

The primary means by which this will be achieved is through showcasing the pilot plant which will take waste input, convert to grid quality gas and then combust it in a conventional consumer appliance.

This tangible demonstration will be backed up by appropriate dissemination of information through publically available reports, journals, website, and appropriate industry conferences. These will be targeted at appropriate sectors, ranging from the waste industry, the energy industry and also policymakers.



Results

- Techno-economic studies have demonstrated that a waste-derived BioSNG facility of 50MWth output would be commercially viable under prevailing support regimes under the UK's Renewable Heat Incentive (RHI). In time, larger scale production facilities will be deliverable with competitive gas prices, even where support levels are reduced, as would be expected for all renewable technologies. Few other low carbon technologies are able to deliver solutions to consumers at prices competitive with conventional fossil fuels.

- A key learning outcome from work undertaken already is the need for value engineering in design of the BioSNG facilities. This has proven to be essential in procurement of the pilot facilities, but will be of even greater importance in the realization of the full-scale plant and its commercial viability.

- The work has also provided confidence in the sustainability attributes of the approach. An independent report assessing the Greenhouse Gas (GHG) emissions from the BioSNG process was produced by National Non-Food Crops Centre (NNFCC) [NNFCC 2010]. Within it the emissions have been calculated using the BEAT2 and EC RED methodologies. BEAT 2 includes alternative disposal of the feedstock e.g. to landfill and therefore provides a greater GHG saving than EC RED and also accounts for the significant difference in emissions observed between the two methodologies. For BioSNG from waste (Municipal Solid Waste Refuse Derived Fuel pellets) the carbon intensity as referenced to the point of use in a gas boiler at 85% efficiency are as follows:

  - BEAT2: -0.01896 kg eq CO_2/MJ, -68.3 kg CO_2 eq/MWh
  - EC RED: 0.02302 kg eq. CO_2/MJ, 82.9kg CO_2 eq/MWh

  For comparison, Natural Gas has the following carbon footprint:

  - BEAT 2: 0.06975 kg eq. CO_2/MJ 251kg CO_2 eq /MWh
  - EC RED: 0.06743 kg eq. CO_2/MJ 243 kg CO_2 eq /MWh

  It is seen that, irrespective of the methodology used, the proposed BioSNG represents a significant saving over natural gas of either 127% (BEAT 2) or 66% (RED). Therefore there is confidence that this approach will provide a low carbon, sustainable solution for heat.

Conclusions

Few other low carbon technologies are able to deliver heat solutions to consumers at prices competitive with conventional fossil fuels. Therefore the project partners have confidence that the project learning can and will be deployed commercially and will lead to substantial reductions in GHG emissions.

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