WLPGA

The role of LPG in shaping the energy transition

2018 Edition

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Acknowledgements

World LPG Association (WLPGA)

The WLPGA was established in 1987 in Dublin and unites the broad interests of the vast worldwide LPG industry in one organisation. It was granted Category II Consultative Status with the United Nations Economic and Social Council in 1989.

The WLPGA promotes the use of LPG to foster a safer, cleaner, healthier and more prosperous world.

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Foreword by James Rockall

A vibrant global LPG (also known as propane, butane or Autogas) supply chain allows those consumers not connected to the gas grid to benefit from clean, versatile and efficient gas. The role of LPG is important and diverse. In mature markets LPG offers solutions as a cleaner alternative to high-carbon fossil fuels for heating and transport that is also versatile and cost effective. In emerging markets, LPG fundamentally improves life quality for instance by serving as an available alternative to hazardous traditional cooking fuels such as wood or charcoal. The opportunities are endless.

The role for this versatile fuel is not time limited. The LPG supply chain is bursting with innovation which makes investment in it a long-term strategic choice not an interim compromise. Today LPG is the optimal and cleanest option amongst fossil fuels. Soon a range of innovations will render use of LPG smarter and more efficient as gas technology breakthroughs available on the grid gain scale off the gas grid as well.

Delivering the global energy and environmental objectives requires scalable low carbon solutions for transport, power and heat. Recent progress on electrification of these energy needs has provided a comfort blanket to policymakers and the public, however it is obvious to many that challenges will emerge as scale is attempted.

Take California which just passed a clean-energy bill targeting carbon-free electricity by 2045.

Clean Air Task Force, an environmental think tank, estimates that such a target will require 36 million MWhs of energy storage capacity. Current capacity stands at 150K MWhs[1].Quickly scaling infrastructure to meet this future need will be challenging and costly. However, MIT researchers estimate that an energy system based on low emissions gas and nuclear power could reduce these future costs by as much as 62% through decarbonisation[2].

Add to this that there are some energy uses which cannot switch easily to electricity (e.g. industrial chemical processing, high powered heating, etc) it is clearly not feasible to meet 100% of future energy needs through electrification.

For example, the array of gas transition technologies such as micro-combined heat and power, hybrid heat pumps or gas absorption heat pumps render the use of LPG much more efficient and unlock exciting opportunities in a smart home setting. Hybrid applications of LPG power generators, trucks even tankers create more cost effective, secure and versatile solutions across the economy sectors and world regions. Increased supply of BioLPG can eventually reduce substantially the carbon footprint of the supply chain in line with global climate efforts.

[1] MIT technology review (2018) The $2.5 trillion reason we can't rely on batteries to clean up the grid

[2] Supulveda, N et al (2018) The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation.

Therefore, the strategic role of LPG should be considered not only over a time span of five to ten years, but until 2030 and beyond. To drive this debate, the WLPGA is launching this paper which explores the role and benefits of the LPG supply chain in key markets and sectors, exploring interesting questions using data-based evidence. We are launching this paper at the 31st World LPG Forum with a focus on opportunities in the US and EU markets. The world of LPG is very broad and very deep and future iterations will address other sectors and regions of the world.

The timing has never been better to do so:

The EU is establishing a new climate & energy framework towards 2030 with many EU member states exploring options to reduce heating emissions by condensing the share of high carbon fossil fuels, such as heating oil and coal, off the gas grid. What are the opportunities that this development is opening for LPG particularly with the emergence of gas transition technologies and BioLPG?

The US now stands as the number one LPG producer and exporter in the world. One of the outcomes of the rise in production has been increased exports without an equivalent increase in the use of LPG in the domestic market. As the global LPG industry is facing a period of increased supply, what would be the benefits of diverting more LPG use into the internal US market in the HGV, power generation and commercial/industrial sectors to replace emission intensive fuels such as diesel and oil?

The outcomes of our research are telling:

- In the US, diesel overwhelmingly dominates the heavy-duty truck sector. If 50% of new diesel trucks are replaced by LPG, then by 2030, the carbon and air quality benefit would be equal to $12 billion and $11 billion respectively. The cost benefit for vehicle owners of converting diesel trucks to LPG would be just over $29,000 over their useful life.
- It is estimated that about 30GW of on-site diesel generators will have been installed in the US by the end of 2018. The carbon and air quality benefit of displacing 50% diesel fuel with LPG would be $2.5 million and $21 million respectively by 2040.
- In the US market the industrial and commercial sectors are dominated by coal and oil for heating. Higher penetration of LPG and eventually BioLPG by 2040 would reduce carbon emissions by 62MtC02. This equates to a social benefit of $11 billion.
- In the EU rural heating market, a mixed technology approach to decarbonisation - including BioLPG and gas-transition technologies - is a third of the cost of a 100% electrification route, whilst delivering substantial emission savings against heating oil and coal.

I hope you will enjoy this paper and that it will be a useful discussion for all those interested in the exciting transition that heat, energy and transport sectors are going through.

James Rockall
CEO and Managing Director
WLPGA

Introduction

Globally, energy is undergoing a period of significant transition. Facing complicated challenges ahead policymakers and industry are having to start to make decisions over what the future of the energy system will look like and how climate mitigation targets can be met whilst ensuring that an incredibly rich and diverse tapestry of energy needs are met.

Recognising that energy can be key to economic prosperity and is the linchpin to effective international development, it is clear that a holistic approach is required, whereby energy sources are considered in relation to a range of factors, be they environmental or social. Given its centrality to economic growth, prosperity and health outcomes, the importance of a reliable, lower carbon, affordable energy source should not be underestimated.

In recognition of these factors, WLPGA has prepared this paper to explore the role and benefits of the LPG supply chain in key markets and sectors. Our intention is to explore interesting questions using data-based evidence.

Focussing on greenhouse gas emissions and air pollution this paper provides an analysis of the monetised environmental benefits which may be delivered by LPG in the following areas:

Replacing 50% of diesel trucks with LPG trucks by 2030.

Displacing up to of 50% of diesel fuel used for backup power across the US.

Substituting existing LPG boilers across Europe to new low carbon LPG technologies such as Hybrid Heat Pumps and BioLPG fuel.

Switching industrial and commercial premises across the US away from oil to LPG.

One guarantee with predictions of this nature is that they are bound to be wrong however our aspiration for the review is to start a conversation. In light of the global energy transition, this report articulates a call for policy makers worldwide to support LPG usage through policy mechanisms and initiatives, and for business and individual users to consider the merits of this energy source. In a world that is transitioning away from more traditional fossil fuels, there is very much a place for LPG in the future energy mix, and, ultimately, LPG has a key role to play in tackling the challenges outlined above. We look forward to the discussion.

Drivers shaping the global energy transition

Air Pollution

One of the most pressing public health concerns of the 21st century, poor air quality is a significant driver of energy policy. The increased focus on air pollution seen in recent years can be attributed to heighted awareness and greater public pressure on political bodies to tackle this urgent, fatal issue.

Media attention and 'airpocalyptic' images filling our screens coupled with accounts detailing the very human impacts of air pollution have bought the issue to the forefront of the public psyche, and the proliferation of campaign groups, public petitions and protests seeking to urge governments to act is indicative of the fact that this is no longer a marginal political issue. In the UK, a series of successful legal challenges against the Government by the non-governmental organisation, Client Earth demonstrated that inaction on air quality was not an option and an ambitious policy trajectory was required, imminently. Further, in recent years Germany, France and the UK have been sent to the European Court of Justice (ECJ) for breaching legally binding EU standards for nitrogen dioxide limits. Additionally, Italy, Hungary and Romania faced similar ECJ trials over their breaching of particulate matter standards. The message here is clear; countries can no longer get away with flouting environmental regulations, especially when the quality of the very air we breathe is at stake.

Meanwhile in the US, citizens are utilising a variety of methods to exert political influence vis a vis air quality. In June, Californian residents voted on, and subsequently passed, Proposition (Prop) 68 which sought to ameliorate air quality by authorising $4 billion in general obligation bonds for parks and environmental protection projects. Further, in upwind states such as Delaware (where 90% of air pollution comes from other states) citizens are petitioning against the Environmental Protection Agency (EPA) and have held public hearings and meetings on the issue. Further, increased use of social media as a tool for activism means that the level of scrutiny on policymakers with regards to air quality is only set to heighten. In 2014, lawmakers in Poland banned the burning of coal as a domestic heating source after being faced down by a Facebook campaign with over 20,000 followers. Whilst it is often hard to quantify the impact of social media on political outcomes, it is clear that such platforms are making people, across the world, far more aware of issues such as air pollution.

The increased focus on air quality and mounting pressure on governments to act is largely due to a growing body of evidence clearly demonstrating the catastrophic mortality and morbidity rates caused by breathing polluted air.

Last year, World Health Organization (WHO) statistics revealed that not only are 90% of the world's population breathing air containing high levels of pollution, but an estimated seven million deaths a year can be attributed to said pollution. Of these deaths, around 90% occur in low- and middle-income countries, therefore certain demographics are more at risk that others - this is clearly not just an environmental or health issue but a social justice one too. The sheer global scale of the profound and pervasive threat posed by air quality means that it is at the forefront of contemporary policy making.

To illustrate the physiological impacts of dirty air further - in essence, particle pollution found within the air can become embedded in people's lungs when they breathe. Leading to, or exacerbating, a myriad of health conditions including lung cancer, heart disease, stroke, asthma and chronic obstructive pulmonary disorder (COPD).

Despite the scale of the challenge, and the fact that pollution levels remain high across much of the world, a number of countries have started to take decisive action to curb emissions. In 2017, the Netherlands faced warnings from the ECJ over its failure to comply with EU emissions targets but has since been told it is doing enough to limit emissions. For some, the threat or process of legal action is the catalyst required to tackle the issue head on. Further, there are many policies (both proposed and realised) that would mitigate, and ultimately, reverse the issue of highly polluted air. With the right mechanisms and initiatives in place, progress can be made.

Inhalable particles are released from a range of mobile and stationary sources, with the main contributors being road transport, combustible heating fuels and heavy industrial processes. Question 1 explores the role that LPG can play in transforming the transportation sector (especially with regards to Heavy and Medium Goods Vehicles).

Given that Particulate Matter (PM) and Nitrogen Oxide (NOx) emissions (the two forms of pollutants most attributed to premature mortality) can be reduced through a switch to LPG, encouraging wider use of LPG for transportation, domestic heating and industrial processes should become a policy priority. Ultimately, LPG can serve as a solution to the toxic air that so many of us currently breathe.

Poverty and Wellbeing

A further driver for energy transition is the increasing recognition of the global energy divide. In certain parts of the world access to energy remains poor – this intersects with, and impacts on, every aspect of people's lives from health, to employment. Ultimately, access to energy lies at the heart of development. Given that, globally, a billion people still live without electricity, and millions more have unreliable or unaffordable power sources, emerging economies are having their growth stunted. Furthermore, it is fair to state that, in some regions, poverty cannot be reduced, nor eradicated, without access to electricity or gas. The reality of this is epitomised by Goal 7 of the 17 agreed Sustainable Development Goals, which were agreed in 2016 and which seek to advance development in various social and economic development issues. Goal 7 specifically addresses the lack of reliable energy sources in much of the world and seeks to ensure all have access to affordable, reliable, sustainable and modern energy by 2030. Meeting this target will not be without its challenges given that many of those who face energy access issues find themselves 'off grid' and there is simply not the financial support or infrastructural means to facilitate them using certain energy types. Nevertheless, the suitability of LPG for decentralised applications renders it the ideal energy source for off grid, hard to reach areas, such as those which currently find themselves without reliable energy.

As a result of its flexibility and abundance, LPG can help increase the accessibility to affordable energy and is a tool for energy development. A modern, sustainable energy source, it can go some way to reducing the number of people without access to energy. Further, it is safer than many other fuel types. As many as one billion people cook with traditional fuels or unsafe biomass stoves worldwide. By facilitating conversion to LPG, the world's most vulnerable can be safeguarded from the ill effects of household air pollution (and their associated mortality rate).

Climate Change

The environment is changing; anthropocentric actions are impacting on every aspect of the world around us, and ever-shifting energy needs coupled with increasing environmental concerns mean solutions are required. At the heart of the move to a sustainable future is the transition of our energy systems towards lower carbon fuel sources. Across a range of sectors, policy has served as a catalyst for change, seeking to solve pressing environmental issues (such as pollution, air quality and climate change) by transforming energy systems.

As a result of the issues mentioned, as well as a number of global negotiated agreements, many countries have a combination of international and national targets to meet in terms of reducing both greenhouse gas and carbon emissions. Fast approaching and ambitious goals render policymakers reliant on a clear trajectory and, subsequently, energy policy serves to continue to drive forward energy system change.

Environmental policy has, and will, continue to drive rapid energy system change. Climate mitigation and decarbonisation targets outlined by policy makers mean that, in some instances, new energy sources are required. With a carbon intensity that is lower than coal, LPG releases 30% less CO2 per unit of energy than coal or oil and consequently serves as an enabler of decarbonisation across the domestic heating, industrial and transportation sectors.

Increased usage of this lower carbon fuel has already proven to reduce total hydrocarbon emissions by 29% (EPA study, Federal Clean Air Standards). Further, LPG emits 57% less nitrogen oxide than the standard fuels in use, something which is explored further in the body of the report. Given that LPG is a lower carbon energy source than traditional fossil fuels, it can serve to aid the decarbonisation agenda. What's more, industry is innovating further by producing even greener, cleaner fuels, such as BioLPG, a fuel source which can be created from wastes and agricultural residues.

Nevertheless, there is more to the story of the energy transition than simply greenhouse gases and climate change. Energy is an environmental, economic and social justice issue, and the choice of future energy mix needs to address what can, at times, appear to be conflicting requirements.

The role of LPG in shaping the transition

With change comes a wealth of opportunities to do things differently and for policymakers and businesses alike to explore new fuel sources. One such option is LPG. Put simply, LPG is defined as a fuel type consisting of hydrocarbon gases in liquid form. Sometimes referred to as propane or butane, LPG has a wide variety of uses, and there is a plethora of ways in which it is ideal for meeting the world's increasingly varied energy needs. The compelling economic, social and environmental arguments behind increasing LPG's uptake as part of the global energy transition are outlined below and explored more extensively in the body of this report.

Transportation

In the realm of transport, vehicular pollutants pose a real threat to both the quality and length of people's lives. The disproportionate impact of transportation on air quality means that utilising alternative fuel types is paramount to improving the air we breathe. Multiple studies show the extensive morbidity and mortality associated with poor air quality. As populations and car usage grow this is only going to be exacerbated – the busier towns and cities become, irrespective of infrastructural changes and road building, congestion will worsen. Sjodin et al. (1998) showed up to 4-, 3- and 2-fold increases in CO, HC and NO_x emissions, respectively, with congestion (average speed of 13 miles per hour, mph; 1 mph =1.61 km per hour) compared to uncongested conditions (average speed, 38–44 mph). Whilst many countries are pursuing an electrification pathway for domestic/consumer vehicles the infrastructural support required and battery restrictions associated with EVs render them largely inappropriate for heavy and medium goods vehicles. LPG offers a lower NOx and GHG alternative to diesel that is well suited to such vehicle types and elicits both environmental and financial benefits.

Heating Homes

As well as being essential to the effective decarbonisation of transportation fleets, LPG can also play a role within the domestic sphere, offering a lower carbon fuel for household heating and cooking. This is particularly true of off-grid households which may be reliant on costly electrical heating or highly polluting oil boilers. Moreover, demand on the electricity grid will increase exponentially if it is used to displace higher-carbon fossil fuels in other sectors. The bitterly cold winters and unusually hot summers experienced in many parts of the world in 2018 further place a strain on the grid, reducing its reliability. As a result, it is anticipated that power outages will become increasingly common. Proposals to manage demand have been explored but ultimately their reliance on behavioural change renders them unlikely to be successful, hence it is better to diversify the heating sources households use.

