A Review of the Irish Residential Heating Sector

The Impact of Bioliquids and other Emissions Reduction Measures

Prepared for: OFTEC Ltd.
Shared by: OFTEC Ltd.; Fuels for Ireland; and UKIFDA

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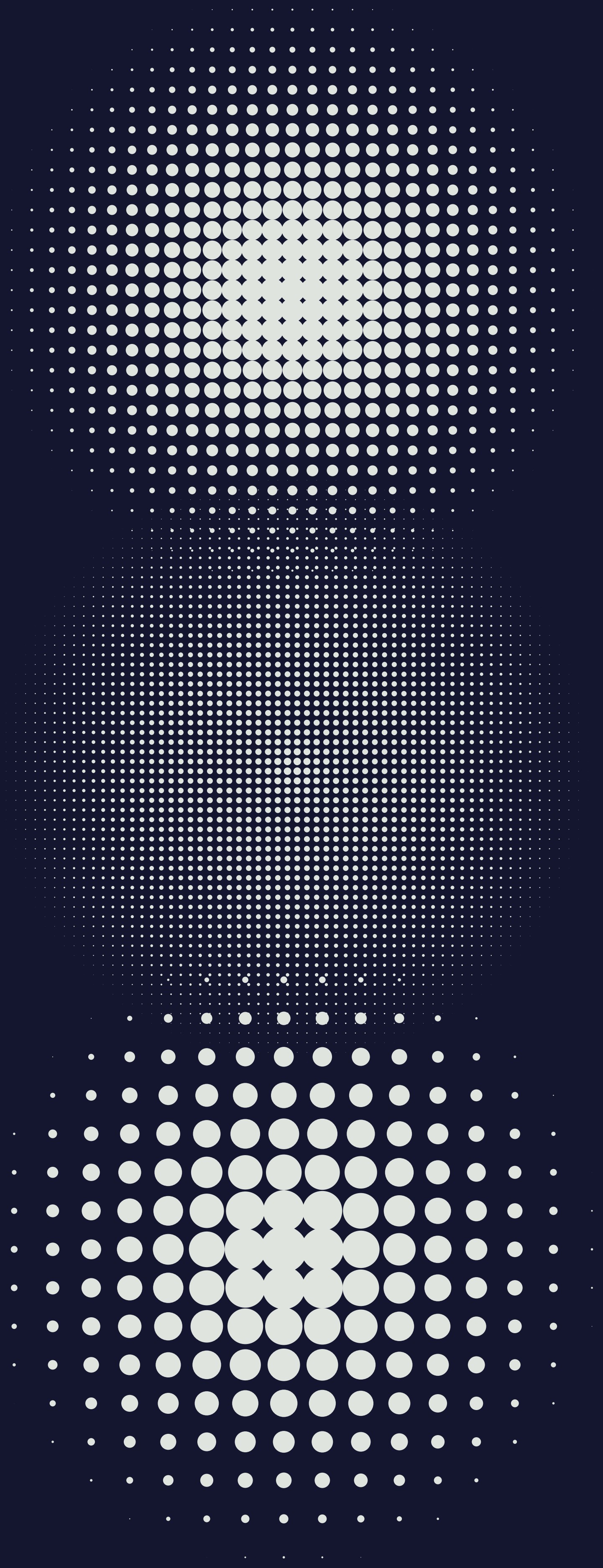

Ireland, as all signatories to the United Nations Framework Convention on Climate Change, have a set of targets and legal obligation to reduce emissions.

Executive Summary

The residential sector was responsible for 10.2% of Ireland's total greenhouse gas emissions in 2018. Of the total energy consumed by the residential sector, 80% was used to generate heat – either for water or heating space. According to the 2016 Census, there were 2,003,645 dwellings in the Republic of Ireland, approximately 1.7 million of which are occupied. Approximately 686,000 of these dwellings, or 37% of Ireland's housing stock, are currently heated using oil-heating (kerosene).

There are plans to decarbonise this residential stock of buildings. Currently, the target in the Government's Climate Action Plan and Programme for Government 2020 is to complete 500,000 building retrofits to achieve a B2 BER Standard by 2030, and to install 600,000 heat pumps, 400,000 of which are to be in existing buildings. These measures, if achieved, will only impact a portion of the housing stock. It is also not evident that the least efficient dwellings (in terms of energy rating) will be prioritised, or that owners/occupants of kerosene heated dwellings will be incentivised to switch to an alternative fuel source.

To date, government policy has focused heavily on electrified heat as the solution to decarbonisation, and there has been little to no discussion about the merits of switching from kerosene to bioliquid as a viable option for reducing emissions in a cost-effective manner.

Key findings of the report include;

1. This report identifies that the use of bioliquid blends in existing kerosene-based home heating systems is a viable transition away from complete reliance on kerosene oil and offers significant carbon savings in a short time frame.

2. The analysis found a 50% bioliquid/kerosene blend would be optimal for the transition, in terms of attaining significant emission reductions while remaining affordable for households with minimal disruption. Additionally, replacing boilers in a large number of homes using existing well understood technology could mean a yearly reduction in fuel usage of up to 22% for each household.

3. Of the bioliquid based options for heating, Hydrotreated Vegetable Oil (HVO) would deliver the greatest reduction in carbon emissions, at 86% per household (currently using kerosene) over a 10 year period.

Bioliquids in the Residential Heating Sector

2 million dwellings in Ireland **Residential Sector** makes up **10.2%** of Ireland's total CO_2 equivalent emissions.
80% of energy in dwellings is used for heating space and water.

37% of dwellings use **Oil**
48% of heating is dependent on oil, whereas it comprises **38%** of all energy sources used in dwellings.

Kerosene (home heating oil) was responsible for **1,055 $KTCO_2eq$** in 2017.
Estimated **386,004** non-condensing boilers in use.
Switching to condensing boilers could result in **reduction of up to 22%** fuel consumption per unit.

Potential emission reductions per dwelling identified in switch from oil to bioliquids;

Hydrotreated Veg. Oil	**86%**	↓
Bioliquids blend B50K *	**41%**	↓
Bioliquids blend B30K **	**23%**	↓

Ireland not on target to meet emissions reduction obligations

Bioliquids are a viable alternative to transition to low carbon, especially in short to medium term

Bioliquids are a cost effective solution from household and emission reduction perspective

B50K biofuel blend is optimal blend to focus on, with the *lowest net costs* for society

Until electricity production is significantly decarbonised, heat pumps are not a solution to reducing residential sector emissions

* B50K refers to a fuel comprised of 50% Fatty Acid Methyl Ester (FAME) and 50% kerosene
** B30K refers to a bioliquid mix of 30% FAME and 70% kerosene

Calculated over a 10-year period, dwellings with kerosene oil have the highest emissions out of the alternative heat sources considered in this report, and hence the desirability of a switch away from kerosene use, from a carbon reduction perspective. The figure below shows a selection of costs at a single household level that kerosene users face, which will affect their choice of switching away from kerosene to other energy types for heating their dwelling. The estimates below are based on a set of assumptions regarding average household energy needs and size for comparative purposes, but we do acknowledge that many factors influence heating demand. We also acknowledge that the emissions values associated with air source heat pumps could change through switching to renewable energy for electricity.

Household Choices: Fuel Options for oil heated dwelling	Energy Efficiency of fuel in heating system (%)	Total Tonnes of CO_2 equivalent emissions per dwelling over 10 years	Household capital and running costs over 10 years	Additional cost faced by each household in switching away from an oil based heating system	Additional net cost for society - carbon costs included
No change/ kerosene	90%*	68	€24,627	-	-
Air Source Heat Pump	260%	53	€29,652	€5,025	€5,048
Wood Pellets	80%	15	€28,836	€4,209	€1,911
Bioliquid Blend (B30K)	90%	52	€23,262	€1,365	€1,899
Bioliquid Blend (B50K)	90%	40	€22,268	€2,359	€3,252
Pure Bioliquid (H100)	90%	10	€34,341	€9,714	€5,023

*note costs presented in this figure are for a 90% efficient boiler. Not all boilers in operation are so efficient, and this is explored further in this report.

There may be reluctance from households to switch away from oil, given that this is the least expensive option to heat their dwellings – any switch will incur a cost to the household. The well-established nature of existing technologies can be a formidable barrier for switching to a low carbon economy.[1]

It is expected the proportion of oil heated houses will decline in the future, as the installation of oil heating systems in new homes is no longer permitted. However, it is not expected that the number of homes using oil heating will decline significantly, as there are barriers for homeowners to switch away from well-maintained, fully functioning oil heated systems, despite incentives offered.[2] The cost of installing the oil heated system is a sunk cost,[3] borne at the time of construction or renovation of the dwelling. The dwellings that use oil for heating currently account for 38% of emissions associated with the total energy used in the residential housing sector.

There is the potential to reduce the emissions associated with oil heated domestic dwellings that does not require significant capital investment for the homeowner in switching to different heating technology. Kerosene users could switch to bioliquid blends, that are comprised of Fatty Acid Methyl Ester (FAME) biomass compounds, that can be blended with kerosene (in differing concentration).

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[1] SEAI (2020) Identify the barriers facing homeowners in adopting heat pumps, citing the tendency to continue using an existing heating system until it breaks down, while then replacing it with the same technology – a resistance to change. https://www.seai.ie/publications/Heat-Pump-Adoption.-Maximising-Savings.pdf

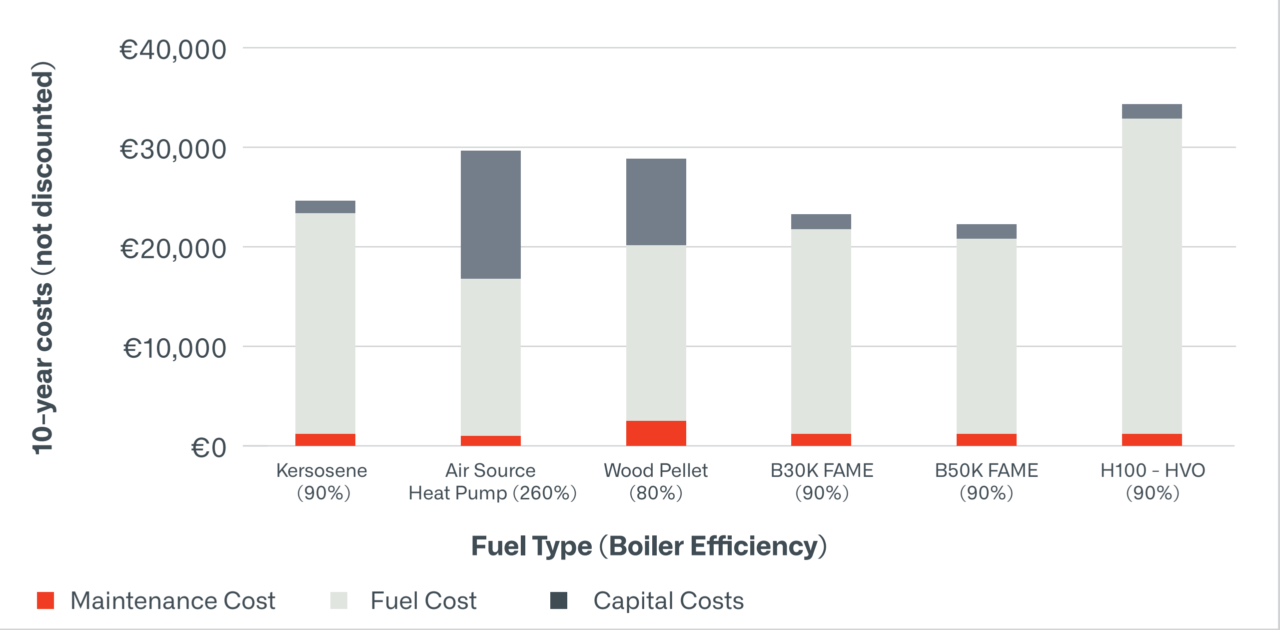
[2] These include: the Better Energy Homes Programme; and in the Energy Efficiency Obligation Scheme (2020-2030) there was a significant increase in the level of monetary support for heat pumps via the energy credits

[3] In economics, a sunk cost refers to money that has already been spent, with no potential for recovery in the future. Decommissioning an asset, such as a heating system, while it still is functional is an example of a 'sunk cost,' and is important to consider when measuring whole life costs and replacement technologies.

If an oil-heated dwelling switches away from kerosene but uses the existing heating system, a 50% FAME/kerosene bioliquid blend (B50K) is the least costly alternative for the homeowner, in comparison to installing or upgrading the boiler and heating systems. This would result in carbon emission reductions from a kerosene heated household of approximately 41%, calculated over a 10 year period. The best option for reducing the carbon emissions from kerosene heated houses is the switch to pure bioliquid, or Hydrotreated Vegetable Oil (HVO), which would result in a reduction of carbon emissions of approximately 86% for that household, as measured over 10 years.

