ENERGY FROM GAS: TAKING A WHOLE SYSTEM APPROACH.

Institution of MECHANICAL ENGINEERS

Improving the world through engineering

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By focusing on gas we have been able to look at the whole UK energy and industrial system. As we utilise the flows of electricity, gas and wastes we can begin to create a circular cycle of resources and ensure that we reduce pollution, carbon emissions and our overall environmental impact.

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This report has been produced in the context of the Institution's strategic themes of Education, Energy, Environment, Healthcare, Manufacturing and Transport and its vision of 'Improving the world through engineering'.

Published May 2018.
Design: teamkaroshi.com

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EXECUTIVE SUMMARY

Emissions and pollution from industry and everyday life are continuing to have a negative impact on the planet and increasing the likelihood of extreme weather conditions, drought and polluted air in cities.

Globally engineers are working to identify realistic solutions to these problems. In our recent Air Quality report – A Breath of Fresh Air,[1] the Institution of Mechanical Engineers identified that in 2014, 514 million tonnes of CO_2 equivalent emissions from all sources in the UK were released to atmosphere. The report calls for much closer monitoring of our emissions, ensuring we understand where emissions are most concentrated. The effect of deteriorating air quality in our cities from these emissions is contributing to up to 40,000 early deaths every year.[2] These alarming statistics mean that we must find solutions to reduce the level of impact we have not only on the environment, but on our health too.

Gases for energy, which include natural gas, biomethane made from waste products and hydrogen, provide us with an opportunity to reduce negative effect. Currently about 32% of our carbon dioxide (CO_2) emissions are produced from our transport systems[3] – due largely to our over-reliance on diesel. Natural gas produces about 50% less CO_2 than coal and about 30% less than oil when burnt, and biomethane reduces the overall GHG emissions further, as it is produced from waste resources. Other gases such as hydrogen, could be used to produce much lower emissions when used for heating or as a fuel for transport.

Using gas as a replacement for diesel or part-replacing methane with hydrogen requires minimal changes to current infrastructure. Gases such as biomethane and hydrogen can travel in existing distribution networks at different percentages, provided the end-use equipment is able to safely combust the mixture. In addition, the gas grid has the added benefit that it can be used as a medium for energy storage, in a way that is potentially much less damaging to the wider environment than lithium ion batteries.

Power to gas is the process of using electricity, usually excess power on the electricity grid or in industry, to create gas, usually in the form of hydrogen. This hydrogen is electrolysed from water and is energy that can be used across all sectors of the energy system, such as electricity, heat, industry, storage and transport, helping to decarbonise. Power to gas provides a conduit for connecting the energy system together, providing fuel from excess power and reducing air pollution and CO_2 emissions.

The use of hydrogen technologies is not a new concept, but as climate change, health concerns and security of energy supplies across sectors begin to impact on our everyday lives, the appeal of the use of hydrogen technologies as part of the whole energy system grows. Clean limitless energy that can fulfil the requirements of all energy sectors, as well as many heavy industries, provides a great option for the UK.

This report provides case study examples of current industrial activities, which use energy from gas that could be scaled up to meet the needs of the Government's Clean Growth Strategy.

RECOMMENDATIONS

In order for power to gas technology to transform the UK energy system, the Institution of Mechanical Engineers makes the following recommendations:

1. UK Government must commit to creating an industrial forum that brings together the nuclear, renewable power and gas sectors to promote the generation and storage of hydrogen for use across the UK energy system in heat, transport, power generation and heavy industry. Investment now in the future hydrogen economy will begin to encourage further innovation, open up markets and help clarify legislation and regulation.
2. UK Government must work with the gas industry to promote the use of up to 20% hydrogen in the gas distribution network including change in pipes and materials by 2023. Funding programmes and demonstration sites are crucial to decarbonising gas. Government has the power to finance research, development and demonstration and support deployment through programmes such as Innovate UK, as well as bespoke programmes designed to deliver future UK infrastructure.
3. UK Government should commission a comprehensive comparative study of the long-term sustainability of materials used to create lithium ion EV batteries versus power-to-gas/gas systems and fuel cells, particularly for energy storage, to identify appropriate technology and life cycle analysis. By understanding this more clearly, UK Government can make evidence-based investment decisions that meet the requirements of sustainable development in the electricity, transport and heat sectors.

INTRODUCTION AND POLICY BACKGROUND

With the recent release of the UK Government's Clean Growth Strategy[4] along with a plethora of other energy-related documents, there is clear commitment from Government to reducing the emissions across sectors.

Specifically, the Clean Growth Strategy proposes the following policies:

Table 1: Policy Proposals from the Clean Growth Strategy[4]

Policy proposal	**Outcome**
Demonstrate international leadership in Carbon Capture Usage and Storage (CCUS), by collaborating with our global partners and investing up to £100m in leading-edge CCUS and industrial innovation to drive down costs. Work in partnership with industry, through a new CCUS Council, to put us on a path to meet our ambition of having the option of deploying CCUS at scale in the UK, and to maximise its industrial opportunity.	Lower emissions Reduces air pollution Storage of CO_2 and potentially hydrogen (H2) Develops new industry
Support the recycling of heat produced in industrial processes, to reduce business energy bills and benefit local communities. Innovation: invest about £162m of public funds in research and innovation in Energy, Resource and Process efficiency, including up to £20m to encourage switching to lower carbon fuels.	Reduces energy demand Reduces air pollution and emissions
Build and extend heat networks across the country, underpinned with public funding (allocated in the Spending Review 2015) out to 2021. Phase out the installation of high-carbon fossil fuel heating in new and existing homes currently off the gas grid during the 2020s, starting with new homes. Improve standards on the 1.2 million new boilers installed every year in England and require installations of control devices to help people save energy; invest in low-carbon heating by reforming the Renewable Heat Incentive, spending £4.5bn to support innovative low-carbon heat technologies in homes and businesses between 2016 and 2021. Innovation: invest about £184m of public funds, including two new £10m innovation programmes to develop new energy efficiency and heating technologies to enable lower cost, low-carbon homes.	Reduces fuel requirements Lowers emissions and reduces air pollution
End the sale of new conventional petrol and diesel cars and vans by 2040.	Reduces emissions and air pollution Encourages use of alternative low-carbon fuels
Phase out the use of unabated coal to produce electricity by 2025.	Reduces emissions and air pollution Encourages growth in alternative power generation solutions
Explore new and innovative ways to manage emissions from landfill.	Reduces emissions Encourages opportunities for methane storage

MAKING THE MOST OF OUR EMERGING ENERGY SYSTEM

Our energy systems are changing. Heavy GHG-emitting technologies, such as coal-fired power stations and diesel internal combustion engines, are being replaced by lower emitting technologies. Coal has given way to gas and renewables, and recently we have seen the rise of the electric vehicle. These are positive moves for humanity, but with them new challenges emerge.