The aforementioned need for reliability highlights how important it is that, worldwide, there are dependable, storable sources of energy. Renewable energy sources such as solar and wind are less predictable, and can fail to supply, hence we need reserves of other energy sources (such as LPG). After all, we cannot rely on the wind to blow, nor the sun to shine.

Industry and LPG

Another area of opportunity lies in industry, where there is an urgent need to decarbonise. In 2017, the industrial and commercial sectors accounted for 44% of total energy consumption in the US and produced over 5,000 million metric tons of CO2 (MtC02). Tackling the emissions produced by these sectors would make substantial inroads in reducing emissions and, without a shift in the types of fuels industry and commerce are utilising, it is unlikely that any carbon or GHG reduction targets will be met. The fact that nearly 50% of the industrial sector in the US uses coal means a significant opportunity exists to switch fuel type to LPG here.

Energy Security

The increasing abundance of certain energy sources serves as another marker of the global energy transition. With concerns about the scarcity of some energy sources, LPG bucks the trend given its natural, and increasing, abundance, especially in the US, where, in 2016, 66 million tonnes of it were produced.

What's more, globally, as of 2017, LPG production exceeded consumption by around 6 million metric tonnes, demonstrating its potential and also the fact that it is, at present, an underutilised resource.

In an economic climate where countries are searching for diverse emerging market opportunities, the LPG industry offers substantial economic growth. Furthermore, at a time of political instability and global volatility, security of supply is safeguarded due to its natural abundance. There are a wide range of sources of LPG both inside and outside of Europe. The US is the world's largest producer of LPG and has seen domestic production increase by nearly 70% in a decade. In 2017, over half of all US LPG production (67Mt) was exported. Further, export utilisation averaged only 59% in 2016, meaning that, in terms of exporting LPG, the US is not meeting its full capacity. Whilst it is anticipated that this figure will reach 70% by 2020, and there is a projected growth of the global LPG market of 2.75% by 2024, a push (be it political or industrial will) is required in order to stimulate the global LPG market and allow it to meet its full potential. Consumer LPG sales are anticipated to grow by around three million metric tonnes (800 million gallons) between 2014 and 2025 (ICF), clear this is a market that, with the right support mechanisms in place, has a huge amount of potential. LPG is an incredibly abundant fuel source, an abundance which, up until this point has not been truly capitalised on. Given that the US currently exports 51% of the LPG it produces, and the shale gas revolution has pushed down the price of LPG, demand can certainly increase in order to match the heightened supply.

The compelling economic arguments for increased LPG usage and the financial savings it can elicit for both consumers and businesses are explored further in the body of the report.

Flexibility

The transition towards decentralised energy systems, and the consumer empowerment and autonomy that accompanies this shift means that flexible power sources are required to meet households individualised energy needs. Such systems require a flexible energy solution – LPG is a flexible solution which can serve to satisfy the energy needs of even the most remote communities, with little centralised infrastructure required. The flexibility of this source is epitomised by recent proposals to use LPG as a fuel source in Qatar to enable them to meet the increased power demand anticipated during the 2020 world cup when there will be a near 50% temporary increase in population. Ultimately, LPG can be accessible to everyone everywhere without major infrastructural investment given that there are ample reserves which can be easily transported using sea, rail or road.

Low Emission

LPG is a very low particulate-matter, NOx and sulphur emitting fuel, meaning that it's consumption can improve air quality when displacing highly-polluting fuels such as diesel. Ambient air pollution kills millions of people prematurely each year and is increasingly understood to be associated with several serious physical and psychological ailments. Energy, transport and environmental policy cannot be said to be succeeding if it does not reduce harm to health.

In addition to its potential positive impact on air quality, switching away from high-carbon fossil fuels – such as oil and coal – to LPG will immediately lower GHG emissions, thereby reducing our impact on climate change. Indeed, the carbon footprint of LPG is 20% lower than that of heating oil, and 50% lower than coal.[3] Consuming this fuel in highly-efficient gas-transition technologies such as LPG-hybrid heat pumps or LPG gas-absorption heat pumps, can lower emissions even further.

In addition to this product innovation, the industry is starting to deliver a low emission fuel – bioLPG – which can be consumed in existing LPG heating appliances without any modifications needed. BioLPG is already being produced and supplied in small volumes, but the production routes and opportunities to scale are growing, providing an exiting chance to support even lower emission vehicles, heating systems, and generators.

[3] WLPGA (2017) The LPG Charter of Benefits.

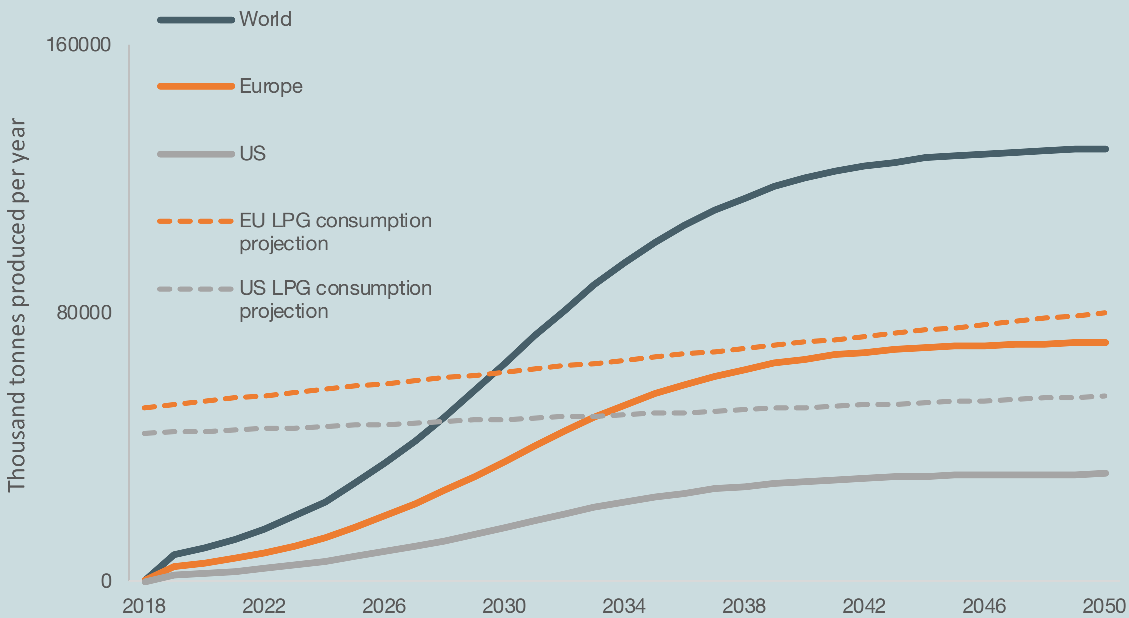
Information box: BioLPG – production, emissions and potential

BioLPG production has been growing rapidly over recent years. The fuel is currently predominantly produced from hydrotreated bio-oils in refineries. However, BioLPG can be produced in several ways and numerous processes, such as gasification and pyrolysis - which are already proven technologies, and from various feedstocks including agricultural residues and municipal waste.

The varied routes of production and feedstocks available means that the carbon footprint of BioLPG can vary. This report will assume a central carbon intensity of 20 gCO2e/MJ (informed by source below) – which can provide an 80%-90% reduction against diesel, oil and coal.

Whilst future production volumes are uncertain and the product of policy decisions and industry development, the analysis in this report is informed by current production potential estimates (see reference below). In our scenario modelling we assume that BioLPG is preferred to conventional LPG as a lower-emission fuel, and production and consumption gradually increases over time (see figure below).

This report's analysis should not be understood as a projection of the take up of BioLPG – which is highly uncertain at this early stage – but more as a scenario analysis considering what if policymakers and industry support its growing development.



Atlantic Consulting (2018) BioLPG: A survey of markets, feedstocks, process technologies, projects and environmental impacts. Commissioned by Liquid Gas Europe/WLPGA

The regional context

2018 has been marked by extreme weather events[4]. In Europe, and around the world, extremes of both hot and cold, precipitation and high winds have impacted people, business, communities, energy, transport, health and public safety. Although individual extreme weather events are hard to pin down as a symptom of global warming, they can have the effect of galvanising political action towards tackling the causes of climate change.

United States

The trajectory of US national environmental policy recently represents a marked shift from the policies enacted and priorities upheld in the past. Previous administrations, prioritised carbon emissions reduction whereas, today we are seeing attempts to increase fossil fuel use, and denouncements of environmental policy as an impediment to business.

Recently, fourteen state governors outwardly vowed to uphold previously national agreements on climate, and, recently, substantial efforts have been made by individual states to influence federal climate policy. Whilst not every legislative attempt in this realm has been successful, this marks a significant shift in the way in which environmental policy is devised and implemented in the US.

Currently, a range of initiatives are in play to support federal efforts to mitigate climate change. At present, twenty states, plus the District of Columbia, have individualised greenhouse gas emissions targets, and the Regional Greenhouse Gas Initiative (RGGI), established in 2005, uses a cap and trade program to help states reduce their power sector C02 emissions. The nine RGGI states have set a goal of reducing emissions to 45% below their 2005 level by 2020.

Under previous administration, fourteen states bandied together to form The Climate Alliance, who have been predominantly focused on cleaning up electricity grids. The result of this is that emissions from electricity in alliance states are expected to drop to half of their 2005 levels by 2025.

Further, in the state of New York, the formation of a green bank which seeks to garner $1 billion in private sector investment for cleaner energy serves as a mechanism to support the Governor’s 50% renewable energy by 2050 goal. Capital availability not only aids in decarbonisation and climate change mitigation but also demonstrates the potential profitability of the ‘green’ sector.

As the second largest polluter in the world, it is vital that the US adopts policies and initiatives to harness cleaner energy, even if they have to be at a state-based level for the time being.

[4] World Meteorological Organisation (2018) Start of 2018 marked by extreme weather.

Europe

Across the EU and its Member States there are strong drivers to accelerate the transition towards cleaner technologies and energy sources, and improved security of supply and infrastructure. Three key targets[5] for 2030 have been set:

1. At least 40% cuts in greenhouse gas emissions (from 1990 levels)
2. At least 27% share for renewable energy
3. At least 27% improvement in energy efficiency

More than 90% of European Union territory is rural and 52% is predominantly rural. Over half of the EU population (57.4%) live in rural areas and around 22% in predominantly rural areas. In addition, there are approximately 40.7 million homes with no access to the natural gas grid due to their remote rural location.

Any transition to cleaner heating fuels must clearly consider the needs of rural consumers who may also be those facing highest heating costs. There is some evidence that the pace of change is accelerating:

Firstly, in France where there has been a carbon tax on transport and heating fuels since 2014. The Government's most recent 2018 Finance Bill confirmed an increase in the price of carbon from 30.5 Euros per ton (2017) to 44.6 Euros, a rise of 46% in a single year, with further increases projected for 2019 (55 Euros) and beyond. The carbon tax is paid directly by consumers and is no doubt having an impact on consumption patterns and heating system choice.

Meanwhile, German energy and climate policy has been a central issue within the general election and subsequent difficulties in forming a coalition. Electoral politics and the growth of the far right in key industrial areas presents serious challenges to more ambitious climate policy, however a Commission for Growth, Structural Change and Employment was formed at the beginning of June. The Commission will publish a timeline by the end of 2018 with a concrete date for the end of coal power generation alongside plans to mitigate the impact on employment in mining regions of the country.

Turning to off-grid heating, a number of countries have signalled their intent to tackle high fossil fuel heating with proposals for a ban on sale of oil boilers. The federal government in Belgium has established its "Energy Pact" collective of short, medium and long-term energy policy objectives and a set of concrete policies which support these aims. The Pact sets 2035 as the end-date for the sale of new oil boilers.

Finally, in 2018 a coalition in the Netherlands (including boiler manufacturers) proposed that the country should phase out new sales of 100% gas boilers by 2021 leaving hybrids, heat pumps, and district heating as the options available when replacing or installing a new heating system.

[5] EU Commission (2014) 2030 climate & energy framework.

Chapters

1-4

C1. LPG use for heavy and medium duty road transport in the United States

Diesel overwhelmingly dominates the heavy-duty truck sector in the US and is also the number-one power source for medium-duty vehicles. What are the monetised environmental benefits that could be accrued through a transition to LPG?

Executive Summary

Medium and heavy duty trucks almost entirely use diesel for fuel. The negative impact this has on air quality is well-documented.

LPG can play a significant role in reducing the adverse impact on air quality.

Replacing new diesel trucks with LPG could save the US economy $11 billion in abated NOx emissions and $12 billion abated C02 emissions by 2030.

Poor Air Quality: a public health crisis

Poor air quality in the US poses a profound, persistent threat which cannot be ignored by policy-makers and industry.

The morbidity and mortality rates associated with air pollution are appalling; globally pollution kills more people than war, Malaria and HIV/Aids combined. In the US, it is estimated that around 200,000 people a year die from pollution related causes. Of these, at least 53,000 premature deaths a year are attributable to emissions from road transportation alone. This means that, each year, vehicular pollutants kill more people than other leading causes of death such as road traffic accidents, kidney disease and septicaemia.

Further physiological impacts of air pollution include the induction of acute exacerbation of both COPD (the third leading cause of death worldwide[6]) and asthma. High levels of air pollution can increase the likelihood of acute asthma episodes amongst those with moderate to severe asthma, and, even short-term exposure to poor quality air can increase the likelihood of needing to visit the emergency department for asthma treatment.[7]

[6] Lopez-Campos, JL et al (2016) Global burden of COPD.
[7] Jaffe, DH et al (2003) Air pollution and emergency department visits for asthma among Ohio Medicaid recipients 1991-1996.

In addition to the physical impacts, being exposed to high levels of airborne particulate pollution has psychological effects and can cause or worsen, a myriad of mental health issues. There is increasing epidemiological evidence to suggest an association between air pollution and depression, anxiety, dementia and cognitive development. As well as potential links to a reduction in intelligence and cognitive performance[8].

Whilst ambient air pollution is derived from a range of fuel combusting sources (including industrial processes and domestic heating), the most significant contributor is vehicular pollutants. NOx emissions from the transport sector account for 59% of total US NOx emissions and, at the heart of this issue lies diesel usage.

Despite the bleak picture painted above, the air quality crisis is rectifiable and, in fact, reversable. With the right policy mechanisms in place, the harm caused by vehicular pollutants can be reduced exponentially and the ideal starting point is with Heavy and Medium Goods Vehicles (HGVS and MGVS), vehicle types which not only contribute disproportionately to air pollution but which, encouragingly, can be easily, and cost effectively, adapted to using LPG as a fuel.

The Contribution of the Transport Sector

The EPA targets six "criteria air pollutants" which are known to be particularly harmful to human health and are most persistent in the US. These six are - ground-level ozone, particulate matter pollution, carbon monoxide, lead, sulphur dioxide and nitrogen oxide (NOx). NOx emissions are primarily produced from the combustion of fossil fuels – and are associated with transport activity. NOx – and in particular NO_2 emissions – are known to cause a variety of respiratory illnesses, which have real-life social and personal health impacts.

Figure 1 provides an overview of the state of NOx emissions in the US. The graphic shows that despite a gradually improving picture of technology improvements over time, transportation remain the most significant source (59%) of NOx emissions.

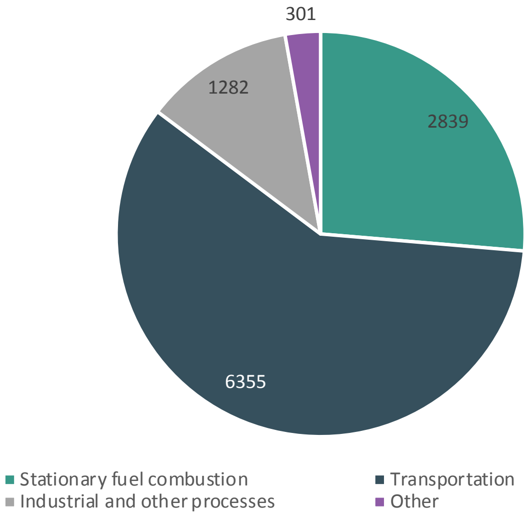


Figure 1[9]- US NOx emissions by sector (thousand tons) (EPA, 2017)

[8] Zhang, X et al (2018) The impact of exposure to air pollution on cognitive performance.
[9] EPA (2018) Air pollutant emissions trends data.

