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Combustion report for the OFTEC and UKIFDA HVO demonstration project

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2 Executive summary

This report has been published to remark on the 135 properties that have been used to demonstrate the use of waste-derived Hydrotreated Vegetable Oil (HVO) liquid biofuel as an alternative to kerosene in heating and cooking appliances. The properties, which are a mix of residential and commercial buildings, had their kerosene fuelled heating appliances converted to be fired on HVO. The demonstration project has been successfully trialled over three consecutive heating seasons and all installations have undergone cost effective adaptions in accordance with the OFTEC HVO Handbook to enable them to operate on HVO. The HVO was manufactured to BS EN 15940:2023 and that it now includes information and guidance on the use of HVO in heating applications], The HVO is derived and certificated to be from sustainable waste sources in accordance with OFTEC Standard BLPS 25 (now replaced by PAS 5420:2023, which came into effect on 30th April 2023).

Using HVO instead of kerosene has a marked reduction in CO_2 emissions, reducing equivalent carbon emissions from these installations by up to [1]88% when compared to burning kerosene. [add reference to SAP Table 12 if this is where the 88% value is derived from]

The project has been managed and funded by both OFTEC and UKIFDA, with the support of their respective associated members, heating technicians and external consultants.

The properties selected for the project are geographically spread, north to south from Scotland into and across England and Wales. HVO demonstrator projects are also being privately sponsored in Guernsey, Jersey, and Ireland, with comparable findings although these are not included within this project.

A range of appliance types in the study include:

- vaporising cooker (converted)
- pressure jet cooker
- pressure jet cooker and boiler
- pressure jet boilers

The appliance outputs range from 15kW in residential buildings to 100kw in non-residential buildings, demonstrating the versatility of HVO as a direct replacement for kerosene.

The demonstration has been closely monitored since its start to identify any issues, such as diminished performance because of the change of fuel and any unusual combustion characteristics. The fuel distribution companies managing individual sites were asked to provide site monitoring service reports including any unusual operational observations to the OFTEC technical department so these could be logged, scrutinised, and any issues

[1] BRE SAP 2012 10.2 Table 12

investigated. This report includes and discusses some isolated incidences and specific findings from the project. The OFTEC Specimen site was used as a benchmark to provide detailed monthly recordings and analysis which is reported further on in this report.

After three successful heating seasons trialling HVO, with only minor incidences, it is recommended that the demonstration continues in a reduced capacity to capture any further learnings or characteristics. The project will continue to:

a) gain further evidence about long term operation of equipment components in contact with HVO.
b) facilitate further real-life testing of fuel and marker dyes.

All future conversions should follow instructions published in the OFTEC HVO Handbook and OFTEC Technical Manual.

Due to the success of this problem-free demonstration project, it has been shown that HVO biofuel can constitute a key part of the solution to helping meet the Climate Change Agreement 2008 - contributing towards net zero emissions by 2050 as a complementary solution.

3 Introduction

In 2019, the UK Government amended the Climate Change Act 2008 at this time OFTEC and industry partners developed B30k to commence sector decarbonisation to create a legally binding target for the nation to become a net zero society by 2050. This ambitious target will drive change in all areas of society, including energy sources, technology, and even how we go about our daily lives. Heating buildings account for 23% of the nation's annual emissions.

There are approximately four million residents living in properties containing around 1.7m oil boilers in the United Kingdom, with a further 670,000 in the Republic of Ireland. The many challenges associated with improving energy efficiency and reducing reliance on the use of fossil fuels in these, typically off gas grid homes, is well documented.

Heat policy had identified rural off gas grid buildings for early decarbonisation treatment, commencing in 2024 for large non-domestic and 2026 for domestic and small non-domestic buildings. There was belief that this would facilitate a maturing of the heat pump supply and installation market using a strategy of "learning by doing", but with risks typically associated with early technology adoption. These could include consumers paying the highest costs and experiencing the most unpredictable outcomes as the heating installer base diversifies and develops skills required to install heat pumps, that operate under different parameters to more traditional fossil fuelled heating appliances.

To date, the use of sustainable waste-derived renewable liquid fuels as a replacement for heating kerosene has largely been overlooked as policy developers continue the path of electrification being the best solution for heating buildings and reserving mobile energy sources for harder to treat applications such as transport. This is despite independent analysis showing that sustainable renewable liquid fuels offer a real opportunity to reduce carbon emissions in buildings by up to 88% when compared to kerosene. These fuels are manufactured, certified, and traded to international standards and can be quickly deployed at scale using existing infrastructure. Appliances can be converted to operate on the new fuel cost effectively by an existing skilled workforce and with minimal disruption for consumers.

In the summer of 2020, OFTEC partnered with the United Kingdom and Ireland Fuels Distributors Association (UKIFDA) to develop plans to demonstrate the feasibility of substituting kerosene with a renewable waste-derived liquid biofuel known as Hydrotreated Vegetable Oil or "HVO".

The project aims were to:

- Demonstrate the simplicity of fuel switching from kerosene to HVO.
- Demonstrate the technical feasibility of combusting HVO in real life situations.
- Gauge consumer acceptance on the use of HVO to displace kerosene.
- Demonstrate the fuel supply infrastructure's ability to deliver HVO to the point of use.
- Demonstrate fuel and emission savings when investing in a new appliance and smart heating controls.

This report summarises findings to date as the first sites converted successfully conclude a third heating season of consecutive firing.

4 Renewable liquid fuels

4.1 General

In pursuit of a greenhouse gas emission reduction pathway, for over a decade the liquid fuel heating industry has been evaluating liquid biofuels in order to identify a sustainable and stable fuel that can displace the use of kerosene in both new and existing heating appliances.

Fuels derived from virgin plant-based feedstock are inappropriate for use in heating appliances, as far less carbon savings are achieved compared to using fuels derived from verified sustainable waste sources such as used cooking oil (UCO), agricultural waste or forestry residues. The use of virgin materials also raises concerns over appropriate land use. Equivalent carbon emissions from combusting virgin derived biofuels can be as high as 200g CO_2e/kWh.

Equivalent carbon emissions from combusting waste-derived fuels can be lower than 40g CO_2e/kWh. This is due to the waste feedstock being considered net zero carbon, as its carbon impact associated with land use, cultivation, harvesting, etc. has already been counted in its previous life cycle.

The Renewable Energy Directive establishes common rules and targets for the development of renewable energy across all sectors of the economy.

4.2 Fatty Acid Methyl Ester (FAME)

During the period 2008 – 2010, respective members of OFTEC partnered with the University of East Anglia to investigate and field trial varying blends of BS 2869 heating oils (C2 kerosene and Class D Gas Oil) mixed with EN 14214 FAME biofuel. Following laboratory combustion tests, volumes of 30% and 50% biofuel blended with fossil fuels were successfully trialled for a period of 12 months in 25 installations across the Norfolk and Lincolnshire area. On completion of these early trials, the project was not taken forward as Government support for the cost differential between kerosene and biofuel was withdrawn during the development of the Renewable Heating Incentive scheme.

The work was revisited in 2018 following the publication of the Government's Clean Growth Strategy, but with no developed pathway for the deployment of higher blend biofuels, and off gas grid homes being selected for early decarbonisation, it became apparent that blended fuels were no longer an option and a 100% "drop in" biofuel was required.

4.3 Hydrotreated Vegetable Oil (HVO)

Towards the 2020's, volumes of HVO were steadily increasing and the fuel was becoming more widely available due to its use as a transport fuel. An evaluation of its characteristics identified it as a high-quality paraffinic fuel manufactured to EU standards with characteristics similar to kerosene. It also came with some safety and environmental advantages. For example, HVO supplied for the demonstrator project by Crown Oil has a flash point >61°C and therefore is not classed to be a flammable liquid when stored under atmospheric conditions.

The table below summarises some of the similar characteristics between Kerosene and sustainable waste-derived HVO. More detailed information can be found in the OFTEC HVO Handbook.