Our energy system comprises three main parts: power (electricity), heat and transport, with heat and transport making up about 40% each and power at about 20%.[5] From recent ONS data we know that transport is the biggest energy user, at 40% of total energy consumption, followed by the domestic sector and industry respectively.[6]

In most sectors gas is a key player: for electricity approximately 43% of annual total electricity is produced using gas,[7]; for heat it provides 82% of domestic heating and 53% of domestic cooking requirements[8]; with very little in the transport sector. Currently, the transport sector is the only part of the energy system that is increasing its use of oil, which is due to an increase in freight and shipping movements,[9] and an area where gas and particularly hydrogen could help reduce overall emissions. Hydrogen is already in use across many European cities for bus and train services.

UK Government recently announced a ban on the sale of new passenger vehicles with conventional diesel and petrol internal combustion engines by 2040. This has been followed by an announcement to also phase out diesel-only trains by 2040. The passenger vehicle ban is being replicated in similar ways across Europe and further afield. This means that vehicle manufacturers and fuel providers are looking diversify to meet this target.

THE CHANGING ELECTRICITY GENERATION ENVIRONMENT

When we talk about energy, often it is the electricity system that is being discussed, which is just a small part of a much larger system. Since 2015 the power sector has been experiencing a transformation: we have seen a drop in the use of coal to generate power, an increase in renewables and an increase in gas use to fill the gap. Natural gas and renewables are now the UK's primary sources for power generation.[10] The nuclear component of power generation has remained broadly the same and is expected to continue as a reliable low-carbon electricity source.

One area that isn't being addressed clearly by UK Government, is the security of electricity supplies. The rapid reduction in electricity generated by coal-fired power stations has been met primarily by additional gas, where there was additional capacity in the system. In addition to this there will be a gradual shutdown of the current generation of nuclear power stations. Currently nuclear provides about 20% of electricity demand, however depending on weather conditions and renewables generating capacity along with demand, this can be as high as 30%. There is a concern that the UK Government is not providing a clear vision for the nuclear power sector; this has meant that investment has stalled, leaving us in a position where our current fleet is due to come off line by 2030 and we have not positioned ourselves to replace this.

As the grid changes along with our demands for electricity, this is driving interest in batteries and power to gas as storage solutions. These provide flexibility on the network and ensure that there is available electricity, even with higher levels of intermittent renewable generation on the grid. Natural gas currently provides a large, and effective, part of the current storage system, but hydrogen can also perform this role. There are still many questions surrounding the materials and recyclability of batteries that should be answered before large-scale roll-out onto the system, particularly as a strorage solution.

THE ENERGY HIERARCHY: A JOINED-UP APPROACH

Nuclear power is a low-carbon technology, where one uranium fuel pellet provides as much energy as 481m^3 of natural gas.[11] New smaller reactor designs are reducing costs, reducing fuel requirements and reducing wastes leading to more flexible and effective electricity generation. A clear pathway for small modular reactors will help to maintain low-emission electricity generation, and when renewables are generating can be used to electrolyse water, creating hydrogen for use across the energy system.

These changes in electricity generation have led to more gas being required to generate power; gas plants are both large power stations and smaller peaking units used to build resilience into the system. Additionally, the variability of renewable generation has increased the need for flexibility on the supply and demand sides, and increased the need for more innovative ways to store electricity.

In 2009, the Institution of Mechanical Engineers introduced the Energy Hierarchy and this is still relevant today, particularly when we consider a joined-up, connected system.

In the National Grid's Future Energy Scenarios, the amount of renewable electricity in the UK energy system could increase to as much as 60% by 2050 as seen in its Two Degrees scenario.[12] This, combined with rapid changes in technologies, business models and consumer expectations, means that using all our energy effectively will become more important than ever.

Opportunities for engineers with the training and skills to develop these new systems, both large and small scale, will increase. Apprenticeships, cross-sectorial working secondments, industry-sponsored students and degrees are all ways that new skills can be developed. Greater collaboration and joint projects across the energy system will be needed to ensure that the resources we use and have as wastes are maximised, meeting sustainable development goals and minimising the intergenerational impacts.

Encouraging people to engage with their energy system through awareness raising campaigns, science communication and primary and secondary school education, is also an important element of creating a new and diverse group of energy experts and innovation in the system.

The Institution of Mechanical Engineers, through its education and skills programme, makes a significant contribution to raising awareness of alternative pathways to engineering.

Figure 1: Energy Hierarchy[13]

SUSTAINABLE

Priority 1: Energy conservation. Changing wasteful behaviour to reduce demand

Priority 2: Energy efficiency. Using technology to reduce demand and eliminate waste.

Priority 3: Utilisation of renewable, sustainable resources.

Priority 4: Utilisation of non-sustainable resources using low-carbon technologies.

Priority 5: Utilisation of conventional resources as we do now.

UNSUSTAINABLE

GAS: THE TRANSITION FUEL

This report focuses on the role of gas in the energy system, however there are opportunities for gas produced in the UK in the non-energy sectors, such as manufacturing and chemical production. Further reductions in emissions could be found in these areas, including using biomethane and green hydrogen in place of the current conventionally sourced gases.