The advantage of switching to bioliquids from kerosene is that it does not require significant capital investment from the homeowner. The analysis shows that bioliquid alternatives have lower switching costs for households with oil-based heating systems, less than either air source heat pumps or wood pellet alternatives. The cost comparison for a typical dwelling that uses oil is shown in the figure below.

Comparison of user costs for different heating systems, 2020 - 2030

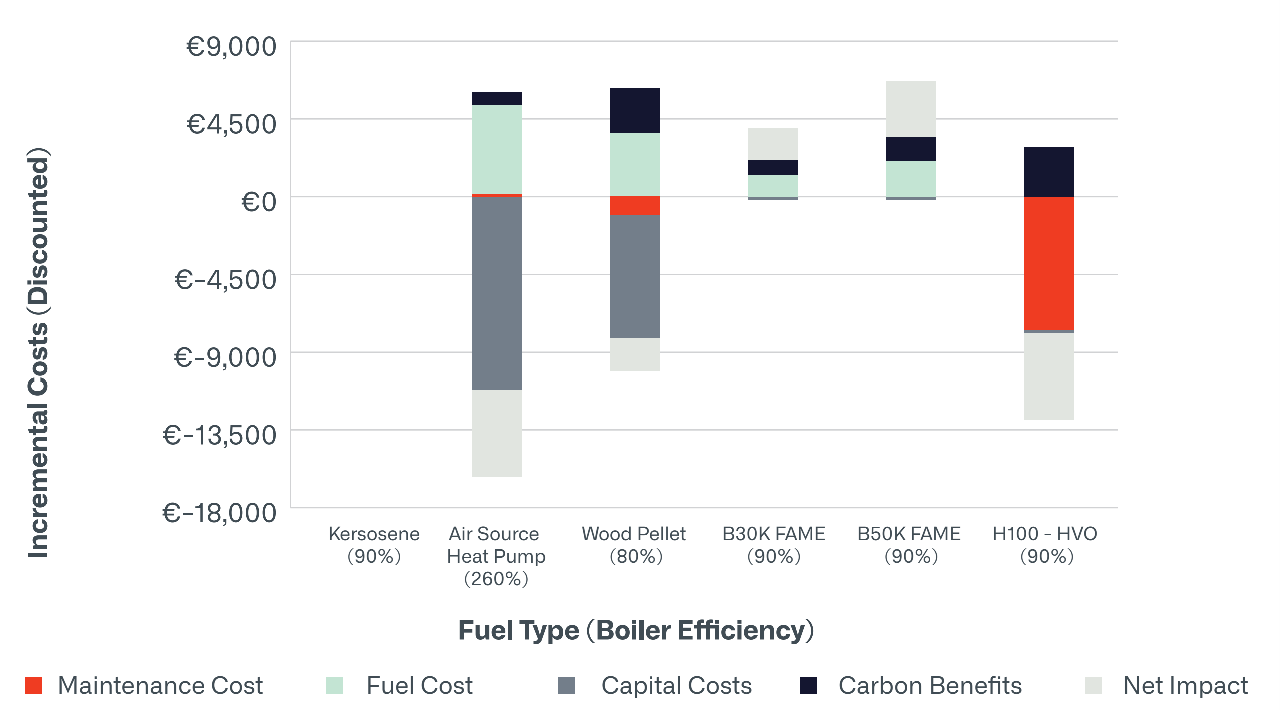


Pure bioliquids were found to have lower associated emissions than wood pellets and air source heat pumps, and have a lower cost (for installation and maintenance) as measured over ten years. However, the higher fuel cost associated with H100 would cause it to become less cost-effective than these alternatives over time, unless action is taken to reduce these costs significantly.

Looking at the options from a societal perspective, it is possible to incorporate the shadow cost of carbon into the analysis (shown as carbon benefits, represented in green in the figure below). The analysis focuses on the options for oil alternatives, therefore oil use is taken as the baseline against which changes are measured. Both costs and benefits for oil dwellings to switch to alternatives is shown in the figure and the black dots show the net societal cost, again for a typical oil household, of switching away from oil.

Bioliquid blends were found to be the best value alternative for current kerosene users and provide carbon reductions on par with air source heat pumps. If and when electricity generation switches to renewable resources, the emissions associated with heat pumps will reduce. Bioliquid blends provide an opportunity to balance cost and carbon savings in the short term. The cost of pure bioliquid (H100) is currently too high, rendering it unlikely that individuals would switch to its use without Government support, although HVO is on the market in Belfast and Dublin currently, with ongoing trials and testing occurring. The market for bioliquid is in its nascency, and the industry would benefit from clear government signalling on the role of bioliquid in the residential sector; as a plausible solution to transition to a low carbon economy.

Net Costs and Benefits of switching away from kerosene, over period 2020-2030



Source: AECOM analysis

Clear signalling, or 'a nudge' is required from the government to encourage consumers to adopt bioliquids as an alternative to kerosene. The quicker this occurs, the less carbon that will be emitted, contributing to Ireland's reduction in carbon equivalent emissions. The end goal of this phasing process should be to remove all fossil fuels by 2030.

Current constraints in moving to a low or near zero carbon residential sector include the reliance on fossil fuel for electricity generation, which is required for air to water heat pumps. Although the proportion of renewable energy used in electricity is increasing, there are still considerable carbon equivalent emissions associated with electricity use.

The use of bioliquid blends in existing kerosene-based home heating systems is a viable transition away from complete reliance on kerosene oil. The analysis found a 50% bioliquid/kerosene blend would be optimal for the transition, in terms of attaining significant emission reductions while remaining affordable for households.

While we acknowledge the government has signalled an end-date for fossil fuels in home heating, there is an argument to be made to upgrade conventional boilers to condensing boilers – as there are fuel savings and hence emission reductions associated with that switch. Providing a total ban for kerosene use by 2030 will ensure that all replacement boilers will be compatible with pure bioliquids in the future, and will reduce incentives to continue the use of fossil fuel blends. It will encourage suppliers and others to invest in research and development to bring the cost of pure bioliquids down for consumers.

1. Rationale, Purpose and Objectives

1.1. Rationale

AECOM was commissioned by OFTEC to undertake an analysis of the potential for bioliquid substitution in residential home-heating systems in Ireland. The residential sector was responsible for 10.2% of Ireland's total Greenhouse Gas emissions in 2018.[4] Winter heating demand is the most important variable determining emissions from this sector. Home heating oil, or kerosene, is estimated as the primary source of heat for at least 37% (324,424) of dwellings.[5] Oil was responsible for 38% of emissions (Carbon Dioxide, or CO_2 equivalent) from home heating (see Table 1). Oil is predominantly used to heat water and space in dwellings.

There are alternatives to the use of kerosene, without requiring homeowners to switch to new technologies, or face the costs associated with capital investment or replacement of existing functional water and heating systems. Given that the installation of air source heat pumps often requires a deep retrofit process to be undertaken, and given that the average cost of a full-scale deep retrofit in 2020 was €56,000,[6] it is vital that these alternative options are thoroughly examined.

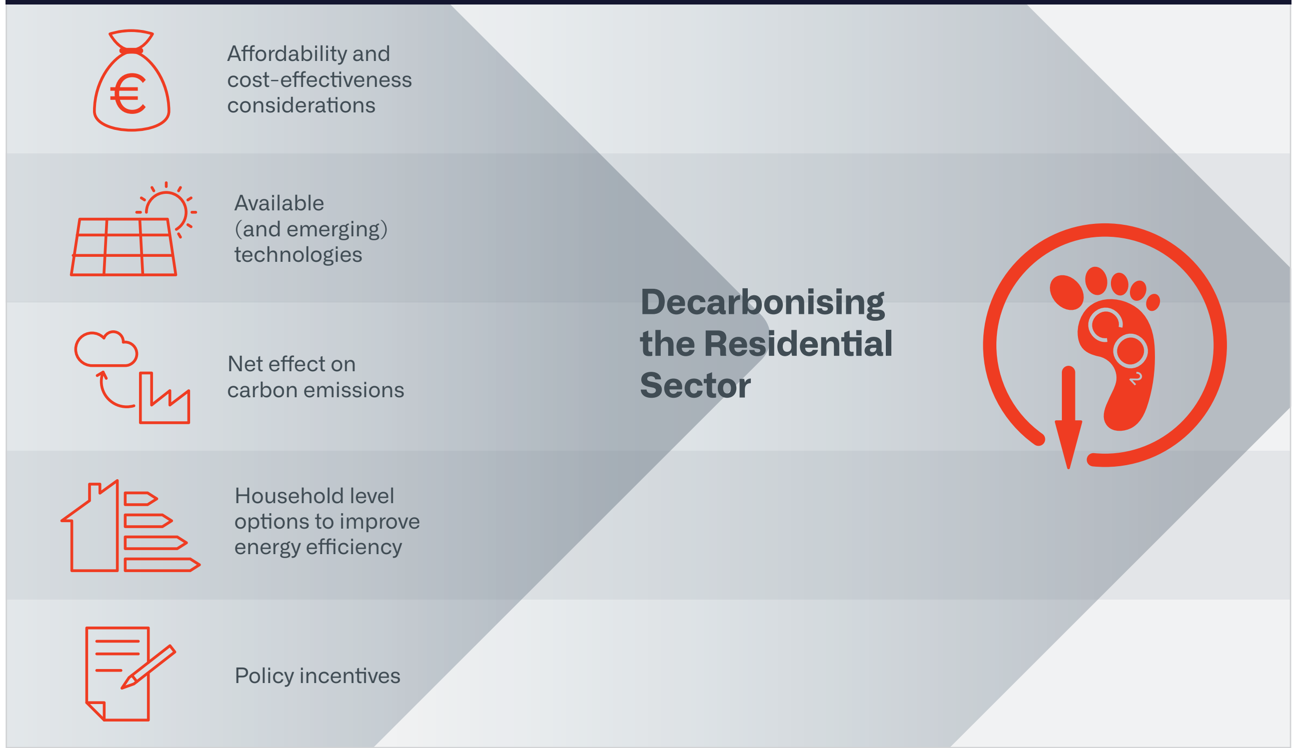
In particular, there is an option to switch from kerosene to completely substitutable bioliquids such as H100 (hydrotreated vegetable oil), or a blend thereof. The cost of H100 is the highest of all bioliquid options examined, but bioliquid blends are more affordable. B100 FAME (derived from a mixture of used cooking oil and animal fats) is not compatible with domestic boilers/heating systems, but it can be blended or mixed with kerosene. As with the introduction of biodiesel for vehicle fuels, there are opportunities for blending kerosene with B100 and H100 in various strengths. There are clear potential CO_2 savings from transitioning from kerosene to other home heating methods, at least for a transition period to a low carbon society, as kerosene use is phased out.

Every property in Ireland needs a Building Energy Rating (BER) certificate prior to going on the market for sale or for rent.[7] Under the European Union (Energy Performance of Buildings) Regulations 2012 (S.I. 243 of 2012). The Sustainable Energy Authority of Ireland (SEAI) is designated as the Issuing Authority with responsibility for the BER scheme. There is a focus on energy efficiency, building performance and increased awareness and measurement of associated CO2 emissions from homes and dwellings.

The Climate Action Plan (Government of Ireland, 2019) focused on a range of actions across many sectors to decarbonise the economy. Measures identified in the Climate Action Plan that will allow the residential sector to decarbonise include the planned ban on the installation of oil boilers by 2025 and plans to retrofit 500,000 homes to a B2 BER Standard by 2030. Both measures have the potential to improve the carbon efficiency of residential heating in Ireland significantly, however, there are many unanswered questions with the Climate Action Plan:

1. What is the pathway provided for the remaining 1.2 million homes which currently exist in Ireland (outside of the planned 500,000 retrofits)?
2. Which houses are prioritised for the planned retrofit (in terms of their BER rating), and what is the intervention logic for this selection?
3. Despite clear guidance on the ban of installing oil boilers in new homes, what is the guidance on the existing boilers currently in use in at least 37% of dwellings?[8]
4. What are the motivations and incentives to switch technologies within homes, and have these transition pathways been evaluated?
5. What additional extra cost is the government expecting households to bear, in the switch to alternative home heating systems?
6. What is the evidence base for the measures relating to decarbonising the residential sector, and have a range of options been properly considered and costed for the measures?
7. Have the distributional impacts of the measures to reduce emissions from the residential sector been taken into account, in terms of affordability of retrofitting and/or switching toward technology?

Figure 1: Variables to consider in decarbonising the residential sector



This report:

- Provides an overview of the Irish Residential heating sector;
- Contextualises Irish decarbonisation targets;
- Examines EU policy on biofuels and bioliquids;
- Quantifies the potential savings which could be achieved in switching to bioliquids at a household level and from a societal perspective;
- Calculates the carbon savings which could be achieved by upgrading oil boilers in Ireland.