	Kerosene to BS 2869	HVO to EN 15940
Gross Calorific Value (MJ/ kg)	46.2 NOTE 1	46.96 NOTE 1
Density (kg/m^2@15°C)	775 - 820	765 - 800
Viscosity (mm^2/s@40°C)	1 - 2	2 – 4.5
SAP 10.2 Emission Factor ($kgCO_2e$/kWh)	0.298	0.036
Minimum Flash point (°C)	38	>55

NOTE 1 Independently analysed fuel samples provided to KIWA for boiler efficiency comparative testing. Report no. 80637, 5th November 2020

Whilst HVO can be blended with fossil heating oils, its performance and the ease with which existing appliances can be quickly and cost effectively converted to use 100% HVO made it the obvious choice to be used in a national demonstrator project.

4.4 HVO availability

During the demonstration project, UKIFDA commissioned Portland Analytics to conduct a study on available feedstocks that could be used to produce renewable liquid fuels and compare this to the forecasts of demand for those fuels up to 2030.

The report covers the North American and European markets only and excludes imports from regions such as Southeast Asia, India and the African continent. While these regions potentially offer a source of used cooking oil (UCO) feedstock for renewable liquid fuels, they were excluded based on advice from experts that there were no reliable sources of data.

The study objectives were:

- To identify technologies capable of producing renewable liquid fuels, the feedstocks used in each process and potential GHG emissions savings.
- To analyse current and projected feedstock availability (to 2030) using a variety of published studies and to calculate potential renewable liquid fuels (RLF) yield.
- To analyse current and projected product demand and to establish the proportion that may feasibly be replaced by renewable liquid fuels.

The highlights within the report include:

- The UK domestic heating oil market can easily be accommodated within the overall requirement for renewable liquid fuels.
- There is more than enough projected feedstock availability to meet renewable liquid fuel consumption requirements in Europe and North America.
- Europe has potential feedstock availability to produce between 64 – 105 million tonnes of oil equivalent (mTOE) of renewable liquid fuels per annum by 2030. European biofuels consumption (biodiesel, biojet and renewable diesel) is expected

to be between 19 – 26 mTOE per annum by 2030, meaning projected renewable liquid fuels yield would exceed demand by between 243 – 560%.

- North America has potential feedstock availability to produce between 123 – 151 million mTOE of renewable liquid fuels per annum by 2030. North American biofuels consumption (biodiesel, biojet and renewable diesel) is expected to be between 21 – 30 mTOE per annum by 2030, meaning projected renewable liquid fuels yield would exceed demand by between 415 – 728%.

	Demand (mTOE)		RLF Yield (mTOE)		RLF Yield (% of demand)	
	Low	High	Low	High	Low	High
Europe	18.69	26.18	63.57	104.59	243%	560%
North America	20.76	29.50	122.52	151.20	415%	728%
Total	**39.45**	**55.68**	**186.09**	**255.79**	**334%**	**648%**

In a scenario where 50% of existing oil heated homes were converted to run on HVO by 2030, the requirement for RLF would amount to c1mTOE p.a. In this context, the current UK liquid fuel replacement requirement would be between 0.4% and 0.5% of renewable liquid fuel production in Europe and North America.

HVO production from 2013 to 2020 increased from 2.2m metric tonnes to 6.2m. Forecasts suggest that European production of HVO is expected to increase to 11.3m tonnes by 2025 and in the USA to 12.6m tonnes. Total world production is expected to reach almost 30m tonnes by 2025 – 14 times that in 2013.

Since the study was concluded, the UK has lifted import tariffs previously imposed on US and Canadian biofuel, which further increases access to UK importers.

4.5 Fuel sustainability

As with all decarbonisation solutions, it is important that technologies are sustainable and deliver a no regrets long term solution that should ideally reduce in cost over time and not encourage poor practices that do not deliver on their intended purpose.

All fuel used in the project was accompanied with International Sustainability and Carbon certification (ISCC) documentation, which is a globally applicable sustainability certification system and covers all sustainable feedstocks, including agricultural and forestry biomass, circular and bio-based materials and renewables.

During the project, a Publicly Available Specification, PAS 5420, was developed with the British Standards Institution and published on 30th April 2023. This specification was designed to debar environmentally damaging bio-liquid fuel feedstocks and processes from the heating and hot water supply chain, and limits future fuel feedstocks to waste derived sources. It also provides the fuel distribution sector with a robust specification for auditing and reporting on renewable liquid fuels used for heating applications. The standard makes reference to legislation of UK and European origin where practicable, with the addition of requirements resulting from laboratory testing on HVO. It includes detailed instructions and

procedures which aligns to the parameters necessary to achieve and maintain fuel carbon equivalent point of use emissions (CO_2e) which do not exceed those values published within Table 12 of SAP 10.2 - SAP being the UK Government's Standard Assessment Procedure for assessing the energy performance of dwellings.

5 Demonstration project

5.1 General

This project was wholly designed, funded, and managed by the liquid fuel heating industry and followed successful laboratory trials combusting HVO and HVO/kerosene blend fuels.

The project commenced with the ambition to convert between 150-200 existing oil-fired installations to operate on 100% HVO. Sites would be selected to provide national coverage with performance being monitored for three consecutive heating seasons.

One “specimen” site would be selected for the gathering of detailed information on fuel use and heating system performance.

Many rural households not only use oil for heating, but also for cooking, and often regard their cooker as a focal point within their kitchen. Consequently, it was important that the project included the conversion of cookers as well as boilers so that one fuel source could be used.

Whilst OFTEC and UKIFDA advocate the application of insulation and energy efficiency measures to reduce fuel use, emissions and running costs at every opportunity, it was important for the project to evaluate the performance of HVO against kerosene in a “like for like" scenario. With the exception of the “specimen” site, where a new fuel storage tank, fuel meter and modulating boiler with OpenTherm controls was installed, all boiler installations were converted with only minor adaptions to the burner and some fuel-carrying components. There were no:

- internal or external insulation measures applied.
- adaptions applied to the heat distribution system.
- impacts placed on the electricity grid or DNO or planning permission applications required.

Conversion was undertaken during what was effectively equivalent to a routine boiler service visit and fuel replenishment. In most cases, conversions were completed entirely by the local fuel distributor sponsoring the fuel for the site. Where fuel distributors were unable to convert and recommission appliances, a local boiler service technician attended.

To date 135 properties have been converted, of which nine were commercial buildings, including a school, church, and a public house. Regular heat-only boilers, cookers, cooker boilers feature in the project, as have combination boilers which have provided domestic hot water on demand throughout the year.