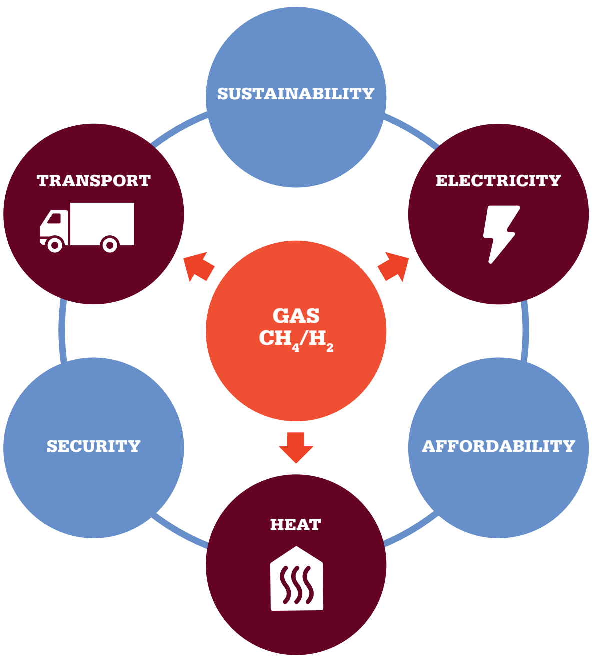
When we stop considering the energy trilemma as trade-offs and start considering the energy trifactor, we can see that gaseous energy performs well across the board; it is affordable as a commodity, produces around half or less of the GHG emissions of coal and currently there is a reliable and secure supply from both UK extracted and generated gas and from overseas imports. This trifactor demonstrates particular benefits, in that gas performs well in meeting the needs of the whole energy system of electricity, heat and transport.

Gas provides us with fuel for a wide set of applications. Gas is flexible, it can be produced using a variety of methods, used to meet peak electricity demands, used to absorb surplus renewable electricity, stored in the system to meet peak heat demands and used to power heavy goods vehicles.

One key challenge emerging over the last year or so is that of energy storage. How do we manage the changing demand profile of electricity requirements, what will happen when more electric vehicles are on our roads and our railways are upgraded to electricity? There has been significant focus on battery technology that provides an established and cheap pathway using lithium-ion, which has no tailpipe emissions. However, there are still difficulties facing this technology in terms of duration of electricity storage, efficiencies and losses, size, and perhaps more concerning the sustainability of the materials used in battery technologies and the long-term management of wastes and recycling.

The Institution of Mechanical Engineers encourages policy-makers and industry to look at longer-term planning for energy storage and wider successful use of energy vectors across the system ('sectoral integration'). Gas produced from renewable sources, including electrolysis for hydrogen and anaerobic digestion/landfill gas for biomethane, along with other gasification techniques, provides us with more flexible options not only for storage, but as fuels for heat and vehicles. Gas provides a potential solution for heavy goods vehicles, aircraft and shipping, all forms of transportation that are currently increasing their oil use.

Figure 2: Gas Opportunities and Benefits[14]



The Committee on Climate Change has provided details of how it expects UK electricity demands to change over the coming years. The graph below reveals that, with the likely increases in electrification of transport and possibly heat, the Central Scenario shows demand increasing from about 2025. It is also likely that without any emissions reduction action, as shown in the Baseline Scenario, electricity demands will increase as well.

When considering the future, one aspect that many leading energy authorities agree on, is that gas is going to play a significant part in our energy future for some time to come. The Committee on Climate Change, National Grid, the Sustainable Gas Institute and KPMG all agree that gas is not likely to disappear, and that much of our decarbonisation is likely to come from switching from oil in the transport system to gas-generated electricity. It is likely that natural gas will act as a transition fuel to the next generation of hydrogen and renewable technologies.

Gases that can be used across the system have different properties and may require different levels of upgrade for use in a variety of systems. Details of the different characteristics of gas are given in Table 2, following.[16]

By widening our use of gas in the energy system, the UK will not be restricted to an electricity and battery future and will be able to adapt to a changing climate, emerging technologies, population and political demands. Indeed gas is a prerequisite to achieving the envisaged low-carbon electricity system, because the gas grid has a greater capacity and can offer longer duration storage than any other energy storage approach. Therefore, besides its role in providing heat, the gas grid will be needed to cover both the deficits and surpluses in renewable electricity generation.

As we explore the case studies in this report, the possibilities for power to gas and biomethane will become evident, along with the challenges and opportunities facing this industry.

Figure 3: Economy-wide Demand – TWh/yr[15]

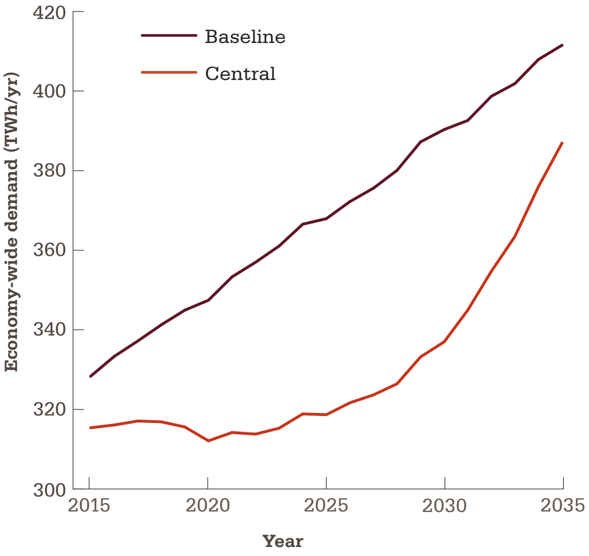


Table 2: Gases in our Energy System and Their Properties[16]

Gas Type	Production Method and Quality
Natural Gas (CH_4)	Extracted using offshore and onshore drilling to release gas from underground reservoirs: • Tends to be available locally • Quantities may increase as a service to the renewable power industry • **But** compatibility with inter-seasonal demand curve poor/very poor • Reduction in carbon emissions modest (~3%)
Shale Gas (CH_4)	Extracted using onshore and offshore drilling and hydraulic fracturing of rock to release the gas: • Probably variable quality • Available only in local areas but in quantities surplus to local demand in summer • Minor reduction in kg CO_2/kwh • If treated could be compliant with Gas Safety Management Regulation GS(M)R
Biomethane (CH_4)	Produced by upgrading biogas from the fermentation of waste products using anaerobic digestion, including plant materials, waste food, sewage and gas from landfill. CO_2 is removed to create CH_4. Anaerobic digestion gas: • Tends to be available locally • Waste quantities finite and probably subject to downward trend • Poor inter-seasonal response without storage • May (or may not) require propanisation • Carbon footprint good but less so after propanisation • May contain siloxanes • When treated can be compliant with GS(M)R
BioSNG (CH_4) Bio – Synthetic Natural Gas (SNG)	Produced through the gasification and methanation of biomass. Can also be produced as SNG from fossil fuels such as, lignite coal or oil. Can be used in the same way as Liquid Natural Gas (LNG) and Compressed Natural Gas (CNG).
H_2NG Blends Hydrogen-enriched natural gas blends	Hydrogen produced by low-carbon electrolysis is added to natural gas reducing overall carbon intensity. Hydrogen blends can be at different percentages.
Hydrogen (H_2)	Produced using water electrolysis, by alkaline and polymer electrolyte membrane electrolysers and through steam methane reforming and gasification techniques. Some new anaerobic digestion techniques are beginning to produce hydrogen and carbon monoxide separately, this is an emerging technology. Hydrogen can be used in fuel cells to power vehicles and for domestic CHP, directly in an internal combustion engine, mixed with methane for use in heat and cooking or used alone for heating.