1.2. Methodology and Assumptions

This report was prepared using secondary sources of data and officially published statistics. Information was obtained from several sources with data on how energy is consumed for residential heating and emissions associated with different fuel types. Converting energy use (Kilo Watt hours) to equivalent fuel source (quantity of oil equivalents) is of central importance in the methodology, given the differing metrics used in datasets. As for any heating systems, the amount of energy required depends on the size of space that is being heated along with thermal properties of the structure. All dwellings in Ireland vary in size, age, materials used and heating systems. Each building has unique characteristics, which make it difficult to typify an 'average' dwelling. It was imperative to convert values for comparison of the options and scenarios, and a set of assumptions was used in the analysis. The calorific values for each fuel type enabled this comparison, and SEAI conversion factors were used.

A methodology to measure the costs and benefits of bioliquid substitution for kerosene oil in the Irish residential sector was developed. This report details the various steps required to this end.

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[4] Environment Protection Agency (2020). Greenhouse Gas Emissions. http://www.epa.ie/ghg/ accessed August 19th, 2020.

[5] This figure is taken from CSO (2020) data on the number of oil heated houses recorded on BER evaluations in the period 2009-2020. (CSO, 2020). Note however, that older houses that are not offered for sale or rent are not counted in this figure, nor are exempted buildings (protected structures and temporary buildings). Older houses are more likely to be oil heated.

[6] SuperHomes (2021) SuperHomes Cost of Works. https://superhomes.ie/ accessed August 31st, 2021.

[7] A Building Energy Rating (BER) certificate measures the efficiency of a dwelling by calculating the CO2 emissions and kWh /m2/year of the property.[8] SuperHomes (2021) SuperHomes Cost of Works. https://superhomes.ie/ accessed August 31st, 2021.

[8] CSO 'Household Environmental Behaviours – Energy Use Quarter 3 2021' (2021) https://www.cso.ie/en/releasesandpublications/er/hebeu/householdenvironmentalbehaviours-energyusequarter32021/ Accessed November 19th, 2021.

The analysis provided an estimate for the number of dwellings still heated by the less efficient conventional boiler systems, which would benefit from the installation of condensing boilers to improve fuel efficiency. These estimates are contained in the appendix.

A literature review was undertaken, along with an appraisal of recent Irish and European policy to inform the options and scenarios. Several strategies and directives were examined to provide context for the report. A set of high-level decarbonisation scenarios are explored, and an assessment of the feasibility and cost of each scenario developed.

Costs were developed for individual households (using assumptions to generate the costs facing an 'average' Irish household – while acknowledging that there is a great variance in size, efficiency, energy use etc). Costs were also developed for society, by incorporating the cost of carbon into the analysis (using the shadow cost of carbon). The costs of transitioning to the different scenarios are measured against a baseline of energy used by oil dependent dwellings in the residential sector. Thus, the inevitable switch away from the current dependency on oil is not contested, as per the imperative to switch away from fossil fuel use in addressing climate change.

2. An Overview of Energy use in the Residential Sector

Key Messages

- The most significant opportunity for decarbonisation in the Irish residential sector is to reduce emissions associated with the heating of space and water.
- The residential sector has the potential to reduce its total emissions by 90% - through upgrading all dwellings to A1 standard. In practice this is unaffordable.
- 686,000 residential dwellings use kerosene oil.
- There is the potential of fuel substitution (substituting kerosene with bioliquid) as a bridging technology.

2.1. Introduction

The residential sector was responsible for 10.2% of Ireland's total greenhouse gas emissions in 2018. Of the total energy consumed by the residential sector, 80% of it was used to produce heat. Oil is used for heating space and water. It is the largest source of energy used in Irish dwellings, and it accounts for 38% of CO2 equivalent emissions from all energy sources used by the residential sector. According to the most recent census, approximately 686,000 residential dwellings are currently heated using kerosene oil (CSO, 2016).

Table 1: Final Residential Energy Demand by End-Use and Source, 2017, kt CO_2eq

Energy Source	Space Heating	Water Heating	Cooking	Lighting and Appliances	Other End Uses	Total	Energy Source as % of Total
Oil	819.68	234.87	-	-	-	1,055.55	**38%**
Electricity	68.06	82.45	49.01	477.47	25.96	702.95	**25%**
Gas	431.82	157.85	14.43	-	-	604.09	**22%**
Solid Fuels	324.24	31.99	-	-	-	355.23	**13%**
Renewables	43.24	25.14	-	-	-	63.38	**2%**
Subtotal Energy Source	**1686.04**	**532.30**	**64.44**	**477.47**	**25.96**	**2,786.21**	**100%**
Oil as % of total	**48%**	**44%**	-	-	-	-	-
Energy use as % of total	61%	19%	2%	17%	1%	100%	-

Source: (SEAI, 2020)

2.2. Energy Consumption in the Irish Residential Sector

In carbon dioxide equivalents (CO_2 eq.), residential energy consumption was responsible for 2,786 kilo tonnes of carbon equivalent (kt CO_2eq.) emissions in 2017 (SEAI, 2020). This energy was used for a range of purposes, and the primary source of that energy came from a range of forms, including solid and liquid fuels and renewables. Electricity, a secondary source of energy, is generated by a mix of primary sources.[9] The choice of energy use at a household level is dependent on the age of the dwelling and extent of upkeep/renovation, available technology at the time of building or renovation, proximity and availability of reticulated energy systems (electricity and gas). Table 1 provides a breakdown of how energy was consumed and how it was produced in the Irish residential sector for 2017 (SEAI, 2020).

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[9] In conventional thermal electricity generation, typically 60% of energy is lost as waste heat, while there is a further 7% to 8% lost in transmission (www.seai.ie and eirgridgroup.com)

2.3. Decarbonising Home Heating

Setting aside the challenges of decarbonising the national electricity grid in a timeframe that could enable the electrification of domestic heating (thereby reducing residential emissions), there are three main options (albeit simplified) available for homeowners to decarbonise home heating, namely:

- Reduce heat loss
- Better control the heat produced
- Decarbonise heat production

2.4. Condensing Boilers and Emission Reduction

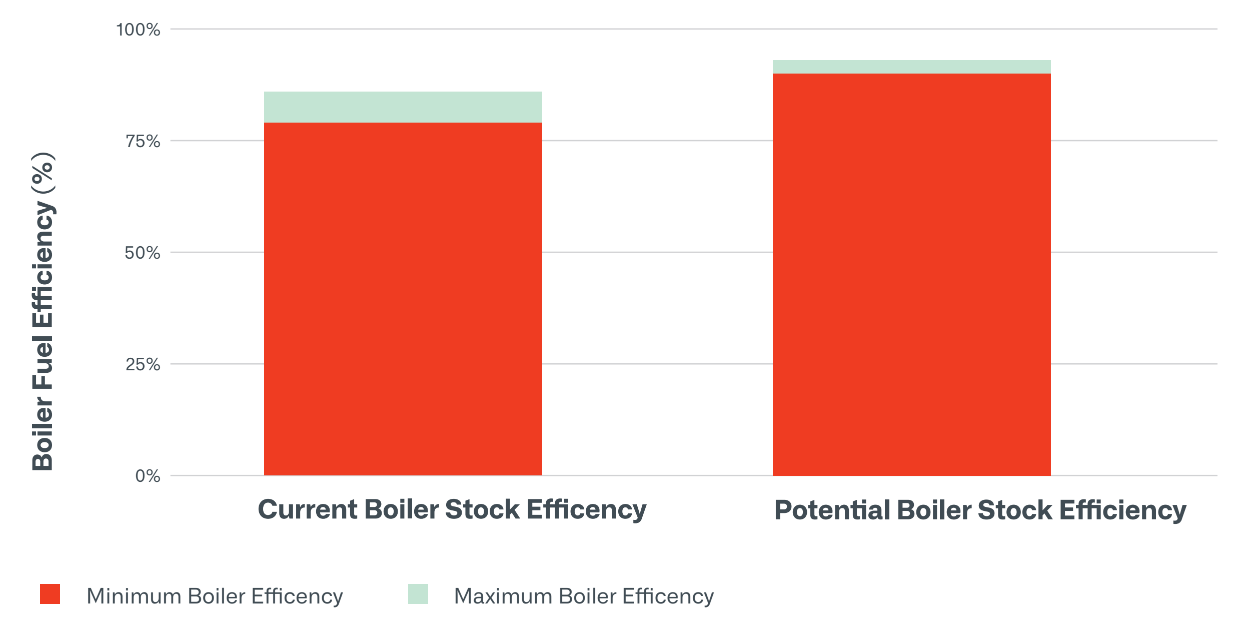
In an oil boiler, fuel is ignited in a combustion chamber, which produces hot combustion gases. The heat energy contained within the gases pass through a heat exchanger and the heat is given up to water that passes over hot surfaces in contact with the combustion gases. The heated water is then pumped around a heating system to where the heat is then further transferred for space or water heating.

A conventional boiler burns fuel to produce hot gases which pass through a heat exchanger, where a significant portion of the heat is transferred to water, raising the temperature of the water. Condensing boilers take additional steps to capture heat from the combustion gases before they exit the boiler and cool the gases to such an extent that moisture in the gases, derived from air, chills to below its dew point and forms condensate, which drains away from the boiler or exits the flue terminal as white plume.

Condensing boilers have been available on the market for approximately the past 15 years and, over this time, have become the standard installation for new and replacement systems. Typical condensing boilers range in efficiency between 90% - 92%.

There is no official estimate of the number of non-condensing boilers still in use in Ireland, but condensing boilers have been available for installation for approximately ten years, and during this time OFTEC estimates that 30,000 condensing boilers were installed per annum. As the 2016 Census identifies 686,000 homes heated by oil, it is estimated that non-condensing boilers continue to heat 386,000 homes.

Figure 2: Boiler Upgrade Potential



Source: AECOM Analysis of (CSO, 2020) and (DHPLG, 2020)

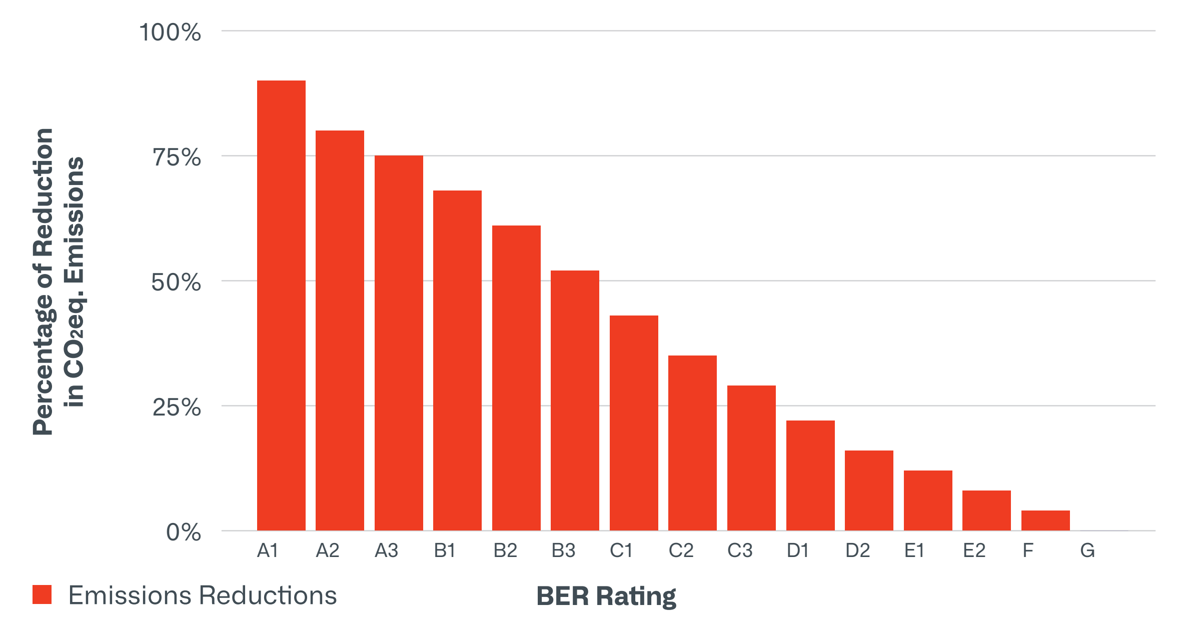
Based on these figures, it is estimated that the average efficiency of existing boilers is between 79 – 86% (Figure 2). As such, upgrading existing conventional boilers to condensing boilers would significantly improve the fuel efficiency of the oil heated housing stock to between 90% – 93%, dependent on which condensing boiler model is installed. The impact on kerosene fuel consumption would also be significant. **The assessment of efficiencies and conversion of non-condensing boilers in this analysis showed a range of a between 6% - 22% potential reduction in kerosene consumed** (and hence cost savings), **based upon minimum-maximum calculations** (see section 6.2).

2.5. Energy Efficiency Ratings

Based upon the observed weighting of BERs (excluding exempt buildings) and the values for CO_2eq. by BER rating, it is possible to estimate the potential CO2eq. savings that could be made by upgrading houses/dwellings.[11] Each BER rating is assigned a kgCO_2/m^2/year and weighted by the national average.