It is clear that transport emissions must be tackled if NOx is to be reduced to safe levels.

Within the transport sector, the combustion of diesel is recognised as a key contributor to localised air quality issues. According to EIA data - in 2017 total diesel fuel use by the transport sector stood at 168 million tonnes of oil equivalent. The medium and heavy-duty truck sector accounted for 75% of this (126 Mtoe). Given that diesel as a fuel is harmful to the environment and medium and heavy-duty trucks account for 75% of its consumption, policies to tackle this segment should be considered.

Diesel powertrains dominate the MGV and HGV market (see figure 2). Without supportive policy frameworks to encourage the development and deployment of alternative fuels, this dominance will not change over time. Add to this an expectation that the annual sales of trucks will rise over the coming decades (figure 3), and it is clear that policymakers and industry need to urgently consider the ways in which vehicular emissions can be reduced, else face a worsening air quality crisis.

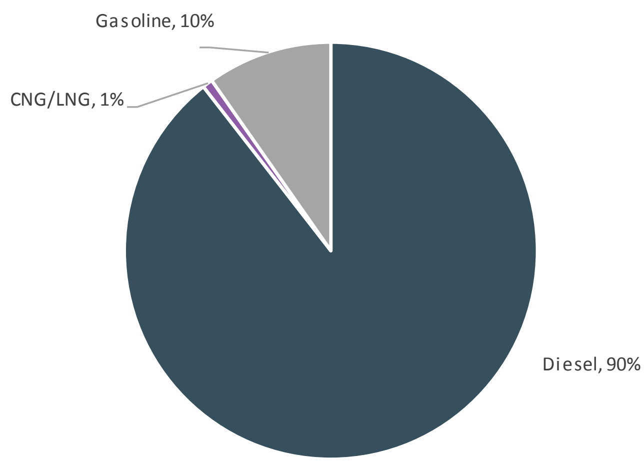


Figure 2 - % fuel use of MGVs and HGVs in the US (EIA, 2017)

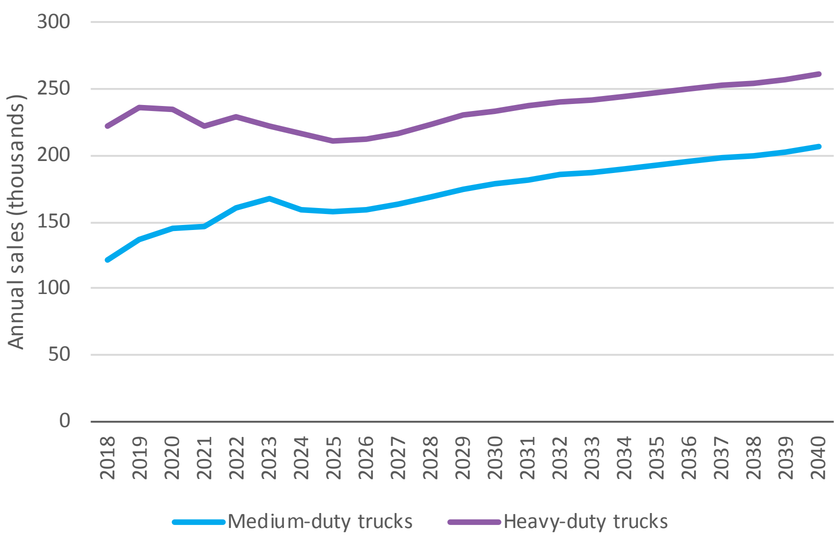


Figure 3 - projection of new medium and heavy-duty trucks in the US (EIA)

Pollution Reduction Challenges: how to tackle emissions from new and existing trucks?

This chapter considers how the US can immediately tackle diesel MGV and HGV emissions – both in terms of air pollutants (NOx) and GHGs. We consider that policy solutions will be needed for new OEM vehicles – which must be low emission, and practical in terms of operation, cost and range.

For new trucks - whilst electrification proves problematic for very large vehicles – the challenge is to support low emission standards. The energy density of batteries means that EV trucks would either need to be re-charged often, or large and impractical batteries would need to be installed to provide the required range. For this reason, low emission, non-electrical alternatives need to be found in the near-term.

Playing its Part: an increased role for LPG

LPG (also known as Autogas) can play a role in lowering emissions from both the OEM-new vehicle and existing aftermarket retrofit segments.

Figure 3 shows increasing annual sales of new-trucks projected out over the coming decades. Here, LPG OEM trucks can replace some of the growth in new diesel sales.

As of 2016, according to the WLPGA, there were around 155,000[10] LPG vehicles in the US, with 13,045 new LPG vehicles and fuel systems sold in 2017 alone, 40% of which were medium/heavy duty trucks.

The environmental benefits are clear - LPG is a lower NOx and GHG alternative to diesel. NOx savings have been found to vary from 96%[11] to 5%[12] depending on vehicle-type examined and study (see figure 4). In addition, GHG emissions are typically lower in LPG vehicles (see figure 5).

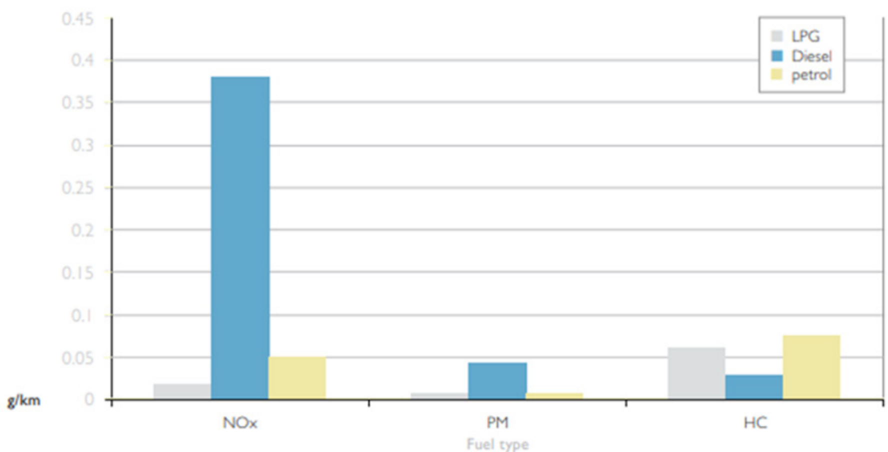


Figure 4 - automotive pollutant emissions by fuel type[3]

[10] WLPGA (2017) Statistical Review of Global LPG 2017.
[11] Atlantic Consulting (2009) LPG and Local Air Quality.
[12] PERC (2017) GHG and Criteria Pollutant Emissions.

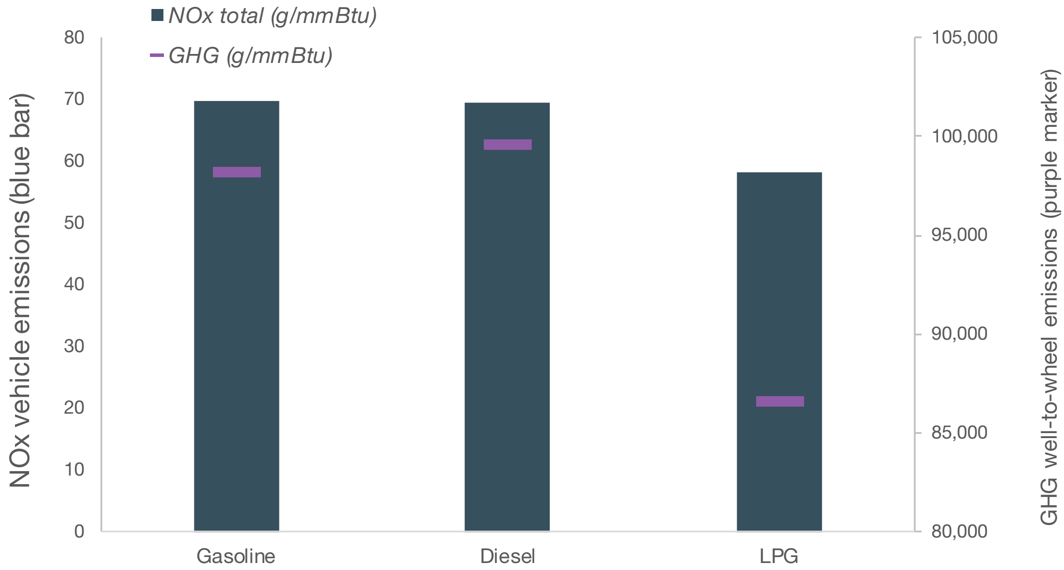


Figure 5 - US vehicle NOx and GHG emissions by fuel type (GREET, 2017)

Significant cost savings can be achieved from switching diesel trucks to LPG trucks. We consider three lifetime costs - maintenance, operational and fuel. The total lifetime undiscounted cost of a diesel truck comes to $299,266 while the cost for an LPG truck comes to $270,700. This yields a cost saving of $28,566 (refer to appendix for a full breakdown of assumptions).

Figure 6 below shows LPG trucks have lower fuel and maintenance costs compared with diesel trucks. The capital costs, however, are slightly higher as this is due to converting the truck to use LPG as a primary fuel.

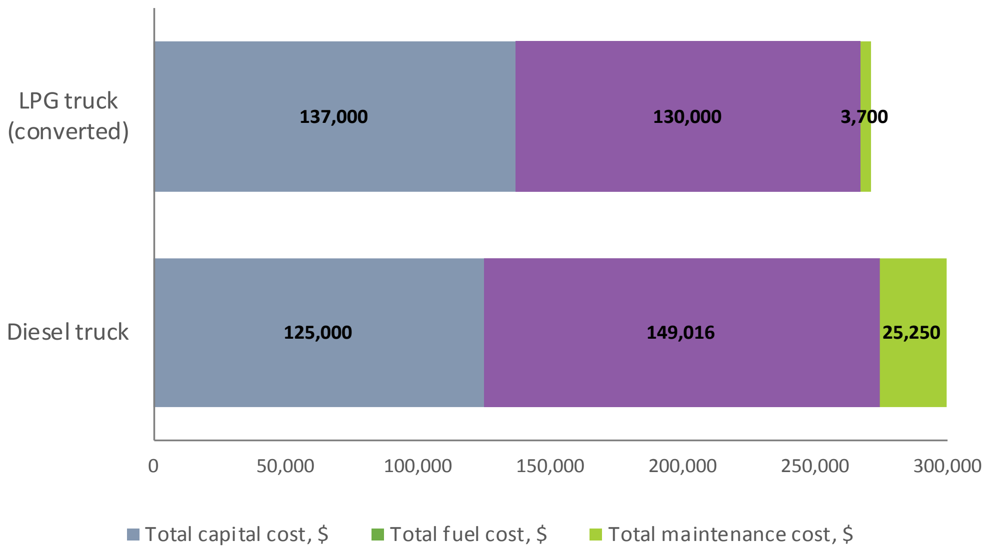


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Figure 6 - diesel vs LPG truck lifetime cost comparison (see appendix at end of chapter for assumptions)

Converting all school buses to LPG could pay salaries for over 23,000 extra teachers.

Take school buses for instance; Blue Bird have recently delivered 12,000 LPG buses to schools across the US with great success. Given the health risks conventional diesel buses pose, having LPG buses picking up children reduces their exposure to harmful air pollution, as well as offering environmental benefits to their communities. Improving health outcomes for children and young people in turn improves their ability to succeed in education, a study by Rondeau et al reported a link between long-term exposure to ambient levels of particulate matter and NOx and illness-related school absenteeism. Additionally, LPG school buses are quieter, reducing noise pollution and also better equipping drivers to focus on the road ahead.

Not only do LPG buses increase levels of student comfort and safety, they have also been proven to save school administrations money. In the state of Nevada, the 48 LPG buses in operation transport 18,400 students daily and save the state around $80,000 a year (in comparison to their diesel counterparts). This saving demonstrates the potential of LPG vehicles to save significant amounts of money. There are currently 15,600 LPG school buses in operation across the US; if the remaining 458,594 (according to SBF the 2018 total bus population is 474,194) school buses which are currently fuelled by diesel are converted to LPG then – based on this saving achieved in Nevada - $1.37 billion dollars (per year) could be saved. Using the median salary of a US school teacher ($58,950) as a measure, this saving could provide the funds to hire an extra 23,338 teachers. Reflecting on the impact that an extra 23,338 teachers would have on young people's education and wellbeing, it is only logical to move to a more cost-effective fuel. The external savings, from abated NOx emissions, total $1.4 billion.

There are numerous reasons why LPG can be a lower overall cost option than diesel on a total cost of ownership basis - including federal and state incentives which make the fuel cost very competitive, lower maintenance costs, and a lower likelihood of downtime for repairs given the absence of complex after-treatment systems required with all diesel engines.

In the Alvin ISD school district, a large suburban area located just outside of Houston, which operates more than 100 LPG auto gas school buses, drivers reported a strong preference for using LPG buses, stating improved performance and reduced maintenance times as key factors. In this district, where LPG buses comprise half of the school bus fleet and cover nearly a million miles each year, 50% is saved on fuel costs each year, refuelling time has been halved and extended oil changes only occur every 10,000 miles as opposed to every 6,000 miles (as seen with diesel fuelled buses).

Sources:

Rondeau et al (2004) A three-level model for binary time-series data: the effects of air pollution on school absences in the Southern California children's health study.

The Propane Education and Research Council (2015) Propane autogas proves a perfect fueling solution for Texas school district

Scenario Analysis: a shift to new LPG OEM trucks

Between 2018 and 2030, this analysis considers the emission reduction potential from supporting:

- Over the period, 50% of new diesel truck market share is addressed by LPG OEM alternatives. This is equivalent to 2.5 million new LPG trucks replacing diesel trucks.

New vehicle emission standards have become more stringent - to match improvements to technology and increased environmental pressures. NOx emissions of medium and heavy-duty trucks have fallen from 19 grams/mile between 1998 to 2002 to 1.4 for new diesel trucks built after 2013[13].

The US government could encourage switching to new LPG trucks by offering financial grants to truck fleet owners. The benefits of switching to LPG could also be communicated with a particular focus on lifetime cost comparisons to diesel trucks. A range of policy options could be executed to encourage fleet owners to switch from diesel to LPG trucks.

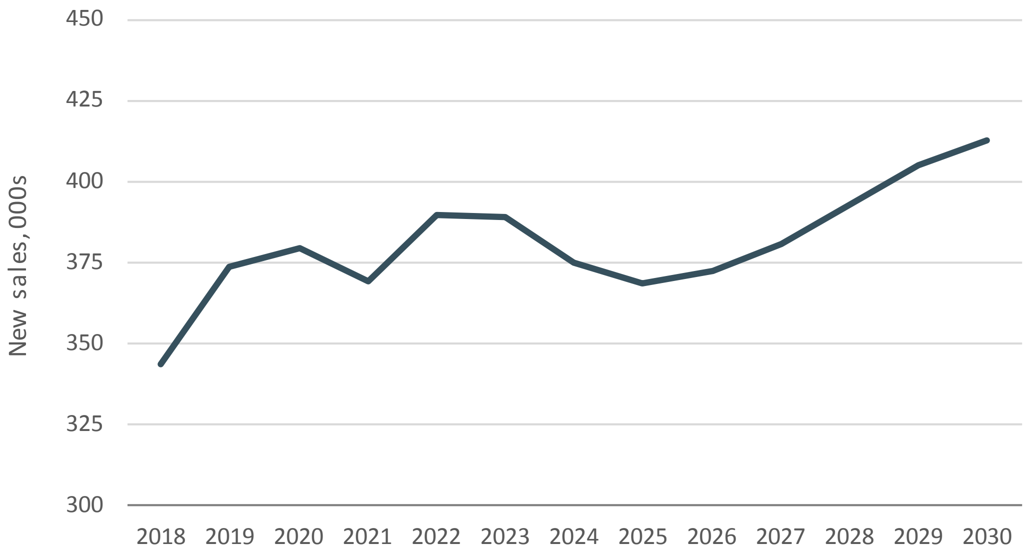

Figure 7 - new diesel truck sales between 2018 and 2030 (EIA)

The EIA[14] predict that new sales of new diesel medium and heavy-duty trucks will rise from 343,000 in 2018 to 413,000 by 2030, an increase of 20%.