GAS FOR ELECTRICITY

At present gas provides approximately 43% of our electricity needs through conversion in power stations. There are three types of gas-fired power station: the combined-cycle gas turbine (CCGT), used for burning natural gas; simple cycle gas turbine (SCGT) used in peaking plants; and integrated gasification combined-cycle turbine (IGCC) used for burning syngas from coal.

There are currently 41 CCGT power stations in the UK with a capacity of 32GW.[17] A CCGT produces electricity by burning gas to produce heat and run a turbine; the waste heat is then collected and used to make steam that is pushed through a second turbine, increasing the efficiency of the plant by up to 50% relative to an SCGT.[18] The turbines drive generators that convert the spinning energy into electricity.

The CCGT and SCGT processes are simple and have led to an increase in smaller plants, known as peaking plants, to pop up across the electricity networks, building resilience into the electricity system at peak times. These peaking units are both reciprocating engines and SCGTs; they are, however, not responsive enough and have a knock-on effect on the gas networks, because at the same time that demand is high from larger power stations and heating systems, they too are trying to obtain gas from the distribution system. One possibility for these units would be work with distributed gas suppliers, such as farms offering biomethane outside the main distribution grid, and develop local systems for local needs.

Hydrogen and methane/hydrogen blends can also be used to generate power, via fuel cells, gas turbine or internal combustion engine technology. Fuel cells are relatively expensive at present, but mass production in the automotive sector is imminent, so costs are likely to fall substantially. Importantly, because they do not rely on combustion, fuel cells provide a zero-emissions solution (zero NOx, COx, SOx and particulates) for future power generation based on hydrogen. Also, blends of low hydrogen concentration can be combusted in conventional heat engine technologies without modification for power generation.

POWER TO GAS (PTG)

Power to Gas is a straightforward idea – when there is superfluous electricity on the National Grid from either high renewable sources or low demand, rather than curtailing electricity generation or using 'turn-up' techniques, the excess power can be used to create hydrogen through electrolysis. This method provides energy storage in the form of hydrogen, allowing all power produced to be stored. This can be stored locally to use and access when required, or injected into the gas grid at a low hydrogen concentration. Power to Gas plant can thereby provide a 'green' gas and simultaneously participate in electricity grid balancing markets.

There are many benefits to using hydrogen across the energy system. Hydrogen can be used in fuel cells to power vehicles both large and small, reducing the need for multiple infrastructures and for domestic use in place of boilers. There are also options for hydrogen to be used for direct injection into the existing gas distribution grid, either mixed with natural gas, or as 100% hydrogen to help decarbonise heating in the UK and meet 2050 CO_2 reduction targets. In addition to these uses in the energy system, hydrogen produced through PtG could also be used in manufacturing application as a reducing agent in steel manufacture, or to top up brown hydrogen to reduce CO_2 emissions in petrochemical, fertilizers and food manufacturing.

Using PtG techniques and Power to Liquids (PtL) reduces the UK's reliance on hydrocarbon fuel imports, including gas and oil, and creates potential new markets in the UK across energy and manufacturing industries. These new markets can support UK industry now.

Figure 4: Hydrogen Production and Consumption Globally[19]

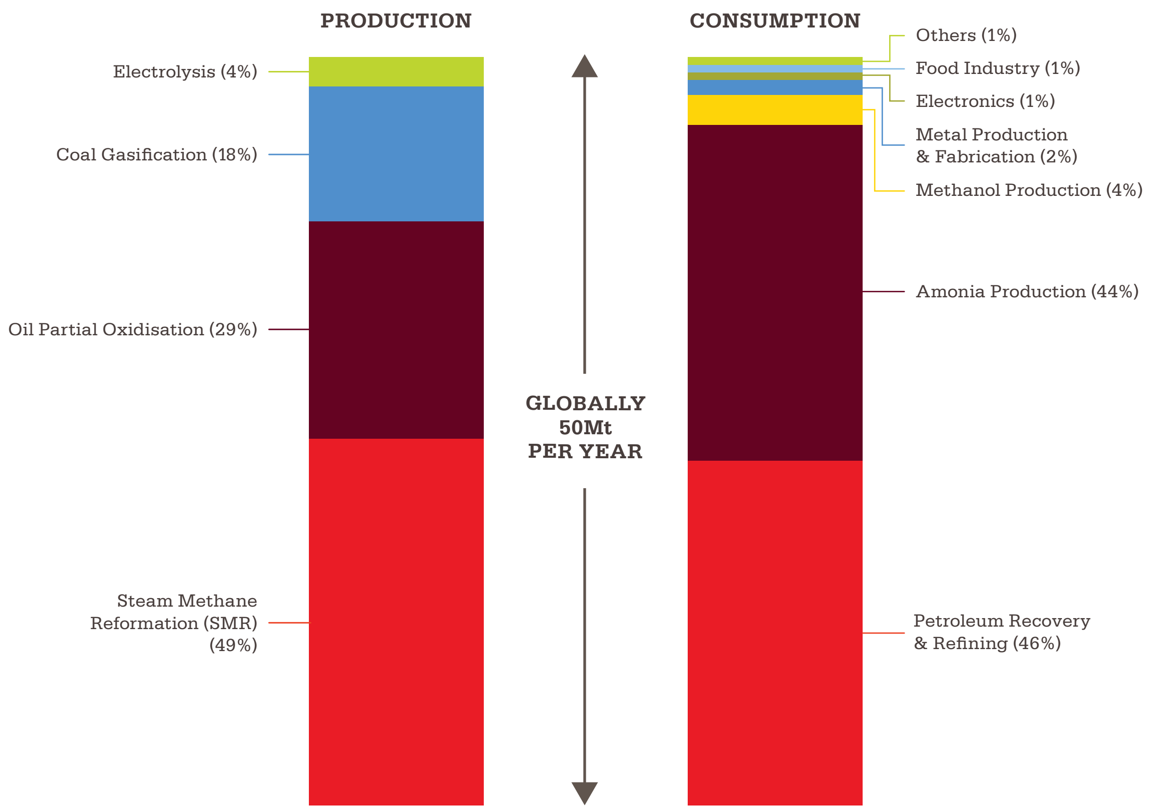


Table 3: Power to Gas Technologies[20]

Power to Gas (PtG)

Power to gas uses the electrolysis of water to generate hydrogen.
Examples of electrolysis technologies are given below.