Figure 5 below shows the impact of setting a minimum BER Rating, that is if all homes were upgraded to a minimum standard. For example, SEAI currently seeks to upgrade the Irish housing stock to the B2 standard. If all existing dwellings were to be increased to the B2 standard at minimum, household emissions would fall in total by 61%. If the housing stock were upgraded to A2 standard, 80% of emissions associated with the residential sector could be saved per year. Figure 5 should be viewed from left to right – as the reductions are realised when G-Rating houses are upgraded to F Standard or higher. Interpreting the percentage for C3 in Figure 5, this graph shows that if all houses of Ratings G, F, E2, E1, D2 and D1 were upgraded to a C3 rating, there would be emissions reductions of 29%. Similarly, if all houses were upgraded to the highest Standard – A1 – there would be 90% savings of emissions. This is the maximum potential savings (indicating that there would be some emissions still associated with the residential sector e.g. not zero emissions). However, this argument is hypothetical, as it does not take the cost or feasibility of upgrading the housing stock into account. Nor are the target reductions in emissions set so high for the period of transition to a low carbon society.

Figure 5: Potential Energy Savings (kgCO_2/m^2/Year) if housing stock were upgraded to each BER standard



Source: AECOM Analysis of (CSO, 2019)

The following section reviews the energy and climate policies and targets, along with the EU Renewable Energy Directives which are of relevance to kerosene use. The feasible alternatives to kerosene use in the residential sector are considered (section 4), along with technological efficiency of boiler use in section 5. Scenarios are developed and assessed for their cost effectiveness and emission reduction potential in section 6.

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[10] The electrification of domestic heating systems is not a feasible option for attaining emission reductions within the timeframe specified under the Climate Action Plan. There are legacy investment, infrastructure and time constraints on switching to electrification of domestic heating. See SEAI, 2020. "Generation Renewable: Decarbonising our national electricity & gas grids" https://www.seai.ie/blog/decarbonising-grid/

[11] An assumption is made that house sizes are relatively consistent across BER categories.

3. Energy and Climate Change Policy

Key Messages

- Main EU regulation is the Effort Sharing Decision (ESD) and the Effort Sharing Regulation (ESR)
- National targets were set in 2014 in the National Policy Position for 2050
- Two Renewable Energy Directives were issued REDI (2009) and RED II (2018)
- Ireland's Climate Action Plan published in 2019, but the National Mitigation Plan (2017), which underpinned it, was successfully challenged in the Supreme Court in 2020
- The Climate Action and Low Carbon Development (Amendment) Bill 2020 commits to 5-year economy-wide carbon budgets, starting in 2021
- The Environmental Protection Agency foresees that Ireland will not reach its carbon emission reduction targets

Three sets of targets guide climate change policy in Ireland. The first two of these targets have been established at an EU level, and these are called the *EU Effort Sharing Decision (ESD)* and the *EU Effort Sharing Regulation (ESR)*. These set Greenhouse Gas reduction targets for 2020 and 2030, respectively. The final set of targets were set nationally in 2014 in the *National Policy Position* for 2050. The Irish Government's plan to meet these targets are captured under the umbrella of the *Climate Action Plan* (DCCAE, 2019).

3.1. Climate Change Targets

Communicating climate change targets are often complicated by the inconsistent definition of reductions between targets. For example, targets are measured against differing base years (e.g. 1990 levels and 2005 level), include and exclude different industries (e.g. agriculture), or apply to a narrower range of gases (e.g. CO_2 in physical terms versus CO_2 equivalent). This makes comparison difficult to achieve. To make targets more comparable, in this report all targets were converted to 2005 levels, to ensure 2050 targets are comparable with 2020 and 2030 targets.

3.2. Climate Action Plan

The Irish government's response to the climate crises is identified in the Climate Action Plan. The plan aims to ensure gradual progress on climate goals and unify the government's response. However, in 2020 the Supreme Court ruled that the 2017 National Mitigation Plan was not specific enough to comply with the Climate Action and Low Carbon Development Act 2015 – or that an 80% reduction in emissions could be achieved by 2050 (from 1990 levels). Until the Climate Action Plan (DCCAE, 2019) is replaced, however, it is considered the default position of the government. Overall, the Climate Action Plan sets out 183 actions cutting across every sector of the economy and includes timelines for delivery. However, measures outside the National Development Plan have not been costed. Although emission reductions targets exist for 2020, 2030 and 2050, the action plan focuses on the 2030 targets.

Under the Climate Action Plan, the government has a target to complete 500,000 building retrofits to a B2 standard, at a minimum, by 2030. Currently, less than 6% of 1.7 million Irish dwellings meet this standard. Based on this plan, approximately 500,000 of the existing 1.7million households will be rated B2 or above by 2030, plus any new housing stock constructed according to NZEB regulations. This means there is currently no pathway to lower emissions for 1.1 million households for the period up to 2030.

The Climate Action Plan does not explicitly target any specific subset of houses for retrofitting. The houses which will be upgraded will likely be those on the margins of the B2 Standard if costs only are considered. These houses will have the lowest marginal cost for an upgrade. As shown in Figure 5, there are more potential emissions savings from upgrading a G-Standard dwelling, which produces 4.2 times more CO_2eq. than B3-Standard dwelling per m².

Six of the 183 Actions contained within the 2019 Climate Action Plan are directly related to home heating and bioliquid:

Action 53: Identify additional options for targeted financing for energy efficiency retrofits in the domestic and commercial sectors

Action 60: Effectively ban the installation of oil boilers from 2022 and the installation of gas boilers from 2025 in all-new dwellings through the introduction of new regulatory standards for home heating systems and ensure the supply chain for the installation of renewable heating systems is in place. Enact the NZEB performance requirements in regulation in 2019 to facilitate the effective banning of oil boilers

Action 62: Examine how and when fossil-fuel heating systems could be phased-out of public buildings, including disallowing the installation of any new fossil-fuel heating systems

Action 69: Complete the rollout of the Support Scheme for Renewable Heat (SSRH), including support for biomass and anaerobic digestion heating systems

Action 70: Develop a policy framework for the development of district heating in Ireland and support the delivery of two district heating projects under the Climate Action Fund

Action 128: Support the use of biomass to increase the level of renewable energy in the heat sector.

The intention to move away from fossil-fuel heating systems is clear (Action 62), yet the transition pathways are not set out or given due cost consideration. Action 128 signals the potential for using biomass, which also needs to be considered under the Renewable Energy Directives.

3.5. Renewable Energy Directives

Renewable Energy Directive I

The Renewable Energy Directive I (RED I) was established in 2009. The Directive set a target for the EU to meet 20% of its energy needs through renewable sources by 2020. It also created an overall policy for the production and promotion of energy from renewable sources in the EU.

RED I introduces several measures to:

- Ensure biofuels are not sourced from carbon-rich land or carbon sinks;
- Improve compliance with environmental and social sustainability criteria, when exporting fuels;
- Increase energy efficiency by 20%; and
- Reduce the greenhouse gas lifecycle emissions of transport fuels by 6%.

The legislation is seen as complementary to:

- Fuel Quality Directive (FQD) – 2011; and,
- Consideration of Indirect Land Use Changes (ILUC) – 2015.

The ILUC Targets stated in the ILUC directive complement RED I. Targets outlined in ILUC account for GHG emissions arising from the land-use, as opposed to solely biofuel combustion. It also limits the share of biofuel crops that can be grown on agricultural land as well as several reporting/ethical obligations for fuel providers.

The Fuel Quality Directive was revised in 2011 to harmonise with both RED and ILUC, where it introduced greenhouse gas intensities for fuels used in transport and machinery, reducing them by 6% by 2020.

Renewable Energy Directive II

The Renewable Energy Directive (RED) II is a policy that sets out the framework for the EU Renewable Energy Policy 2021 – 2030. RED II is a revision of RED I which applied to the period 2010-2020. RED II must be transposed into national legislation by EU member states by July 2020 before it takes effect. Key targets set out in the legislation include:

- 35% increase in energy efficiency;
- 35% share of renewable sources in total final energy consumption;
- 12% of renewable energy used in transport; and
- a ban of palm oil by 2021.

One essential aspect of RED II is that it provides a definitive description of fuels produced from organic matter, defined as all fuels that are produced from biomass which is biological in origin and biodegradable. Biomass is classified as a product, waste or residue from agriculture, forestry and fisheries. It may also contain biodegradable wastes arising from industrial and municipal waste, with the proviso that it is of organic origin e.g. plant-based cooking oil.

4. Biomass and Reducing Emissions

Key Messages

- The net calorific value of biofuels and biomass is lower than fossil fuels
- Bioliquid blends - mixing bioliquid with kerosene – were trialled by industry, and are seen as a viable alternative fuel source. Bioliquid blends are compatible with existing kerosene boilers (in low percentage blends, without having to incur capital costs)
- Bioliquid blends are a viable option in the transition to a low carbon economy, while acknowledging that kerosene is still used in this transition

As defined in the RED II directive, biomass is classified as a product, waste or residue from agriculture, forestry and fisheries. It is from this biomass material that biomass fuel derivatives originate. RED II identifies four biomass fuel derivatives which are differentiated by their state and use:

As defined in the RED II directive, biomass is classified as a product, waste or residue from agriculture, forestry and fisheries. It is from this biomass material that biomass fuel derivatives originate. RED II identifies four biomass fuel derivatives which are differentiated by their state and use:

- **Biofuels:** liquid fuels used in transport and produced from biomass
- **Bioliquids:** liquid fuels produced from biomass and used for purposes other than transport, including electricity, heating and cooling
- **Biogas:** gaseous fuels produced from biomass, and
- **Biomass fuel:** means gaseous and solid fuels produced from biomass

Further details on and definition of biomass is given in Appendix 1.

4.1 Bioliquids and Carbon Reductions

RED II sets out the criteria that bioliquids must meet to be classified as a bioliquid. Several acceptable examples are identified in Annex V of the RED II Directive along with efficiency estimates. These include the following examples:

- Sugar beet ethanol;
- Corn ethanol;
- Other cereals ethanol;
- Sugar cane ethanol;
- Rapeseed biodiesel;
- Sunflower biodiesel;
- Soybean biodiesel;
- Palm oil biodiesel;
- Waste cooking oil biodiesel;
- Various hydrotreated vegetable oils; and
- Pure vegetable oils

OFTEC trialled FAME blends in domestic trials (testing B30K blend and B50K blends) and for commercial purposes (B30K, B50K and a B30 mix with gas oil). The corresponding energy efficiency of both are outlined in Table 3, with the Net Calorific Values associated with each bioliquid.

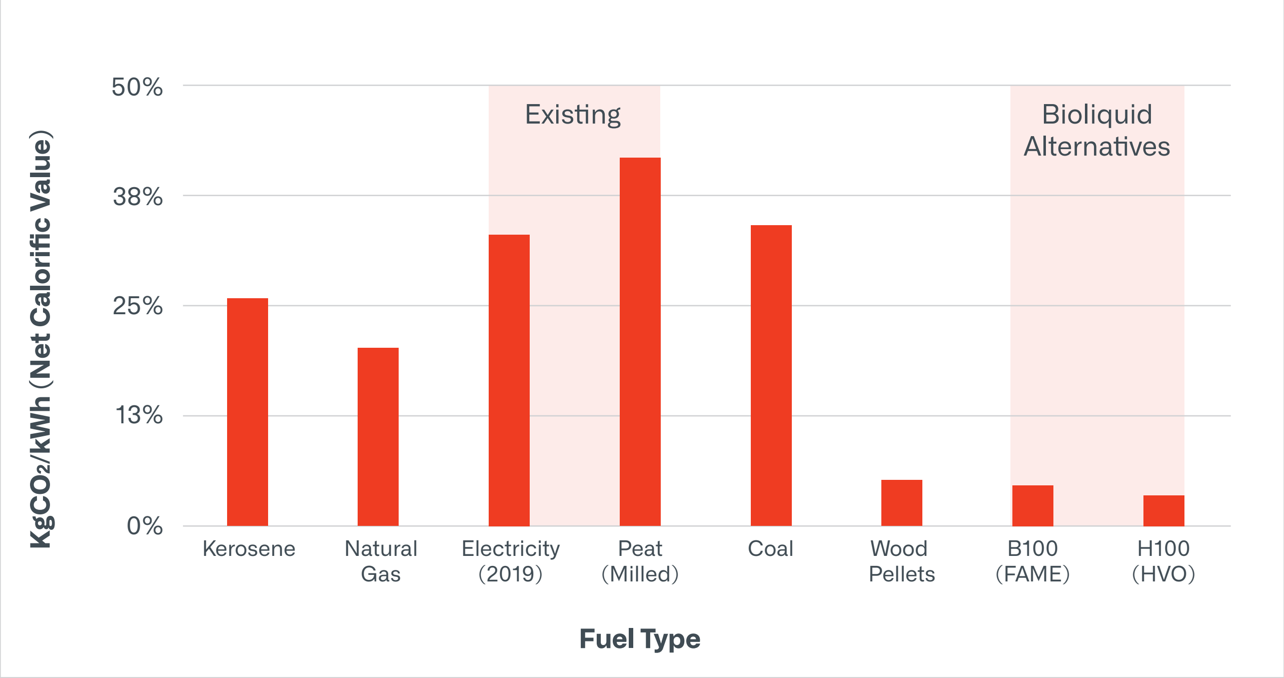
A comparison of these bioliquids in terms of use and emission intensity is provided in Figure 7 below. This comparison shows that B100 and H100 are significantly less carbon-intensive than natural gas or kerosene, as measured by net calorific value.

