Opportunities to Decarbonise the Non-Domestic Off-Grid Sector with LPG and bioLPG

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Liquid Gas UK

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Introduction

The non-domestic sector of the UK economy[1] accounts for 31% of final energy consumption with over half of this (~55%) fuelled by fossil fuels, of which a third is from the highest-carbon fossil fuels, coal and oil. With the UK leading the way globally in transitioning to a net zero carbon economy by 2050, it is essential that energy-use in the places we work, go to when sick, learn, worship or which our goods and services come from decarbonise quickly and cost-effectively. As part of this transition, reducing emissions at a national scale must be achieved with consideration for the economic impact on individuals and organisations so as to build support and momentum for decarbonisation.

The use of the highest-carbon fossil fuels for heating (oil and coal) is most common in areas which are off the gas grid where there is no mains natural gas connection. Businesses and industries in these locations often cannot rely solely on electricity and still require a viable fuel to satisfy end use requirements. However, given the climate emergency it is imperative those using the highest carbon fossil fuels lead the charge in switching to low carbon alternatives. This report evaluates the options off-gas grid non-domestic energy users have to lower their carbon footprint by switching away from high-carbon fossil fuels and to lower-carbon alternatives. The potential options considered include electrification, hydrogen and biofuels. This report will demonstrate that LPG and bioLPG should play a leading role in this transition to off-grid biofuel consumption.

For this report, the non-domestic sector is considered to encompass commercial, industrial, and agricultural users. Under this definition, energy consumption of the non-domestic sector was estimated at 452 TWh or 27% of total final energy consumption in 2018[2]. Energy consumption of industrial users amounted to 264 TWh (58% of non-domestic energy consumption). This was followed by commercial services consuming around 170 TWh of energy (37%), and agriculture demanding 18 TWh of energy (4%).

Scope of the Non-Domestic Sector,
Final Energy Consumption (TWH/year)

Figure 1 - Energy Consumption in the Industrial, Commercial and Agricultural Services (2019)

Around 14% of non-domestic energy consumption is fuelled by the highest-carbon fossil fuels oil (11%) and solid fuels (3%). Natural gas (36%) and electricity (40%) consumption account for 76% of overall non-domestic energy demand. The remainder of energy consumption is met by bioenergy and waste (7%) and heat (2%).

[1] Defined in this report as the commercial, agricultural and industrial sectors

[2] Energy consumption in the UK (2019) - BEIS

The Challenge

The Pathway to Net Zero

The UK government has a binding target to meet net zero emissions by 2050 and was one of the first major economies to write this into law. The UK has also been leading on emission reduction internationally. Since 1990, emissions as a whole have fallen by 41%, at a time when the economy has grown by 78%[3], however the power sector alone contributed to nearly half of this progress, with limited emission reductions achieved in other parts of the economy.

Figure 2 below shows the current contribution of individual sectors to the UK's greenhouse gas emissions. Surface transport is the sector that produces the most emissions, closely followed by industry and buildings – both residential and commercial.

This report will focus on non-domestic energy use in industrial, agricultural and commercial sectors, and the need for an off-grid, low-carbon fuel to support the UK's decarbonisation efforts.

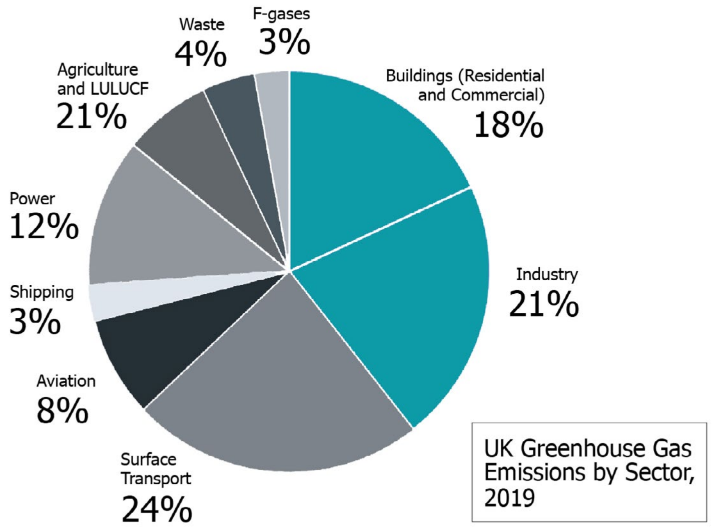


Figure 2 - greenhouse gas emissions by sector (2019)

Figure Y provides an overview of the changes in sectoral emissions over time in the UK. As illustrated, the power sector has witnessed the most substantial decline in emissions over the period, with a reduction of 72% achieved since 1990. This has been driven by fuel and technology switching, away from coal power to a combination of gas and renewable power production. In comparison, surface transport sector emissions are the same value in 2019 as they were nearly 30 years ago in 1990.

[3] CCC (2020) Reducing UK emissions: Progress Report to Parliament

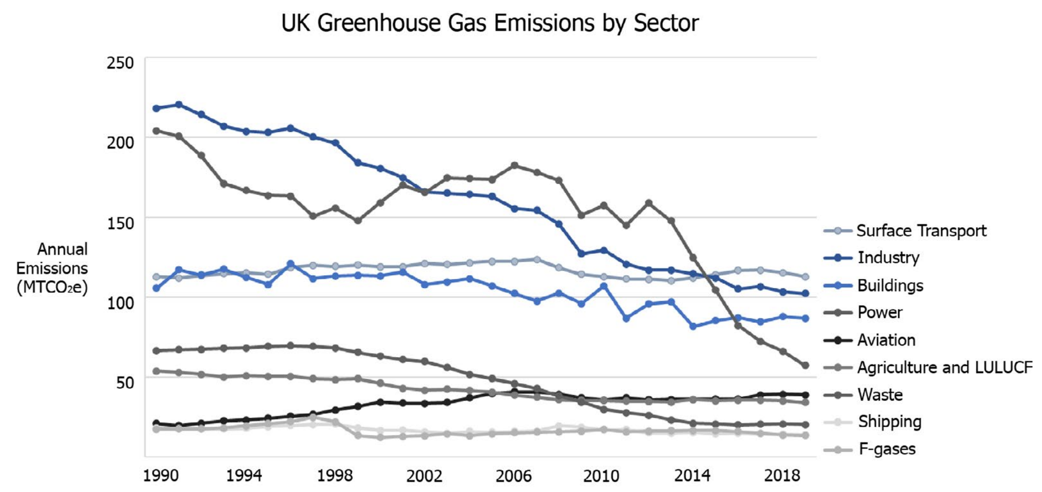


Figure 3 - Greenhouse Gas Emissions by Sector (2019)

The need for deep decarbonisation, over the next 30 years, at a national level will require some significant changes to the way non-domestic energy demand is met. Given the unique and complex nature of the off-grid building stock and underlying infrastructure constraints, it will be important that a future off-grid heat policy for the non-domestic sector considers this and sets out a transition pathway that ensures optionality and doesn't lock in non-domestic businesses into a costly and disruptive decarbonisation pathway.

Commercial Sector Landscape

Energy Consumption and Emissions

Commercial energy consumption totalled 170 TWh in 2018 across all end-uses. Around three-quarters of this consumption was met by electricity (44%) and natural gas (30%). This was followed by oil-fuelled heating which accounted for 16% of total commercial energy consumption. The remainder was met by bioenergy & waste and heat.

BEIS estimate there to be around 62,000[4] non-domestic buildings heated with oil or LPG. Oil fuel use represents about 9% by end use for space/water heating and cooking across the non-domestic in the UK.

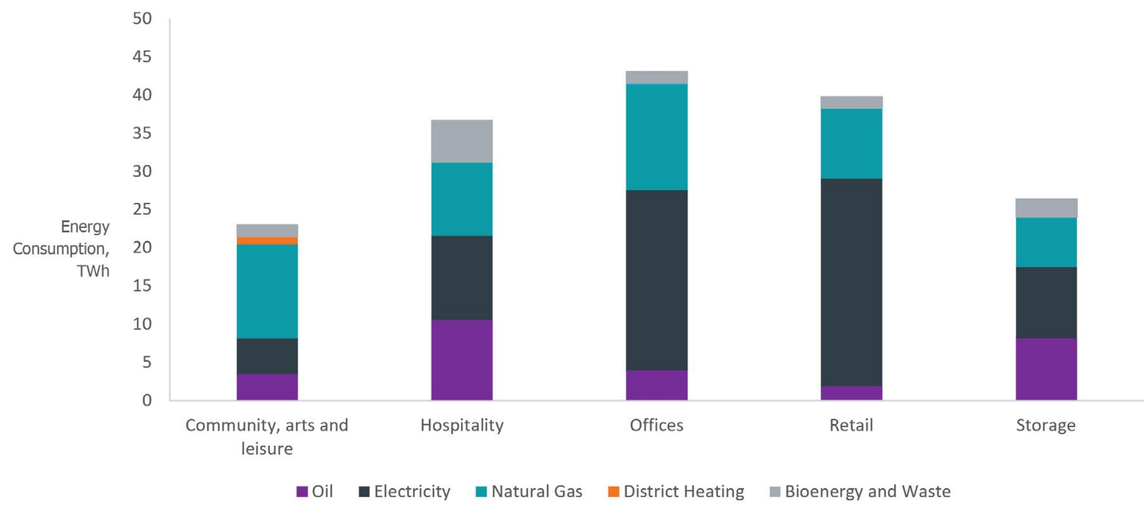


Figure 4 – Heating, Hot Water and Catering Consumption in the Commercial Sub-Sectors by Fuel Type

[4] A Future Framework for Heat in Buildings: Call for Evidence (2018) - BEIS

Offices consume the most energy for heating, followed by storage and retail businesses. However, the type of fuel consumed by each sub-sector varies somewhat. The majority of offices and retail businesses meet their heating demand by natural gas whereas the majority of storage businesses meet their heating requirements with heating oil. Other commercial businesses such as the hospitality and storage industry meet their heating requirements by consuming oil. Around 27 TWh of oil is consumed by commercial businesses of which the majority (39%) is consumed by the hospitality industry (10.6 TWh), followed by the storage industry which consumes around 8.1 TWh of oil (30%). There is a sizeable consumption of oil in Offices (3.4 TWh) and in the Community, arts & leisure sectors (3.0 TWh).