If 50% of these trucks were replaced with OEM LPG trucks then over 0.5 million tonnes of NOx and 265 million tonnes of CO2 would be abated.

[13] The current emission standard for heavy-duty trucks is 0.2 g/bhp-hr of NOx (equivalent to 1.4 g/mile of NOx). Taken from EPA (2016) Heavy-Duty Highway Compression-Ignition Engines and Urban Buses.

[14] EIA (2018) Transportation Sector Key Indicators and Consumption.

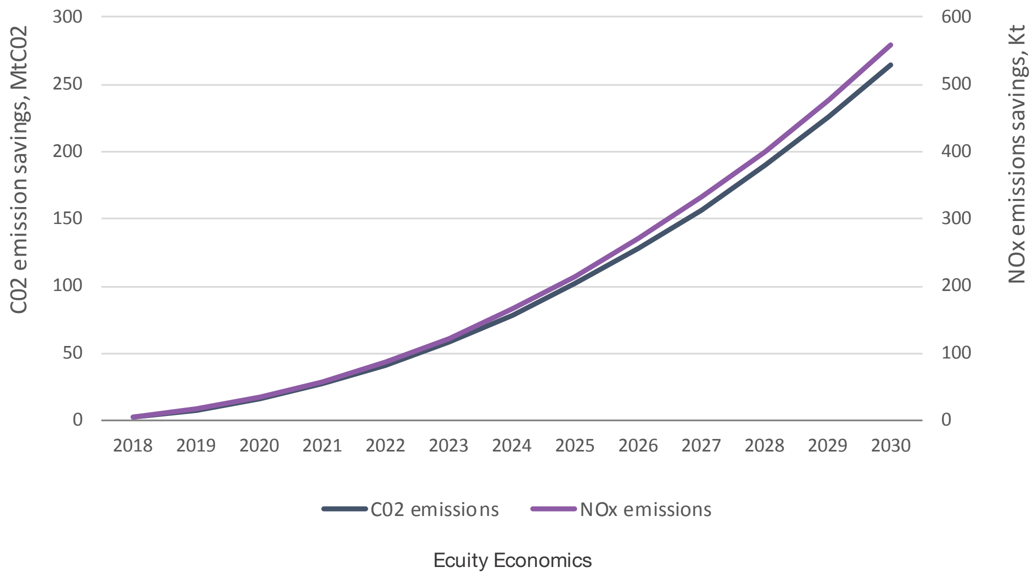

Figure 8 - cumulative CO2 and NOx savings from displacing new diesel trucks with LPG trucks (truck replacement scenario)

When monetised using the social cost of carbon[15], the US economy could save $12 billion worth of carbon emissions by supporting LPG trucks over diesel. The dollar figure represents the benefit of a CO2 reduction.

Additionally, the social and health impact of air pollution is substantial. Our scenario saves the US economy $11 billion from abated NOx emissions - utilising the EPA and Lepeule et al's (2012)[16] assessment of the dollar value of one ton of emissions from on-road vehicles. This table sums the expected impact of air pollution on morbidity and mortality rates and provides a best estimate of the harmful effects of NOx pollution on the populous.

Savings from replacing 50% of diesel trucks to LPG	NOx	CO2
Cumulative savings (2018-2030), $ billion	10.7	12.0

Table 1 – cumulative saving between 2018 and 2030 from replacing 50% of new diesel trucks with LPG trucks.

In our analysis, we assume 2.5 million pure-LPG trucks displace diesel trucks. A key question to ask is whether the existing US LPG production can satisfy this increase in LPG use?

The US produced 67Mt of LPG in 2017 and exported 51% (34Mt) of this. Our modelling shows that an increase in 2.5 million LPG trucks will require 50Mt of LPG by 2030, equivalent to 3.8Mt per year. This annual level of LPG is equal to 6% of current production levels and 11% of current export levels - so appears to be feasible.

[15] EPA (2017) The Social Cost of Carbon.

[16] EPA (2018) Technical supporting document – estimating the Benefit per Ton of Reducing PM2.5.

What would be the environmental and monetary benefits of converting existing diesel trucks to run on LPG?

In the US, there are a myriad of ways that existing vehicles can be modified to use alternative fuels such as LPG.

These include:

- Conversion - a vehicle makes use of a conversion kit which enables it to run on a fuel source that is different from the one if was originally designed to operate on. For example, a diesel truck is converted to use LPG
    - Bi-fuel – vehicle makes use of two fuel sources i.e. diesel and LPG. Fuel use is independent and can be changed by a flick of a switch
    - Dual-fuel – vehicles make use of two fuel sources simultaneously. For example, a heavy-duty diesel truck is converted to use LPG but requires a small amount of diesel for ignition assistance
- Fumigation – alternative fuel source (LPG) is injected into the intake air stream of a compressed ignited engine
- Retrofits – Hardware options that can be added to further reduce emissions from certified diesel engines i.e. Diesel Particulate Filter (DPF).

Below we model the environmental and monetary from converting a cohort of existing medium and heavy duty diesel trucks. Trucks built between 2004-09 emit over ten times more NOx (per mile) then trucks built after 2013. These trucks are likely to be operating well after their useful life of 10 years - according to the EPA's Motor Vehicle Emissions Simulator (MOVES), the survival rate of medium and heavy duty trucks up to 30 years old is 89%. Tackling these trucks will enable GHG-emission reduction.

According to the EIA, two million diesel trucks were built between 2004 and 2009. We assume a bi-fuel conversion to LPG is undertaken. The cost to convert these trucks is expensive (c.$10-11k) however, this upfront cost can be offset by relatively lower operating and maintenance costs over the truck's lifetime.

We assume a five year 'scrappage scheme' is employed effective from 2020. Between years zero to four, 10% of these trucks are converted and, the remaining number of trucks are converted in the final year.

378Mt of CO_2 and 965Kt of NOx could be saved if these two million trucks built between 2004 and 2009 were converted to use LPG. When monetised, this would save the US economy just under $20 billion in abated carbon emissions and over $18 billion in abated NOx emissions.

Savings from converting 2 million diesel trucks to LPG	NOx	CO_2
Cumulative savings (2018-2030), $ billion	18.4	19.4

Appendix: Assumptions for LPG vs diesel truck lifetime cost comparison

Variable/input	Diesel truck	LPG truck (converted)	Source
Upfront cost, $	125,000	125,000	https://www.ccjdigital.com/what-does-a-class-8-truck-really-cost/
Conversion cost, $	-	12,000	PERC
Average MPG	6.1	5.7	US Energy & Information Administration (EIA) https://www.eia.gov/outlooks/aeo/data/browser/#/?id=7-AEO2018&cases=ref2018&sourcekey=0
Fuel cost/ gallon, $	3.03	2.83	AFDC https://www.afdc.energy.gov/fuels/prices.html
Federal incentives, $	0	0.36	PERC Autogas Calculator https://www.LPGcouncil.org/Products-with-Options/LPG-Autogas-Cost-Calculator/
Lifetime preventative costs*, $	14,000	2,700	PERC Autogas Calculator https://www.LPGcouncil.org/Products-with-Options/LPG-Autogas-Cost-Calculator/
Other lifetime costs**, $	11,250	1,000	PERC Autogas Calculator https://www.LPGcouncil.org/Products-with-Options/LPG-Autogas-Cost-Calculator/
Average heavy-duty truck miles travelled, miles	30,000	30,000	EIA/Ecuity assumption
Lifetime, years	10	10	EPA

**Includes assumed costs for oil and oil filter changes; numbers are based on industry averages. $100 per visit and 27 lifetime service visits for LPG; $350 per visit and 40 lifetime service visits for diesel.*

***Includes assumed additional costs for air and fuel filters for LPG ($1,000) and air and fuel filters ($2,500), DPF cleaning cost ($7,500), and DEF fluid ($1,250) for diesel. Numbers are based on industry averages.*

C2. LPG use for on-site back-up power across the United States

Around 30 GW of cumulative on-site diesel generator capacity is currently installed in the US. What are the monetised environmental benefits of displacing up to 50% of diesel fuel with LPG by 2040?

Executive Summary

- Power interruptions in the US costs the economy $80 billion per year. The costs largely fall to the industrial and commercial sectors.
- Compared to diesel, LPG has a lower nitrogen and carbon intensity.
- Displacing 50% of diesel fuel with LPG can save the US economy $21 million in abated NOx emissions by 2040.

Context

Weather-related incidents are the leading cause of power interruptions and outages in the US. Between 2003 and 2012, 679 major power outages occurred due to bad weather[17]. These outages impact households, businesses and critical services. Research has shown that the total cost to the US of power interruptions is $80 billion per year[18]. Of this, 71% is attributed to the commercial sector. For many commercial and industrial customers, the key determinant of cost is not necessarily the number of interruptions, but the length of the "down-time" resulting from a loss of power.

Loss of electrical grid power can also be caused by high power demand and electrical grid failures. Many healthcare, industrial and commercial establishments require continuous and uninterrupted power to maintain critical services or avoid cost prohibitive issues such as stock spoilage.

[17] US DOE (2013) Economic Benefits of Increasing Electric Grid Resilience to Weather Outages.
[18] Berkley Lab Research News (2005) Berkeley Lab Study Estimates $80 Billion Annual Cost of Power Interruptions.

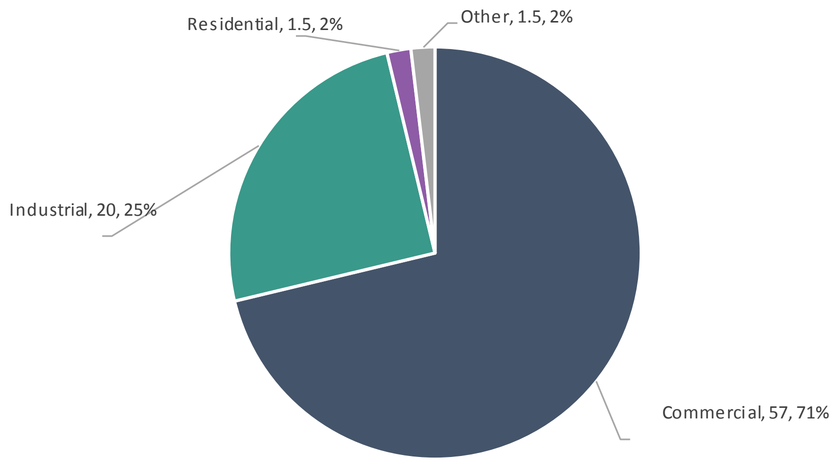

Figure 9 - cost of US power interruptions by sector ($bn), (Berkeley Lab Study Estimate, 2005)

Dell Children's Medical Centre of Central Texas utilises black-start services

A distributed generated system is an integral part of a children's hospital at the site of Austin's former Robert Mueller Municipal Airport site. The system has been designed to provide electricity, hot water, chilled water and black-start capabilities to the hospital.

In the US, there are more than 12 million distributed generated units, which is about one-sixth of the capacity of the nation's existing centralised power plants[19]. Emergency and backup applications account for around 79% of distributed power capacity, while providing just 2% of the total power produced[20]. Small commercial and industrial diesel generators (20kW – 3.5MW) dominate this market however their market share is declining in favour of natural gas generators. According to Frost & Sullivan and Generac, the market share of diesel generators was 63% in 2013[21]. This has fallen to 48% in 2018, most likely due to stringent emission standards for diesel-powered generators and lower operating costs for alternative fuelled gensets.

[19] EPA (2018) Distributed Generation of Electricity and its Environmental Impacts.

[20] Brookings Institution (2011) Assessing the Role of Distributed Power Systems in the U.S. Power Sector.

[21] Generac (2015) Generac Investor Presentation.

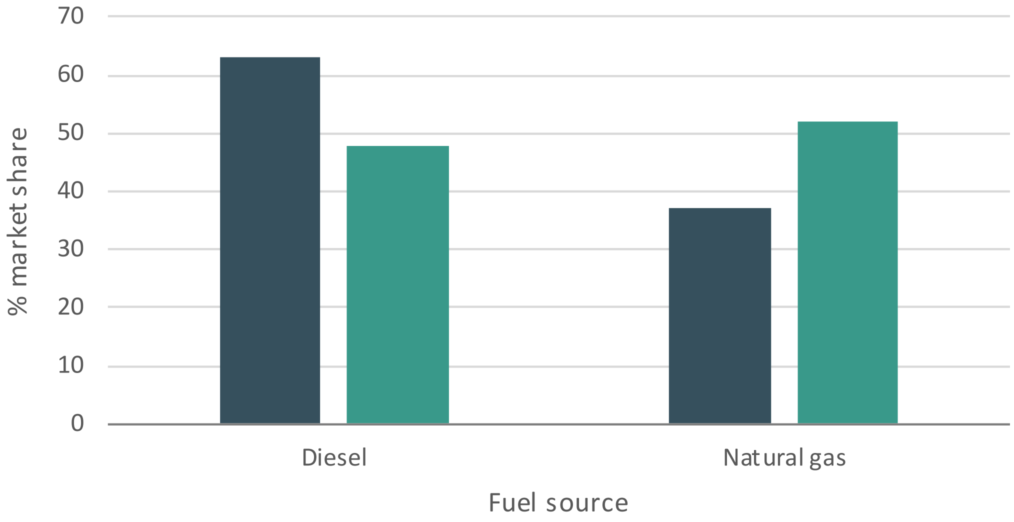

Figure 10 - % market share (North America) of generators by fuel type (Generac Investor Presentation)

Of course, access to a natural gas supply is essential for any shift from diesel to natural gas and this is not possible in many rural and coastal areas. With the broader market shifting away from diesel-fuelled generators, there is a pertinent case to consider LPG as a realistic alternative – especially where natural gas is not available. Diesel fuel releases 15% more CO2 (per British Thermal Unit) than LPG[22]. Natural gas produces, per unit, 46% more NOx (nitrogen oxide) then LPG. LPG also has a longer life then diesel fuel.

The US is the largest producer and exporter of LPG. In 2017 production reached 67 million tonnes[23] - more than the combined output from China and Saudi Arabia. Exports accounted for 51% of production - more than the combined output from Europe & Eurasia.

Tackling the Emissions from Existing Diesel Generation Capacity

The EIA forecast electricity generation from diesel generators to increase 1% per year on average between 2018 and 2040. This would raise the current level of electricity generation from 6,000GWh to 7,388GWh. As a result, carbon and nitrogen dioxide emissions would rise cumulatively by 195 and 5 kilo-tonnes respectively.

We consider the environmental impact of displacing diesel generation with LPG. Between 2018 and 2040, this could occur through a range of measures such as natural replacement, conversions where possible and making use of fumigation technology where LPG is injected into the diesel generator.

We assume that between 2018 and 2040, 50% of diesel fuel-use is gradually displaced by LPG and BioLPG.

[22] PERC (2014) A Comparative Analysis of Greenhouse Gas Emission from Propane and Competing Energy Options.
[23] WLPGA (2017) Statistical Review of Global LPG 2017.