Table 3: Net Calorific Values associated with Fuel Designation B100 (FAME) and H100 (HVO)

Fuel Designation	Fuel Name	Net Calorific Value (kg CO2/kWh)	Included in Annex V of Red II (Y/N)	Key Information
B100	Used Cooking Oil (UCO) and FAME (Tallow)	0.0470kg CO_2 per kWh	Y	Boilers cannot be converted to B100 FAME. The trials showed that the storing and burning of B100 FAME requires specialist equipment. For blended FAME, upgraded appliances which included replacement fuel pumps, flexible fuel line, fuel filter and fuel valves with biofuel/fossil fuel compatible components were required.
H100	Hydrotreated Vegetable Oil	0.0357kg CO_2 per kWh	Y	HVO is compatible with existing oil-fired equipment. The conversion only requires inspection, cleaning and adjustment to recommission the combustion process to the new fuel per appliance manufacturers guidance

Source: Net Calorific Values from (CSO, 2020) and (SEAI, 2020)

Figure 7: Comparison of Home Heating Alternative Fuels



Source: (EPA, 2020), (Biofuel, 2010) and OFTEC

4.1.1. Pure Bioliquids and Blended Bioliquids

Bioliquids may be burned in a pure form or blended with fossil fuels. There are trade-offs between the decision to use pure or blended forms. Although, a pure bioliquid will typically yield the highest carbon benefit by avoiding the use of fossil fuels, only H100 is compatible with existing boilers and heating systems. Furthermore, the fuel usually costs more than fossil fuel alternatives, as the market for these fuels is comparatively small.

Limited testing indicates that blended bioliquids (30% to 50%) are compatible with existing heating oil units, subject to minor modifications. There is, therefore, only a small cost of conversion, making it more attractive to customers. Also, as the blend is only part biofuel, it is much cheaper than pure bioliquid alternatives at present. These blends provide a lower environmental benefit but strike a balance between environmental efficiency and cost. There is, therefore, the potential to reach a higher market penetration to scale to bioliquid production, reduce costs and gradually phase out liquid fossil fuels for pure bioliquid counterparts.

4.1.2. Bioliquid Blend Efficiency

OFTEC conducted field trials using biodiesel/kerosene blends in 2010, following on from laboratory tests in 2007.[12] The laboratory evaluation process established that 30% and 50% FAME/kerosene blends, (B30K and B50K) both had long-term potential and could perform in United Kingdom winter conditions. The report also confirmed that the B30D (30% FAME/gas oil) blend was suitable for use in existing heating systems. The field trial encompassed 25 heating oil sites in Norfolk, UK, three domestic heating oil sites in Ireland and one site in Lincolnshire, UK. The Irish field trials were important, given that the majority of Irish boilers are located outside of the dwelling (in boiler houses), whereas this is not the case in the United Kingdom (boilers located internally in the dwelling). Field trials showed no major operational issues, or bioliquid storage issues. The Net Calorific Values were estimated for this report based on the Net Calorific Values for pure bioliquid B100 (FAME) and kerosene. Table 4 below shows the Net Calorific Values and the percentage emission reductions in moving from kerosene (baseline or 0%) to the blended bioliquids (25% emission reduction in the switch from kerosene to B30K (FAME); 41% reduction in switch to B50K(FAME), and to pure bioliquid (82% carbon emission reduction).

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[12] OFTEC Liquid Biofuels Heating Project (2010). Results supplied to AECOM for this analysis.

Table 4: Net calorific Value Estimates for Bioliquid Blends

Fuel Designation	Description	NCV (kg CO_2/kWh)	Emission Reduction (%)
B100 (FAME)	Used Cooking Oil (UCO) and Animal Fats (Tallow)	0.047	82%
B50K (FAME)	50% Biofuel/50% Kerosene Blend	0.152	41%
B30K (FAME)	30% Biofuel/70% Kerosene Blend	0.194	25%
Kerosene (K)	A low viscosity hydrocarbon liquid obtained from the fractional distillation of petroleum	0.257	0%

Source: AECOM analysis of (Biofuel, 2010) and (SEAI, 2020)

The use of bioliquid and a blended bioliquid is preferable to the use of pure kerosene, from a carbon emission reduction The use of bioliquid and a blended bioliquid is preferable to the use of pure kerosene, from a carbon emission reduction perspective.

4.2. Transitioning to Pure Bioliquids

OFTEC and the wider oil industry are of the opinion that H100 will become the leading bioliquid for home heating. However, the technology will need to be advanced to bring costs down. The following section develops plausible scenarios for a transition to lower carbon home heating. A comparative analysis of the different scenarios is presented below, in terms of effect on CO_2 equivalent emissions and financial cost. These scenarios were developed to assess how bioliquids compare with actions and measures already signalled by the government in the Climate Action Plan, and to highlight the potential efficiencies (both in terms of carbon reduction and cost) that switching to bioliquid offers.

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5. Energy Saving Scenarios

Key Messages

- The Government's planned retrofit programme could reduce residential emissions by between 6 and 40% (min and max scenarios; shallow and deep retrofit)
- Switching to bioliquid use could reduce emissions in the range of 8 and 26% (blended bioliquid and pure bioliquid)
- Bioliquid alternatives are a credible option to reduce emissions associated with the residential sector, preferable to a shallow retrofit programme, due to the certainty of savings of using bioliquid

The 2019 Climate Action Plan – recently updated - sets targets for retrofitting 500,000 dwellings to a B2 BER Standard, with the installation of 400,000 heat pumps in existing dwellings. These measures, if achieved, will only impact a portion of the housing stock, and it is not evident that the measures are targeted at the most energy inefficient dwellings. A further consideration relates to affordability, and ability for property owners to pay for retrofitting dwellings, notwithstanding the SEAI subsidy and the SEAI Better Energy Communities Scheme.[13] Lower income social housing tenants have a high prevalence of fuel poverty and a 2015 study found that oil heated dwellings had the highest prevalence of fuel poverty.[14] Energy efficient properties are generally associated with lower running costs and possibly higher levels of comfort and health. The investment required from the property owner to upgrade their dwelling means that subsidies will favour middle to high-income households.

It is likely that a range of BER Standard dwellings will be upgraded in the forthcoming retrofit programme, although it is unlikely that the most inefficient privately owned dwellings will be upgraded (due to affordability issues). Scenarios 1 and 2 explore the effects of the minimum and maximum emission reductions that could be realised through the retrofit programme – giving a range of potential energy savings. The minimum retrofit scenario – or "low hanging fruit" scenario - would be that 500,000 dwellings are retrofitted from a C1 to a B2 BER Standard. The maximum retrofit scenario – or "deep retrofit scenario" – would see the dwellings with the lowest BER Standard upgraded to the highest standard (A3). These two extreme scenarios show the range of potential emission reductions that are possible under the retrofit programme. They were used to provide a sense of scale of potential energy savings in the transition to a low carbon society, and how bioliquid compares to the likely savings with the 500,000 dwelling retrofit plan.

Three additional scenarios were developed to explore the effect of substituting the use of kerosene oil for bioliquids. Three different grades of bioliquids were assessed: H100 (HVO) bioliquid, and blends of bioliquid – B50K(FAME) and B30K (FAME). The estimation of potential carbon equivalent savings was derived from data published by the CSO and SEAI.

Table 5: Scenario Descriptions

Scenario	Description	Affordability
1	"Shallow retrofit" - 500,000 dwellings are retrofitted, from a C1 to a B2 BER standard by 2030	Yes
2	"Deep retrofit" - 500,000 dwellings are retrofitted, from the lowest BER Standards to the highest - A3 BER standard by 2030	No
3	Kerosene use in dwellings is substituted for hydrotreated vegetable oil (H100 bioliquid)	No
4	Kerosene use in dwellings is substituted for a 50% blended bioliquid/oil mix (B50K)	Yes
5	Kerosene use in dwellings is substituted for a 30% blended biofliquid/oil mix (B30K)	Yes

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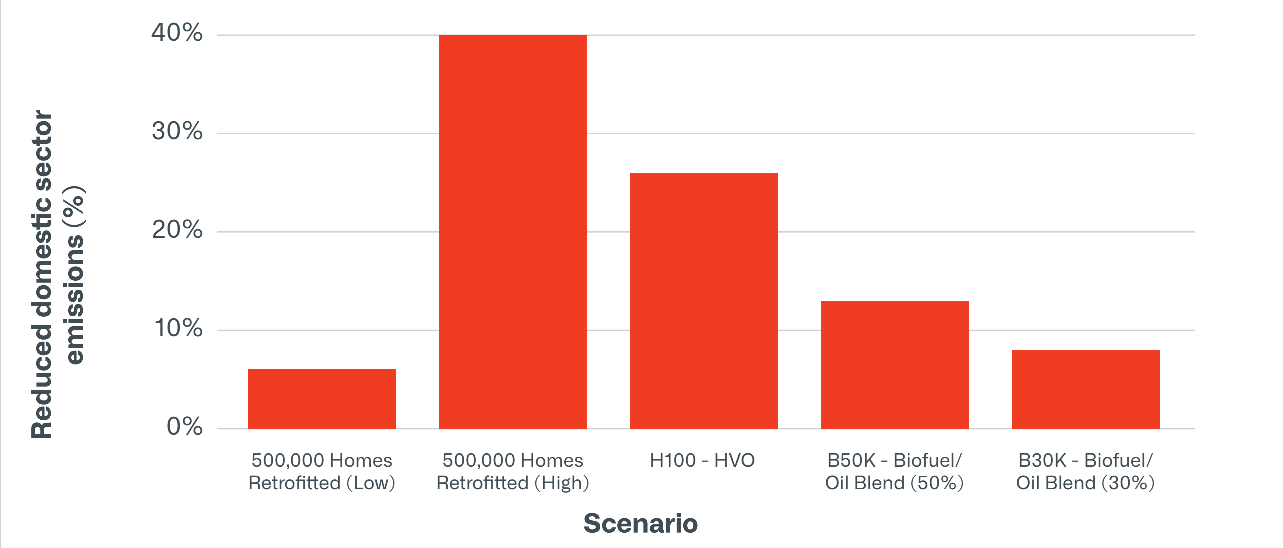
[13] Coyne, B., Lyons, S and McCoy, D. The Effects of home energy efficiency upgrades on social housing tenants: evidence from Ireland. Energy Efficiency. ISSN 1570-646X

[14] Element Energy Ltd. 2015. Bottom-up analysis of fuel poverty in Ireland. Final report prepared for Department of Communications, Energy and Natural Resources. Accessed on 10/9/20: https://www.gov.ie/en/publication/14e2b-strategy-to-combat-energy-poverty/

A high-level affordability sense-check is provided in Table 5, in recognition that although the scenario is plausible, it may not be affordable, due either to scale of retrofit requirements (it is estimated that a "deep retrofit" costs between €35,000 to €75,000) or current limitations in the scale of production (for pure bioliquid).[15] The costs of each scenario are explored further in the next section.

Figure 8 shows the impact on total reductions in emissions from the residential sector under each scenario. The proportion of emission savings is presented as a percentage or change/reduction from current levels. The emission reductions under each scenario is discussed.

Figure 8: Residential Energy Savings, Comparison



Source: AECOM Analysis

The first scenario identifies the minimum potential saving if the most efficient homes are upgraded to a B2 BER Standard. Figure 5 (presented previously) showed the potential emission reductions if all dwellings below each BER standard were upgraded to that BER Standard. This scenario estimates the savings if the retrofits were undertaken on the nearest lower 500,000 dwellings to B2. This assumes that the least energy efficient dwellings (BER Standard G and F) are not retrofitted. **Scenario 1 yielded a reduction of 6% carbon equivalent emissions.**

The second scenario assumes that 500,000 of the worst dwellings in terms of energy efficiency are upgraded to an A3 standard. This would assume that BER Standard G, F and E dwellings get upgraded to A3. **Scenario 2 results in a 40% reduction in carbon equivalent emissions. Of these six scenarios, this has the highest reductions in emissions.** This scenario is unlikely – it was merely constructed to illustrate the potential range of savings. The cost of these retrofits is expected to be between €20 billion - €30 billion based on estimated upgrade costs from the retrofit industry.[16] The number of retrofits and deep-retrofits fell short of the National Development Plan targets in the last few years, and in 2019 an allocation of only €10million was given to SEAI's retrofit programme. The retrofit programme had to close as it did not have the money to pay for all applications.