The service sector is also a large consumer of high-carbon fossil fuels. The hospitality and storage sectors together account for 19 TWh of final energy consumption and have not seen substantial fuel switching to lower carbon fuels like LPG. As kerosene remains un-taxed under the Climate Change Levy – unlike LPG and natural gas - this is unsurprising. As a result, emissions have remained high in these sub-sectors. The graph below shows four sectors which historically have been difficult to decarbonise. Emissions from accommodation and food services – equivalent to the hospitality sector – have actually increased from 2.8 million tonnes of CO2e in 1990, to 3.8 million tonnes of CO2e in 2018.

Businesses that consume high quantities of heating oil will require a reliable, off-grid, low-carbon energy source. In particular, the hospitality sector includes a significant number of rural hotels and restaurants located in heritage properties.

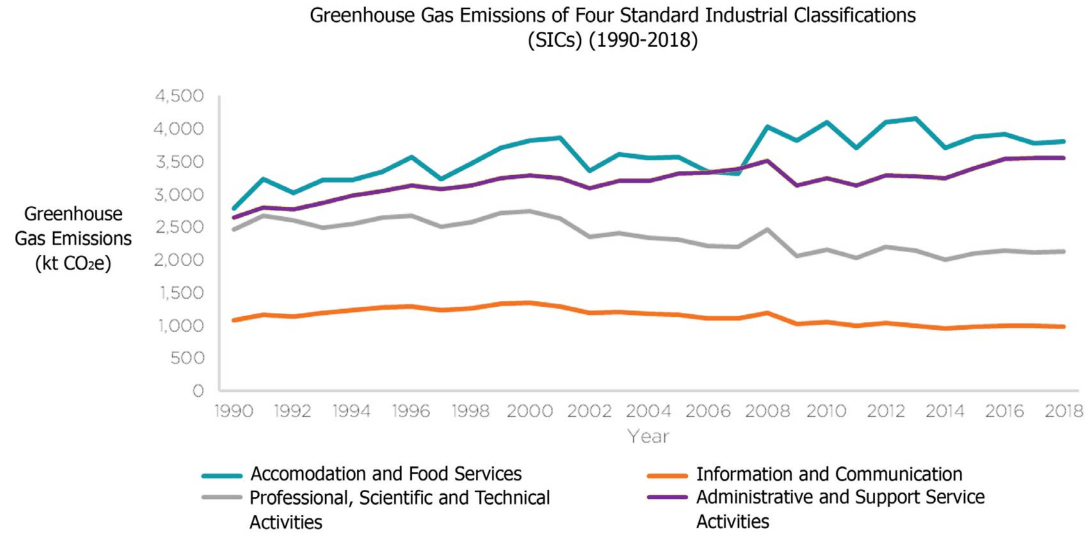


Figure 5 - Greenhouse Gas Emissions Across 4 Major Commercial Sub-Sectors

Commercial Sector Landscape

Energy Consumption and Emissions

Space heating and hot water account for nearly half (48%) of all commercial energy consumption. The UK Government currently sees the electrification of heat using heat pumps and hydrogen in the gas grid as the two main options for decarbonising heat, with low carbon heat networks and biogas also playing a role[5]. This report provides evidence to show that LPG and bioLPG have key roles to play in decarbonising off-grid energy use.

Electrification of heat can be more onerous for businesses located in off-grid rural locations. Around 48% of all non-domestic retail businesses were built before pre-1919[6] suggesting a high share of old retail businesses. The same study showed that older buildings had an average EPC rating of D or below, suggesting the underlying level of existing thermal insulation is low. Taking the hospitality industry as an example, electrified heating may not be suitable for a pub in a rural, off-grid location. This pub is likely to be old, quite large and have a low underlying level of thermal insulation - together, this suggests a high level of heat loss. If this business were to contemplate a switch to electric heating (e.g. heat pumps), it would need to consider a range of factors. The first key factor is upfront cost. The cost of a commercial air source heat pump is around ~£14,000[7], whereas the cost for a commercial gas/LPG boiler is around £4,300 - more than three times more expensive. Since many rural off-grid commercial businesses have a low EPC rating, this suggests an expansive programme of upgrading the existing level of insulation to ensure the heat pump can operate at its claimed efficiency. Many of these buildings are stone-built and therefore are likely to require solid wall insulation which can reach costs of more than £8,000[8]. Another key factor is the reliability and reinforcement of the local grid. Given the low customer (domestic and non-domestic) density (~100 customers per square km) in rural locations, the local grid is likely to be under-developed. A sudden increase in electrified heating could pose problems for the local grid and cause localised blackouts. To mitigate this, the local network would need to be reinforced and this cost (one estimate suggests ~£50bn[9]) would ultimately be passed on to customers.

[5] HM Government (2020), Government Response to the Committe on Climate Change's 2020 Progress to Parliament

[6] Correlating maintenance, energy efficiency and fuel poverty for traditional buildings in the UK (2018) – Cardiff University

Hydrogen could play a role for commercial businesses located on the gas grid, however the deployment pathway for the fuel is uncertain, with a recognition that a patchwork of regional solutions[10] – including repurposing the grid to run on hydrogen – could be the optimal pathway. This could mean that more businesses essentially become located 'off-the gas grid,' without a piped supply of low-carbon gas, and that the development of low-carbon off-grid fuels will be a crucial part of meeting net zero.

Biomass heating is one such option for off-grid businesses. It does have advantages, including the fact that heat can be produced with very low CO2 emissions. However, it is often an inconvenient and costly solution that can create air quality issues. Indeed, Users of commercial biomass boilers will need a large space to store wood fuel – either pellets, chips or logs, and the system often needs regular maintenance and oversight to ensure it is working properly. This could be inconvenient for a business, such as a country-pub, that might have limited space to use.

Additionally, the upfront cost of a biomass boiler is often many times that of a traditional gaseous or liquid fuel boiler. For some businesses, this creates financial barriers and challenges. Here, a lower upfront cost option, such as bioLPG boilers, could unlock the fuel switching away from heating oil and coal that will be needed to meet net zero.

The need for an off-grid biogas like bioLPG is clear. Hydrogen is an option on-the gas grid, electrification is not a solution for all businesses and property-types, and biomass can be expensive, difficult to store and create air quality issues.

BioLPG is a compelling solution for commercial buildings - like pubs, restaurants and hotels – that require a low-carbon, convenient, off-grid solution that works for their building and budget. This is particularly prescient during the recovery from the COVID crisis, as many commercial businesses like pubs and hotels have struggled to maintain profitability. For instance, the food and beverage industry's economic output fell by 89% in April 2020[11], and despite the 'Eat out to Help Out' scheme, is 20% lower in August 2020 than at the same point in 2019[12].

It is therefore important that the full-range of low-carbon heating options are made available to these businesses, including bioLPG boilers that have a lower upfront cost than alternatives such as electric heat pumps and biomass boilers.

Chapter 3 will estimate the fuel switching potential in this sector.

Summary

- BEIS estimates that there are approximately 62,000 non-domestic buildings currently being heated by oil or LPG – off the gas-grid.
- Greenhouse gas emissions produced by many commercial sub-sectors such as accommodation and food services haven't declined substantially since 1990.
- As the UK enters a period of recovery from the COVID-crisis it is important that businesses are given the option to invest in several low carbon heating options, including bioLPG boilers that benefit from a low upfront cost.

[7] RHI monthly deployment data: August 2020 - BEIS

[8] Energy Cost Obligation: ECO3 (2018) - BEIS

[9] Accelerated electrification and the GB electricity system (2019) – Vivid Economics et.al

[10] Net-Zero Infrastructure Industry Coalition (2020) The path to zero carbon heat

[11] ONS (2020) Coronavirus and the impact on output in the UK economy: April 2020

[12] ONS (2020) Coronavirus and the impact on output in the UK economy: August 2020

Industrial Sector Landscape

Energy Consumption and Emissions

Across all end-uses, industrial sector energy consumption totalled 264 TWh in 2018. About 90% of industrial energy use was fuelled by natural gas (47%) and electricity (43%). The rest was satisfied by solid fuel (7%) and oil (4%). In terms of energy consumption by end-use, around half (49%) was needed for low and high-temperature process heating – equal to around 129 TWh of energy consumption. Other noticeable end-uses include fuel to power motors (15%), space heating (10%) and drying/separation processes (10%).

Oil and solid fuels are typically consumed to satisfy low and high-temperature process heating. These processes, including direct heating at high temperatures, require the process fuel to interact with the end product - here electrification is likely to be unsuitable. Sectors that consume the most oil for process heating include the mineral products sector, food & beverage sector, vehicle production and chemical production. These sectors use these fuels to undertake processes such as rolling, melting, sintering, kiln firing, drying and other low and high-temperature processes.

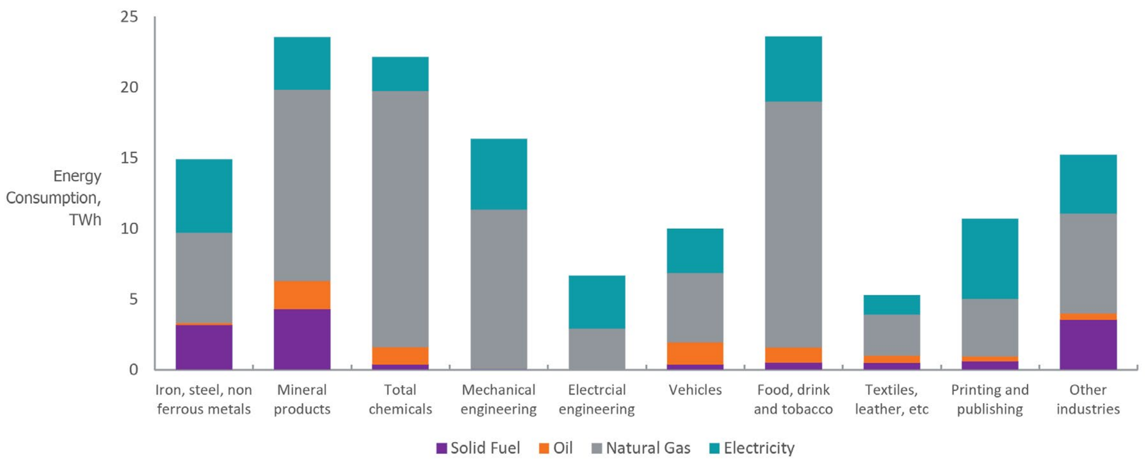


Figure 6 -Industrial Energy Consumption by Sector and Fuel (2018)

Since 1990, industrial emissions have fallen by 53%. This is largely a result of improved energy intensity, and a shift to lower-carbon fuel sources. Nevertheless, emissions from industry contributed over 102 million tonnes of CO2e in 2019, which represented 21% of the UK's total greenhouse gas contribution. With several processes and sub-sectors with no obvious route to decarbonisation, tackling these emissions will be crucial for the UK to meet its net zero target in 2050.