Alkaline electrolysis (AEL)	This is the most mature of the three electrolysis technologies. In AEL an aqueous alkaline solution (KOH or NAOH) is used as the electrolyte. AEL can be used at atmospheric or under pressurised conditions. The only advantage that pressurised AEL has over atmospheric is that it can produced pressurised hydrogen that could be used directly for grid injection.
Polymer electrolyte membranes (PEM)	PEM is a relatively new technology in comparison to AEL. PEM uses solid polymer membranes and a noble metal catalyst in the electrolysis process, and produces high-grade hydrogen. It offers much higher current densities and greater operational flexibility for providing grid services, but tends to cost more per MW than AEL. PEM electrolysers of multi-MW capacity are now available.
Solid oxide electrolysis (SOEC)	SOEC is also known as high-temperature electrolysis and is still in the exploratory phase. SOEC is thermally and chemically stable and reduces the electricity demand required for the electrolysis process, if a source of suitable waste heat is available. This low electricity demand is currently the main advantage and could potentially lead to higher overall efficiencies.

Power to Liquids (PtL)

PtL brings together electric energy, water and carbon dioxide/carbon monoxide to create liquid hydrocarbons. Utilising excess electricity generated by renewable power to make hydrogen with stored CO_2 from either electricity generation or industrial applications, provides the opportunity to convert these into refined fuels. Potential uses for this type of synthesised liquid hydrocarbons include jet fuel, an area of transport where oil use is currently increasing. These methods contribute to the decarbonisation of the transport system.

Fischer-Tropsch (FT)	Using CO_2 from stored sources, inverse CO shift-reaction can be used to create CO. H_2 is produced from electrolysis and SOEC can be used for the possibility of creating H_2 and CO in one step, then using the FT pathway and upgrading to the required fuel level.
Methanol	The methanol pathway is an established process that has been used for decades in industrial activities, such as natural gas reforming. Electrolysis is used to create H_2 and this is synthesised with either CO or CO_2. The conversion of the methanol to hydrocarbon fuels requires a number of further steps including DME synthesis, olefin synthesis, oligomerisation and hydrotreating. By using renewable electricity, excess heat from the electrolysis process and stored CO_2, the energy requirements for synthesised fuels are reduced.

CASE STUDY 1
HYDROGEN INTO THE GAS GRID – ADELAIDE

Funded by the Australian Federal Government's Renewable Energy Agency, a new electrolyser will be installed at AGN's Kidman Park and designed by Wollongong-based company AquaHydrex. The electrolyser will be powered by excess renewable power from solar and wind, splitting water to make hydrogen and oxygen.

The hydrogen will be injected into Adelaide's gas grid up to approximately 10%, and the Renewable Energy Agency does not expect any changes to system to be required at this percentage. Recently, South Australia has experienced power cuts due to heatwaves and the need for additional electricity for air conditioning, as well as usual activities. When excess hydrogen is produced, it will be stored and used to top up supplies in times of peak loading on the system. There is a three-fold benefit for Adelaide here: it adds security to the electricity supply; reduces emissions impact from gas use; and effectively uses all the resources, ensuring no renewably produced electricity is wasted.

This project could lead to Australia's gas infrastructure storing hydrogen equivalent to 6 billion household lithium ion-batteries.[21]

CASE STUDY 2
PETROCHEMICALS

ITM, an energy storage and clean fuels company, and Royal Dutch Shell have joined forces to install a 10MW electrolyser at the Shell plant at the Wesseling refinery site in Germany. The electrolyser used to produce hydrogen will be the largest PEM (polymer electrolyte membrane) electrolyser in the world.

The electrolyser will help stabilise the grid, using renewable energy to produce the hydrogen. Currently the refinery uses 180,000 tonnes of hydrogen, all of which is being produced through steam methane reforming. The hydrogen produced from the electrolyser will be used in the oil refining process, to reduce the emissions and energy intensity of the process.

The majority of hydrogen use in industry is in the petrochemical, ammonia, methanol and food production industries. The use of low-cost renewable power to produce CO_2-free hydrogen will begin to reduce the global impact of these industries.[22]

BIOMETHANE

In 2011, the UK Renewable Heat Incentive (RHI) was introduced. Prior to this there were no full-scale biomethane plants operating in the UK; the RHI has been the catalyst to kick-start this market. In the recent REA Biomethane Report,[23] by the end of 2015 there were 50 completed projects, injecting approximately 2.5TWh/year of biomethane into the gas grid. However, today Wales and West Utilities alone have about 1.5TWh capacity connected. This is equivalent to meeting the heating and cooking needs of 100,000 homes.

The majority of this biomethane was produced by agricultural plants treating crop residues and livestock slurries, and from waste and sewage treatment. These are all industrial sectors that will continue to provide feedstock for biomethane production, and maximise the use of our resources by ensuring that the gases produced in their treatment are subsequently used. This begins to reduce the demand for natural gas extraction and imports.

The majority of biomethane projects supply gas to the National Grid are in the North West/Central England, as well as Scotland and a number of projects in the South of England.

Biogas requires upgrading to produce biomethane of a suitable specification for injection into the grid, and primarily this requires CO_2 removal, the most common being permeation using membranes to separate the CO_2 from the gas. Furthermore, this CO_2 can also be combined with hydrogen from Power to Gas via methanation to produce synthetic methane. Therefore there are three forms of Renewable Gas (biomethane, hydrogen and synthetic methane).

One sector where most UK householders will be familiar with gas use, is in heating and cooking. Approximately 82% of UK homes use gas for heating. In recent years the majority of attention in reducing GHG emissions has been on electricity, primarily due to the use of coal to power our lives. Attention is now being turned to heat, and the different ways that the UK can decarbonise heat. UK Government recently awarded £24m to a number of different low-carbon heat network projects,[24] and it is clear that reducing the impact of heat is the next big fix to be made.