Scenario 3 is the switching of fuel used in oil boilers from kerosene **to H100** (hydrotreated vegetable oil). According to SEAI kerosene and biodiesel, the closest comparator to H100, have conversions factors of 1.1. They, therefore, are directly comparable in terms of transmission and distribution costs, keeping in mind that adjustments are made for energy consumption lost in transmission and in the distribution process (e.g. delivery of oil to site) These values may vary fuel to fuel.[17]

Pure Bioliquid has the potential to reduce overall emissions from home heating significantly. In its pure form, H100 can achieve total residential sector emission savings of 26%. This is within the range of emission reductions associated with the upgrade/retrofit of 500,000 dwellings, and is significantly higher than the minimum emissions reductions achieved in Scenario 1

Scenario 4 is a blend of Bioliquid B50K – with 50 per cent FAME and 50 per cent kerosene mix. As expected, the emissions savings are lower than the pure bioliquid, but switching to the B50K blend would result in 13% emission reductions.

Scenario 5, B30K, is the scenario with the lowest proportion of bioliquid blend, with 30% FAME and 70% kerosene. Switching from kerosene to this blend would result in 8% total reductions in residential sector emissions. Of note, this reduction in emissions for Scenario 6 is higher than the lowest retrofit reductions (Scenario 1).

This analysis shows that bioliquids are a viable alternative to transition to a low carbon society, especially in the short term, where emission reductions are achievable *without requiring significant disruption to homeowners or without requiring their significant capital investment, or without the cost to government of the retrofit programme.*[18] It is noted that Measure 52 of the 2019 Climate Action Plan is to "Develop and optimise Government funding and grant schemes to drive demand for energy efficiency retrofits that deliver value for money."

The following section explores the cost of the transition options to alternatives, starting off with the premise that the switch is away from pure kerosene-based heating systems.

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[15] It is estimated that between 18-20,000 million tonnes of Used Cooking Oil (UCO) is collected in Ireland per annum, that is sold to bio plants in Ireland or the UK. All category 1 tallow that is generated in Ireland is sold only to bio plants in Ireland and the UK. There is a very small amount of Oilseed Rape grown in Ireland at present. Teagasc reported a total of just over 700ha of Oilseed Rape (625 Winter Oilseed Rape and 92ha Summer Oilseed Rape) in 2017

[16] Superhomes, https://superhomes.ie/what-is-deep-retrofit/ accessed 10/9/2020:

[17] It is worth noting that on-site generation of energy systems are currently more efficient than mains electricity due to the high carbon intensity of electricity production (.03314 kg CO2/ kWh – 2019 Provisional) in Ireland and the high loss of energy in transmission and distribution (1.895605) (SEAI, 2020).

[18] Note, the analysis assumed that there are no supply constraints on retrofitting – that there are sufficient skills and labour supply to undertake the retrofit programme and that the uptake of the programme meets the target number of 500,000.

6. Cost and Benefit Estimates

Key Messages

- Households currently using kerosene will want to retain the status quo, when considering the costs over 10 years – to avoid capital costs and higher costs of fuel
- Switching from oil to bioliquids is preferable for oil users, as there are fewer capital or replacement costs associated, particularly for those who already own condensing boilers. B50K blend is the most cost effective switch for households over a 10 year period
- The continued use of kerosene in home heating would be the most pervasive for CO_2 equivalent emissions – with an estimated total of 68 tonnes of CO_2 equivalent emissions over 10 years for an average oil fuelled household. Air source heat pumps would not significantly reduce emissions per household, as there is still a high dependency on fossil fuels for electricity generation, although this may change as the carbon intensity of the grid decreases. Hydrotreated vegetable oil would have the lowest emissions over the period, with 10 tonnes of CO2 equivalent associated. When factoring in the cost of carbon, the least cost option on a societal level is to switch to B50K

6.1. Assumptions

This section of the report estimates the cost of the conversion of an oil heated home to alternative energy sources for heating - wood pellets, electricity (for air to water heat pumps), bioliquid blends, and pure bioliquid fuels. The purpose of this comparison is to show the incentives and choices available to homeowners to reduce heating costs. In addition, the carbon cost is estimated for each alternative energy source. There is the cost of physically exchanging goods and services in a market – referred to the 'financial cost' – typically reflected in the prices for goods and services for example the cost of equipment, fuel and maintenance of systems. There is also the 'economic cost', which is the cost to society. The shadow cost of carbon is used, in line with DPER's recommended values.

For all the calculations, the analysis was simplified to a standardised hypothetical house. The range, size, age and general heterogeneity of the building and housing stock is acknowledged. However, for cost comparative purposes, a set of assumptions was made. These are listed in Table 6.

The rationale behind these assumptions is that the focus is only on the 686,000 oil-heated dwellings, as the installation of oil heating systems in new houses is not permitted. There is a shift in building standards toward electrical heating for new dwellings. As acknowledged, the energy efficiency of houses varies significantly from dwelling to dwelling. By assuming an average house size and the average energy rating for an oil-heated home, this variance will be reduced. Further details of calculations are given in Appendix 2.

Table 6: Assumptions used for calculating costs
The hypothetical house is 112m², D1 BER Standard dwelling with an oil heating system, chosen to demonstrate the typical features of the average/standard oil heated dwelling for the baseline. A D1 rated house is the median BER rating for the stock of Irish dwellings.
Boiler efficiency is 90%, although as outlined previously, the average boiler efficiency is between 79% - 86%. This is a conservative assumption, to ensure that potential savings are not overstated. An analysis of boiler efficiency is presented in the Appendix.
The cost of switching to a condensing boiler was included in the analysis for the kerosene and bioliquid scenarios. For the bioliquid scenarios, an additional charge of €200 was included in the capital costs to reflect minor modifications that may be required to facilitate their use in conventional boilers.
According to BER standards a D1 Standard house needs between 226 -260 kWh/m²/yr. A central value of 243 kWh/m²/yr is assumed.
80% of energy usage is required for the heating of space and water. Therefore, the average annual heating requirement for a D1 BER Standard oil-heated house is assumed to be 194.4 kWh/m²/yr. This equates with an average annual consumption of 21,772.8 kWh for the hypothetical house.
A period of 10 years is taken for the assessment, assuming the property owner is switching from kerosene to a new type of biofuel in 2020. A comparison of other heating systems with assumed lower carbon emissions is also provided, to assess the options currently available to each household. This timeframe to 2030 was chosen as it aligns with Ireland's 30% emission reduction target.
The government has not yet signalled its intention for fossil fuel use in home-heating, but an assumption is made that a decision will mirror that taken for petrol and diesel cars, which will be banned for sale from 2030. It is assumed that existing systems will still be in operation.
Values are presented undiscounted and in constant prices. It is assumed property owners finance housing upgrades from a mortgage, meaning the appropriate financial discount rate should be aligned with mortgage lending rates, at the time of upgrade (2.5% -3.5%). Note, this is lower than the 4% social discount rate used by the Department of Public Expenditure and Reform for economic analysis. The 4% discount is applied to the economic analysis (measuring the cost to society) (NESC, 2018).

6.2. Upgrading Conventional Boilers to Condensing Boilers

Section 2.4 discussed the energy efficiency of boilers in oil heated housing – acknowledging that the efficiencies in the stock of boilers in use varies considerably. A conventional oil boiler may have an efficiency as low as 70%, while the newer condensing boiler model can be up to 93% efficient. The fuel savings to the household are significant between condensing and non-condensing boilers, and in turn, the potential for carbon reduction is significant.

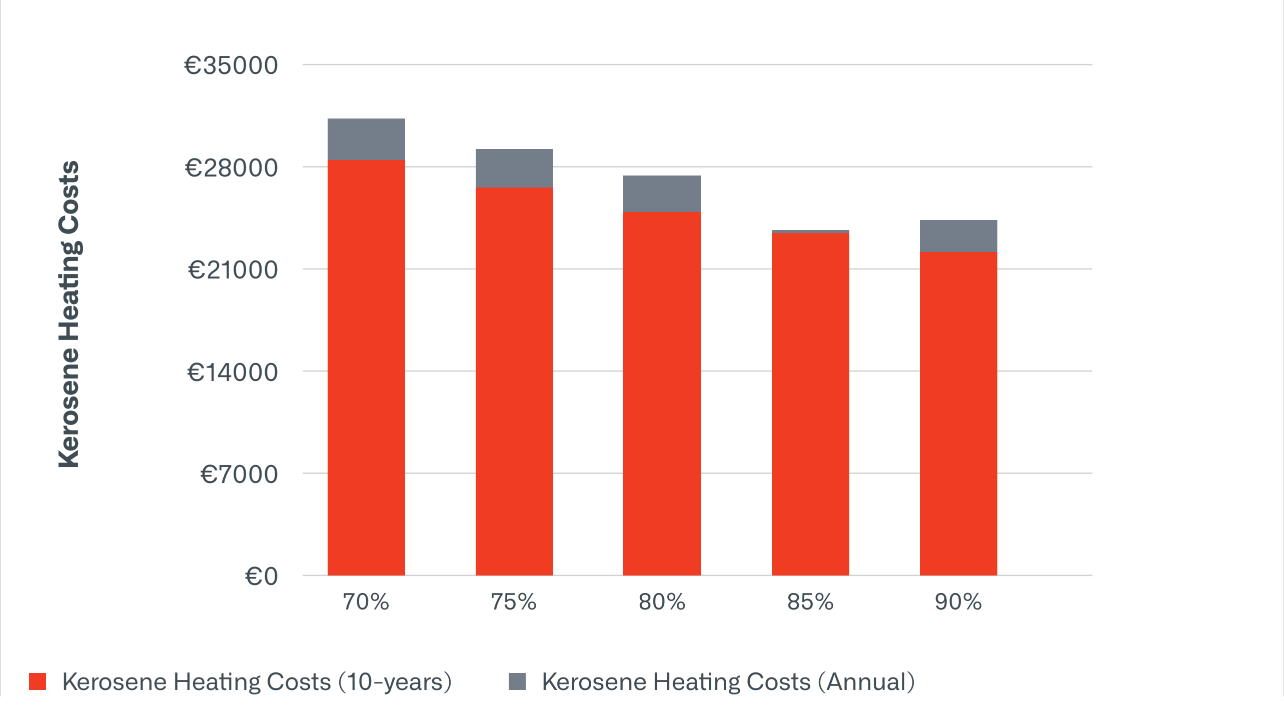
There is limited data available on the number of non-condensing boilers in use. OFTEC estimates that 300,000 of the 686,000 boilers installed in Irish homes are condensing boilers (assuming from industry estimation that approximately 30,000 new boilers were installed annually over the last 10 years. On this basis, it is estimated that on average oil boilers in Ireland are between 79% and 86% efficient, but by upgrading older, less efficient boilers, fuel consumption could be reduced by between 5% and 22%.

Upgrading these boilers would have a positive impact on the environment in terms of reduced emissions and reduced fuel costs, especially for people who may have difficulty heating their homes. The financial and economic costs of upgrading non-condensing boilers was calculated, to determine whether a programme of upgrades is warranted. For simplicity, the comparison of boiler models was undertaken using kerosene fuel only as the reference case.

User Cost Comparison

The 10 year kerosene cost for a hypothetical average-sized house with a poorly performing conventional boiler (70% efficient) is €28,458, whereas the cost of fuel of a more efficient condensing boiler (90% efficient) over the same period and for the same average sized house would be €22,134 (Figure 9).

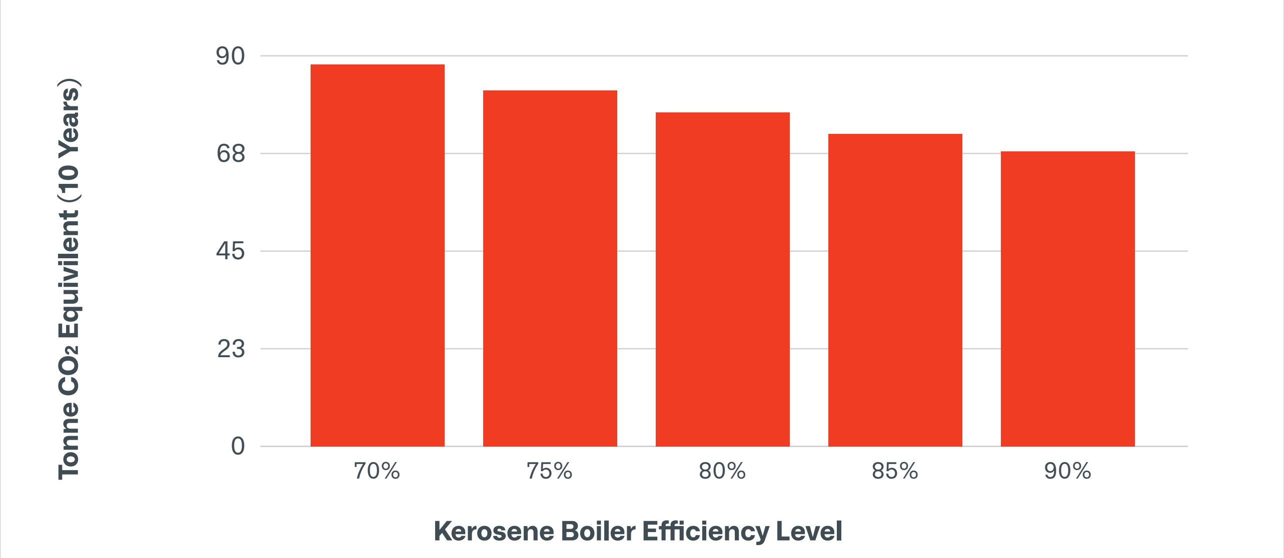
Figure 9: 10 year kerosene heating costs for boilers of differing efficiencies



The assumptions detailed in Section 6.1 are used, and similarly, the estimates are applied to a hypothetical dwelling 112sqm, D1 rated home with an oil heating system. A D1 rated house needs between 226 -260 kWh/m2/yr, according to BER Standards. A central value of 243 kWh /m^2/yr was assumed. As outlined earlier in the report, 80% of energy usage is required for the heating of space and water. This means that the average annual heating requirement for an oil-heated house is 194.4 kWh /m^2/yr. This implies an average yearly consumption of 21,772.8 kWh per hypothetical dwelling.