Industrial heat demand and emissions can be split[13] between the UK's 'Big Six' industrial sectors:

1. Coke and refined petroleum products
2. Food and drink manufacturing
3. Pulp and paper production
4. Basic metals
5. Non-metallics
6. Chemicals

[13] UKERC (2018) A Transformation to Sustainable Heating in the UK: risks and opportunities

As illustrated in the previous section, these industries currently consume significant volumes of energy, in particular industrial consumption of oil and solid fuel totalled 24 TWh in 2018. To contextualise this figure, this is roughly equivalent to the final energy consumption of kerosene by off-grid homes.

Looking forward, it is likely that many of these industries will still play an important role in the UK economy over the coming decades, and indeed many of these sectors and processes will be needed to support the deployment of new clean technologies. Take for example the UK's basic metals industry which refines nickel, a valuable component in electric vehicle battery cathodes.

It is therefore important that decarbonisation solutions are developed for the range of industrial energy users. This will include businesses – such as Scottish distilleries – that value an off-grid, flexible, and reliable low carbon energy source. Especially in this context, bioLPG should play an important role.

Industrial Sector

Decarbonisation Options Available

Historically, industry has been difficult to electrify due to the long lifetime of industrial facilities, resulting in high technology swapping costs, especially for those with recent infrastructure upgrades. The high levels of integration in industrial processes has complicated this further, often meaning change to one section results in requirements to change other parts of the process increasing cost significantly.

Industrial sites producing iron require a flame to come into contact with the product or material being produced[14]. In this case a gas is required to provide high temperatures and maintain the quality of the product. It is possible to produce steel in an electric arc furnace, however this secondary production does not create a product that is suitable for all UK applications. Furthermore, electrification is unsuitable for primary iron production due to the requirement for reduction alongside combustion[15]. Iron, steel and cement production are the most difficult industrial sub-sectors to electrify with the IEA estimating just 13% of cement production can become electric by 2040 compared to 60% for aluminium production[16].

Hydrogen has been discussed as a solution to the decarbonisation of industrial energy consumption that cannot be electrified[17] - such as for the production of steel, cement etc. However, green hydrogen production is currently low and supply is expected to initially be concentrated around particular demand hubs[18]. Therefore, there is scope for an additional low-carbon gaseous solution for parts of the UK that remain out of reach of hydrogen or (bio)methane – off-grid. Here, bioLPG could play a role as a flexible, easily-storable and transportable biofuel, and support a portion of 38 MtCO2e emissions that needs to be reduced from this sub-sector – see Figure 3 for analysis.

Carbon capture and storage also has a long-term role to play in supporting the decarbonisation of industrial processes, but is a nascent technology that does not yet have a market mechanism to support its development.

In addition to these industrial processes, stationary combustion from other manufacturing sectors and off-road mobile machinery has a high decarbonisation potential with a greenhouse gas emission reduction of 33.9 Mt CO2e by 2050 (see Figure 3). There is also a strong opportunity for bioLPG in this sector grouping, particularly for off-road mobile machinery such as in food vans where a versatile and portable fuel is required. One market leader in the drinks sector has switched fuels to bioLPG for their fleet of 14 forklifts in one of their warehouses. This project has been a resounding success with no change in operational performance but significant carbon savings.

[14] Hydrogen in a low-carbon economy (2018) – Committee on Climate Change
[15] Industrial Fuel Switching Market Engagement Study (2018) – Element Energy and Jacobs
[16] Frontier electric technologies in industry (2019) – International Energy Agency
[17] HM Government (2020) The Government Response to the Committee on Climate Change's 2020 Progress Report to Parliament
[18] Hydrogen Taskforce (2020) The Role of Hydrogen in Delivering Net Zero

Agricultural machinery is another opportunity for bioLPG in this industrial grouping, however the reduced fuel duty currently available for red diesel makes bioLPG relatively expensive. If the UK is to meet its emissions objectives the combustion of diesel in agriculture will need to be phased out, bioLPG is an obvious replacement option.

The removal of the red diesel subsidy would also help LPG and bioLPG compete in the mobile generator market, where non-road mobile machinery (NRMM) is used on construction sites to power important infrastructure projects. Take the developers of High-Speed Rail 2 (HS2) for instance, who are trailing the use of cleaner LPG and bioLPG generators on construction in recognition of the important clean air benefits of switching away from diesel[19]. The transition away from diesel systems, which currently dominate the mobile generator market, will be game-changing for air quality whilst also lowering GHG emissions. This is an important consideration given the proximity of many construction sites to densely populated areas.

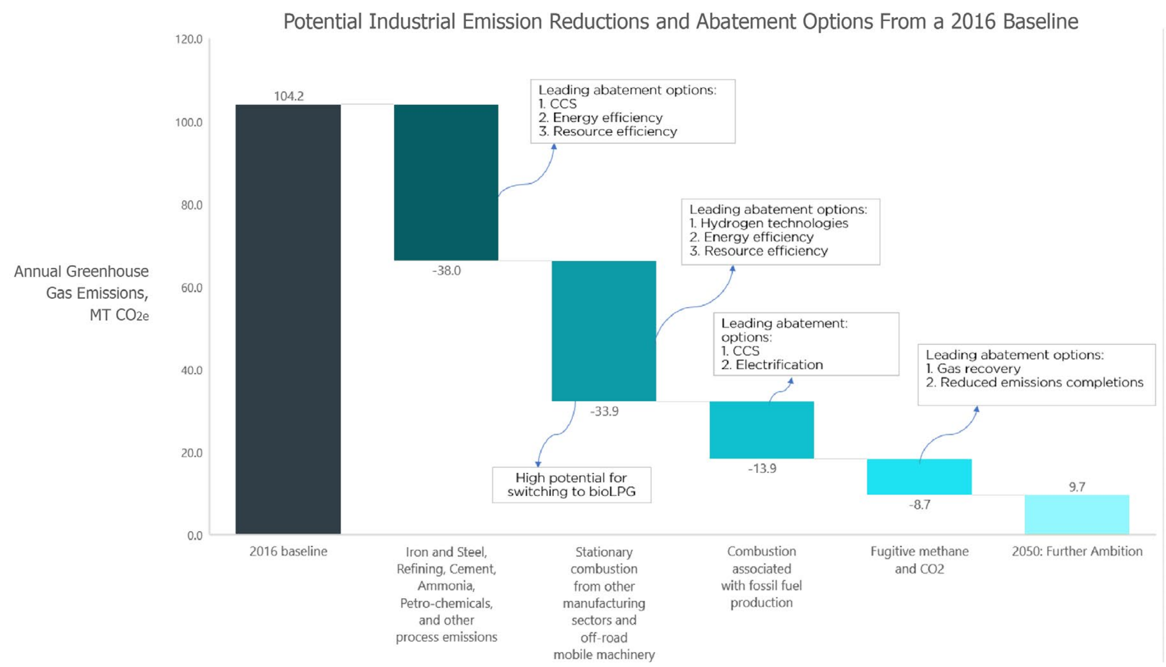


Figure 7 - potential industrial emission reductions and abatement options - based on CCC (2019) analysis[20]

Summary

- Whilst natural gas and electricity are major energy sources for the industrial sector, the consumption of oil and solid fuel is commonly used for process heating in the mineral products, iron & steel, food & beverage, vehicle production and chemical production sectors.
- Industrial emissions have fallen by 53% since 1990 predominantly as a result of improved energy intensity. Fuel switching will be needed to reduce emissions further.
- BioLPG is a good replacement for oil or solid fuels consumed to provide stationary combustion from manufacturing processes (e.g. food and drink) and in an off-grid setting (e.g. NRMM).

Agriculture Sector Landscape

Energy Consumption and Emissions

Energy consumption in the agriculture sector totalled 18 TWh in 2018. The majority of this consumption was met by oil (61%), followed by electricity (23%) and bioenergy & waste (6%). Total energy consumption has fallen by 16% between 1970 and 2018 however, this decrease has not been linear. Between 1970 and 2009 energy consumption fell by 54% but then increased 64% between 2010 and 2018. The share of oil consumed fell from a high of 80% in 1979 to a low of 31% in 2014, before doubling to 61% by 2018.

While data on end-use consumption is not available, a review of the literature[21] found that the majority of energy consumption in agriculture is for heating and field operations. Combined, these end-uses account for a little over 70% of overall energy consumption in agriculture. The highest energy consumption on typical farms varies depending on the main activity. Machinery supporting milk cooling comprises the greatest element of energy use in dairy farming (25%), followed by milking production and lighting (17%), with crop storage and cultivation the greatest consumers of energy on arable farms. On livestock farms forage production and silage consume the most energy. On pig farms, heating, ventilation and lighting are the largest sources of energy consumption. Poultry farms use the majority of their energy on lighting, feeder machinery and ventilation.

Key agricultural end uses for field machinery, water pumping, drying, heating and cooling currently heavily on high-carbon fossil fuels such as oil and diesel. One potential decarbonisation option is to fuel these processes with hydrogen, given its stable energy characteristics. With plenty of viable space, hydrogen could be produced on-site to power key processes. However, it is extremely cost prohibitive to set up the necessary infrastructure to produce hydrogen on-site.

Another potential decarbonisation option is to electrify processes such as greenhouse heating, space heating and poultry rearing, where energy saving is critical. Given the volatile and recently increasing price of oil, it can become very costly for farmers to heat their greenhouses. This can force farmers to shut down operations and wait for the coldest portion of the heating season to pass. The impact of this is to limit the amount of income that these farmers can attain from their operations. However, the relatively high upfront cost of heat pumps and inability to provide constant and reliable heating can impact agricultural processes. For example, a gaseous fuel is better at providing constant and reliable heating which is important for poultry rearing as it helps even feathering and weight gain.

Summary

- There is a high and increasing share of oil consumed in the agricultural sector – which has risen from 31% of energy consumed in 2014 to 61% by 2018.
- Agricultural sites are typically located off-the gas grid and in relatively remote locations. Networked energy sources – like hydrogen and electricity – may be unsuitable. Here bioLPG as a easily storable and flexible low carbon fuel is well-placed to offer a practical route to low-emission operations.