5.2 Site selection

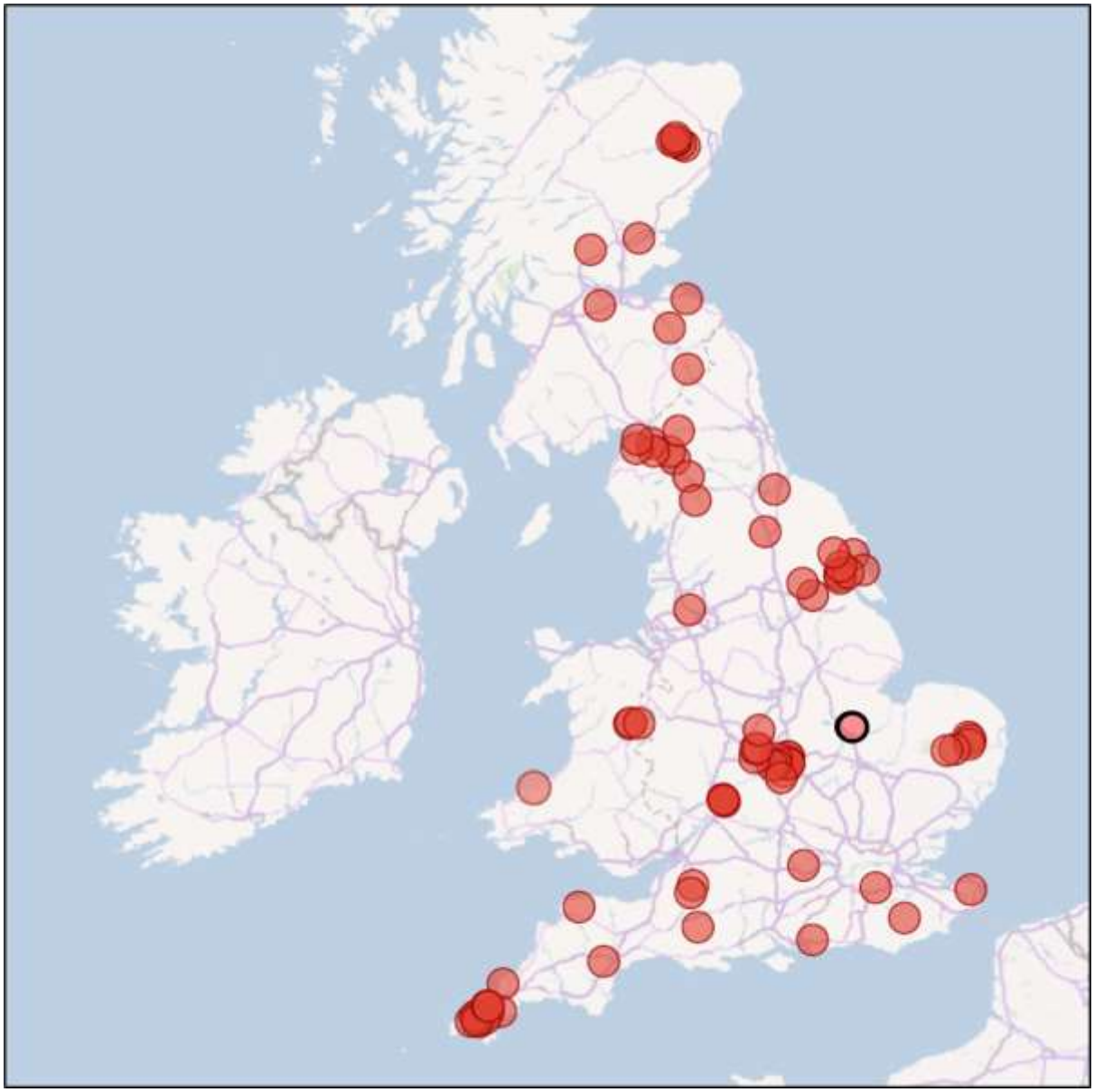
The project was designed to capture a diverse range of equipment, installation features, and locations that would be representative of oil installations throughout the UK.

Fulfilling the above, sites for the project were reliant upon the willingness of property owners to participate. Many sites were identified by the local fuel distributor and were existing customers enthusiastic about a low carbon liquid fuel option and the ease of conversion.

The OFTEC technical team were presented with a variety of properties, appliances and heating systems recommended for participation in the project. Before sites were accepted, an assessment of suitability was made based on the following criteria:

- Location: Fuel availability, inland, coastal, elevation and temperature.
- Appliance: Type, output, age and condition.
- Fuel tank: Material, age and condition

The map below shows the geographical location of sites selected to take part in the project. The site marked with a black ring, near Peterborough, was the “specimen” site.



5.3 Equipment

In preparation for the project, SMS Analytical were commissioned to conduct a detailed study on the characteristics of HVO. The study would enable equipment manufacturers to make enquiries with their material suppliers and ascertain whether there would be any negative effects on materials/components that are in direct contact with the liquid fuel or combustion gases. The summary of characteristics is contained within the Annexes of the HVO Handbook v1.5, available from www.oftec.org

In selecting sites for conversion, the equipment already installed was evaluated for its compatibility with HVO via liaison with the original manufacturer of the item. This included metal and plastic fuel tanks, rigid and flexible fuel supply lines, fuel gauges, fuel filters, burners, boiler heat exchangers and flue components. If components could not be identified, or any doubt existed as to their compatibility with HVO, they would be changed for known compatible components upon conversion.

Appliances selected for the project feature 15 different manufacturers and include burners manufactured by 8 burner different manufacturers.

The tables below provide a summary of the appliances by output and type.

Number of appliances by output

Appliance output range (kW)	No. of boilers
10 - 20	38
20 - 30	63
30 - 40	22
40 - 50	7
50 - 60	1
60 - 70	2
70 - 80	0
80 - 90	1
90 -100	1

Number of appliances by type

Appliance type	No. of appliances
Regular on/off boiler	86
Regular modulating boiler	1
Combination boilers	45
Cooker	1
Cooker boilers	2

5.4 Fuel supply and delivery

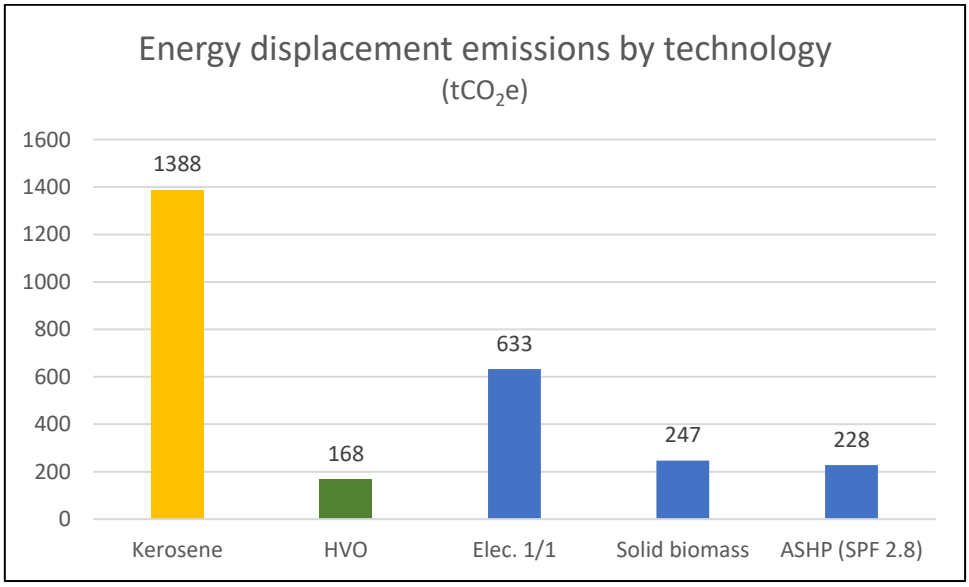
Sixteen fuel distributors participated in the project and sponsored the cost of the fuel and conversions.

The liquid fuel supply infrastructure is very mature and flexible and HVO is already widely available within the UK due to its growing use as a transport fuel. The fuel used in the project was largely manufactured by Neste in Finland and accompanied by an ISCC Sustainability Statement. However, in the spring of 2023, due to the lifting of import tariffs, the UK received its first shipment of HVO from the US.

The consumption of HVO to date is estimated to be 450,000 litres delivered to 135 locations. In terms of carbon dioxide emission reductions, the volume of kerosene displaced by HVO to date equates to a reduction of approximately 1,220 tonnes.

The following chart below shows various low carbon technologies that may have displaced the same energy content as kerosene and the resultant emissions. As can be seen, HVO delivers the greatest carbon saving across these technologies.

Project CO_2e emission displacement to date



NOTE $CO2_e$ emissions calculated using emission factors published in SAP 10.2, Table 12.

For logistical reasons, HVO was delivered to the individual sites either by a dedicated tanker or where a tanker was not viable, delivery was made via an intermediate bulk storage container (IBC) and decanted on site into a fixed storage tank. It is forecast that as uptake of HVO increases for heating, direct delivery into fuel storage tanks will replace kerosene delivery today.

5.5 Site conversions

5.5.1 General

Conversions were undertaken by competent service technicians under direction from the local fuel distributors responsible for individual sites. The OFTEC HVO Handbook (available via www.oftec.org) was used as a main source of reference for the technical aspects of the conversion.

All appliances used in the project utilised an existing flue system, which was inspected for integrity and cleanliness at the time of conversion.