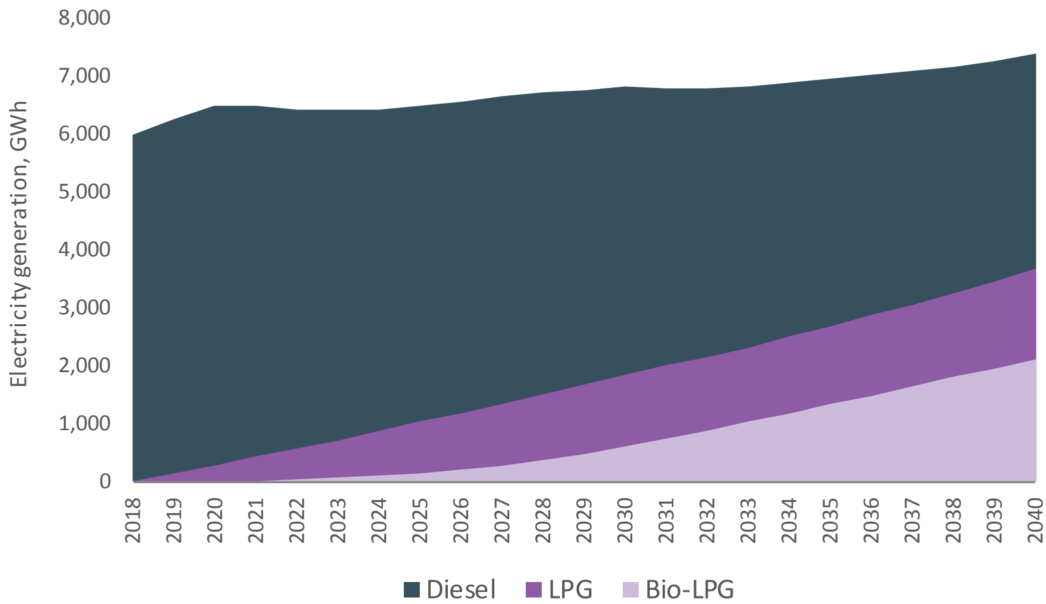

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Figure 11 - electricity generation from distributed generators by fuel source

Between 2018 and 2040, electricity generation from generators using LPG increases from 0 to 3,964GWh. By 2040, this level of generation displaces 50% of existing diesel-fueled generation. The potential for BioLPG is also modelled. Over this period, a proportion of BioLPG is added so that by 2040, BioLPG accounts for 57% of total LPG use (2,123GWh).

The net effect of displacing 50% of diesel fuel with LPG is an overall reduction in carbon emissions of 3,007 tonnes. This reduction increases by 30% if diesel fuel is displaced by BioLPG.

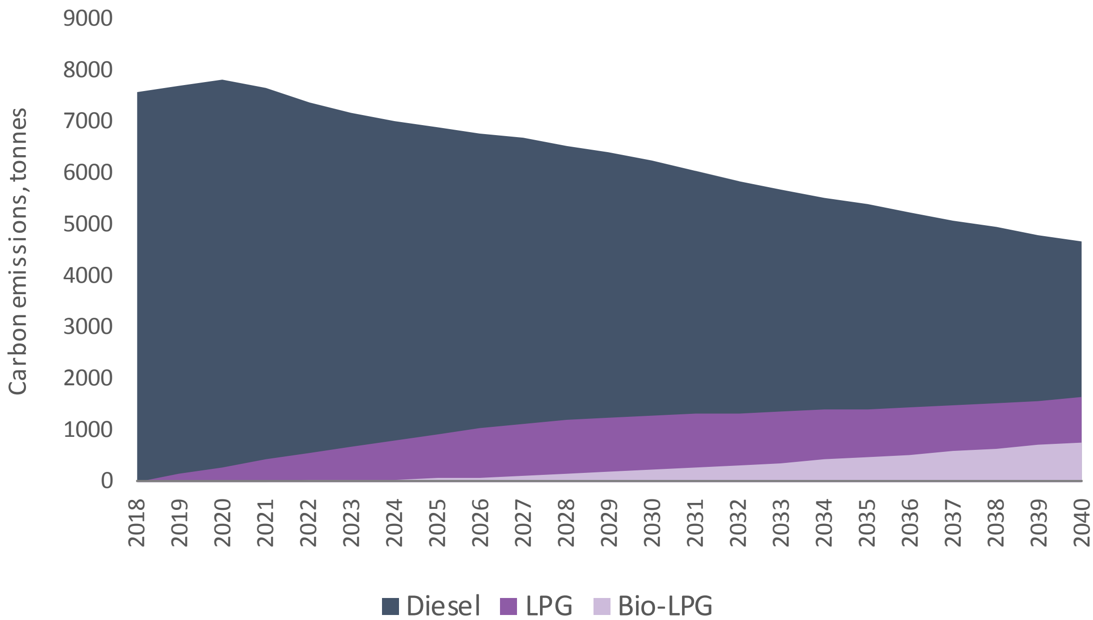

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Figure 12 - carbon emissions from displacing a proportion of the diesel fuel used in emergency power generation (fuel displacement scenario)

When monetised using the social cost of carbon[24], the total savings, from displacing a proportion of diesel fuel for LPG, between 2018 and 2040 is $1.6 million. The savings increase to $2.6 million if BioLPG is utilised.

Switching from diesel to LPG also has an impact on air quality.

Figure 13 shows that by displacing 50% of diesel fuel reduces NOx emissions by 38% to 131 tonnes. This displacement of diesel is replaced with LPG which causes NOx emissions to rise from 0 to 22 tonnes. The net effect of this is an overall reduction of 109 tonnes of NOx.

When monetised this could save the US economy $21 million by 2040, this is over 13 times the carbon savings.

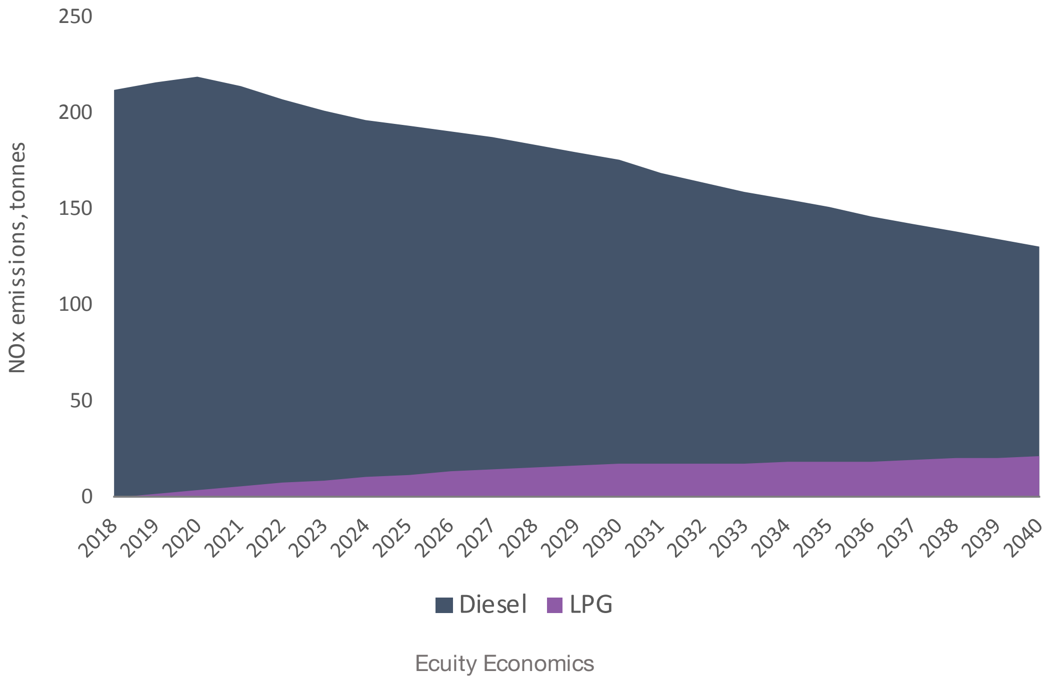


Figure 13 - NOx emissions from displacing a proportion of the diesel fuel used in distributed power generation (displacement scenario)

	LPG	BioLPG
Social benefit from abated CO2 emissions (2018-2040), $ million	1.6	2.6
Social benefit from abated NOx emissions (2018-2040), $ million	21	-

Table 2 - Cumulative saving from displacing diesel fuel with LPG and BioLPG

[24] EPA (2017) The Social Cost of Carbon.

C3. American industrial and commercial application switch to LPG

Coal and heating oil make up 49% of fossil fuel energy consumption in the US industrial sector whilst the figure is 20% for commercial applications. How substantial is the potential impact of introducing BioLPG in the industrial and commercial segments?

Executive Summary

- Coal and heating oil account for a significant proportion of fossil fuel energy consumption.
- The current potential for industrial and commercial operators to switch to LPG and BioLPG is modest and can be accelerated through replacements and other incentives.
- Switching to LPG could save the US economy $4 billion in abated carbon emissions and 62MtCO2 by 2040. Commercialising BioLPG could see this increase to $10 billion and 178MtCO2.

Context

Between June 2017 and August 2018, over 3,000 leaders from American business, politics and civil society signed the *We Are Still In* pledge to support action on climate change. Together the group's signatories are said to represent over half of all Americans and preside over more than $6 trillion worth of the economy[25]. This group of influential leaders from across American major institutions recognise the need to act on reducing dangerous greenhouse gas (GHG) emissions.

The US has made a pledge to reduce economy-wide emissions by 26-28% below 2005 levels by 2025[26]. The US National Determined Contributions (NDCs) to the Paris Agreement found that this reduction in emissions by 2025 is consistent with a linear emissions reduction of 80% or more below 2005 levels by 2050[27].

[25] We Are Still In (2018) About.
[26] NRDC (2017) The Road From Paris.
[27] The White House (2016) United States Mid-Century Strategy.

Whilst the US has for now exited the Paris Agreement, there is a clear global trend away from highly polluting fossil fuels – such as coal and oil – towards lower carbon gaseous fuels and renewable energy. Coal consumption is down by 40% in a decade, whilst consumption of lower carbon alternatives such as gas and renewable energy has risen. Crucially this trend has wide support from citizens[28] and political leaders[29] in the US.

In this frame, the abundance of distillate oil and coal-powered space, water and process heating consumed by the industrial and commercial sectors is an opportune area for switching to lower emission fuels. Indeed, coal and heating oil make up 49% of fossil fuel energy consumption in the US industrial sector. For the commercial sector this share is 20%, with the remainder natural gas. One option is switching to an alternative lower-GHG fuel source. LPG is a realistic alternative. The carbon intensity of LPG is 35% lower than coal and 16% lower than heating oil.

US-LPG production has nearly doubled in a decade. This abundance of native energy resource newly developed in conjunction with shale, puts the US in an excellent position to cost-effectively transition away from highly-polluting coal and oil, to cleaner gas and biogas.

67Mt of LPG was produced by the US in 2017, just over half was exported outside of the country. This analysis will consider the impact of utilising a proportion of this resource to power the industrial and commercial space, water and process heating demand currently powered by higher-emission fuels – oil and coal. While electrification and natural gas may have arguably lower margins; the abundance, low-cost and lower emissions from LPG make this fuel a credible choice for changing.

To do this we develop two scenarios which we compare to a business-as-usual 2040 pathway:

- Switching scenario which takes advantage of existing switching opportunities from oil/coal to LPG
- Capital replacement scenario – encourage the development of more fuel switching through the replacement of old oil and coal boilers

Our analysis shows that emissions from this sector can be reduced by 178MtC02, saving the economy $11 billion in terms of abated GHG emissions[30].

Industrial and Commercial Sector Account for 44% of Final Energy Consumption

The industrial and commercial sectors (I&C) accounted for 44% of total final energy consumption in the US[31]. Total economy-wide emissions in 2017 were 5,142 million metric tons of C02 (MtC02)[32]. The I&C sector accounted for 44% of these emissions.

[28] 83% of US adults surveyed think that it is important to create a world fully powered by renewable energy as of 2017 (Orsted ,2018). 71% of adults think that global warming is happening with only 13% thinking that it is not (Yale Program on Climate Change, 2017).

[29] 407 Mayors have signed up to the Climate Mayors initiative in the US.

[30] See modelling for capital replacement scenario

[31] EIA (2018) Energy Consumption by Sector.

[32] EIA (2018) Primary Energy Consumption, Energy Expenditure and Carbon Dioxide Emissions Indicators.

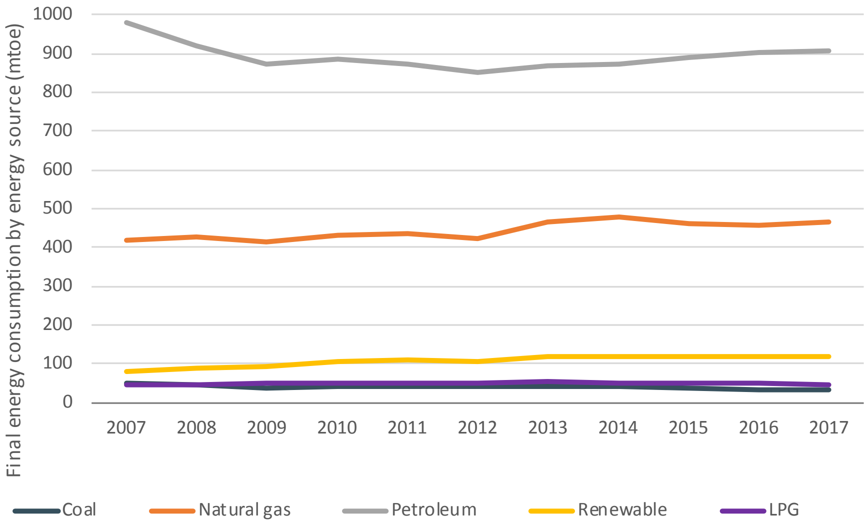


Figure 14 - final energy consumption by energy source (EIA)

The industrial and commercial sectors are important because for genuine action on air pollution and climate change, businesses and policymakers will need to consider how to support a transition away from highly polluting fuels – such as coal and oil. In 2017, the consumption of coal and petroleum accounted for 51% of total economy-wide energy consumption.

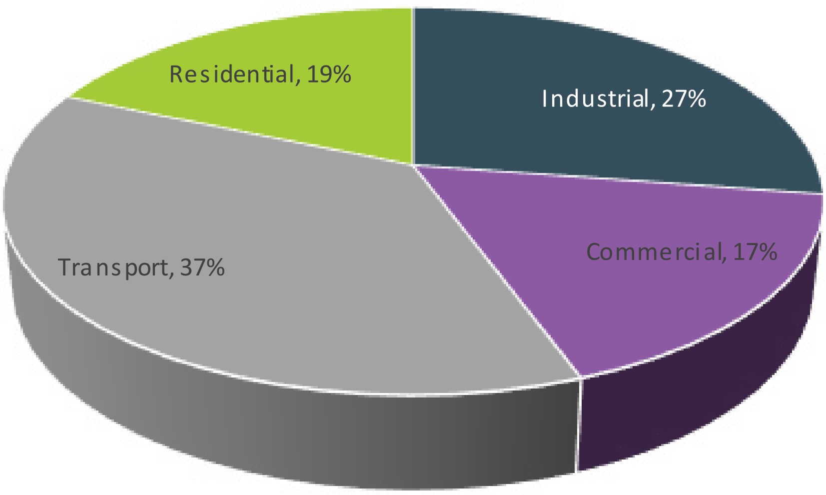


Figure 15 - share of carbon emissions by sector (EIA, 2017)

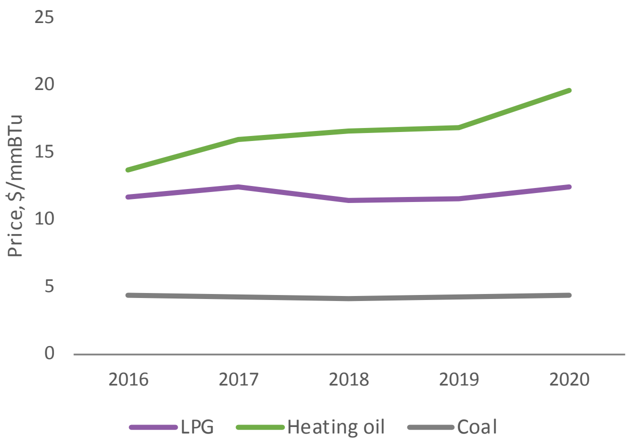
Coal and heating oil make up 49% of fossil fuel energy consumption in the US industrial sector. For the commercial sector this share is 20%, with the remainder natural gas. One option to combat GHG emissions is switching to an alternative lower-carbon fuel source such as LPG. The carbon intensity of LPG is 35% lower than coal and 16% lower than heating oil.