[19] HS2 (2020) HS2 trials game-changing Clean Air Gas Engine technology to dramatically cut carbon on construction sites

[20] CCC (2019) Net Zero Technical Report

[21] Direct energy use in agriculture (2005) – Warwick HRI (for DEFRA)

Catering and Street Food

Case Study

The street food market in the UK has grown rapidly in recent years, with an estimated value of £1.2bn in 2018, an increase of 9.1% on the previous year[22]. High consumer demand coupled with low start-up costs enabled over 8,000 street food and mobile vans to operate in 2018[23]. In the same year there was over 9 TWh of oil consumption in the catering sector[24], with food trucks contributing to this through cooking and diesel generators. For the UK to hit its decarbonisation targets, consumption of these carbon intensive fuels must be reduced..

Food truck operators have specific energy needs, and require a fuel source that is:

- Easily storable and transportable
- Flexible in use
- Reliable

As a versatile, low carbon fuel that meets these needs, bioLPG provides a decarbonisation opportunity for food vans which would otherwise be 'hard to treat'. BioLPG can be used with existing LPG equipment, due to its nature as a 'drop in' fuel. Figure 8 shows estimated annual fuel costs and carbon dioxide equivalent emissions of using LPG, bioLPG, red diesel and diesel for a food van owner. The government is consulting on removing subsidy support for red diesel in hospitality[25], at which point users will required be to use regular diesel (DERV). Not only could over 11 tonnes of CO2e emissions be saved by switching to bioLPG, food truck owners could also save around £1,500 annually in fuel bills.

Food van owners could also significantly reduce their air pollutant emissions by switching fuel to LPG or bioLPG. As can be seen in Figure 9, NOx emissions are 79% lower and PM 2.5 emissions are 98% lower when using LPG or BioLPG rather than diesel as a generator fuel. In this case switching to LPG or bioLPG from diesel results in damage cost savings of approximately £1,100 annually.

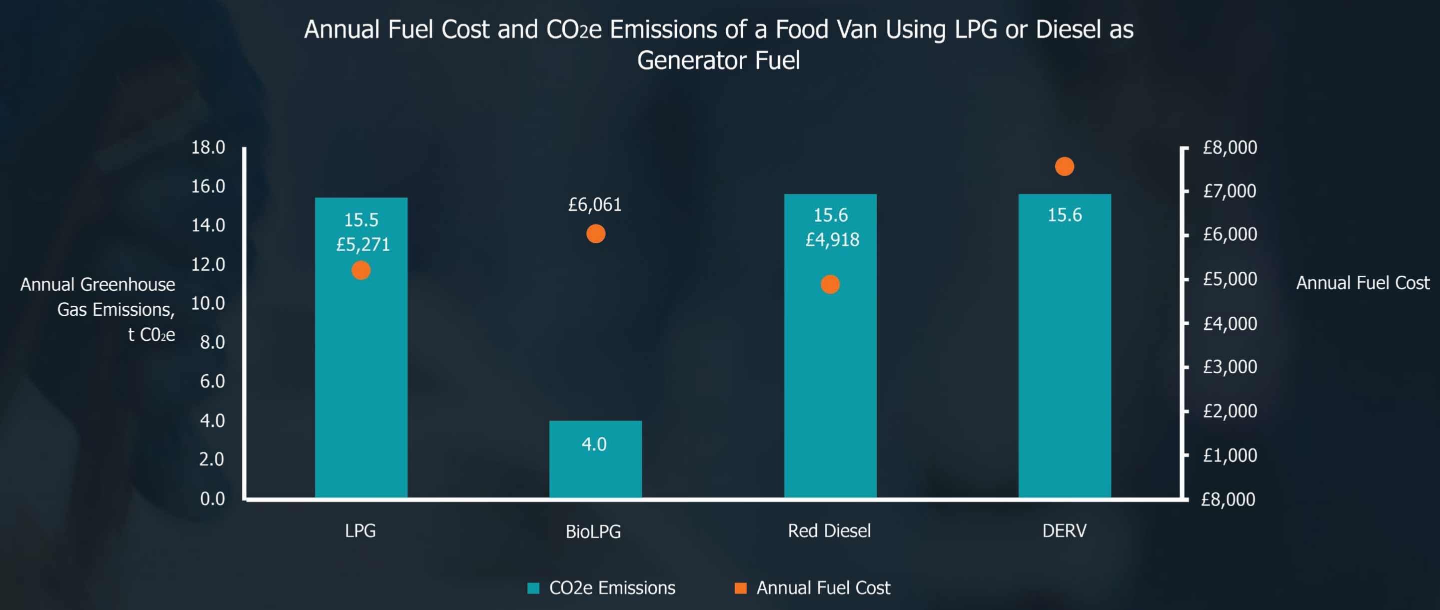


Figure 8 - Annual Fuel Cost and Greenhouse Gas Emissions of a Food Van Using Either LPG or Diesel as Generator Fuel

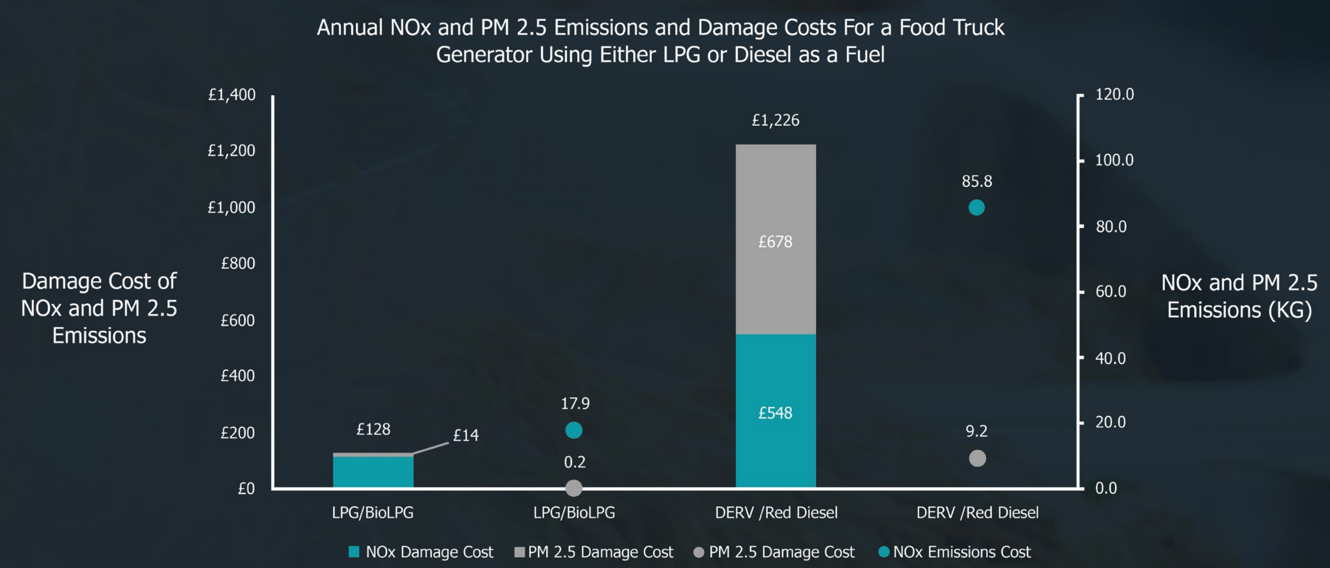


Figure 9 - Annual NOx and PM 2.5 Emissions and Damage Costs for a Food Van Generator Using LPG or Diesel as Fuel

[22] Street food: the new trends shaping foodie culture - The Grocer
[23] Number of fast food restaurant outlets in the United Kingdom (UK) in 2018, by type - Statista
[24] Energy Consumption in the UK (2019), End use tables, Table U5 - BEIS
[25] Budget 2020: Red diesel tax 'loophole' will be closed for many industries – inews

Drink Processing and Distillery

Case Study

The majority of energy consumption in the manufacture of drinks is provided by natural gas and electricity. However, there is a significant amount of drinks processing which takes place off the gas grid. LPG makes up 166 GWh of the off-grid energy consumption, with oil and coal contributing 80 and 113 GWh respectively[26]. This oil and coal consumption results in annual greenhouse gas emissions of 62 kt CO2e, equivalent to the annual operation of 34,000 ICE cars .

Scotland is home to over 130 whiskey distilleries[27], which are split into five whisky-producing regions; Campbelltown, Highland, Islay, Lowland and Speyside. In 2019, these whiskey producers contributed £5.5bn to the UK economy. The sector directly employed over 10,000 people in Scotland, with 7,000 of these jobs in rural regions[28].

The distillation of whiskey is energy intensive, with the majority energy consumed generating steam[29]. This need for high temperature heat creates a decarbonisation challenge for the many rural distilleries which are off the gas-grid and will not have access to low cost hydrogen. Hydrogen is relatively expensive to store and transport, particularly down narrow country roads making it unsuitable for rural distilleries. The distillation process has a very uneven energy demand profile and requires high temperatures making electrification through heat pumps impractical. The emissions and social cost of biomass, BioLPG and the assumed current fuel, oil, have been considered.

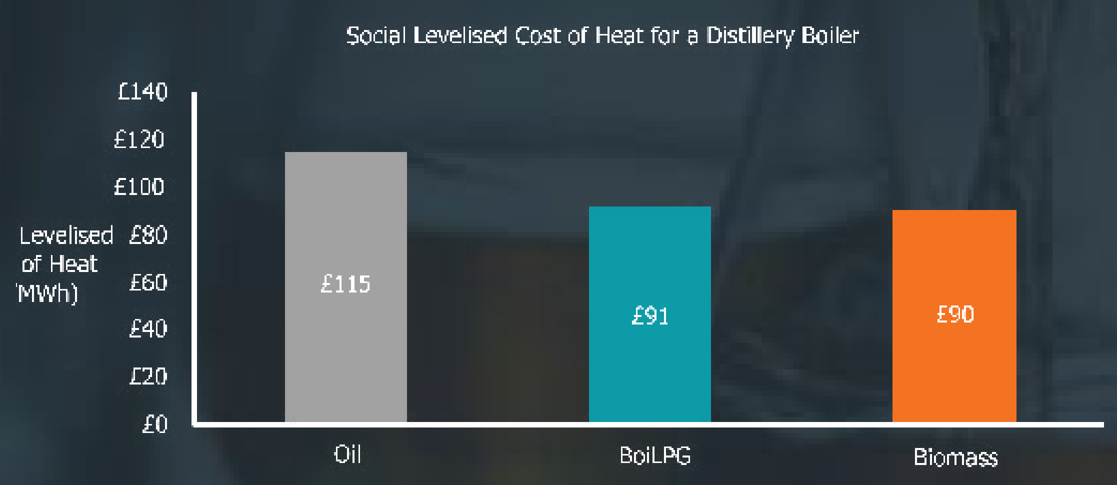


Figure 10 - Social Levelised Cost of Heat For a Distillery Boiler Using Either Oil, BioLPG or Biomass as Fuel

This social levelised cost of heat takes into account the cost of carbon, PM 2.5 and NOx emissions as well as capital and operational costs of the distillery boiler. The cost is highest when using oil even when assuming no capital cost due to existing infrastructure because of the high carbon emissions when using this fuel. The social cost of biomass and bioLPG are comparable, with biomass approximately £1/MWh cheaper over the distillery lifetime. However, a distillery manager will need to consider a variety of factors including capital cost where biomass is much less competitive.