Fuel storage tanks were also visually inspected for integrity. Fuel tanks were replaced with new tanks on some sites due to the existing tank being in either poor condition or had exceeded its design life.

5.5.2 Boilers

Boiler installations were converted with focus on the following aspects of the installation:

1. Emptying and cleansing of existing fuel storage tanks.
2. Replacing fuel carrying components if not HVO compatible. For example, fuel filter, deaerator, fuel pump, etc.
3. Labelling of equipment to declare it had been converted to operate on HVO.
4. Calculating new combustion settings to achieve the required heat output.
5. Fit a new HVO calibrated burner nozzle.
6. Appliance commissioning.

All boilers converted in the project, with the exception on one, utilised the existing burner(s) supplied with the boiler. A decision was taken at one site to exchange a manufacturer's burner for a different manufacture's burner to allow wider variance in the equipment.

5.5.3 Cookers

In addition to points 1 through 4 and 6 above, an AGA OC90 cooker was converted to operate on HVO using a conversion kit manufactured and supplied by Howarth Heating Ltd. The conversion required the replacement of the original vaporising sleeve burner with a pot burner. The fuel control valve was also replaced with a valve specifically calibrated for use with HVO.

The cooker commissioning process is consistent with that of using fossil liquid fuels.

5.5.4 Cooker boilers

Cooker boilers with pressure jet burners were converted in the same way as boilers.

5.5.5 Fuel contamination simulation

Two sites were selected to evaluate a situation if a customer declined or failed to have their fuel storage tank properly emptied and cleansed prior to transitioning to HVO.

Site a) utilised an existing storage tank. Approximately 50 litres of kerosene and storage residues (water and sludge) were left in the tank and 100% HVO was added. The calculated HVO/kerosene blend was 92% HVO / 8% kerosene.

Site b) also utilised an existing storage tank. 150 litres of kerosene and storage residues were left in the tank before HVO was added. The calculated HVO/kerosene blend was 87% HVO / 13% kerosene.

Both sites suffered the formation of combustion deposits on the burner blast tube following conversion. This issue was monitored over twelve months and the incidence of residues on the burner head had greatly reduced over the time and had disappeared completely at the annual service.

On investigation and analysis of the issue it was found that the problem was caused by remaining dirty fuel left at the bottom of the tank which was contaminated with residues leading to incomplete combustion. When the tank was first filled at conversion with HVO it caused the remaining fuel with residues to be stirred up.

The tank had not been cleaned satisfactorily and the residues which remained were mixed on filling with the new fuel. This contaminated fuel was drawn downstream and into the appliance burner and when combusted left tiny sooty deposits on the burner head. The issue eventually cleared itself as the tank was replenished with new HVO, each time diluting the residues, these being suspended in the fuel and combusted at the burner. The monitoring reported that after 12months the incidence of deposits had disappeared.

5.6 Site surveillance

5.6.1 General

For the first 12 months of the project a tight schedule of site monitoring and reporting was performed at the point of conversion and commissioning, and thereafter at intervals of +24 hrs, +72hrs, +1 week, +1 month, and +3 months where technical observations and measurements were recorded.

After 12 months, confidence in the use of HVO had grown to the point that boilers were converted/serviced and no further surveillance was performed at site, other than the specimen site, which continues to be routinely monitored to gain statistics on fuel use and allow the ongoing calculation on emissions.

Service technicians monitoring sites were instructed not to intervene with the cleanliness of the burners, combustion chamber and flue systems, unless for reasons of safety or avoidance on imminent breakdown. Any such intervention was to be recorded on the site surveillance records.

Site monitoring reports were sent to OFTEC by the person responsible for site and were reviewed to identify any unusual operational characteristics.

5.6.2 Specimen site

Other than undertaking annual routine servicing, the specimen site has had no operational intervention following the boiler being installed and commissioned.

5.6.3 Fuel storage and supply

During the project, there were several reports of fuel contamination issues, which equates to around 4% of the total number of sites. The first case was reported at the beginning of the first heating season, in September 2020, when a consumer reported that their boiler had stopped working. The fuel distributor responsible for the conversion investigated and reported that the filter and nozzle were blocked with a red/brown substance that had the appearance of a thick red and brown greasy substance.

The images are typical of the findings on these sites. The left image shows the comparison between a blocked and new nozzle. The image on the right shows a heavily blocked fuel filter.





Over a further period to January 2023, extensive fuel analysis was undertaken by a SMS Analytical on five separate fuel samples, including fuel filters and nozzles, to find the cause of the contamination. The final report concluded that filter blocking was likely to be caused by fuel marker dye binding on contact with non-polar solvents such as n-hexane, or the HVO itself, and producing a sediment large enough to be trapped on contact with filter elements.

The SMS report states:

> *"The sediment appears to be the degradation of oxidation products (or possibly less soluble components) of the marker dye used for excise duty. Solvent red marker dyes have been reported to have some stability issues but the sediment may also be possibly attributable to solvency issues in HVO"*

A taskforce has now been formed within the fuel supply chain to consider alternative marking of HVO.

Further investigation by partners Mitchell and Webber highlighted issues caused by sediment or sludge particles remaining in tanks at point of conversion.

The importance of storage tank maintenance reduces the potential for sludge, sediment and particles being stirred up when fuel is delivered, which can contribute to filter blinding. Their experience of sites affected by the issue had fuel lines connected to the bottom of the storage tanks which provided a route for the contaminated fuel lying at the base of the tank to find its way to the burner rather than a top outlet which takes fuel further up the tank.

Many of the fuel storage tanks used in the project were constructed of rotationally moulded polyethylene. No issues have been reported relating to degradation of the tank material whilst in contact with HVO. Steel tanks are known to be resilient to HVO.

5.6.4 Combustion

5.6.4.1 Performance

All appliances used in the project have successfully operated on HVO and there have been no reports of diminished performance resulting from the combustion of the fuel. However, early in the project, due to nozzle supply issues, some sites were converted using standard kerosene and gas oil nozzles. Surveillance at some of these sites identified a formation of light combustion deposits on burner assemblies and in heat exchanger. Consistently, the first area to show signs of soot deposits is at the blast tube and diffuser disc. On changing nozzles to HVO calibrated nozzles it was reported that the previously formed deposits had disappeared. No appliances suffered breakdown as a result of deposits forming.

Combustion deposits were also reported to have formed at the two sites simulating fuel contamination and using a percentage of fossil kerosene mixed with HVO. Unfortunately, the boilers converted on these the two sites were commissioned using nozzles calibrated for kerosene. It therefore remains inconclusive whether the formation of deposits was attributable to combusting a blended fuel or the use of a kerosene nozzle. As the project progressed, nozzles were replaced for HVO calibrated ones and the blended fuel was replaced with 100% HVO, further diluting the concentration of kerosene compared to the original commission and the deposits diminished over time. No breakdowns occurred during this period.

On withdrawing burners for inspection, some sites showed a “wetting” of the burner nozzle assembly indicating that a tiny amount of fuel may have escaped from the nozzle outlet on burner shut down. Other suggestions postulated that the formulation of HVO could leave a “grease mark” which could be observed as a wet look at the tip of the nozzle.

Enquiries were made with burner manufacturers who responded that “wetting” is a normal occurrence that has also been witnessed with fossil fuels in the same burners. The situation was monitored and reported over the first two heating seasons with further no consequence on boiler performance or reliability.