By comparing the costs associated with different boiler efficiencies using kerosene, it was possible to calculate at what point a boiler upgrade becomes worthwhile to the consumer. Efficiency test comparison of both condensing and non-condensing boilers was undertaken in 5% increments, starting at 70% up to 90%, to determine the point where an upgrade becomes in terms of both financial affordability and carbon emissions. Maintenance costs are assumed equal for all boilers, so not explicitly factored into the incremental costs. Based on replacement cost information there is no financial return for consumers to upgrade a boiler operating above 80% efficiency, as the cost of additional fuel over ten years is less than the cost of upgrading the boiler unit.

Figure 10: Emissions comparison by switching to condensing boiler, 2020-2030



Source: AECOM

Emissions Comparison

Emissions comparisons were compared on a ten-year basis (2020-2030). Emissions were based on the annual home heating requirement of 21,772.8 kWh. Emissions were calculated using NCV (kgCO_2/ kWh) factors from (SEAI, 2020). According to (DHPLG, 2020) an oil boiler system will cost between €4,100 and €4,525 in an existing home, including radiators and thermal controls. Directly replacing a system's boiler assuming the rest of a heating system is compatible can cost between €1,293 and €1,923, depending on the specific model selected.[19]

As can be seen in Figure 10 replacing a boiler with 70% efficiency with a model that is 90% efficient may reduce oil related emissions up to 23% over a 10 year period (reducing emissions from 88 tonne of CO_2 equivalent over ten years to 68 tonne).

Combined Economic and User Costs

The economic cost of switching to an improved boiler system was calculated in addition to the above. This calculation includes not just the charges to the user, but the cost to society, whereby the cost of emissions is included. The shadow cost of carbon was applied in line with Irish Government guidelines – non-ETS emissions have a cost of €32 per tonne, rising by €6.80 every year, until it reaches €100 per tonne in 2030.

As can be seen from Figure 11, the incremental economic cost of a non-condensing boiler (70% efficient) versus a condensing boiler (90%) amounts to €6,087 over ten years. Almost 16% of those costs fall on society in terms of additional or unnecessary carbon costs (€958). The remaining 84% of costs accrue to the property owner, in terms of the additional fuel used by the less efficient boiler (€5,129).

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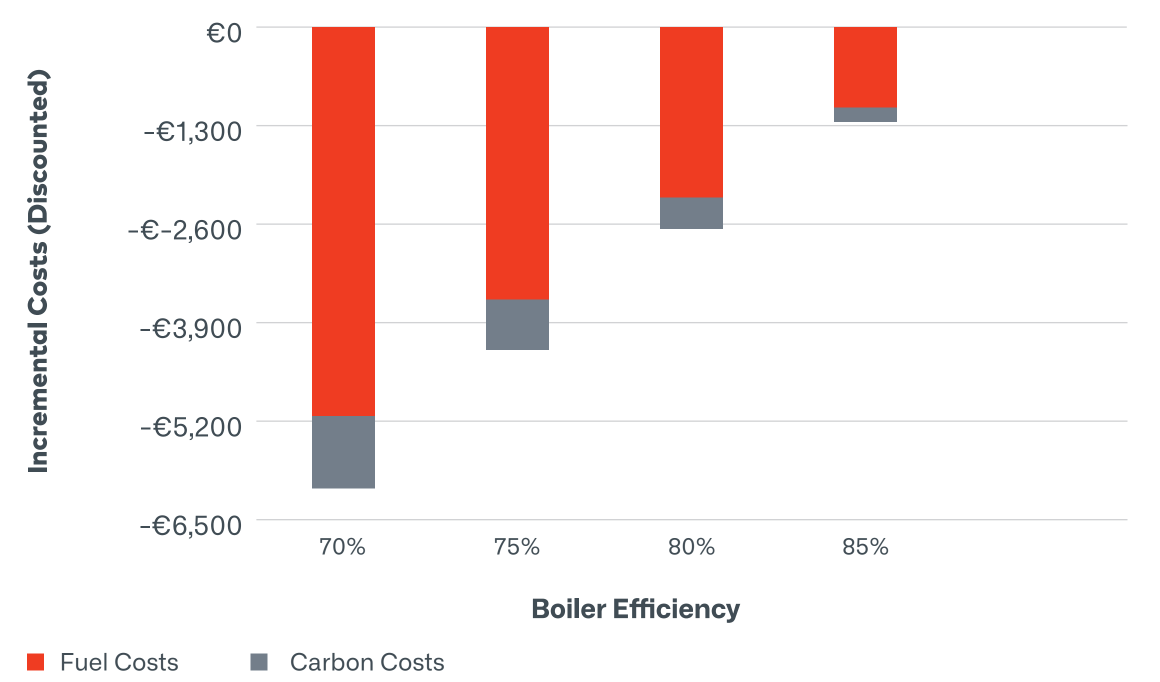
[19] https://greener.ie/boilers/oil-boiler-replacement/

The potential fuel savings are offset by the cost of a boiler upgrade. Our analysis finds that the benefits of a boiler upgrade only exceed the cost where a boiler is 75% efficient or less. At this point, the savings to the consumer (lower fuel costs) and to society (lower carbon emission) exceed both the lower- and upper-bound costs of a boiler replacement (€1,293 and €1,923). We do acknowledge that there is an anomaly or discord with advocating the use of condensing boilers. The intention and signalling from Government is that oil based heating systems are to be phased out. There are immediate (short term, up to 10 years) carbon benefits (for society) and benefits at the household (fuel savings) of switching to condensing boilers. There is merit in advocating the replacement of the most inefficient boilers in existing dwellings. However, this position is at odds with the Government's policy of phasing out oil-based heating systems and we acknowledge the difficulty in reconciling the efficiencies that can be obtained and the promotion of a system that 'locks' people into a technology that the government wants to phase out.

Figure 11: Net Economic Impact of Converting to a condensing boiler, 2020-2030



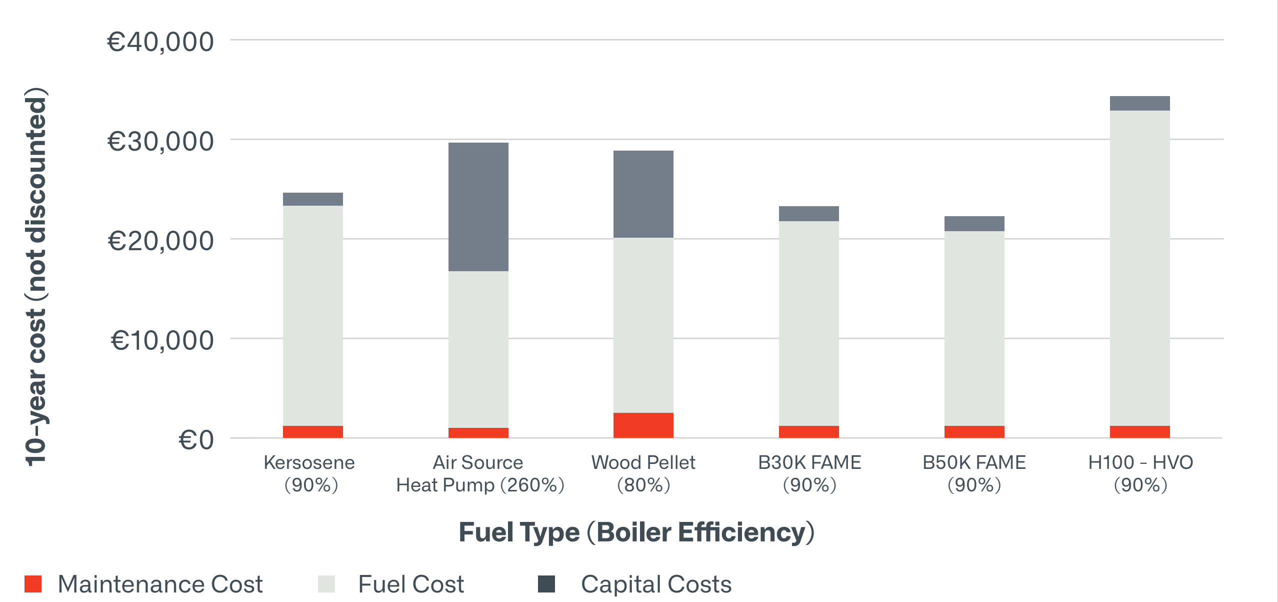
Source: AECOM
Notes: **1.** negative costs = savings **2.** maintenance costs are zero, as assumption is made that maintenance costs do not depend on the boiler efficiency – hence the incremental cost for maintenance is zero.

6.3. 3. Bioliquid Substitution

User Cost Comparison

The respective costs to the user or property owner for different heating systems is given in Figure 12. This graph shows the total cost of operating a kerosene heating oil system for the period 2020-2030 on the first bar on the left. This total cost is comprised of maintenance costs, fuel costs, and capital costs associated with the conversion to a condensing boiler. It compares the financial cost of operating this system for the period to the two most common non-fossil fuel alternatives: an electrical air source heat pump and wood pellet burner. It shows the cost of switching to bioliquid blend alternatives, specifically B30K FAME and B50K FAME bioliquid alternatives, as well as a pure bioliquid alternative H100.

Figure 12: User Cost Comparison for an individual household, by Fuel Type, 2020-2030



Source: AECOM
Note: Cost of B30K FAME and B50K FAME and H100 HVO were obtained from OFTEC. It should be noted that the market for these fuels is in its nascency, Further information on the international market for bioliquid is available from https://www.greenea.com/en/market-analysis/. The cost for a litre of H100 was €0.85 per litre, and the cost used for B100 was €0.65 per litre. Both were converted to €/kWh.

The lowest capital cost estimates for conversion from oil-based systems to alternative heating systems was chosen, to give a conservative approach and to avoid a criticism of overstating costs. Note, the cost of deep retrofitting is not included in above calculations, but are estimated in the range of €40,000 to €60,000 to reach BER B2 or A3 Standard. The above costs relate to heating costs only, and we note that all heating can be optimised through insulating the dwelling, though these costs are not incorporated/included in this cost comparison.

The first on bar in Figure 12 shows the cost over ten years to the hypothetical property owner of making no change from kerosene. This includes maintenance, fuel and capital costs associated with converting to a condensing boiler, which means that the boiler efficiency is given at an assumed rate of 90% (shown in brackets). If the property owner switched to an air source heat pump, they would incur more significant capital and fuel (electricity) costs. Again, the efficiency of the air source heat pump is given, and at 260% may seem counterintuitive; but it reflects the ability of air source heat pumps to invert air temperatures after electricity is used to drive the compressor and pumps. The efficiency of air source heat pumps can also vary based on weather and operating conditions and require proper installation and operation. In particular, the above assumption of 260% efficiency assumes correctly sized radiators and pipework along with no inefficiencies due to low external ambient temperature (less than 7 °C).

Converting to a wood pellet system also has a higher capital cost compared to the use of bioliquids in a condensing boiler.

Overall this analysis shows that the switching costs for existing kerosene users to an air source heat pump and wood pellet biomass heating systems are high. The capital cost of an air source heat pump is between €9,304-€12,900, although additional costs may be incurred for the installation of new piping or insulation. The figure of €12,900 for the capital cost of the heat pump was used in this analysis, which does not include additional costs for the installation of pipework and upgrading of radiators. The cost of a wood pellet heating system ranges between €8,700-€24,974. The high initial cost of both options is a significant barrier to change. Bioliquid/kerosene, and pure bioliquid alternatives do not incur as high capital switching costs for heating-oil users, particularly if users already have a condensing boiler, making kerosene users more likely to switch to bioliquids (i.e. they can use their existing heating systems). An additional €200 charge was added to the capital cost of these alternatives to reflect some minor modifications that may be required in order to use biofuels in conventional boilers.