Switching fuels from oil to bioLPG or biomass produces the same greenhouse gas emissions saving at 94 kt CO2e. While biomass has a lower greenhouse gas emission factor, a biomass boiler is less efficient than bioLPG, resulting in the same CO2e emissions. Biomass has a low carbon intensity, however it produces much more air pollutants than bioLPG. Over its operational life the biomass boiler emits 250 tonnes of PM 2.5 emissions, significantly more than oil or bioLPG at 32 tonnes and 1 tonne, respectively. Furthermore, lifetime NOx emissions produced during combustion are 63 tonnes lower for bioLPG than biomass.

Fortunately, off-grid distilleries looking to decarbonise have options. Not all distilleries will be able to afford the high capital cost associated with a biomass boiler, and others may have air quality concerns in which case bioLPG is the obvious low carbon choice.

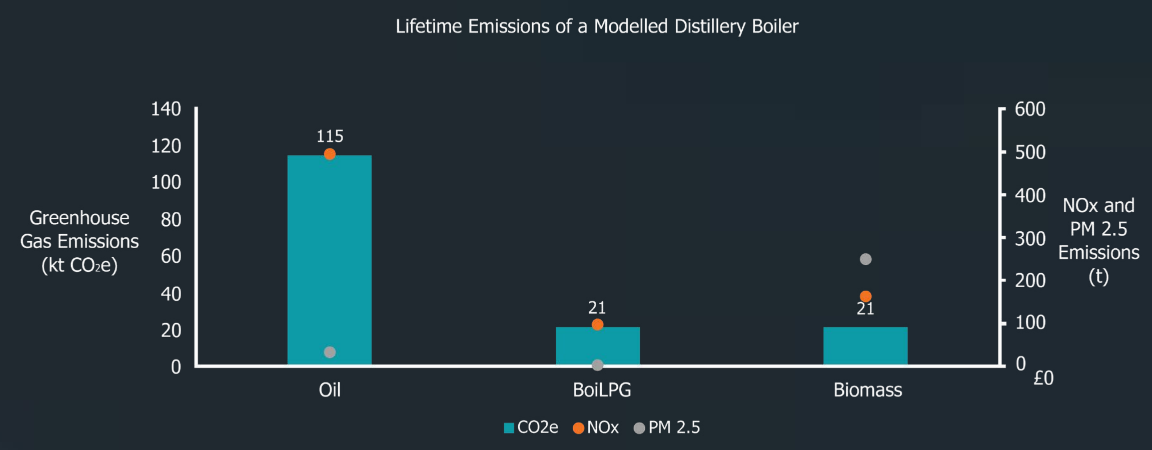


Figure 11 - Lifetime Emissions of a Distillery Boiler Using Either Oil, BioLPG or Biomass as Fuel

[26] Energy Consumption in the UK (2019), Final Energy Consumption Tables, Table C3 - BEIS
[27] Distilleries Map – Scotch Whiskey Association
[28] Facts and figures – Scotch Whiskey Association
[29] In Keeping with the Spirit: Energy Innovation in the Distilling Sector – Pale Blue Dot.

Rural Pub

Case Study

The pub industry is estimated to contribute £17.7bn to the UK economy annually. The sector supported almost 800,000 jobs with a wage cost of £9.1bn in 2017[30].

There were around 39,000 pubs in the UK in 2018[31], with many of these in rural areas. Of the 4.37 TWh of energy consumption used in heating pubs in 2018, 2.17 TWh came from natural gas and 2.12 TWh from oil[32]. This similar oil and gas consumption in pub heating shows the high number of pubs which are off the gas grid and therefore will not be suitable for decarbonisation through hydrogen.

These off-grid businesses will need a form of low carbon heat which is available at a competitive cost. The analysis below has considered bioLPG, biomass and air source heat pumps (ASHPs) as well as oil and LPG as technologies to heat a rural, off-grid pub with poor thermal efficiency. The uninsulated nature of this pub reduces the efficiency of a heat pump, which is estimated to be 200% for this analysis.

Both biomass and ASHPs have a higher levelised cost of heat (LCOH) than bioLPG at £113, £104 and £94 / MWh respectively. Furthermore, the capital cost of a biomass boiler or ASHP is likely to be restrictive at £41,300 and £33,250 respectively. A relatively high discount rate of 10% has been applied to reflect not only the time value of money but also the cost of borrowing for a pub. High capital costs have resulted in government support for these technologies through the Renewable Heat Incentive (RHI), reducing the LCOH. However, this does not compensate for the higher costs under the assumptions made. An LPG or bioLPG boiler is much more reasonably priced at approximately £5,000, making this an attractive decarbonisation option for businesses without large sums of readily available cash. This is likely to be increasingly relevant in the period following the COVID-19 pandemic. During this time, the hospitality sector took a large economic hit due to social distancing restrictions, reducing the likelihood of biomass or an ASHP being an affordable option for a pub.

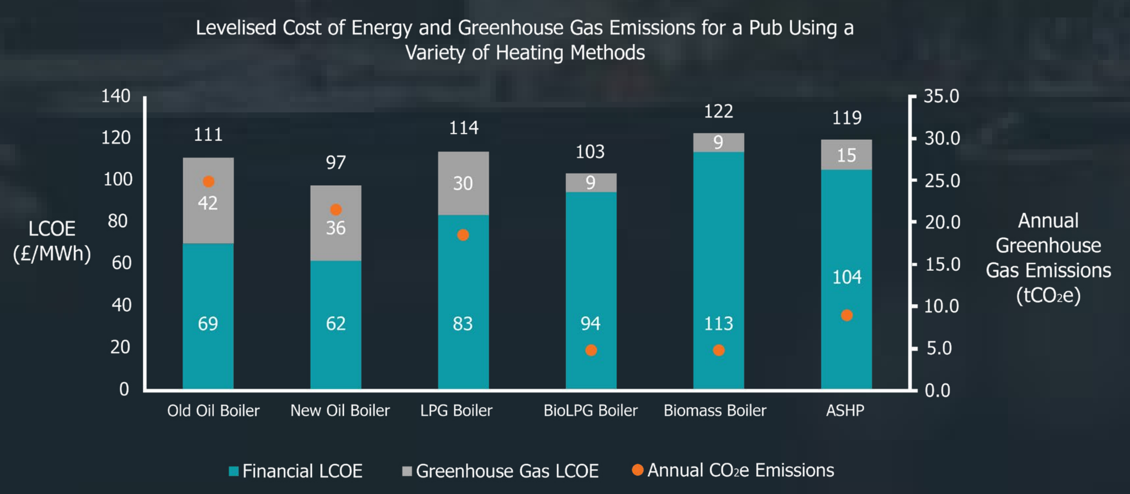


Figure 12 - Levelised Cost of Heat and Greenhouse Gas Emissions for a Pub Using a Variety of Heating Fuels

[30] THE LOCAL IMPACT OF THE UK BEER AND PUB SECTOR - Oxford Economics
[31] Economies of ale: changes in the UK pubs and bars sector, 2001 to 2019 - ONS
[32] Energy Consumption in the UK, End Use Tables, Table U6 - BEIS

The Role of BioLPG in the Non-Domestic Energy Mix

BioLPG - An Overview

BioLPG is a versatile, 'drop-in' renewable solution which can provide up to 90% emissions reduction[33]. Already available on the market today, bioLPG is chemically indistinct from LPG and can be used as it is, just like conventional LPG. This means it can be 'dropped-in' to existing supply chains and can be used by consumers in their existing heating appliances, stored in existing bulk tanks and cylinders, and transported using today's infrastructure and skilled workforce.

BioLPG can be produced by several general processes all with a varying level of technical readiness[34]. Today nearly all bioLPG production is via the hydrotreating of oil. In most cases, bioLPG is produced as a by-product, or as a smaller output of a multi-product process. However, most process types lead to the production of 100% bioLPG reducing the dependence on another production process, futureproofing the bioLPG supply chain.

BioLPG is a convenient off-grid fuel given its 'drop-in' nature. It can be combusted in existing LPG heating systems without impacting performance or requiring additional infrastructure changes. This means existing non-domestic LPG users can switch to 100% bioLPG at zero additional infrastructure cost. Furthermore, bioLPG offers a relatively more cost-effective decarbonisation pathway for non-domestic businesses. This could be unlocked by incentivising and encouraging the switch away from inefficient and high-carbon oil and coal boilers to LPG, in the immediate term, and then progressively to bioLPG. This switching route represents a cost-effective pathway to deep emissions reduction. Indeed, research by Liquid Gas UK found that a 100% switch to electrification is a 37% more costly route to decarbonisation compared to a switching to a range of technologies, including bioLPG[35].

The transition to a net-zero economy is likely to be challenging and disruptive for many non-domestic businesses in off-grid areas. However, incentivising a switch to lower-carbon technologies such as bioLPG can reduce some of the barriers to transition. BioLPG is an impactful renewable solution due in part to its 'drop-in' nature which substantially reduces the need for disruptive and cost-prohibitive infrastructure upgrades.

The Scope for BioLPG as a Decarbonisation Solution

Commercial and industrial businesses continue to consume oil and solid fuel to power a range of end-uses such as space and process heating. However, these fuels do not have a route to deep decarbonisation. Modelling was undertaken to ascertain the fuel-switching potential of oil and solid fuel to LPG (and bioLPG). Not all end-uses can be powered by bioLPG and therefore only the most appropriate end-uses were considered.