In 2015, the Institution of Mechanical Engineers released Heat Energy: The Nation's forgotten crisis,[25] drawing attention the amount of energy wasted in the UK. The provision of heat for domestic, commercial and industrial needs is primarily through the consumption of gas, delivered through an ageing infrastructure designed to exploit our North Sea gas reserves. These reserves are depleting and the UK relies more each year on imports from around the world.

In order to reduce our GHG emissions from the use of gas in heating, there are a number of options open to us:

1. Reduce the amount of gas we use, energy efficiency through insulation and efficient appliances and processes.
2. Change the type of gas used for heating. Increase biomethane, hydrogen and synthetic methane in the system to reduce emissions of the extraction, transportation and use of natural gas.
3. Change the heat source, convert heating activities to electricity. The infrastructure changes in homes and businesses, the overloading of electricity networks and the likely need to use gas to make electricity, make this option less desirable; although with hybrid systems some of these difficulties can be overcome.

This interest in heat from the Government has led a number of gas distribution companies to begin to look at different ways the current system can be decarbonised. The two main options are introducing a mix of hydrogen into the existing system, reducing methane use; and in the longer term converting to 100% hydrogen.

In a recent workshop conducted by the Institution of Mechanical Engineers to understand the potential for decarbonising our gas networks, the following key challenges were highlighted by the gas industry.

1. Demonstration of hydrogen distribution, combustion and safety is required to ensure funding and investment in further research & development and scale-up.
2. Different requirements in different gas networks such as rural and urban.
3. Housing stock is poor and varied, meaning that requirements for gas is variable. Advances in Passivhaus and 'zero-carbon' homes would mean less gas required in new developments. (Currently there is no UK policy for this.)
4. New appliances would be required to manage different gas types; for a compulsory change-over, these would have to be supplied. No change is required for low concentrations of hydrogen in the mix; higher concentrations will require changes to billing/metering, burners and appliances, as well as infrastructure. This will require significant investment; whereas for biomethane and synthetic methane no change is required.
5. Billing for different gas types and fairness to all consumers.
6. The lack of policy and vision for the role of CCS in supporting delivery of decarbonised gas networks.
7. The lack of policy and vision for the role of Power to Gas in supporting the delivery of decarbonised gas networks and grid services for the power sector.

These are not engineering challenges; the concepts and technologies largely exist, but proof of concept and long-term funding are required to enable the gas distribution companies to meet the demands of upcoming UK carbon budgets. There is a need for UK Government to work with the gas and manufacturing industries on raising awareness of the potential of change in this system. Many householders and businesses rely heavily on their current gas supply, and may be concerned that it could change.

The gas distribution industry recognises that there may be different solutions in different regions; the way the gas system is designed allows for this to be the case. Some companies believe that the pathway to decarbonisation is incremental, with small changes to the gas mix happening over many years, whereas others believe a full switch to 100% hydrogen is the best solution.

Using PtG technologies to produce additional gas, whether hydrogen or synthesised methane, creates a loop of resources between the power and gas sectors, and continues to reduce the impact of gas utilisation further.

Investment is needed in:

- P_2G systems, their manufacture and integration into gas and electricity grids
- CO_2 utilisation for producing synthetic methane
- Domestic appliance and industrial process development for 100% hydrogen
- Safety studies by HSL of H_2NG blends and 100% H_2

CASE STUDY 1 **H21**

In the North of England, a consortium of companies led by Northern Gas Networks is exploring the possibilities of replacing natural gas in the gas network in Leeds with 100% hydrogen. Leeds is the third largest city in England. This is an ambitious project that will aim to decarbonise the heating and cooking activities through the injection of hydrogen into the gas system, with minimal impact to customers.

The aim of this project is to determine the feasibility both technically and economically of converting the existing natural gas network in Leeds to 100% hydrogen. The hydrogen demand for the area would be met by four steam methane reformers, using CCS at Teesside. The hydrogen would be injected into the existing gas network and additional storage of hydrogen for intraday and inter seasonal variations in demand. Any excess hydrogen would be stored in local salt caverns. The compressed CO_2 from the CCS process would be permanently stored under the North Sea. All these activities and technologies are emerging, exist and are local to Leeds.

The successful completion of this project would be a step change in the way gas is used in the current system, transforming technologies for gas use in the UK and moving the CCS agenda forward.

CASE STUDY 2 **HYDEPLOY POWER TO GAS**

The HyDeploy consortium, led by National Grid and Northern Gas Networks, aims to reduce the carbon intensity of heating, by blending hydrogen with natural gas in the heating network.[26] This project will establish a framework for hydrogen gas grid injection in the UK and support the establishment of new markets for power to gas.

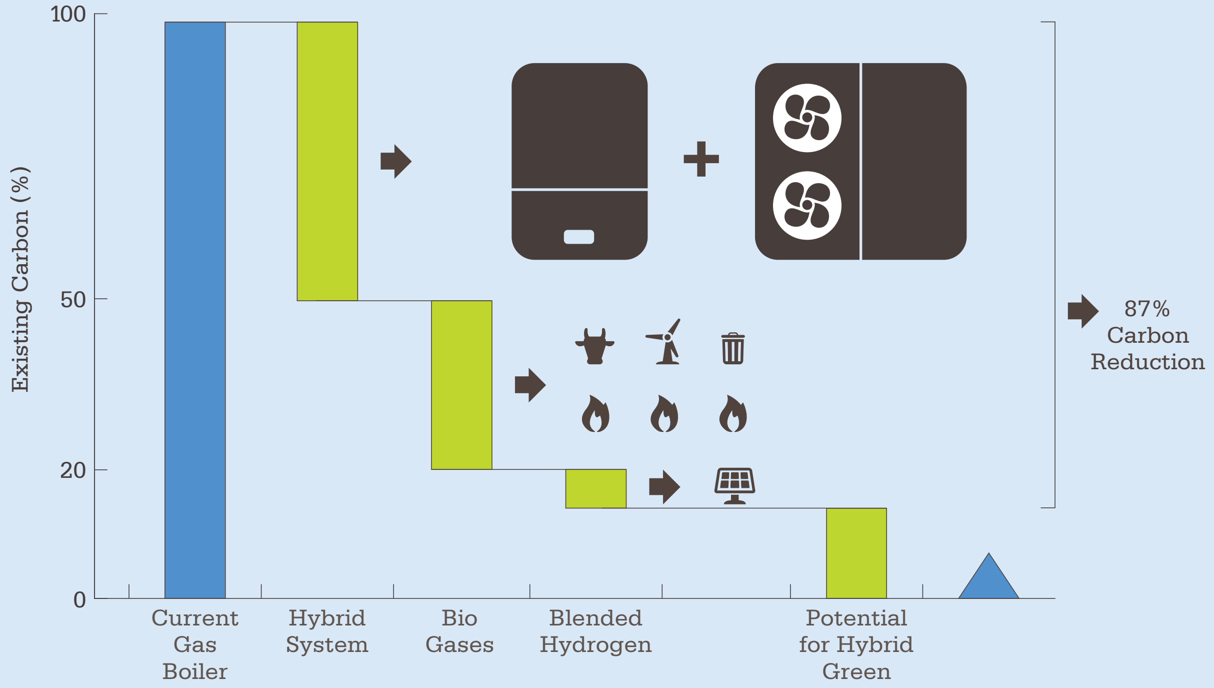
HyDeploy aims to inject hydrogen produced by ITM electrolysers into the existing gas grid at Keele University, Britain's largest university campus. The gas is used to provide heating at the site and hydrogen will make up a maximum of 20% of the blend. This means that users will not notice any difference in their supply, but the gas will be significantly decarbonised. This project offers the opportunity to demonstrate how heating supplies across the country can be decarbonised with no change in use.[27]