Comparing measured boiler efficiency pre and post conversion to HVO, the aggregate differential ranged from negative 1.1% to positive 4.7% when compared to measurements obtained when the same appliance was fired on kerosene. The collective mean variance across eight boilers evaluated equates to a 0.97% increase in boiler efficiency when fired on

HVO. This result is consistent with findings published in Kiwa Test report 80637 – "*Assessment of the efficiency and emissions of an oil-fired condensing central heating boiler operating on kerosene and Hydrotreated Vegetable Oil (HVO), dated 5th November 2020"*, in which it is stated within the conclusions:

> *"It has been shown that the full load efficiencies were unchanged, and the part load efficiencies were marginally higher for the HVO, but within the uncertainty of the test regime and apparatus."*

5.6.4.2 Emissions

During the project, laboratory testing of a 20.5kW nominal output boiler was performed to assess oxides of nitrogen (NOx) and sulphur dioxide (SO_2) emissions resulting from combustion and to evaluate any notable difference in NOx and SOx emissions between HVO and kerosene. Reference is made to Kiwa Test report 80637 – "*Assessment of the efficiency and emissions of an oil-fired condensing central heating boiler operating on kerosene and Hydrotreated Vegetable Oil (HVO), dated 5th November 2020"*, in which it is stated:

> *"Measured NOx (in ppm) is similar, but only differs when converted into a mg/kWh value using different formulae for kerosene and fuels other than kerosene in EN 267."*
>
> *"Sulphur dioxide (SO_2) concentrations were very low with HVO showing slightly higher concentrations (2 ppm) than the kerosene (1 ppm). However, these values were at the lower end of the measuring range and at the limit of resolution."*

Further laboratory work was undertaken by Enertek International Ltd who were asked to undertake work to convert the calculated NOx values, from Kiwa report 80637, to mg/kWh which was to compare results with those in the Kiwa report.

The reasons behind this were to investigate the relatively large difference in the NOx emissions in mg/kWh with HVO fuel compared to that with the kerosene fuel. This was despite the measured NOx values in ppm, operating conditions, and constituents' fractions being relatively similar for both fuels.

The object of the report was to use the test data from the Kiwa report 80637 together with the appropriate Enertek test sheet to perform the conversion of the NOx emission values from ppm, two mg/kWh.

The table below shows a comparison on the results of conversion of measured NOx emissions from ppm to mg/kWh gross and net.

	Kiwa results		Enertek results	
	Kerosene	HVO	Kerosene	HVO
NOx net, mg/kWh	80	112	78	80
NOx gross, mg/kWh	75	105	73	75

The table below shows the calculated oxygen and the corresponding volume of air required for stochiometric combustion of the kerosene and the HVO fuel under investigation.

	Kerosene	HVO
Stoichiometric oxygen requirement m^3_n oxygen/kg fuel	2.474	2.411
Stoichiometric air requirement m^3_n air/kg fuel	11.78	11.48
CO_2 content in dry flue gas, by volume, corresponding to stochiometric combustion	14.61%	14.78%

Stochiometric Combustion

Enertek were asked to establish the stochiometric combustion requirements of HVO fuel, the results of which are provided in Table 2.

SMS were able to update their calculated theoretical values with new values and these are published in the HVO Handbook v1.5 in which there us a further explanation about the differences between the previous and new values.

The new calculated values produced have been provided to the relevant CEN technical committee responsible for BS EN 50379 in a proposal that CO_2 values can be published so that combustion analysers can be set to reliably measure flue gas emissions when commissioning all liquid fuel and HVO fired appliance to:

- Calculate CO_2 from the measurement of oxygen
- Calculation of combustion efficiencies

5.6.4.3 Power consumption

Not directly relating to combustion but notable in terms of comparative performance between boiler operation on kerosene and HVO, during the same test for emissions it is reported that:

> *"Minor increases in electric usage of approximately 4.5 W were noted at full load and with one of the part load conditions with HVO. The other part load condition showed slightly more electric use with kerosene, but this was marginal with 1 W difference*."

6 Case study – Specimen site

The Five Horsehoes Public House at Barholm, (Specimen site)



6.1 General

The Five Horseshoes public house is located in the estate village of Barholm, Lincolnshire.

The building was chosen to enable OFTEC and industry partners to demonstrate the feasibility of achieving carbon reductions in what would be a hard-to-treat building, when considering a combination of cost, technical feasibility, disruption, and the need to preserve the building's aesthetic character.

The original part of the building is 300 years old and constructed of limestone with single glazed wooden doors and windows. It consists of mixed floors of solid stone and suspended timber with and has an uninsulated roof. In addition, much of the heating systems pipework is built within the fabric of the building rendering it inaccessible for the application of any pipework alterations. The property lies in a conservation area and, as such, fabric updates to the building, both external and internal, are not permitted.

Prior to conversion the property utilised an aging Myson Velaire kerosene fired on/off, single stage, standard efficiency boiler with an efficiency of approximately 78%. The oil storage tank was also deemed to have exceeded its design life.

6.2 Site preparations

In preparing the site for conversion, a new steel fuel storage tank was installed, together with a fuel meter. A new fully modulating liquid fuel boiler was installed to replace the Velaire and a new OpenTherm weather compensation controls package was fitted to the heating system.

The upfront cost of replacing the fuel tank has not been considered within this report as the tank was changed to fulfil environmental responsibility, not as a result of fuel switching to store HVO.

The weather compensated controls are referred to as OpenTherm, which is a weather compensation system and communication protocol between heating controls and the boiler.

When a heating system is designed, the size of the boiler for heating is based on the difference between the desired room air temperature and the external air temperature, relative to a design water flow temperature to the radiators. A common scenario is that a target temperature in rooms of 20°C is required when the building is located such that a common external air temperature experienced in winter is -3°C. This requires a boiler to have a heat output that allows the heat emitters to raise the air temperatures in rooms by 23°K. With a conventional on/off boiler, the boiler is sized to satisfy the maximum demand being a 23°K differential. This means that when the external air temperature is higher than -3°C, the boiler is oversized for the demand and using more fuel than necessary.

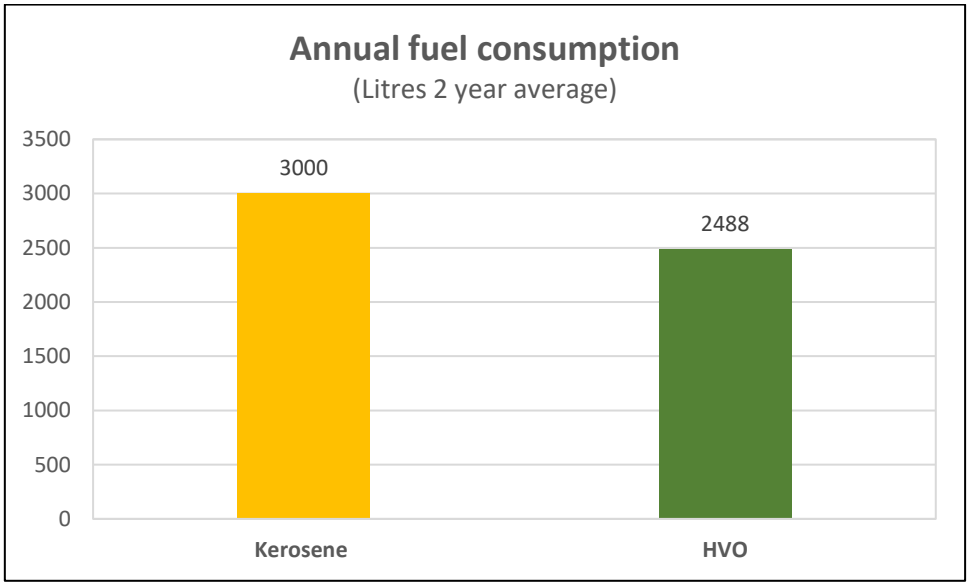
The OpenTherm weather compensation systems enable modulating boilers to adjust the firing rate of the burner to match the demand. In effect, as room temperatures rise, the burner output is automatically reduced. This causes the flow temperature from the boiler to also reduce. providing savings in fuel use, fuel cost and resulting GHG emissions.

6.3 Fuel consumption

For the specimen site, it was important to have specific measurables against which comparisons could be made of the differences in performance before and after conversion from kerosene to HVO. To achieve this, the previous six years' kerosene fuel purchases were reviewed to form a reference datum of annual and monthly kerosene usage.