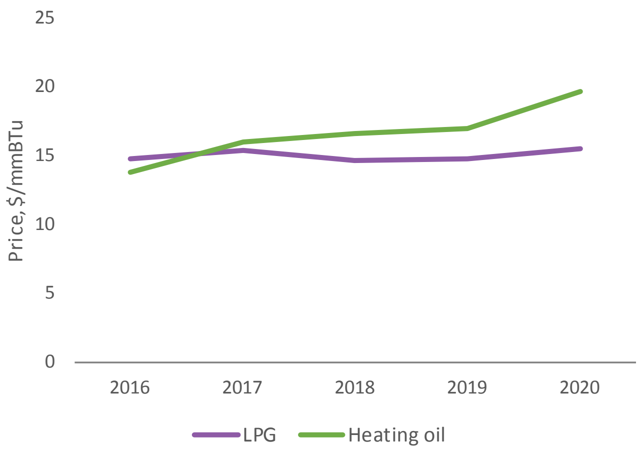
Opportunity – abundant, low-cost and lower emission LPG

Additional to the environmental benefits, a shift in consumption of high-emission fossil fuels to LPG is interesting for two reasons: US-domestic production is booming – creating security of supply benefits, and cost-savings are achievable, especially against distillate oil.

The US is the world's largest producer and exporter of LPG. In 2017, the US produced 67 Mt[33] of LPG of which 51% was exported, signifying that this domestic fuel is abundant in supply. Supply has boomed as a result of the shale gas revolution and increased by nearly 70% in a decade, with further expansion expected over coming years. Diverting some of the surplus production to displace high-emission fuel consumption in the I&C sector would be environmentally beneficial, facilitate US decarbonisation pledges and support security of supply.

Indeed, the price of LPG is also favourable when compared to oil. In the commercial sector EIA data suggests that LPG is 12% cheaper on average than distillate oil in 2018. For industrial users this price saving is even greater against distillate oil per MMBtu (30% cheaper) – but, unabated coal remains cheaper than both LPG and oil despite its very high GHG and air pollutant emissions.





Figures 16 and 17 - industrial and commercial fuel prices (EIA, 2017) (no commercial fuel price for coal)

Yet, high-emission fossil fuel consumption is projected to rise

However, the opportunities for switching are not being realised. According to the latest projections by the US EIA[34], consumption of coal and heating oil in the industrial sector is projected to increase 0.2% and 1% respectively on average per annum between 2018 and 2040. Indeed, it seems that the opportunity to switch from high emission fossil fuels to lower emission alternatives such as LPG has yet to be taken. In 2018, final energy consumption of industrial coal and heating oil was 22 million tonnes of oil equivalent. A third of this consumption was attributed to process heat (7.2 Mtoe).

For the commercial sector, final energy consumption (coal and heating oil) was nine million tonnes of oil equivalent, with space heating accounting for a quarter of this. Consumption of energy for space heating in the commercial sector is projected to increase 0.2% on average per annum over the same period.

[33] WLPGA (2017) Statistical Review of Global LPG 2017. Data converted from tonnes to toe using 1.18 factor.

[34] EIA (2018) Annual Energy Outlook 2018.

The levels of process and space heating in the I&C sector and the EIA projections to 2040 form the basis of our business-as-usual (BAU) scenario.

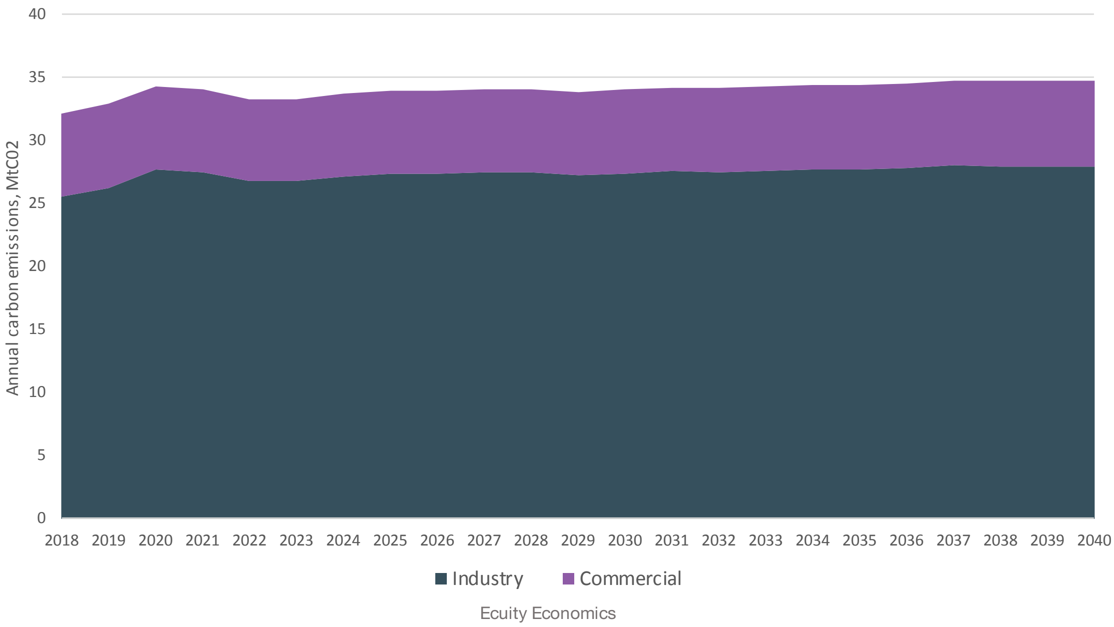


Figure 18 - annual carbon emissions from the I&C sector (business-as-usual scenario)

Figure 18 models the business-as-usual GHG emissions from the industrial and commercial heating sectors. Between 2018 and 2014, total I&C emissions increase 8% to 34MtC02. This is equivalent to 7.5 million passenger vehicles driven for one year[35] or 14% of the number of passenger vehicles in the US in 2016[36]. Nitrogen Oxide (NOx) pollution increases 8% to 41Kt over the same period, equivalent to 3% of total industrial NOx emissions[37] in 2017.

Low hanging fruit: existing fuel-switching opportunities

There are existing and immediate opportunities for switching high emission fossil fuel consumption – oil and coal - to cleaner alternatives in the industrial and commercial sectors. The Manufacturing Energy Consumption Survey (MECS) - prepared by the EIA and sent to industrial companies every four years - enquires about the fuel-switching capability of a respondent's facility. The survey questions the capability of a facility to substitute energy sources (i.e. coal to LPG) over a short timeframe (within 30 days and without extensive modifications to existing capital equipment).

The latest results for US industrial users showed that in 2014 the volume of coal and heating oil that could be switched to an alternative fuel source was 17% and 6% respectively. This is an immediate win and suggests that just under a fifth of coal consumption can be substituted for LPG without major disruption.

[35] EPA (2017) Greenhouse Gas Equivalences Calculator.

[36] Bureau of Transportation Statistics (2018) National Transportation Statistics 2018 1st Quarter.

[37] EPA (2018) Air Pollutant Emissions Trends Data.

Figure 19 shows the impact fuel-switching can have on the I&C sector. In 2040, emissions from switching are 5% lower than emissions from the BAU level (35MtC02). BioLPG consumption can reduce emissions further to 13% against the BAU level. NOx emissions are 35.1Kt in 2040, a decrease of 8% on 2018 levels.

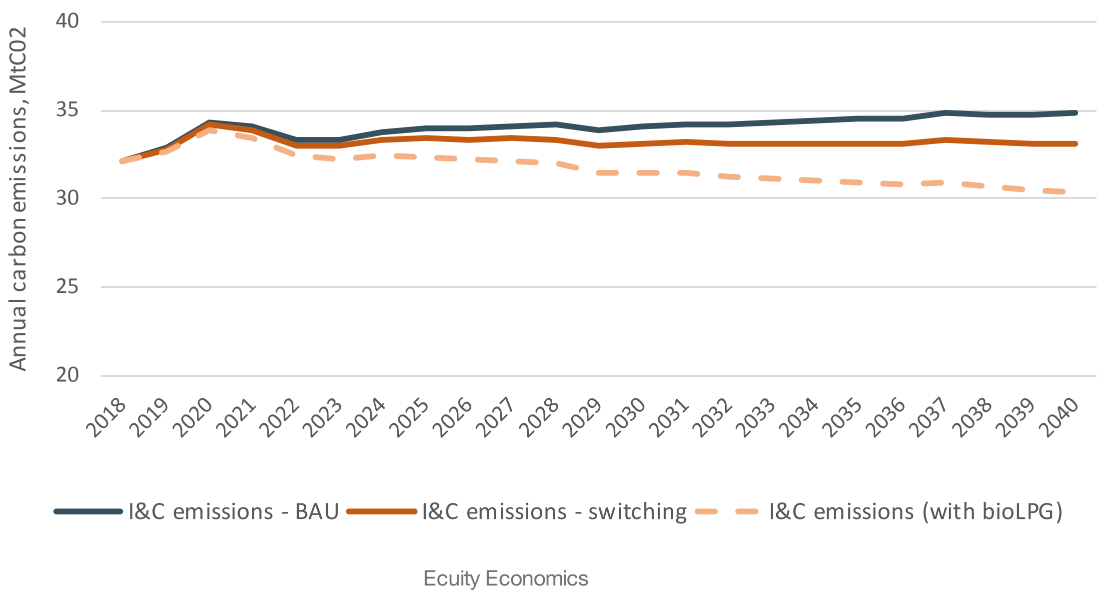


Figure 19 - annual carbon emissions from the I&C sector, 2018-2040 (switching scenario)

	Cumulative emissions, MtC02	**Savings against BAU, MtC02**
I&C emissions (switching)	763	20
I&C emissions (BioLPG impact)	730	53

Table 3 - cumulative emissions (2018-2040) from switching and using BioLPG compared against BAU scenario.

Given the current switching potential, the I&C sector could save 20MtC02 cumulatively by 2040. This degree of switching is too modest to take advantage of the abundance of lower-emission LPG which will be produced in the US over the coming decades.

The MECS results provide insight into the factors which restrain the rate of switching.

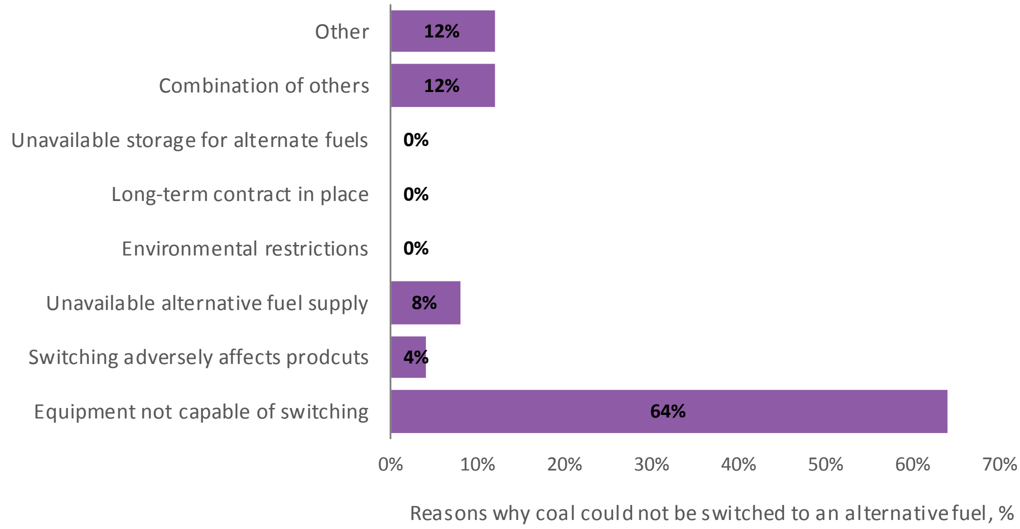


Figure 20 - reasons cited for not being able to switch to an alternative fuel (MECS, 2014)

Over two-thirds of industry operators answered that their coal-powered equipment was not capable of switching to an alternative fuel source such as LPG. This suggests that for greater decarbonisation, a technology and fuel transition will be required.

Challenge – encouraging a technology switch

I&C operators typically look to repair rather than replace their existing boilers – this reduces the number of switching-opportunities. Cost and boiler characteristics typically drive this behaviour. On the cost side replacing a boiler is expensive, operators prefer to repair capital equipment instead. Below is a table comparing the capital cost, maintenance cost and lifetime of the boiler.

	Industrial boiler	Commercial boiler
Retail price, $k	60	16.6
Total installed cost, $k	>60	25.8
Annual maintenance cost, $k	0.6-1.8	1.8
Lifetime, years	40	25

Table 4 - Industrial and commercial boiler cost and lifetime (International Energy Agency & Energy Technology Systems Analysis Programme (2010), EIA (2018)

There are two most-likely pathways for boiler replacements: either the boiler comes to the end of its useful life (25 to 40 years) or the replacement is undertaken as part of an energy upgrade. Table 4 shows the high replacement costs the I&C sector face. It is cost-effective to repair a boiler which for the industrial sector ranges between 1 and 3% of the retail price. For the commercial sector, this increases to 11% of the retail price but at $1,800 annually, this is cheaper than paying $17,000 for a new boiler.

As a result of this tendency to repair rather than replace, the stock of boilers is currently quite old. Research by Energy and Environmental Analysis (EEA) in 2005 showed that the total stock of industrial and commercial boilers was 163,000 – 43,000 industrial boilers and 120,000 commercial boilers. It also provided insight into the age profile of these boilers in the I&C sector.

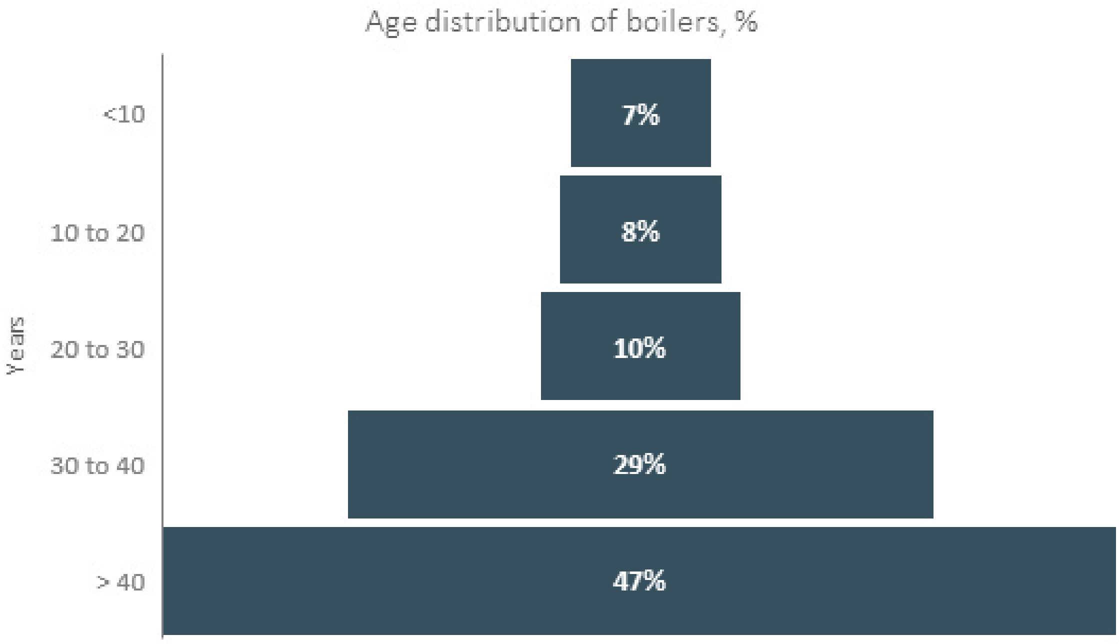


Figure 21- age distribution of boilers >10MMBtu/hr, Energy and Environmental Analysis (2005)[38]

Figure 21 shows just over half (53%) of boilers are between 0 and 40 years old. 47% of boiler capacity is at least 40 years old meaning they are due for replacement. 76% of boiler capacity is at least 30 years old and around 7% of boiler capacity is less than ten years old.