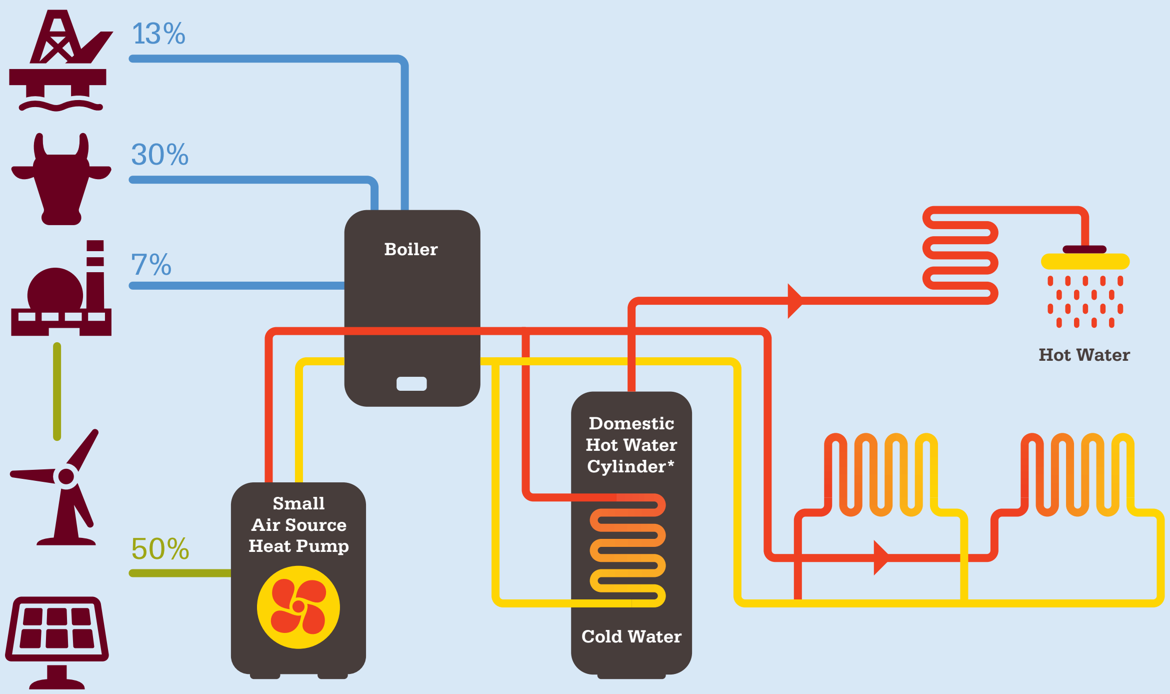
CASE STUDY 3 **WALES & WEST UTILITIES DISTRIBUTED GAS SOURCES**

Hybrid heating technology uses the best of the future electricity and gas networks – using off-peak, cheap, low-carbon electricity when available, and gas when it is not. A unique project jointly funded by Western Power Distribution and Wales & West Utilities (WWU) has sponsored research to develop the smart switching software to control this system, and has been testing the technology in Bridgend. When combined with green gas options, a heating for non-hydrogen cities emerges.

Using information from the trial properties and the WWU Energy Pathfinder Model, carbon emissions reductions in excess of 87% from domestic heat are possible. This is achieved at a very low investment, with no electricity grid upgrades, or expensive heat pump installations. It uses a small, low-cost heat pump to provide the background heat, topped up by the gas boiler, supplied with a blend of biogases, hydrogen and, at peak times, natural gas. By utilising existing assets, little investment is needed, but would include green gas supply and access to storage, primarily in the local transmission system, but with some above ground storage in addition. The concept is demonstrated in the following two diagrams.[28]

Figure 5: The Process Used by Wales and West Utilities as described in Case Study 3[28]





TRANSPORT

As identified earlier in this report, the UK transport sector is responsible for 40% of energy used and around one quarter of all UK GHG emissions. Transport is often considered as the way individuals get around using public transport and personal vehicles. However, there is much more to the transport sector: freight movements using trains and HGVs in the UK, light commercial vehicle movements and the role of shipping for import and export are just some of the areas not well highlighted. The transport sector is often dominated by the future of the passenger vehicle; however freight movements, shipping and air cargo are seeing increases in oil use. Focusing on UK heavy goods vehicles, the road networks combined with PtG and biomethane offer a unique and simple solution to begin the process of decarbonising freight.

In the UK, approximately 70% of heavy goods vehicle movements happen on just 2% of the road network.[29] This is the 2% made up from major roads, such as motorways and trunk roads; an infrastructure that has incumbent filling stations and is often in close proximity to towns and cities with good gas grid access.

Hydrogen and biomethane can be injected into the existing high-pressure grid; the current major roads infrastructure could be developed for a fleet of HGVs that run on either biomethane or hydrogen fuel cells. Both have the advantage of long ranges and fast filling times. This idea could be potentially scaled up, to one day meet the needs of 70% of heavy goods vehicle movements in the UK.