To enable accurate monthly and annual monitoring and reporting of HVO usage, a fuel flow meter was added to the fuel supply system at time of conversion. The meter is read on the first day of every month, the readings recorded and applied to a simple comparative monthly fuel use spread sheet, from which emission calculations are derived utilising SAP 10.2, Table 12. See https://bregroup.com/sap/sap10/.

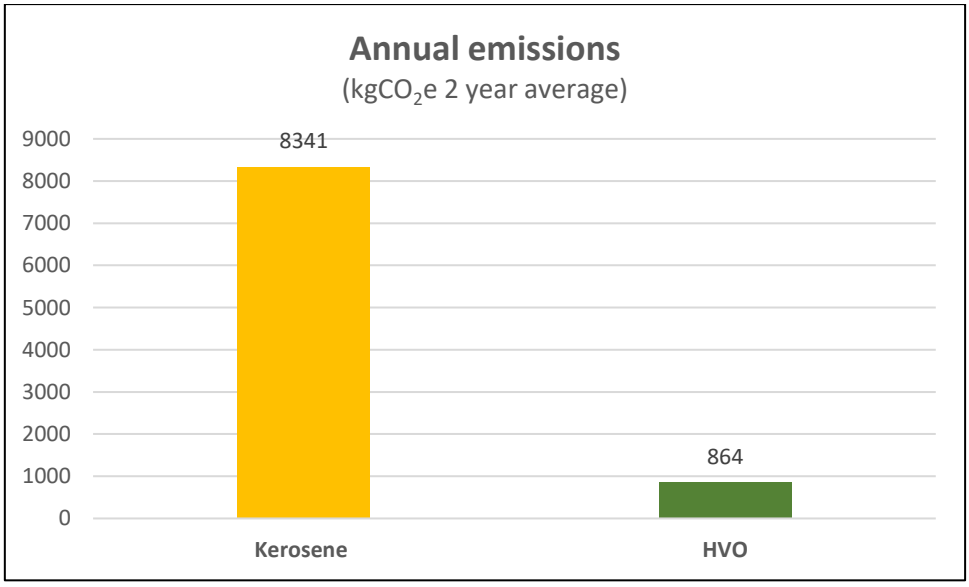
The chart below shows a fuel saving of 17% when comparing HVO used for the project over the period 1st August 2021 to 31st July 2023 when compared to the average kerosene consumption over a period of six years prior to the replacment of the boiler and controls.



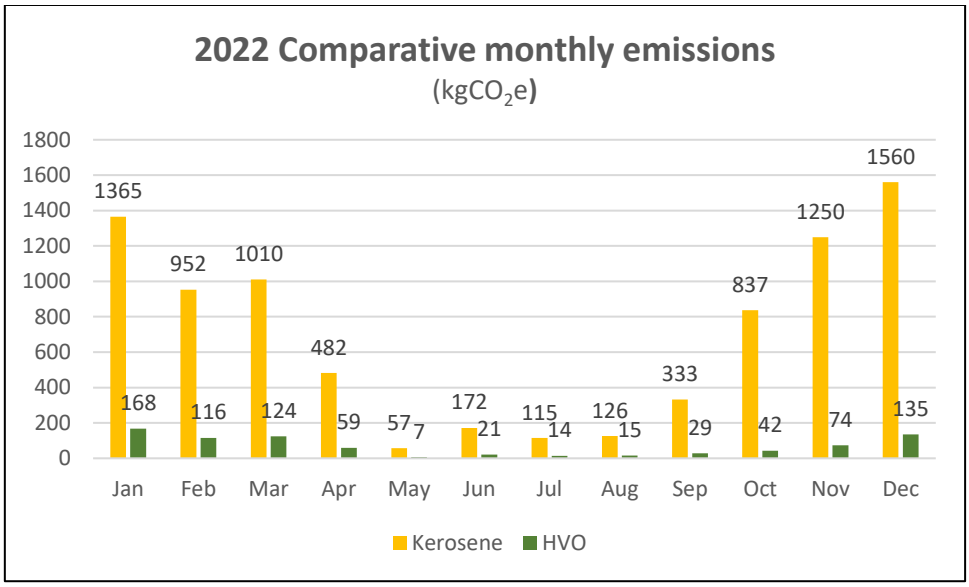
6.4 2022 Annual comparative emissions

Relative to the volume of fuel used in 2022, the charts below show comparative emissions between kerosene and HVO by year and by month.

Comparative annual carbon emissions



2022 Comparative monthly carbon emissions



6.5 Building Performance

6.5.1 Energy Performance Certificates

Energy Performance Certificates (EPC's) were produced for the specimen site, one prior to conversion and one after conversion for comparative purposes.

The advances in liquid fuelled domestic combustion technology demonstrated by the installation of a fully modulating HVO boiler, in conjunction with the ability to utilise OpenTherm weather compensating controls on the heating system, is shown on the following two EPCs.

They show that the overall energy efficiency rating of an existing "oil" property can be improved from a low Band D 91 property to a Band C 65 property, simply by replacing the liquid fuelled boiler and controls with their modern counterparts at the end of their natural life cycle.

Pre conversion EPC

Energy performance certificate (EPC)

FIVE HORSE SHOES INN HORSE SHOE LANE BARHOLM PE9 4RA	Energy rating **D**	Valid until: **13 July 2031** Certificate number: **3328-5088-8547-5565-4701**

Property type	A3/A4/A5 Restaurant and Cafes/Drinking Establishments and Hot Food takeaways
Total floor area	235 square metres

Rules on letting this property

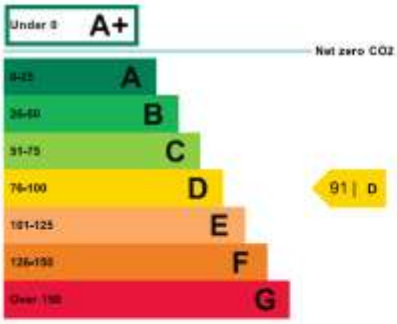
Properties can be let if they have an energy rating from A+ to E.

If a property has an energy rating of F or G, the landlord cannot grant a tenancy to new or existing tenants, unless an exemption has been registered.

From 1 April 2023, landlords will not be allowed to continue letting a non-domestic property on an existing lease if that property has an energy rating of F or G.

Energy efficiency rating for this property

This property's current energy rating is D.



Properties are given a rating from A+ (most efficient) to G (least efficient).

Properties are also given a score. The larger the number, the more carbon dioxide (CO2) your property is likely to emit.

How this property compares to others

Properties similar to this one could have ratings:

If newly built 38 | B

If typical of the existing stock 112 |

Post conversion EPC.

Energy performance certificate (EPC)

Five Horse Shoes Inn Horse Shoe Lane BARHOLM PE9 4RA	Energy rating **C**	Valid until: **17 November 2031** Certificate number: **2337-2031-4517-8332-9564**

Property type	A3/A4/A5 Restaurant and Cafes/Drinking Establishments and Hot Food takeaways
Total floor area	235 square metres

Rules on letting this property

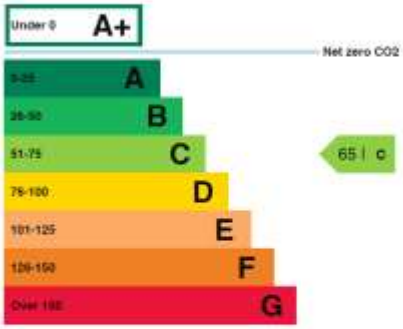
Properties can be let if they have an energy rating from A+ to E.

If a property has an energy rating of F or G, the landlord cannot grant a tenancy to new or existing tenants, unless an exemption has been registered.

From 1 April 2023, landlords will not be allowed to continue letting a non-domestic property on an existing lease if that property has an energy rating of F or G.

Energy efficiency rating for this property

This property's current energy rating is C.



Properties are given a rating from A+ (most efficient) to G (least efficient).

Properties are also given a score. The larger the number, the more carbon dioxide (CO2) your property is likely to emit.