[33] BioLPG – The Renewable Future (2018) - WLPGA
[34] Process Technologies and Projects for BioLPG (2019) – Energies
[35] Analysis of off-grid heat decarbonisation pathways (2019) – Liquid Gas UK

For commercial businesses this was deemed to be space heating, hot water heating and catering. For industrial businesses, the most relevant end-uses included low temperature heat, high temperature heat, drying & separation, and space heating. The share of oil and solid fuel consumption was calculated for each sub-sector. A typical fuel-switching rate was assumed depending on the share of oil (or solid fuel) consumption. The higher the share of oil (or solid fuel) consumption, the higher switching potential to bioLPG. We assumed that not all oil consumption could be switched entirely to bioLPG and acknowledge implicitly that some consumption could switch to other heating technologies.

We estimate that the total fuel-switching potential to bioLPG in the non-domestic sector is around 21.9 TWh. This is equal to 37% of total oil and solid fuel consumption across the analysed end-uses. The commercial sector is predicted to account for the majority of this switching potential – 16.2 TWh (or 74%) – used for heating, hot water, and catering requirements. The industrial sector is estimated to demand around 2.6 TWh (12%) of bioLPG to help fuel key applications such as low and high-temperature process heat. The switching potential in the agriculture sector is estimated to be around 3.1 TWh of (bio)LPG demand, namely for space heating.

Commercial BioLPG Demand

Around 16.2 TWh of total non-domestic bioLPG demand is likely to be required to satisfy the heating, hot water, and catering needs of the commercial sector. The largest commercial consumers of bioLPG are anticipated to be warehouses, hotels, restaurants & takeaways and pubs. These four businesses are projected to account for 79% of total commercial bioLPG demand. For warehouses and large distribution warehouses, (bio)LPG could provide warm-air heating to keep workers warm and maintain worker productivity. For warehouses, (bio)LPG is particularly cost-effective and environmentally friendly when powering forklifts to enable logistic operations. In hotels and restaurants, (bio)LPG could be particularly effective in providing space and hot water heating. As well as providing temperature control, (bio)LPG can power kitchen appliances (e.g. frying, simmering, baking). For other commercial premises such as community centres and leisure centres, (bio)LPG can power and maintain specialist vehicles. In colder climates it can help power maintenance equipment such as ice edgers and resurfacers. In warmer climates, (bio)LPG can fuel golf carts and watercraft. A full breakdown of the key end-uses of (bio)LPG in the commercial sector can be found in the adjacent table.

Commercial BioLPG Demand

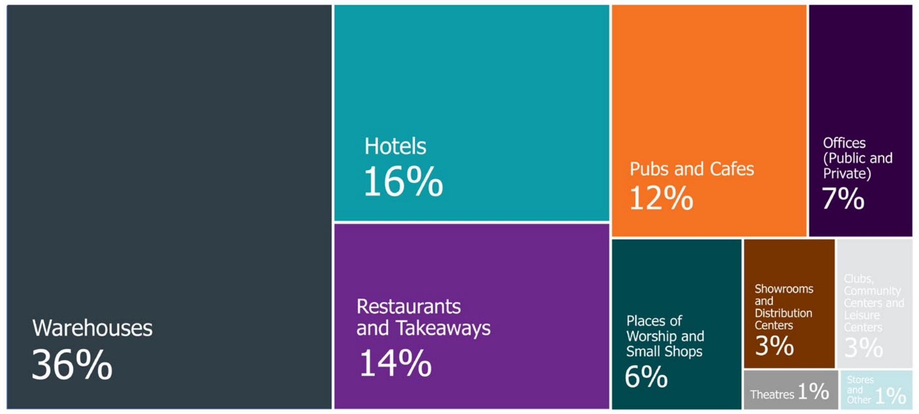


Figure 13 - Commercial BioLPG Potential End Use Proportions

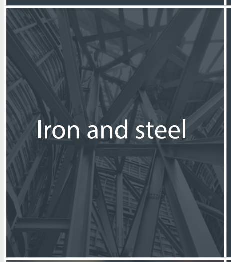
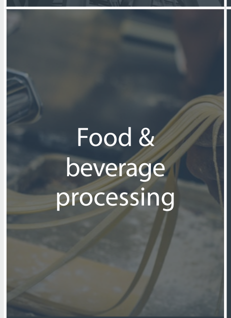
The characteristics of bioLPG – versatile, flexible, clean-burning – align with the business operations and energy requirements of commercial businesses such as warehouses, hotels and restaurants & takeaways. As a result, these sectors are estimated to account for the majority of commercial bioLPG demand. At the other end, off-grid businesses such as cafes, large food shops and leisure centre may also demand bioLPG to support with heating and hot water needs. BioLPG is also portable and can be scaled to meet any specification, with the fuel delivered to 1 tonne (2,000 litres), 2 tonne (4,000 litres) or 4 tonne (8,000 litres) tanks which can sit above or below ground. High volume users often choose to have multiple tanks installed.

Commercial	BioLPG switching potential, TWh	Key End-Uses
Warehouses & large-distribution centres	5.8	• Warm air heating (keep workers warm) • Space Heating • Cooling • Powering Forklifts (Loading/Unloading)
Hotels	2.7	• Space Heating • Water Heating • Catering/ Cooking • Tumble Drying/ Laundry
Restaurants and takeaways	2.3	• Space and Hot Water Heating • Powering Kitchen Appliances (e.g. Frying, Simmering, Baking, Grilling and Roasting) • Temperature Control
Pubs and Cafes	2.0	• Space and Hot Water Heating • Outdoor Heating • Flexible and Reliable Cooking
Offices – Public and Private	1.1	• Space and Hot Water Heating • Powering self-containing generators and combined heat & power systems
Places of Worship and Small Shops	1.0	• Space and Hot Water Heating • Constant and reliable temperature control
Showrooms and large distribution centres	0.6	• Space Heating • Constant and reliable temperature control • Powering forklift operations
Clubs, community centres and leisure centres	0.4	• Maintenance and powering specialist vehicles • In winter climates it can power maintenance equipment such as ice edgers and resurfacers • In warmer climates, fuels golf carts and watercraft
Theatres	0.2	• Space and Hot Water Heating • Lighting and powering of equipment • Cleaning and pressure washers
Stores and other (i.e. hairdressers, retail warehouse, museums, non-food shops)	<0.1	• Space Heating
Total	16.2	

Industrial BioLPG Demand

As a low-carbon alternative to oil and solid fuel, bioLPG can be used to satisfy process heat applications such as melting, sintering, drying, and rolling. Compared to electric technologies which are mainly used in a pre-heating capacity, bioLPG can be used to enable key processes such as direct and indirect high-temperature processes. The gaseous nature of (bio)LPG therefore enables industrial users to undertake high-temperature processes such as melting, rolling and kiln-firing. These processes are extremely important to non-metallic mineral manufacturers who produce glass, cement, ceramics and bricks. Other alternatives such as biomass and electric heating are not as appealing because they can compromise product quality. In the glass and ceramic sector it is extremely vital that there is no product contamination - (bio)LPG can facilitate this.

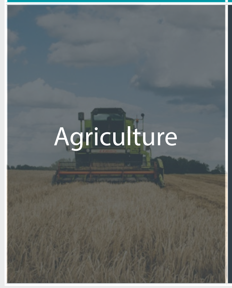
We estimate that the key industrial sectors where bioLPG could be deployed is in food & drink manufacturing, iron & steel production and non-metallic mineral production. In the food & drink sector, around 0.2 TWh of bioLPG could be needed to enable steam and low-temperature heat processes. Around 1.5 TWh of bioLPG could be consumed in the mineral products sector to support the manufacturing of non-metallic mineral products where alternative fuels such as biomass and electricity may impact product quality. A further ~1 TWh of bioLPG could be demanded by iron & steel producers to facilitate processes such as melting and sintering which require really high temperature (~2,000°C) heat in blast furnaces.

Industry	Total energy consumption, TWh	BioLPG switching potential, TWh	Key End-Uses
 Non-metallic mineral manufacturing	23.5	1.5	• Melting (high-temperature process) • Rolling (high-temperature process) • Kiln-firing (high-temperature process) • Reliable and precise heat ensuring product quality • Gloss firing of pottery and ceramics, which can be adversely affected by soot produced by other fuels.
 Iron and steel	14.9	0.96	• Reduction processes • Melting (Direct high temperature process) • Steam generation (Indirect low temperature)
 Food & beverage processing	23.6	0.16	• Temperature control in cooking and baking • Drying of fish and sea food • Steam, hot water production and sterilisation process of canned meat. • Range of food finishing processes – boiling, frying, stewing, simmering, baking, grilling and roasting.
Total	62	2.6	

Agricultural BioLPG Demand

Oil consumption in the agriculture sector accounts for around 61% of total energy consumption. This suggests a significant switching potential to LPG and bioLPG to help decarbonise key end-processes such as space heating. While there is no official breakdown of energy consumption by end-use, a review of the literature found that heating accounts for around 37% of total energy consumption. It is estimated that switching potential to LPG and bioLPG is around 3.1 TWh or 231,000 tonnes.

This potential bioLPG demand could help decarbonise processes such as shed heating for poultry rearing, crop and grain drying, heating of growing sheds, and heating greenhouses for horticulture and fruit or vegetables. BioLPG can also power other processes such as generators, water pumps, weed burning and forklift trucks for the loading of stock. The portability, versatility and precise control of heat, makes bioLPG an ideal fuel for the processes outlined above.

Agriculture	Total energy consumption, TWh	BioLPG switching potential, TWh	Key End-Uses
 Agriculture	18.4	3.1	• Greenhouse heating and heating for crop-drying • Poultry rearing (constant, reliable heating) • Horticulture (to maintain constant temperature) • Forklift trucks (loading/unloading)

Emission Saving Potential from Switching

Most oil and coal consumption occurs off the gas-grid due to the higher costs of these fuels than natural gas. These off-gird sites provide the best opportunity for LPG and bioLPG due to the high current fuel costs. Our estimates suggest that LPG and bioLPG have the potential to replace 21.9 TWh of industrial, agricultural and commercial oil consumption and ~2.3 TWh industrial coal consumption. The majority of this fuel switching comes from commercial space heating where the large heating demand at these off-grid sites makes them unsuitable for electrification. Other end uses thought to be suitable for fuel switching to LPG or bioLPG include hot water, catering, high and low temperature heating and drying.