CASE STUDY 1
JOHN LEWIS PARTNERSHIP WITH BIOMETHANE

Operating with 44 dual fuel gas and diesel trucks for some time, Waitrose introduced two gas-only Scania tractor units to its distribution fleet operation. These new vehicles have a range of 350 miles and are able to refuel at a gas station in Leyland run by CNG Fuels. These new 100% gas trucks enable Waitrose to displace as much diesel as possible with biomethane, reducing the company's emissions.

The fuel offered by CNG is biomethane derived from food waste. It is the most cost-effective and lowest-carbon alternative to diesel for heavy goods vehicles, offering a real opportunity to reduce emissions and use resources effectively. CNG is able to offer the fuel at 65p/kg, equivalent to 49p/litre for diesel. Biomethane is distributed through gas pipelines to the refuelling stations where it is compressed into fuel.[30]

Unlike electricity, the refuelling time for gas is fast, at approximately four minutes per truck. This allows CNG to operate a high throughput of vehicles at its site in Leyland, and reduce the cost of the fuel for the user. In addition to reducing emissions from HGVs, gas vehicles are about 50% quieter than diesel engines, reducing environmental impacts of truck movements further.

As Waitrose is a major food supplier, by using food derived biomethane as its HGV fuel, it is beginning to close the resource cycle and become sustainable.[31]

CASE STUDY 2
HYDROGEN FUEL CELL BUSES

Wright Bus and the Belgian coach and bus manufacturer Van Hool have supplied 18 buses that are running on hydrogen fuel cells in Aberdeen and London. These buses have an advantage of producing zero GHG emissions and zero NOx at tailpipe, meaning that for inner cities they will contribute significantly to improving air quality.

Hydrogen fuel cell buses have significantly better range than their electric equivalents and do not use the materials batteries require, that can adversely impact the environment and people extracting minerals. Hydrogen for the fuel cells is produced in a number of ways; currently in the UK it is produced through industrial steam methane reforming of gas and at an increasing number of hydrogen refuelling stations with on-site electrolysers. However, as this report identifies, the most important factor is that it is possible to create green hydrogen for transport. The hydrogen is stored in a compressed state in cylinders on the roof of the bus, meaning that the appearance of the bus is no different from conventional diesel buses.[32]

ENERGY STORAGE: THE ROLE OF GAS

Interest in energy storage for different technologies continues to grow. The use of batteries in passenger vehicles and for storing renewably produced power in the home has received much attention. The most commonly discussed battery is the lithium-ion battery, however the required increases in the materials needed for battery manufacture could lead to environmental and human suffering. The majority of lithium mined today comes from South America, and is evaporated out of brine using the power of the sun. As demand increases new deposits are being accessed, and more energy-intensive techniques, such as crushing, will be used to extract the lithium. Another component of the lithium-ion battery is cobalt, used in the cathode, a mineral with a poor sustainability in relation to its extraction. There may not be enough cobalt in current mines or mines being developed to meet the needs of the electric vehicle revolution.[33] Another concerning aspect of the life of the lithium-ion battery is the ability to effectively recycle these materials; currently less than 5% of lithium-ion batteries are recycled.[34] As professional engineers, we must consider and account for the ethical aspects of our energy future.

This is where gas comes in; methane and hydrogen are both highly effective energy storage mediums. As it stands, the gas distribution networks provide storage for gas within the grid itself. Gas networks can act as a lung for low-carbon electricity networks, absorbing surplus renewables when required via Power to Gas, and delivering gas for power generation when required to cover periods of lie renewables availability.

Hydrogen produced from power to gas technologies can be stored in the gas grid, in pressurised canisters or in salt caverns, depending on the duration of the storage. Hydrogen can be stored for a matter of minutes, days, weeks or months, making it a more valuable medium than the battery. Electrolysers can provide both sub-second response and continuous operating durations of days, weeks or months as required by electricity grid operators, making them a more valuable energy converter than a battery. Further to this the stored gas, hydrogen or methane can be used for electricity generation through CCGT or fuel cells, in vehicles (passenger, commercial and HGV as well as trains), and in boilers and burners for heating and cooking at various blend percentages or 100%, dependent on the distribution network.

When it comes to fuel cell vehicles, some concerns have been raised about the platinum used in fuel cells and electrolysers. However, industry calculations have shown that the total resource requirement for platinum in the latest fuel cell vehicles is broadly similar to that used in catalytic converters for engine-powered vehicles, this is in the range of 2–7g.[35]


Covent Garden RV1
RV1 via Bankside
hydrogen bus
WRIGHT
SCREENWASH
LK60 HPE

CONCLUSION AND RECOMMENDATIONS

In summary, gas provides us with many opportunities, it can be the transition energy vector taking us towards a low carbon energy system through biogas in transport and heating and in electricity generation reducing coal pollution. It can be the result of the transition where excess power from renewables, steam methane reforming with carbon capture and storage and gasification along with an anaerobic digestion techniques produce green hydrogen for industry, heat, transport and more electricity generation. Hydrogen a gas with very low emissions and flexible for use in all parts of our energy system. These gases are part of our circular economy of resources, where waste resources from electricity to sewage can be used to create energy that can be stored and used reducing emissions and our overall environmental impact.

Institution of Mechanical Engineers makes the following recommendations

1. That UK Government commits to creating an industrial forum, that brings together the nuclear, renewable power and gas sectors to promote the generation and storage of hydrogen for use across the UK energy system in heat, transport, power generation and heavy industry. Hydrogen has the properties to fulfil the requirements of all these sectors. Investment now in the future hydrogen economy will begin to encourage further innovation, open up markets and cement externalities like legislation and regulation.
2. That UK Government works with the gas industry to promote the use of up to 20% hydrogen in the gas distribution network, including change in pipes and materials. Funding programmes and demonstration sites are crucial to decarbonising gas. Government has the power to provide research, development and demonstration and support deployment through programmes such as Innovate UK, as well as bespoke programmes designed to deliver future UK infrastructure.
3. UK Government should commission a comprehensive comparative study of the long-term sustainability of materials used to create lithium ion EV batteries versus power-to-gas/gas systems and fuel cells, particularly for energy storage, to identify appropriate technology and life cycle analysis. By understanding this more clearly, UK Government can make evidence-based investment decisions that meet the requirements of sustainable development in the electricity, transport and heat sectors.

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