How this property compares to others

Properties similar to this one could have ratings:

If newly built — 38 | B

If typical of the existing stock — 112 | E

6.5.2 Energy Performance Rating of buildings

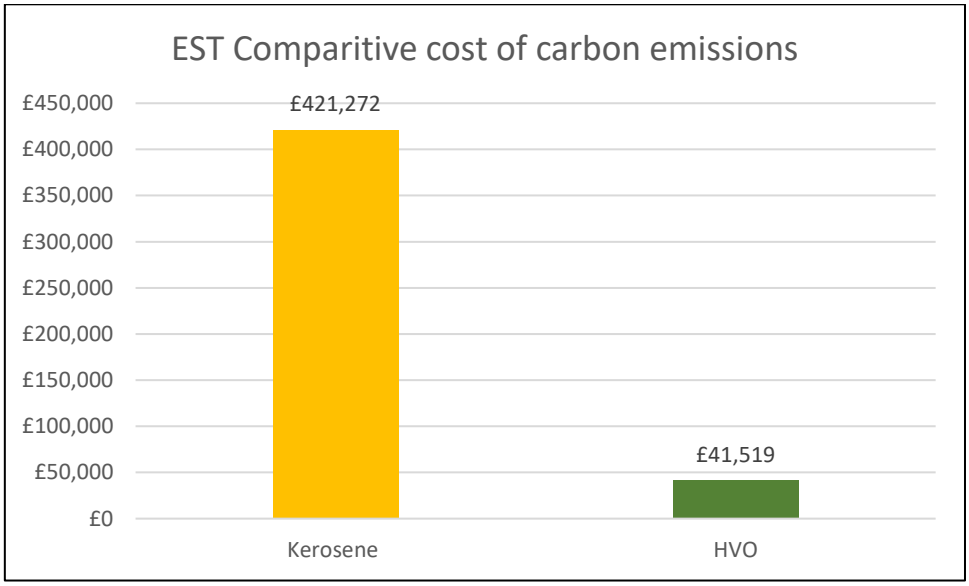
The specimen site has achieved a near 30% improvement in the Energy Performance Rating of the 300-year-old, off gas grid, “hard to treat” rural property, from a Band D (91) to a Band C (65) simply by applying a modern liquid fuel fired appliance and controls as a direct end of life replacement of existing liquid fuel fired equipment.

6.5.3 Cost of carbon emissions

Through detailed monitoring of the specimen site, we can illustrate the variance in financial impact, in terms of cost for carbon emitted, from both kerosene and HVO.

The specimen site has achieved carbon reductions of near 90% over the period of 2022 utilising BRE derived SAP 10.2 HVO CO_2e values.

The following chart calculates the annual financial cost of carbon associated with the specimen site when combusting both kerosene and HVO for heat. The calculations consider the volume of fuel used pre and post conversion and the relative carbon intensity of both fuels taken from SAP 10.2, Table 12 Carbon emission factors, and for illustration purposes applies a CO_2e price of £45.5/t, on 31st July 2023, under the UK Emissions Trading Scheme (UK ETS). See https://ember-climate.org/data/data-tools/carbon-price-viewer/



Energy assessors undertaking an EPC using RdSAP will include HVO from March 2024 to enable HVO updated EPC’s to be produced and SBEM currently doesn’t include HVO for individual non-domestic properties but does include it for heat networks district heating.

7 Case Study 2 - Comparison of heat decarbonisation options for a typical rural UK village - the Kehelland village project

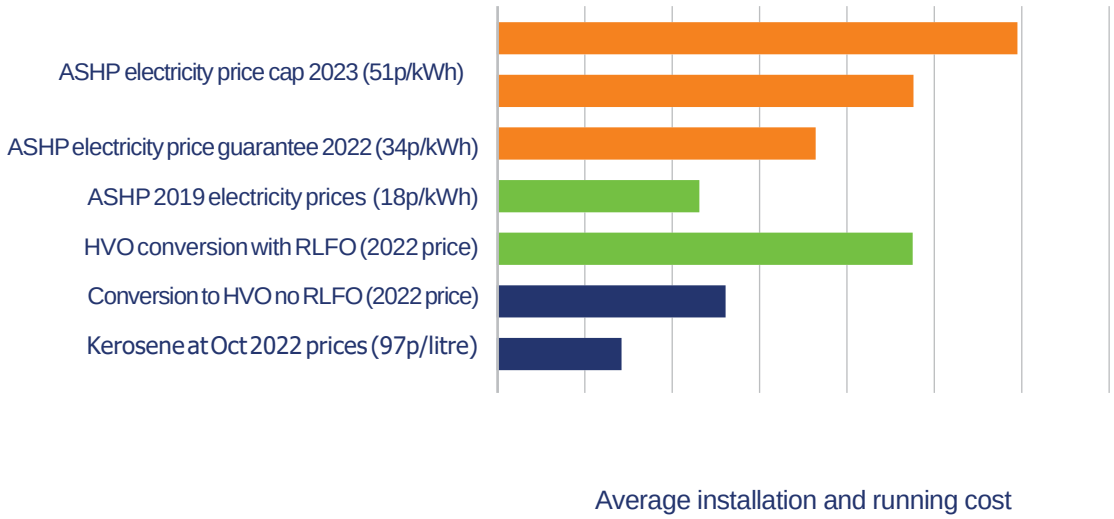
As part of the HVO demonstration project and in addition to technical field work, OFTEC and UKIFDA undertook a detailed comparison of the heat decarbonisation options for 17 homes in the Cornish village of Kehelland that participated in the project.

We compared the capital and running costs for converting the homes from oil heating to either HVO, or an air source heat pump (ASHP) (the government's preferred decarbonisation option), modelled over a 15-year period. The cost of carbon saved was also calculated for each option.

Conversion costs for the HVO option were taken from the demonstration project results for the homes, which averaged £500. The ASHP installation costs for each home were taken from the Department for Energy Security and Net Zero (DESNZ) heat pump checker tool, which outlines the costs of the heat pump and any associated insulation requirements. Costs to dispose of the existing fuel tank, address the coastal location, and for redecoration were added and an average ASHP capital cost of £23,940 was then used for the comparison.

The modelled running costs reflected the changing cost of kerosene and electricity during the period 2019 – 2023. HVO was modelled at the 2022 price (£1.74ltr), and at a lower cost to reflect a proposed Renewable Liquid Fuel Obligation (RLFO) policy intervention and the removal of duty. Heat demand was averaged for the 17 homes (18,573 kWh), and the heat pump was assumed to have an assumed efficiency of 280%, while the boiler was assumed to be 90% efficient.

Average cost of decarbonisation options for homes in Kehelland village compared to existing heating (kerosene)



Project results

- HVO conversion with the benefit of the RLFO is the cheapest decarbonisation option over 15 years.
- HVO conversion has the lowest upfront investment requirement.
- HVO has the lowest cost per tonne of carbon saved under all scenarios.
- Under all scenarios at 2019 kerosene heating oil prices, all decarbonisation options are more expensive than the existing kerosene heating oil.
- Without government policy changes, HVO would be uneconomic compared to the 'do-nothing' option.
- ASHP results are very sensitive to the electricity price. At today's electricity price, the ASHP option over 15 years would be 50% more expensive than HVO.

Implications for policy

Until recently, the government's policy approach proposed that, from 2026, households off the gas grid would no longer be permitted to install boilers fuelled by fossil fuels and would, in most cases, be required to install a heat pump if their boiler is replaced.

In this project, all decarbonisation options were more expensive over a 15-year period than the cost of kerosene heating oil at pre-pandemic, pre-Ukraine invasion prices (2019). However, all the houses reviewed in our project required significant additional retrofit work to install a heat pump, resulting in an average upfront cost of £23,940. This is likely to be beyond the means of most off-gas grid households and represents a significant barrier to decarbonisation.

Renewable liquid fuels offer a potentially attractive alternative solution, requiring minimal conversion disruption and low upfront cost. However, unless the fuel cost is reduced through a Renewable Liquid Fuel Obligation - as it is for operators of vehicles, mobile machinery, and aircraft - and duty is removed, the running costs are likely to be too high to be attractive to consumers.