Whilst the preference for repair of existing technology and the status quo is a challenge for encouraging a transition in I&C consumption to lower emission fuels, the population of older boilers provides an opportunity to cost-effectively switch to modern, efficient gas-heating systems.

[38] Energy and Environmental Analysis Inc (2005) Characterization of the U.S. Industrial/Commercial Boiler Population.

Scenario analysis – benefits of I&C high-emission fuel switching

In this scenario, we assume that policy is encourages a rapid-switching of boilers in the I&C sector which facilitates fuel-switching to LPG. The rate at which boilers are replaced in-part depends on the age characteristic of the existing boiler population. Table 2 shows that the lifetime of a boiler in the I&C sector is between 25 to 40 years old. In addition, figure 7 shows that 53% of boilers are up to 40 years old.

As a result, we assume that a switching rate of 50% could be achieved by 2040. This means that by 2040, half the energy consumption of coal and heating oil in the I&C sector is substituted by LPG.

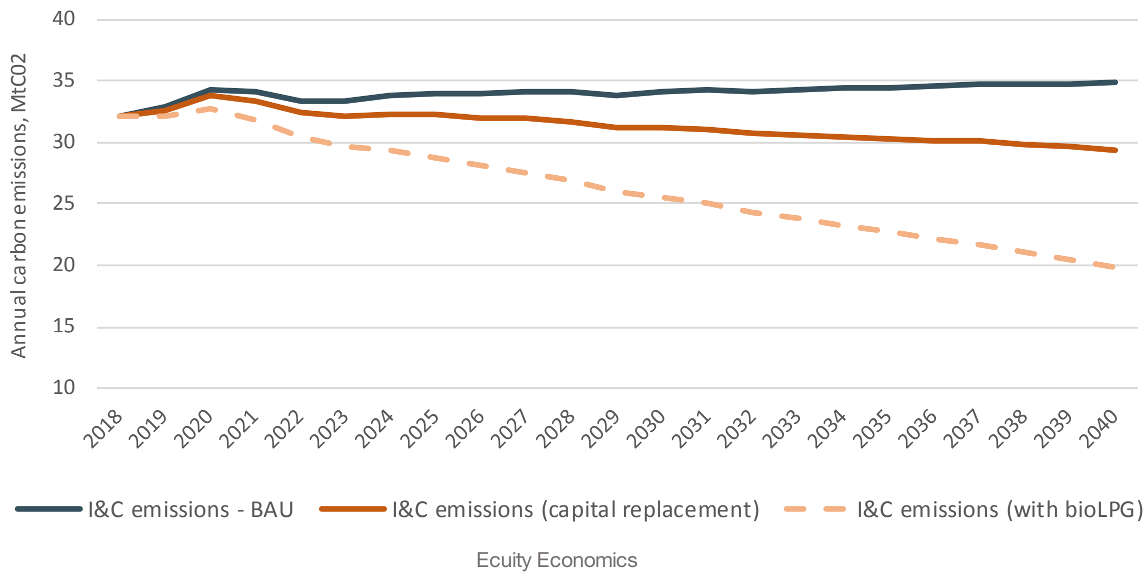


Figure 22: Annual carbon emissions from the I&C sector, 2018-2040 (capital replacement potential modelled)

Figure 22 shows the impact on emissions where the I&C sector replace capital equipment at a faster rate (50%) and substitute coal and heating oil for LPG. By 2040, the I&C sector cumulatively save 62 MtC02 (see table below). The impact of substituting coal and heating oil for BioLPG amplifies the emission savings which, by 2040, is equivalent to 6% of 2017 I&C heating emissions. The impact on NOx emissions is greater with emissions falling to 20.5Kt, a reduction of 46% on 2018 levels.

	Cumulative emissions, MtC02	Savings against BAU, MtC02
I&C emissions (capital replacement)	721	62
I&C emissions (BioLPG impact)	605	178

Table 5: Cumulative emissions from rapid-switching and using BioLPG compared against BAU scenario.

The US Environmental Protection Agency (EPA) estimate the social cost of carbon dioxide[39] (SC-$C0_2$) to value the climate impacts of rulemakings. The SC-$C0_2$ is a measure, in dollars, of the damage done by a metric ton of carbon dioxide in a given year. The dollar figure can also represent the benefit of a $C0_2$ reduction. Using a discount rate of 3%[40], the SC-$C0_2$ in 2018 was $42 (2017 prices) per metric ton of $C0_2$. By 2040, this rises to $70 per metric ton of $C0_2$.

	Switching scenario	Capital replacement
Cumulative GHG emission savings, MtC02	20	62
Social benefit from reduced emissions, $ million	1,178	3,695
Social benefit from using BioLPG, $ million	3,112	10,650

Table 6: Cumulative GHG emission savings and social benefit from reduced emissions

By 2040, the US economy can save just under $4 billion in abated GHG emissions by encouraging the I&C sector to replace existing capital equipment, and switch from high-emission fuels to LPG. This rises to $11 billion as BioLPG is developed and commercialised.

Exposure to Particulate Matter (2.5) can affect both your lungs and heart. Various scientific studies have linked particulate pollution exposure to a range of health effects such as premature deaths in people with heart or lung disease, nonfatal heart attacks, aggravated asthma and decrease lung function. The environmental effects include making river streams acidic, affecting the diversity of the ecosystem and depleting nutrients in soil.

Figure 23 compares the PM2.5 emissions in the business-as-usual scenario compared with the two scenarios modelled; switching and capital replacement.

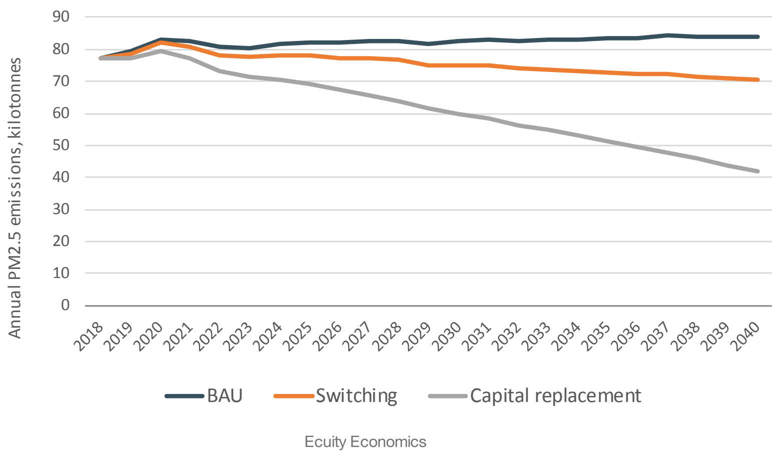


Figure 23 - annual PM2.5 emissions from the I&C sector (BAU, switching and capital replacement scenario)

[39] EPA (2016) EPA Fact Sheet: Social Cost of Carbon.
[40] Yield on 30-year US Govt Treasury bond is 3.01% (Bloomberg, August 2018)

	Switching scenario	Capital replacement
Cumulative PM2.5 savings against BAU, Kt	156	478
Social benefit from reduced emissions against BAU, $ million	205	628

Table 7 - cumulative PM2.5 emission savings and social benefit from switching and replacing capital equipment

There are clear social and economic benefits for the I&C sector to replace the existing stock of old boilers and switch to using a lower-carbon fuel such as BioLPG. The existing potential for the I&C sector to switch to LPG yields total GHG savings of 20MtC02 by 2040 and this saves the US economy $1.2 billion. Encouraging more rapid switching of capital equipment yields emission savings of 62 MtC02 and saves society $3.7 billion. The benefits from developing and commercialising BioLPG have been clearly demonstrated - emission savings and the social benefit increase significantly.

The price of LPG in the I&C sector is favourable against heating oil. While the industrial price of coal is lower than LPG and heating oil, coal has a significantly negative impact on the environment. Several principal emissions result[41] from coal combustion including sulphur dioxide (contributing to respiratory illness), nitrogen oxides (contributing to smog) and particulate matter (contributing to lung disease).

[41] EIA (2018) Coal & the Environment.

C4. Rural heating shift for European households

Can gas transition heating technologies and bioLPG reduce the cost of meeting Europe's decarbonisation targets beyond 2030 for buildings off the gas grid? What is the economic benefit of a future off grid heat mix that includes gas transition technology and bioLPG vs. a silver bullet approach based purely on electrification?

Executive summary

- The decarbonisation of rural heating is challenging but necessary if the European Union and its Member States are to meet their climate change targets. These buildings are typically larger, older and less well-insulated, and more likely to be consuming oil and coal.
- LPG, BioLPG and gas-transition technologies should play a role in a cost-effective transition to lower emission heating. Electrification of heat is less suitable and costlier than gas alternatives in larger, less-efficient homes.
- Such a mixed technology approach - with LPG and BioLPG playing a significant role - is a third of the cost of a 100% electric heat pump approach and provides a net positive social benefit to Europe when carbon savings are accounted for.

Context

The European Union and 194 states signed the Paris Agreement in 2016 to mark an historically significant consensus that action must be taken to tackle dangerous climate change. Together these countries account for almost all of the world's greenhouse gas (GHG) emissions.

As part of the its participation in the process, the EU and Member States re-committed to a 40% reduction in GHGs by 2030 and noted this target's consistency with a 2050 deep decarbonisation trajectory (80-95% reduction on 1990 levels). This action is built on a strong and growing view amongst European citizens that climate change is a serious problem, with 92% of respondents to a recent EU-survey agreeing to this statement[42].

To effectively tackle economy-wide emissions by 80-95%, EU Member States will need to address the energy use of buildings, which account for 36% of the region's emissions[43]. Heat decarbonisation is therefore a necessary but not sufficient part of hitting long-term climate change targets.

[42] European Commission (2018) Citizen support for climate action.
[43] European Commission (2018) Buildings.

But of course, whilst an important element, energy policy should focus on more than just sustainability. Fifty million Europeans live in energy poverty today, a condition which is associated with poor health outcomes, constrained social mobility and lower wellbeing[44].

Energy poverty is a multi-faceted issue, but it is clear that any heat decarbonisation will not be successful if it adds significantly to the cost of heating homes and pushes more European citizens into energy poverty. Therefore, it is important for policymakers to consider both the emission reduction potential of various technology pathways, as well as their costs.

This issue is even more pertinent in rural - typically off-grid - areas where people are on average at a greater risk of suffering from poverty or social exclusion. Indeed, this problem is most severe in Eastern European countries like Bulgaria and Romania, where at least half of the rural population is at risk from poverty or social exclusion. Off-grid decarbonisation cannot be achieved successfully without considering the economic challenges these communities face.

Technology Solutions

Encouragingly there are heating technologies that can deliver immediate and sustained emission reductions against high carbon fossil fuels - such as heating oil and coal - which are commonly consumed in off-grid areas. These include high temperature heating systems which can deliver lower GHG emissions (e.g. LPG boilers), and very low levels (e.g. biomass), and low temperature heating systems - such as electrically driven heat pumps which will in time offer very low emission heating.

Add to this a raft of newly developed technologies and biofuels, including gas-absorption heat pumps which run on gaseous fuels with little electrical input, and hybrid heat pumps which consist of a connected/integrated low-cost boiler with an electrical heat pump. These systems can be termed gas-transition technologies and offer consumers the benefit of even more efficient heating systems.

The LPG industry is additionally developing BioLPG, a low emission fuel which can be used as a substitute for conventional LPG in existing heating systems. Taken together with modern condensing boilers and the gas transition technologies noted above, policymakers have a range of lower carbon heating alternatives which can support a shift away from heating oil and coal consumption in off-grid areas.

Other alternatives to oil and coal also exist. Electrical heat pumps offer potentially high efficiencies and low running costs which is an advantage. But this is contingent on operating in good conditions, which for electrical heat pumps can be characterised by use with large radiators and relatively stable-heating demand which allows operation at a consistently low temperature. Whilst heat pump upfront costs may remain comparatively high, their advantage - potential running cost savings - is greatly influenced by the operating efficiency of the system. This can vary from application to application, and is greatly influenced by the installation quality and the building-type that the system is installed in. Heat pumps typically perform best in energy-efficient buildings, where the system can provide a consistent level of heating output.

As with transport where electric vehicles are seeing increased policy interest and take-up, it is tempting to support mass-electrification of heat as the solution. Especially given reductions in electricity GHG emission intensity over time. But as with other heating technologies, installation may not be suitable in certain building-types.

[44] European Commission (2018) Energy Poverty.

Challenging Building Stock

Unlike with power decarbonisation, which involves the transition from certain centralised generation plants such as coal to lower emission plant (RES), heat decarbonisation is far more complex, and will require changes to the heating systems in millions of homes, offices, and buildings - as well as potential changes to infrastructure to cope with new demands on the electricity grid for example.

These buildings are diverse in character and location. Certain heating systems are more suitable installed in particular properties than others and vice versa. It is therefore challenging for policymakers to know which technologies to support, and which heating systems are not aligned with long-term energy objectives.

Off-grid Buildings

Generally off-grid properties - especially in rural areas - are less energy-efficient, larger in size and older than similar dwellings in urban centres where the pace of renewal and urban development drives the provision of more energy efficient buildings. There are of course exceptions to this, including a proportion of “off-grid” properties situated in town and cities which are heated by electricity.

However, the most pressing off-grid heating challenge is to transition those properties - often rural, older, and less energy efficient - which consume high carbon fossil fuels, in particular heating oil and coal. Consumers rarely change their heating systems and fuel-type, and it is therefore challenging but necessary to switch these properties away from oil and coal to credible alternatives.

This chapter will consider whether gas transition technologies can play a role in this off-grid heating transition, or whether an approach based on electrical heat pump deployment is preferable.

Off-grid fuel Consumption

The EU consumes 785TWh of off-grid fuels[45] for heating each year. Of this, nearly half is attributable to high carbon fossil fuel heating - from heating oil and coal. Over the next 32 years, just this group of heating oil and coal households will emit just under three billion tonnes CO2e - all else equal. This is equivalent to the annual emissions from the whole of the UK, French, Italian, Spanish, German, and Dutch economies[46].

[45] Here defined as heating oil, coal, biomass and LPG. Note that existing electrical is not considered in the scenario modelling in detail - other than as one of numerous solutions, as its decarbonisation pathway is already clear, and no switching is necessary. Switching from biomass is also ignored as this brings no GHG emission saving benefit.

[46] Eurostat (2018) Total GHG emissions by countries (excluding LULUCF, including aviation) – 2016.

Figure 24 illustrates our baseline scenario for off-grid fuel consumption up to 2050 - using DG Energy data as a starting point, and accounting for some energy efficiency improvements over time. In this scenario, there is no switching to other fuels or technology types, but we model an increasing production and consumption of bioLPG (as a superior and preferred alternative to LPG) over the period - as evidenced by the transition in figure 24. This is an assumption, but the levels of production analysed in this chapter are less than current estimates of European potential by 2040 and 2050 - therefore possible with appropriate policy and industry support.