If all of this consumption suitable for fuel switching were to use LPG or bioLPG there would be significant savings in both greenhouse gas and air pollutant emissions. Currently, this oil and coal consumption results in 4.86 Mt of CO2e emissions per year. By replacing this fossil fuel consumption with bioLPG over 3.5 Mt of CO2e could be saved each year. This is equivalent to over 2.1 million cars being taken off the road[36]. The greenhouse gas emissions and air pollutants associated with this level of biomass consumption are also shown. However, this is for illustrative purposes only as not all of the end uses suitable for LPG/bioLPG are also applicable for biomass. While biomass has the lowest greenhouse gas emissions at 0.29 Mt of CO2e, the damage costs relating to air pollutants produced by biomass are over 24 times higher than those of LPG/bioLPG at £730m.

[36] Average CO2 Emissions per Car in the UK (2020) - Niblefins

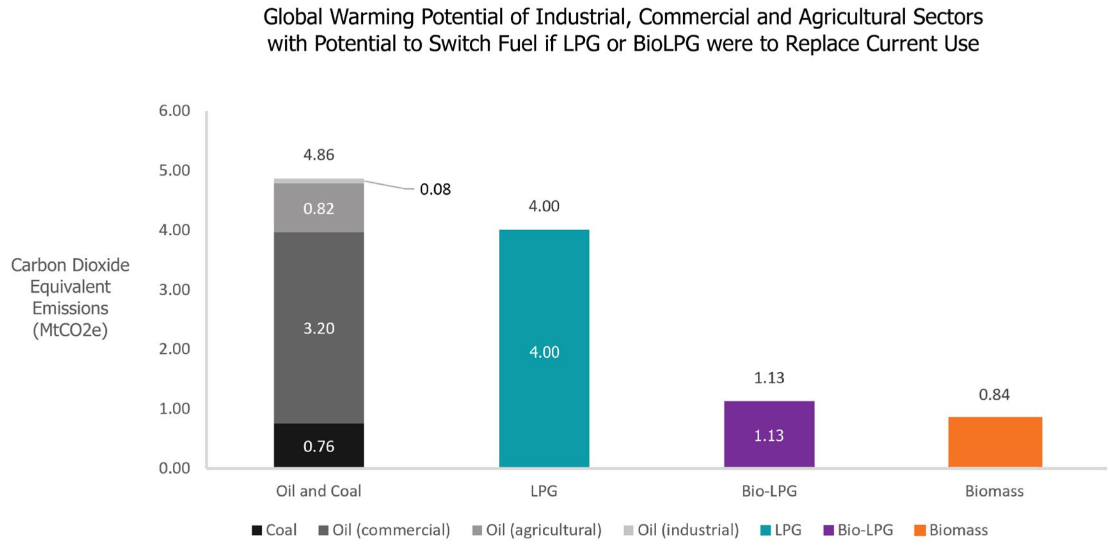


Figure 14 - Greenhouse gas emissions of industrial, commercial and agricultural sectors with potential for switch fuel if LPG or bioLPG were to replace current fuel use

This combustion of oil and coal emits over 19 kt of NOx and 1.9 kt of PM 2.5 annually, which have a damage cost of £127m and £144m respectively. LPG is a much cleaner fuel in combustion, emitting fewer air pollutants at 3.9 kt of NOx and 72 t of PM 2.5. As a result, using LPG or bioLPG in the place of oil and coal for suitable applications could result in damage cost savings of over £240m annually.

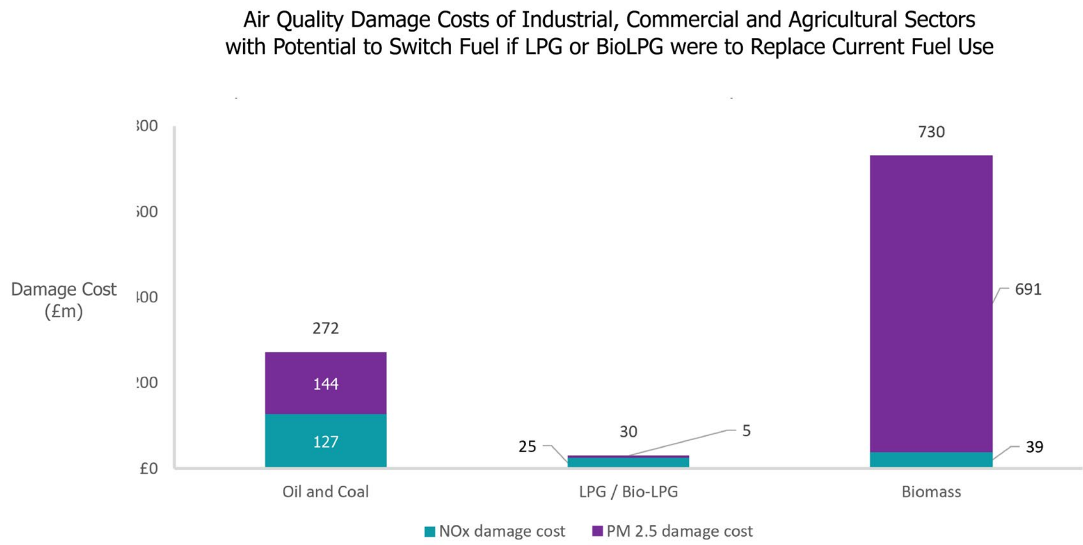


Figure 15 - NOx and PM 2.5 Damage Costs of Industrial, Commercial and Agricultural Sectors with Potential to Switch Fuel if LPG or Bio-LPG were to Replace Current Fuel Use

Policy Reflections

This paper has shown the value of a biofuel energy source for many off-grid applications – from food trucks, to distilleries and food processing facilities – it is clear that bioLPG can play an important role in the non-domestic decarbonisation picture. The LPG industry has developed its vision and defined its target - to transition to bioLPG by 2040.

For policymakers, the 2050 net zero objective is also well-defined. The challenges involved with driving the decarbonisation of the economy in this time are immense. In the UK, many of the 5.9 million businesses currently operating today will need to switch to a decarbonised energy source in the next 30 years. Particularly in the near to medium term, this decarbonisation imperative will vie for investment attention with other projects in an increasingly challenging business environment, with the economic ramifications of the COVID-crisis likely to be felt for several years to come.

As the UK, Scottish, Welsh and Northern Irish Governments develop heat in buildings and industrial decarbonisation strategies in the early 2020s, it is therefore crucial that policymakers are attuned to the reality of non-domestic energy use for many of the businesses that will play an important role in the UK's economic recovery. Failure to do so could put the UK's crucial progress towards net zero back several years.

This paper contributes to the evidence-base by analysing the energy needs of many off-gas grid businesses, such as rural pubs, hotels, food processing and agricultural facilities. The report shows that for many of these businesses, fuel switching to an off-grid biofuel such as bioLPG can deliver hassle-free and cost-effective emission savings.

There is however currently a policy gap in recognition and support for bioLPG, which is only currently incentivised in the transport sector (through Renewable Transport Fuel Obligation certificates). Whilst long-term policy support and certainty will be key to enable investment in the production and supply of bioLPG, this section considers three immediate policy changes.

Policymakers can immediately support bioLPG uptake by taking the following steps:

- Removal of the red diesel subsidy and kerosene exemption
- Ensure that rural businesses are not left behind in the Covid-recovery and post-Brexit stimulus package
- Accept LPG and bioLPG projects in BEIS' Industrial Energy Transformation Fund
- Extend eligibility in the non-domestic RHI and/or successor schemes such as the Green Gas Levy to off-grid biogases such as bioLPG

Address oil tax exemptions

Liquid Gas UK calls on the UK Government and Treasury (HMT) to address the tax breaks which allow kerosene and red diesel to out-compete cleaner off-grid fuels. We support HMT in their intention to remove the red diesel subsidy from gas-oil. This would allow bioLPG and LPG to better compete against red diesel systems, and reflect the emission savings that could be enabled by switching to cleaner fuels.

Kerosene is also currently zero-rated. Users of the fuel in an industrial or commercial setting are exempt from paying fuel duty, or Climate Change Levy payments. By comparison, non-domestic consumers of LPG, incur a CCL charge per kilogram of fuel consumed (2.175p./kg). This puts LPG, which is cleaner burning, lower in carbon emissions, and has a developed route to a decarbonised fuel at a significant disadvantage against kerosene.

Ensure that rural businesses and communities are not left behind in the post-Covid recovery and post-Brexit stimulus

As national governments look to develop a stimulus package to encourage an economic recovery following the turbulence created by the Covid-crisis and Brexit, LGUK calls on policymakers to ensure that rural areas are not left behind. Many rural businesses – such as the distilleries, hotels and pubs considered in this paper - have been impacted severely by the pandemic. Indeed, the accommodation and food services sector experienced the largest decline in output across the UK economy[37]. It is important that first and foremost rural businesses are supported to get back on their feet.

National governments are also then right to consider how the UK can build back better and greener. In this context, LGUK encourages the government to look for fuel switching opportunities from high-carbon energy to lower-carbon fuels such as LPG and bioLPG.

Having a reliable energy supply is absolutely vital for these businesses. Governments across the world recognised that the LPG industry performed an essential role supplying reliable, storable and flexible energy to businesses and communities during the pandemic[38]. The LPG industry is well-placed to continue to provide reliable and lower emission energy to businesses as they recover from the Covid-crisis.

Support projects that deliver LPG and bioLPG fuel switching in the Industrial Energy Transformation Fund

This report has detailed the valuable fuel switching role that LPG and bioLPG can play, in transitioning off-grid industrial sites from high carbon fossil fuels such as coal and oil. In their Industrial Energy Transformation Fund (IETF) criteria documents, BEIS have recognised the important role that fuel switching away from high carbon fossil fuels will play in reducing emissions from the industrial sector. Indeed projects that involve a transition from carbon intensive fossil fuels (e.g. coal, oil) to the natural gas grid are eligible. However projects that include fuel switching to natural gas' off-grid equivalent - LPG - and the low-carbon fuel bioLPG are both currently ineligible for support.

The Industrial Energy Transformation Fund has made an initial £30 million worth of funding available for feasibility and technology deployment projects, with a remaining £259 million available to the fund before 2024. The 2019 Conservative manifesto also included a commitment to invest £500 million to help energy-intensive industries move to low-carbon technologies.