Our comparison showed there is a cost advantage, particularly upfront, for a HVO based solution which employs a new Renewable Liquid Fuel Obligation. Additional carbon reduction and fuel usage savings can be achieved by fitting insulation measures, but the payback periods extend beyond 15 years. HVO also offered the lowest cost per tonne of carbon saved.

To support the rollout of heat pumps off the gas grid at scale, significant additional government financial support will be needed to cushion consumers from the very high upfront cost once any recommended insulation measures are also included. By contrast, the financial support required to deploy HVO requires no state funding while providing consumers with a welcome additional choice, and a more easily adopted and cheaper solution.

Recommendations based on the Kehelland research.

The modelling undertaken allowed us to identify two policy changes that would enable HVO to be offered as a viable and attractive alternative to an air source heat pump for existing oil heated buildings such as the homes in Kehelland.

1. Bring the fuel duty rate of HVO for heating in line with that of kerosene heating oil.

2. Create a mechanism (termed in this report as the Renewable Liquid Fuel Obligation - RLFO) which would extend or mirror for home heating the current provisions within the Renewable Transport Fuel Obligation (RTFO) which creates a price reduction for HVO to end users of vehicles, mobile machinery, and aircraft.

8 Consumer engagement

During the life of the project, we conducted a consumer engagement exercise to ascertain attitudes to decarbonisation.

1,503 households on oil heating across the UK took part in a survey, which was conducted by the Future Ready Fuel campaign. Responses were invited on 16 questions. Questions 1 through 6 gained an insight into the respondent's geographical region, types of house, number of residents, etc. Notable outcome from the remaining questions include.

- Double glazing and loft insulation were the top two insulation measures at 91% and 88% respectively. The installation of cavity wall insulation was the third most popular measure at 45% of homes.
- Asked if HVO should be incentivised for heat in the same way as transport, 98% of respondents agreed.
- Asked how HVO should be prioritised across four sectors of the economy, respondents selected home heating, followed by vehicles, aircraft and mobile plant/machinery.
- Asked who should decide what heating technology should replace existing equipment when the time comes, 97% opted for "I, as the homeowner (or landlord) should be given choice".
- 96% of respondents are interested in reducing carbon emissions.
- Asked to prioritise in order of importance the factors relevant to replacing a heating system, minimal running costs featured as the top priority. This was followed by achieving comfort in the whole home, low up front cost, reducing carbon, ease of installation and finally, access to government funding.
- Asked to indicate how much people would be willing to spend up front to install a low carbon technology, the top answer was 'up to £5,000' (39%).
- From a range of low carbon technologies available to replace an oil boiler, 88% selected to convert an existing oil boiler to run on a low carbon liquid fuel such as HVO.
- On being advised that government proposals indicate oil boilers will not be permitted to be fitted in the UK after 2026, 95% felt there should be a greater choice of affordable technologies available to households.
- On being asked how well they think the UK government has kept off grid homes and businesses informed of decarbonisation plans, 63% replied 'extremely poorly', with a further 33% stating 'not very well'.

From the results, we can conclude that the homeowners have the desire to decarbonise their home heating. Some buildings are more challenging due to current insulation measures, people want choice and affordability and a very high proportion favour keeping a liquid fuelled boiler operating on a low carbon fuel such as HVO.

9 Project conclusions

The number of sites converted during the project, the diversity of appliance types, fuel storage tanks and ancillary equipment is representative of the diverse nature of oil installations throughout the UK.

All buildings included in the trial were converted successfully and remarkably few problems were encountered. Those that were identified were investigated, the cause determined, and a satisfactory solution proposed or achieved. This concluded that the project has been successful in demonstrating HVO as a viable option in displacing the use of fossil fuel heating oil and provided a high level of confidence that HVO can be deployed as a “drop-in” replacement for kerosene in existing liquid fuel heated buildings.

For the cohort of buildings, an 88% CO_2e saving can be achieved simply by converting existing appliances to operate on HVO.

The fuel distribution network has demonstrated its capability to provide renewable liquid fuel to the point of use, albeit via IBC at some sites. Fuel delivery via tanker is predicted to increase, and IBC delivery will diminish as HVO is delivered to an increased number of buildings.

For buildings that require a boiler replacement, or where an existing appliance is shown to be inefficient, investment in modern technology will enable additional fuel and emission savings to be achieved, with minimal disruption and moderate capital investment. The specimen site achieved carbon reductions near to 90% over the period of 2022, based on BRE derived SAP HVO CO_2e values.

The environmental benefits of transitioning from kerosene to HVO as a heating fuel presents a significant environmental advantage. HVO is a renewable and sustainable energy source, resulting in lower carbon emissions and reduced impact on climate change. This move aligns with global efforts to combat climate change and reduce greenhouse gas emissions.

By using HVO, we can reduce our dependency on fossil fuels like kerosene. As HVO is derived from waste vegetable oil, animal fats and unsuitable feedstocks, it offers a more secure and sustainable source of energy, which can help mitigate the risks associated with fluctuations in oil prices and supply disruptions.

Switching to HVO for heating purposes will lead to improved air quality, as it produces fewer pollutants compared to kerosene. This can have direct benefits for public health by reducing respiratory problems and other illnesses associated with indoor air pollution.

HVO is technically compatible with existing liquid fuel heating boilers designed for kerosene through a simple conversion. This means that homeowners and businesses can make the transition without the need for expensive upgrades to alternative heating systems, making it a practical choice for many.

The drop in HVO as a kerosene replacement reflects broader market trends and government policies promoting sustainable and clean energy sources. This transition is in line with the growing momentum towards cleaner and more efficient heating options.

While HVO may initially have a higher price point compared to kerosene, the long-term benefits, including potential energy savings, reduced maintenance costs, and environmental advantages, can make it a cost-effective choice over time.

Providing consumers with the option to use HVO as a heating fuel allows them to make more sustainable and eco-conscious choices. This aligns with consumer demand for cleaner energy sources and can contribute to a positive brand image for companies offering HVO as an alternative.

In conclusion, HVO as a “drop in” replacement for kerosene in heating systems represents a significant step toward a more sustainable and environmentally friendly energy future. It offers numerous advantages, including reduced carbon emissions, improved air quality, and energy security, while also being compatible with existing infrastructure. As we continue to prioritize sustainable energy solutions, HVO emerges as a promising option for cleaner and more efficient heating.

10 Recommendations

The HVO demonstration project should continue but could be scaled down leaving a variety of properties located in selected areas of the UK. OFTEC are satisfied that the project has confirmed that HVO is a reliable drop-in replacement for HVO. However, continuation of the project, perhaps in a reduced form, will provide further evidence and confirmation of its success. Continuation may provide further information about equipment performance, longevity and any effects relating to material compatibility can be observed over time. To date, as highlighted in this report, there have been no harmful effects or impacts reported using HVO in any region of the UK.

Importantly, keeping the demonstration going provides a strong public perception and confidence which is politically useful to positively influence regulatory decisions. This will also help to continue to attract media attention and send signals to investors, such as manufacturers and distributors, that HVO is viable for the long term.

To keep industry informed, OFTEC must continue to revise its training material, field guides and its HVO Handbook in line with any learning that comes out of extended firing on project sites. One of the main observations is that OFTEC will need to emphasise to technicians the importance of ensuring fuel storage tanks are correctly emptied and cleaned at the time of conversion, to minimise the risk of pollution by carefully disposing of and removing the presence of contaminants in liquid fuel storage tanks.

OFTEC must assist in finding a solution to recognise HVO in the EPC calculation methodology. [see previous comment on RdSAP and SBEM]

UKIFDA must continue efforts to find a fuel marker dye which does not cause binding when on contact with HVO and stored over long periods of time.

OFTEC and UKIFDA must work with policy developers across government departments to address the current disparity in the price of HVO relative to its use. HMRC must recognise HVO as a heating fuel for taxation and duty purposes and an RLFHO will be required to bring the price down to be comparable with kerosene.

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