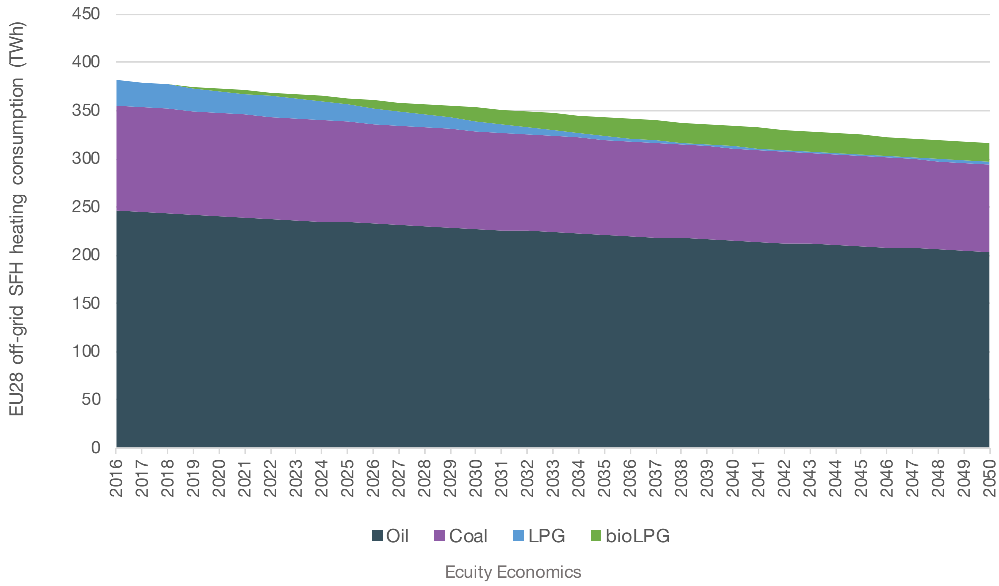


Figure 24 - EU28 oil, coal and LPG consumption profile for heating (baseline scenario)

Figure 25 illustrates the impact that this fuel consumption has on emissions over the period. As expected, emissions remain high - and decrease by 20% as a result of BioLPG inclusion and some energy efficiency improvements.

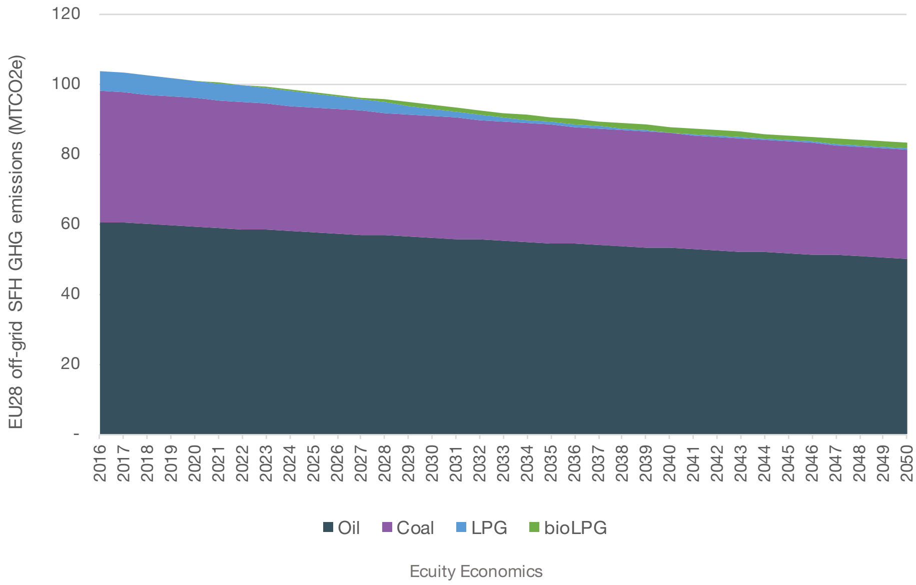


Figure 25 - EU28 oil, coal and (bio)LPG emission profile (baseline scenario)

However, policymakers could act to restrict the sales of new heating oil and coal boilers. Indeed, the UK, Belgian and Dutch governments are currently developing policies which restrict the consumption of these high carbon fossil fuels. To reflect the benefit of such political action, figures 26 and 27 consider an alternative scenario in which the sale of new heating oil and coal boilers is banned from 2025.

Heating oil and coal consumers instead switch to one of the following alternatives in the below proportions:

BioLPG condensing boiler - 30%
Electric heat pumps - 30%
LPG hybrid electric heat pump - 20%
Biomass pellet boiler - 10%
LPG gas absorption heat pump - 10%

These proportions are assumed and are reflective of the relative costs and market-readiness of each of the technologies. The rate at which switching occurs is also based on current typical rates of boiler replacement in European countries.

Figure 26 shows that in this heating transition scenario, fuel consumption falls from 381TWh to 225TWh as household's switch gradually away from heating oil/coal boilers to heat pumps (electric, hybrid and gas driven) and gas transition technologies. This switching starts from 2025 and involves just under 7% of the heating oil/coal household population transitioning to a lower emission system each year.

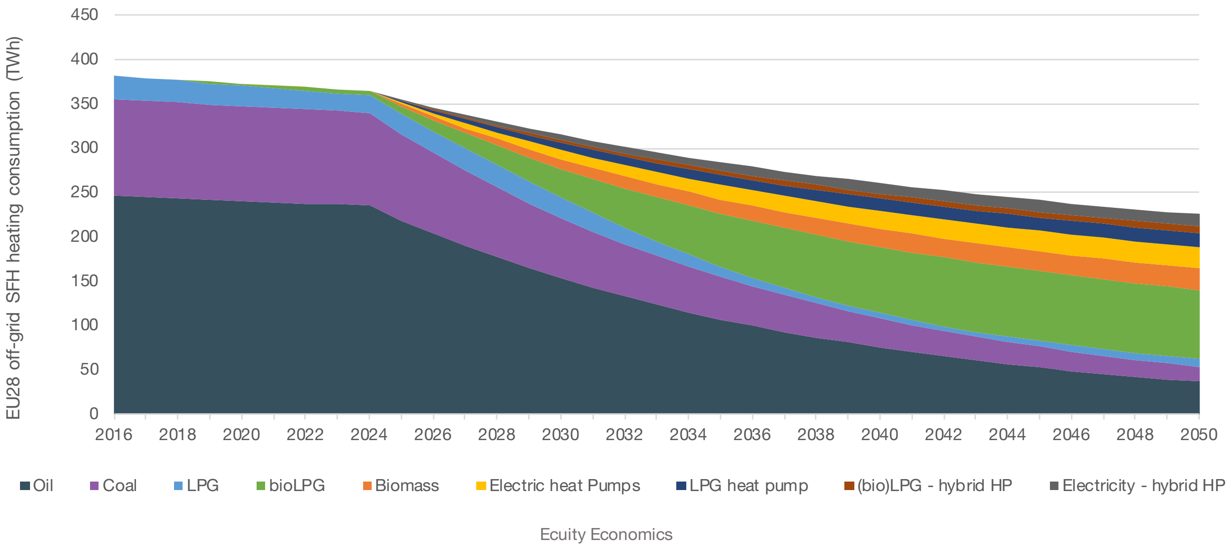


Figure 26 - EU28 off-grid heating consumption (heat transition scenario)

In emission reduction terms, this reduces off-grid annual emissions from heating oil coal and LPG households by just under 80% over the period, and by 1 billion tonnes CO2e against the baseline scenario. Monetised using a social cost of carbon figure (€45/tonne[47]) this equates to €46 billion worth of emission savings over the whole period against the baseline.

Consumption of LPG and BioLPG in condensing boilers and gas transition technologies[48] play an increasing role in this scenario, with fuel use increasing from 26TWh/year to 110TWh/year by 2050 - which is more than a quadrupling of current levels. This helps to lower emissions from rural heating, most immediately through lower emission LPG, and increasingly because of an assumed increased volume of BioLPG. This drop-in fuel can deliver 80%+ reductions in GHG emissions against heating oil and coal and does not come with a high upfront cost for off-grid households who wish to switch heating systems.

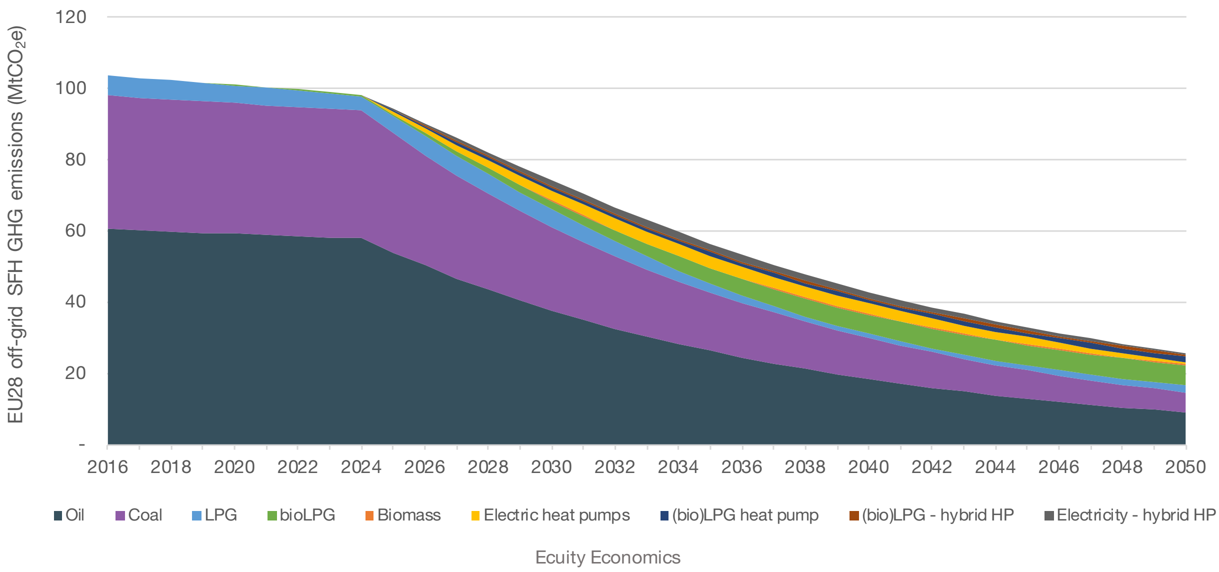


Figure 27 - EU28 off-grid heating emissions (heat transition scenario)

Technology Cost of Transition

This chapter argues that gas transition technologies should play a key role in delivering heat decarbonisation in European off-gas grid homes. The modelling has shown that deep emission reductions (82%) can be achieved by supporting a mixture of technologies - including gas technologies, electric heat pumps and biomass boilers - which can be installed in off-grid properties to best fit the preferences of consumers and the diverse characteristics of the buildings they live in.

However, these new technologies will cost money, and are often at a premium to existing coal and heating oil systems.

[47] OECD & UCL (2015) Monetary Carbon Values in Policy Appraisal.

[48] Hybrid heat pumps and gas absorption heat pumps.

Given that decarbonisation is required and valued (€46 billion carbon savings), we argue that not only does this mixed technology approach make sense from a consumer choice perspective, but also from an economic perspective. Blanket electrification will be a costlier and more challenging pathway to enact, and policymakers should instead look to support a range of technologies rather than just one solution.

Figure 28 shows the modelled levelised costs of the technologies considered here across the top ten high-carbon fossil fuel heat consuming European countries[49]. This levelised cost of heating metric takes account of each technologies' upfront cost (country-specific data), expected operational lifetime, operating efficiency and running costs (based on country specific fuel prices). This analysis clearly shows a large range of electric heat pump costs which is reflective of the range of efficiency levels that we must assume and model for.

Optimising the deployment of technologies into the building types in which they operate best, will reduce the total cost of decarbonising heat in off-grid areas. Electric heat pumps can operate efficiently and at a reasonable levelised cost, but some of the larger, older and less-energy efficient properties in off-grid areas are less suitable for their optimal operation. Instead, gas transition technologies can provide a more cost-effective solution, whilst also lowering carbon emissions - especially with the potential for BioLPG supply over the coming years.

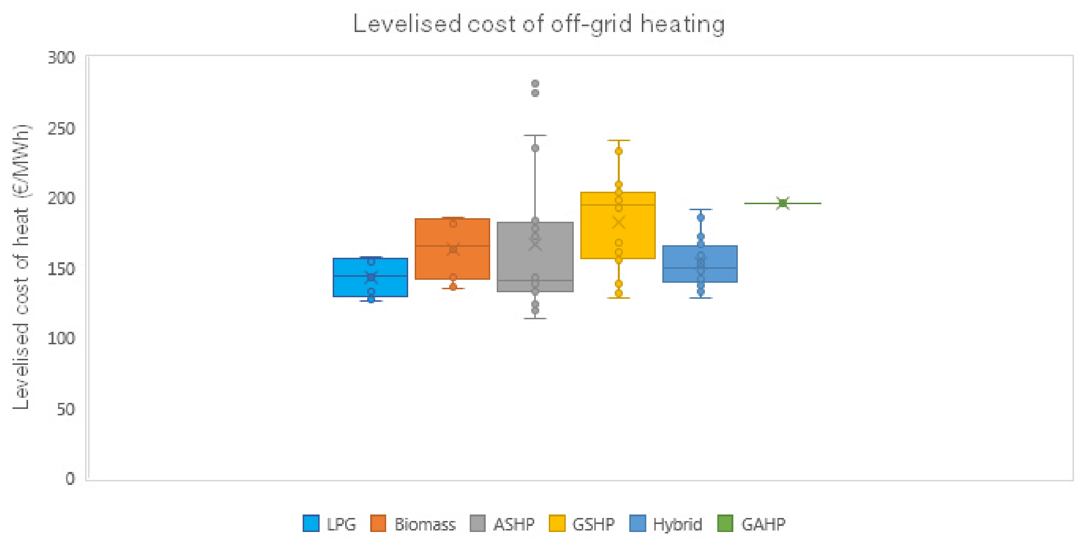


Figure 28 - levelised cost of heat range for off-grid heating technologies covered (€/MWh)

[49] Germany, Poland, France, UK, Spain, Belgium, Italy, Greece, Ireland and Austria. Switzerland is omitted from this list because of data restrictions. Together these countries account for around 90% of Europe's consumption of heating oil and coal for heating.

Using the levelised cost[50] data we modelled the expected cost of transitioning from heating oil and coal to either:

1. 100% electric heating pump pathway (75% ASHP, and 25% GSHP cost split)
2. Pragmatic, mixed technology pathway (with all technologies featured in figures 26 and 27[51])

The table below summarises the analysis results. Firstly, it demonstrates that off-grid heat decarbonisation will cost money, as oil and coal off-grid heating is displaced by new lower emission heating systems. As the social cost of GHG emissions is often undervalued, or not valued at all in the cost of heating, this is not surprising. However, in this scenario the mixed technology pathway is substantially more cost-effective than the 100% electric heat pump decarbonisation route. This involves an increasing role for lower-carbon LPG, highly-efficient gas transition technologies, and ultimately low-emission BioLPG. Policymakers should support a range of technologies to best deliver low emission heating to a diverse building stock, and varied consumer preferences.

The table also shows that both pathways generate substantial carbon savings, which when monetised exceed in value the pecuniary cost of the transition away from oil and coal heating. Therefore, on a social basis the decarbonisation of off-grid heating provides a net benefit to Europe, and LPG and BioLPG should play a key role in this transition.

Transition from high carbon fossil fuels to lower emission alternatives - cumulative costs and savings against baseline, € billion	100% electric heat pump	Mixed technology pathway
Carbon savings (2018-2050) against baseline, € billion	46.4	45.6
Cost of transition against baseline, € billion	37.3	11.2
Net social benefit from transition, € billion	9.1	37.0

Table 8 - Cumulative costs and savings against baseline, € billion

[50] We assume that the fuel price of bioLPG is equivalent to conventional LPG prices based on initial supply which is not expected (source: Mercury Fuel Systems). Note that other production routes may be costlier.
[51] (BioLPG condensing boiler (30%); electric heat pumps (30%); LPG-hybrid heat pump (20%); biomass pellet boiler (10%); and LPG gas-absorption heat pump (10%).

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