Liquid Gas UK calls on the Government to consider the full range of low-carbon fuel options as they develop this industrial decarbonisation policy and support schemes further. As this report has shown, for energy-intensive industries such as food processing, bioLPG should be available as a flexible, and cost-effective alternative to on-grid low-carbon gases such as biomethane and hydrogen. The Scottish distillery case study included in this report demonstrates the cost-effective deep decarbonisation (80%+ emission reductions) opportunities that can be realised by supporting bioLPG.

Extend low-carbon support schemes to bioLPG

In establishing support schemes for renewable heat and low carbon gas – such as the extended non-domestic RHI and the Clean Heat Grant, bioLPG as the primary off-grid biogas is not currently supported under either scheme. The Clean Heat Grant is under consultation, but as at December 2020, has a narrow focus on 2 technologies – biomass boilers and standalone electric heat pumps. Other biofuel solutions, such as hybrid heat pumps with bioLPG boilers, gas-driven heat pumps and standalone condensing bioLPG boilers could be supported to provide consumers with more choice of low carbon heating systems.

Additionally, while the Green Gas Incentive is wholly focused on subsidising green gas (biomethane) for injection into the gas grid, UK Government are missing out on an opportunity to support alternative low-carbon biogas solutions for homes, buildings and processes off the gas grid, such as bioLPG. Conversely, BEIS have placed a value on the emission reductions that can be achieved by switching to biomass, and biomethane from fossil fuels.

Liquid Gas UK would welcome the opportunity to discuss appropriate policy instruments to encourage the production, and supply of bioLPG. A long-term indication of policy recognition and support can enable the investment in UK-supply of bioLPG, to the benefit of many off-grid businesses looking for a convenient and cost-effective decarbonisation solution.

[37] ONS (2020) Coronavirus and the impact on output in the UK economy: April 2020

[38] WLPGA (2020) Cutting Through the Noise

Key Messages

This report has developed the following key messages:

- It is clear that the UK will need to tackle industrial and commercial emissions to meet net zero. Given the limited amount of time before the net-zero target, the UK Government should ensure that all fuel switching opportunities are taken by developing policy that recognises the range of low-carbon technologies that will be needed to meet a diversity of energy.

- There is already a clear need for a low-carbon, off-grid solution for several sectors and use cases – including food and drink manufacturers, users of non-road mobile machinery, agricultural processes and warehouses. This report includes case studies detailing the role that bioLPG can play in supporting convenient and cost-effective decarbonisation for a section of businesses. The UK Government should recognise this bioLPG niche in policy.

- The Government should support a mixed technology approach, and widen it's low-carbon fuel support to include bioLPG, as well as addressing unfair tax exemptions for competitor high-carbon fossil fuels – such as red diesel. Additionally, projects which deliver fuel switching away from the most-polluting off-grid fuels to LPG and bioLPG should be made eligible for the Industrial Energy Transformation Fund support. Long-term policy recognition and support will create the confidence for the industry to invest in delivering the production and supply of bioLPG.

Data Inputs

Street Food Case Study	Amount	Units	Source
Diesel GHG emission factor	0.25568	kg CO2e / kWh	BEIS
LPG GHG emission factor	0.2303	kg CO2e / kWh	BEIS
BioLPG GHG emission factor	0.0603	kg CO2e / kWh	Bilans Ges
LPG fuel cost	7.85	p / kWh	SAP
BioLPG fuel cost	9.03	p / kWh	15% premium
Red diesel fuel cost	86.04	p / l	DfT
DERV fuel cost	132.85	p / l	DfT
Diesel generator power	7.7	kW	Himoinsa
Diesel generator fuel consumption	3.17	l / hr	Himoinsa
LPG generator power	7	kW	Greengear
LPG generator fuel consumption	0.318	kg / kWh	Greengear
Generator output	15.4	MWh / year	Assumption
LPG PM 2.5 emission factor	0.000002808	kg / kWh	NAEI
DERV PM 2.5 emission factor	0.0001512	kg / kWh	NAEI
LPG NOx emission factor	0.0002664	kg / kWh	NAEI
DERV NOx emission factor	0.001404	kg / kWh	NAEI
Central PM 2.5 damage cost	73,403	£ / t	Defra
Central NOx damage cost	6,385	£ / t	Defra

Distilleries Case Study Input	Amount	Units	Source
Heat demand	16,288	MWh / year	UoS
Oil boiler efficiency	76	%	BRE
LPG boiler efficiency	92	%	BRE
Biomass boiler efficiency	69	%	KIWA
Oil boiler size	4	MW	Assumption
LPG boiler size	4	MW	Assumption
Biomass boiler size	4	MW	Assumption
LPG boiler capital cost	336,283	£	DECC Wiki
Biomass boiler capital cost	1,760,000	£	RHI
Oil boiler O&M cost	5,945	£	1% of CAPEX
LPG boiler O&M cost	3,363	£	1% of CAPEX
Biomass boiler O&M cost	17,600	£	1% of CAPEX
Oil price	0.0593	p / kWh	BEIS
BioLPG price	0.0758	p / kWh	Assumption
Biomass price	0.0324	p / kWh	Ricardo
All boiler lifetimes	20	Years	Assumption
Oil GHG emission factor	0.26782	kg CO2e / kWh	BEIS
BioLPG GHG emission factor	0.06030	kg CO2e / kWh	BEIS
Biomass GHG emission factor	0.0450	kg CO2e / kWh	Ricardo
Coal GHG emission factor	0.33183	kg CO2e / kWh	BEIS
Oil NOx emission factor	0.001836	kg NOx / kWh	NAEI
BioLPG NOx emission factor	0.000266	kg NOx / kWh	NAEI
Biomass NOx emission factor	0.000328	kg NOx / kWh	NAEI
Oil PM 2.5 emission factor	0.000072	kg PM 2.5 / kWh	NAEI
BioLPG PM 2.5 emission factor	0.000003	kg PM 2.5 / kWh	NAEI
Biomass PM 2.5 emission factor	0.000504	kg PM 2.5 / kWh	NAEI
Discount rate	10	%	Grant Thornton
Central non-traded price of carbon	70 – 156	£ / t	BEIS
PM 2.5 rural road damage cost	30,697	£ / t	Defra
NOx rural road damage cost	3,166	£ / t	Defra

Pub Case Study Input	Amount	Units	Source
Annual energy demand	76,650	kWh	Assumption
Discount rate	10.0	%	Grant Thornton
Old oil boiler efficiency	76	%	BRE/Ofgem
New oil boiler efficiency	88	%	BRE/Ofgem
LPG boiler efficiency	90.3	%	BRE/Ofgem
BioLPG boiler efficiency	90.3	%	BRE/Ofgem
Biomass boiler efficiency	65	%	BRE/Ofgem
ASHP efficiency	180	%	Ecuity analysis
Oil cost	0.0435	£ / kWH	SAP
LPG cost	0.0659	£ / kWH	SAP
BioLPG cost	0.0758	£ / kWH	15% premium
Biomass cost	0.0465	£ / kWH	SAP
Electricity cost	0.1440	£ / kWH	BEIS
Old / new oil boiler capital cost	5,717	£	BEIS
LPG / bioLPG boiler capital cost	5,017	£	BEIS
Biomass boiler capital cost	41,300	£	RHI
ASHP capital cost	28,500	£	RHI

Oil boiler maintenance cost	178	£ / year	Price Your Job
LPG boiler maintenance cost	138	£ / year	Price Your Job
Biomass boiler maintenance cost	200	£ / year	YouGen
ASHP maintenance cost	243	£ / year	Mitsubishi
Oil GHG emission factor	0.2467	kg CO2e / kWh	BEIS
LPG GHG emission factor	0.2145	kg CO2e / kWh	BEIS
BioLPG GHG emission factor	0.0600	kg CO2e / kWh	France Government
Biomass GHG emission factor	0.0450	kg CO2e / kWh	Ricardo
Electricity GHG emission factor	0.2331	kg CO2e / kWh	BEIS
Average social cost of Carbon	128	£ / t	BEIS
Biomass RHI payment	0.0315	£ / kWH	RHI
ASHP RHI payment	0.0279	£ / kWH	RHI
Heating technology capacity	70	kW	Assumption

Fuel Switching Emissions Analysis Input	Value	Units	Source
Commercial oil consumption	12.95	TWh	ECUK Ecuity analysis
Industrial oil consumption	0.32	TWh	ECUK Ecuity analysis
Agricultural oil consumption	3.12	TWh	ECUK Ecuity analysis
Coal consumption	2.28	TWh	ECUK Ecuity analysis
Average industrial solid fuels GWP emissions factor	0.332	kg CO2e / kWh	BEIS
Average industrial oil GWP emissions factor	0.263	kg CO2e / kWh	BEIS
Average commercial oil GWP emissions factor	0.247	kg CO2e / kWh	BEIS
Average agricultural oil GWP emissions factor	0.263	kg CO2e / kWh	BEIS
LPG GWP emissions factor	0.214	kg CO2e / kWh	BEIS
Bio-LPG GWP emissions factor	0.060	kg CO2e / kWh	Bilans Ges
LPG domestic combustion NOx emission factor	183.6	t / TWh	NAEI (BEIS)
LPG industrial combustion NOx emission factor	266.4	t / TWh	NAEI (BEIS)
LPG domestic combustion PM 2.5 emission factor	4.3	t / TWh	NAEI (BEIS)
LPG industrial combustion PM 2.5 emission factor	2.8	t / TWh	NAEI (BEIS)
Coal industrial combustion NOx emission factor	612.0	t / TWh	NAEI (BEIS)
Coal industrial combustion PM 2.5 emission factor	396.0	t / TWh	NAEI (BEIS)
Oil commercial combustion NOx emission factor	1,116.0	t / TWh	NAEI (BEIS)
Oil industrial combustion NOx emission factor	1,836.0	t / TWh	NAEI (BEIS)
Oil agricultural combustion NOx emission factor	1,116.0	t / TWh	NAEI (BEIS)
Oil commercial combustion PM 2.5 emission factor	64.8	t / TWh	NAEI (BEIS)
Oil industrial combustion PM 2.5 emission factor	72.0	t / TWh	NAEI (BEIS)
Oil agricultural combustion PM 2.5 emission factor	64.8	t / TWh	NAEI (BEIS)
NOx damage cost	6,385	£ / t	Defra
PM 2.5 damage cost	73,403	£ / t	Defra
Biomass GWP emission factor	0.0450	kg CO2e / kWh	Ricardo
Biomass PM 2.5 emission factor	0.000504	kg PM 2.5 / kWh	NAEI
Biomass NOx emission factor	0.0003276	kg NOx / kWh	NAEI

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