Maintenance costs vary considerably between heating options ranging from €1,000 for the air source heat pump to €2,500 for the wood pellet burner over ten years.[20] These costs, although significant, are less substantial than the up-front capital cost of conversion or fuel costs in all cases.

The ongoing costs of kerosene was estimated at € 22,134 over the ten years, which is the cheapest fuel option out of the six options. When all alternatives are compared, bioliquid blends appear to be the least-costly alternative for existing kerosene users. Low capital costs are a key driver of this choice, even where the lowest capital costs are considered, while lower fuel costs also contribute to bioliquids being the least-cost alternatives. Given that bioliquid blends are substantially cheaper than the pure bioliquid, the property owner is unlikely to switch to H100 in the short to medium term. The cost of the H100 would need to be reduced by upscaling production or government support to achieve market uptake.

When all alternatives are compared, bioliquid blends appear to be the least-cost alternative for existing kerosene users. Low capital costs are a key driver of this choice, even where the lowest capital costs are considered, while lower fuel costs also contribute to bioliquids being the least-cost alternatives. H100 bioliquid is a cheaper alternative to air source heat pumps and wood pellets, as it is largely compatible with existing apparatus in dwellings that use kerosene. However, over a longer period, the higher fuel costs associated with H100 could likely cause this situation to reverse. Given that bioliquid blends are substantially cheaper than the pure bioliquid, the property owner is unlikely to switch to H100 in the short to medium term. The cost of the H100 would need to be reduced by upscaling production or government support to achieve market uptake.

To encourage a switch to bioliquid use there is a need for a financial incentive or a regulatory nudge. Penalising existing kerosene users with an additional tax may increase fuel poverty. Additionally, seeking concessions on the taxation of bioliquids is unlikely to be politically feasible for one fuel alone. AECOM therefore recommends that the use of pure kerosene in home heating is phased out gradually using blends. Phasing out pure fossil fuels for blends will increase the market for the blends and should bring costs down for households. Phasing out kerosene in this manner will lead the market to a tipping point in favour of bioliquid, as carbon taxes increase on fossil fuel blends, and the production capacity for bioliquids increase.

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[20] Average costs are current, and estimated from triangulating data from businesses offering maintenance service and recommended servicing frequency. Again, these costs are average estimates only and will vary considerably.

Emissions Comparison

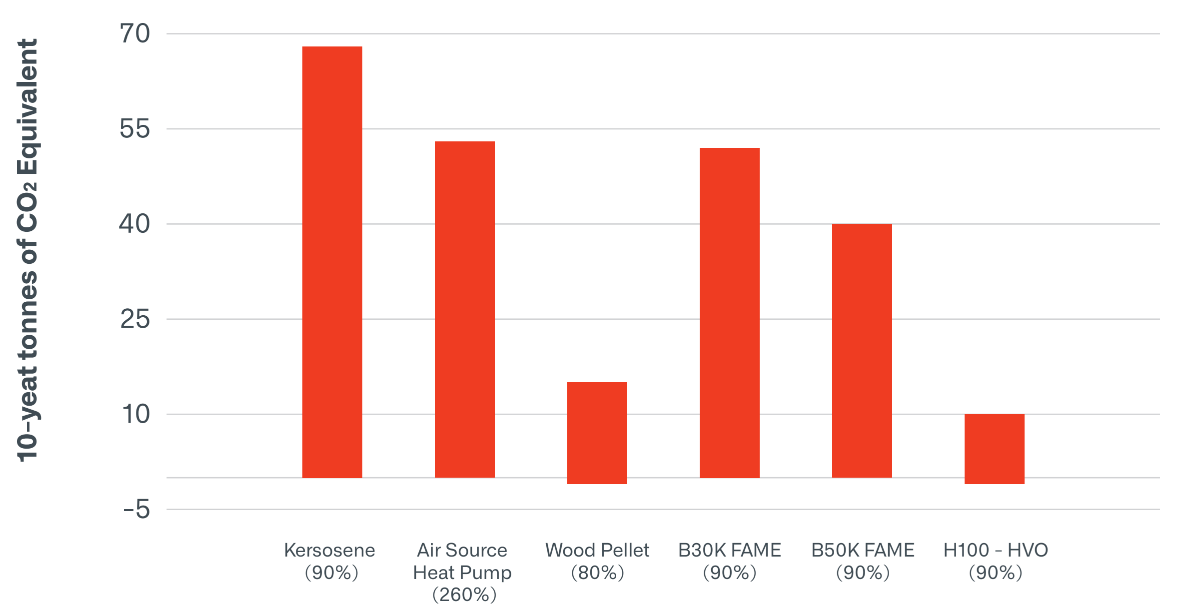
An emissions comparison is undertaken for the ten-year period, from 2020-2030 (Figure 13). Emissions were calculated assuming the annual home heating requirement of 21,772.8 kWh. Emissions have been calculated using NCV ($kgCO_2/kWh$) factors from SEAI, (2020) for electricity (for 2019) and kerosene while OFTEC provided the NCV for H100. The emissions factors for wood pellets were sourced from a report to the UK Department for Environment, Food and Rural Affairs (DEFRA)[21]. It was assumed the wood pellets are domestically produced from sawmill residue in Ireland, although it should be noted that the emissions factor for wood pellets varies significantly depending on their origin and method of production. With some methods of production producing emissions equivalent to those of natural gas, this may result in the carbon emissions of wood pellets being underestimated in this report.

The continued use of kerosene in home heating is the most pervasive for CO_2 equivalent emissions over the period 2020-2030, in comparison to the alternative options, accounting for 68 tonnes of CO_2 equivalent for the hypothetical house, over ten years.

H100, hydrotreated vegetable oil has the lowest emissions identified within our set of alternatives, closely followed by wood pellets. H100 (HVO) results in an emissions saving of 85% when compared to kerosene, while wood pellets result in a saving of 78%.

Air source heat pumps, despite their high efficiency (260%), are not yet the panacea for reducing emissions. This is due to the high carbon intensity of electricity production in Ireland at present, and the loss of energy through transformation, transmission and distribution. However, the carbon intensity of electricity production will likely continue to decline as fossil fuel generation plants close. The decarbonisation pathway for electricity generation is constrained by the quantity and speed of investment directed into energy infrastructure.

Figure 13: Tonnes of CO_2 equivalent Emissions Comparison, by fuel type over 10 year use per average household/dwelling.



Source: AECOM analysis (heating conversion efficiencies shown in brackets)

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[21] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48193/3153-final-report-carbon-factor.pdf

Bioliquid blends are available today and offer a low risk equivalent-or-better emissions reductions when compared to air source heat pumps currently. The B30K blend is directly comparable to air source heat pumps in terms of carbon efficiency, reducing emissions by 24% compared to pure kerosene use. The B50K blend offers greater carbon reductions.

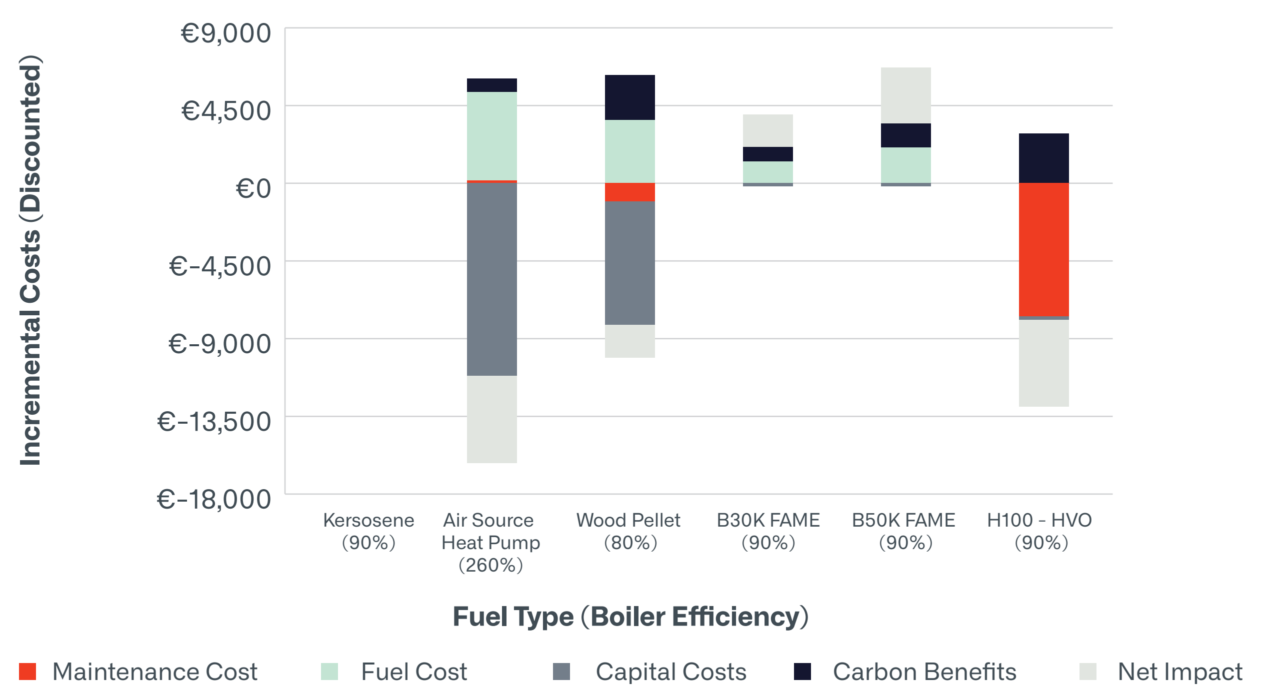
Combined Economic and User Costs

The incremental economic cost of switching kerosene users to other forms of heat generation was calculated, in addition to the above. This metric for economic cost includes not just the costs to the user, but the cost to society, using the shadow cost of carbon. This estimation shows the net economic impact of switching away from kerosene, and the costs and benefits are benchmarked against kerosene, which is the default, or baseline position. (The cost of the baseline option is set to zero). As a boiler replacement was assumed for scenario 1, this also reduces the incremental capital costs of the bioliquid scenarios to zero.

By combining the financial calculations from Figure 12 with the shadow cost of carbon based on values contained in the Public Spending Code, a total cost is obtained for the options available to the hypothetical house to switch away from kerosene. The shadow cost of carbon has been calculated in line with (DPER, 2019) guidelines for the Public Spending Code, where the cost of carbon rises from €32 per CO_2 equivalent tonne in 2020 to €100 in 2030.

All figures presented in Figure 14 are shown in discounted constant prices. Prices were discounted at a rate of 4%, in compliance with the Public Spending Code. The impacts of each scenario are benchmarked against the costs of maintaining an existing heating oil system. Negative figures indicate an increased cost, while positive figures indicate a saving or benefit.

Figure 14: Net Costs and Benefits of switching away from kerosene, over period 2020-2030



Source: AECOM analysis

The net effect of each option is shown by the black diamond. All alternatives incur a cost (all below zero), but the closer the dot to zero, the lower the net costs to switch to that heat source. The least cost-effective option is to switch to H100, and then to wood pellets, with an air source heat pump as the third least cost-effective option. The most cost-effective option is to switch to B50K FAME blend bioliquid, followed closely by B30K FAME. Although H100 and wood pellets have the highest carbon benefit, they are not the overall most efficient choice to switch. However, as outlined previously, the carbon emissions from wood pellets varies depending on the origin and method of production.

7. Conclusions

With the backdrop that Ireland is failing to meet its emission targets, the process of transitioning to a low carbon economy is not fast enough. There is the opportunity to address that lack of progress, and this report has identified how the residential housing sector can contribute. It has also highlighted the complexity of developing policy and moving factors – such as prices and technologies – which need careful consideration. We acknowledge that decisions to upgrade or switch energy sources for home heating systems need to be taken after due consideration of each individual dwelling.

There are a number of clear conclusions from the above review of policy and analysis. There is currently heavy dependence on oil for heating houses and dwellings in the residential sector. Signalling from the government is clear and understood: the intention is to switch away from oil-based systems, to systems with lower carbon emissions. How that will be achieved needs much more attention, given that property owners and residents need affordable and viable alternatives.

There is a role for bioliquid blends under the conditions that were examined in this analysis. This report has explored the option of switching to bioliquids, and the analysis shows that it is a viable and affordable alternative. In the analysis we have made some assumptions, which can be challenged, given the need to consider the heating system on a dwelling by dwelling basis, but also in particular, until the electricity generation system in Ireland can switch to renewable sources. However, the analysis was designed to be as objective as possible, and was undertaken for OFTEC, but independently of them.

Current constraints in moving to a low or near zero carbon residential sector include the reliance on fossil fuel for electricity generation, which is required for air to water heat pumps. Although the share of renewable energy used in electricity is increasing, there are still considerable carbon equivalent emissions associated with electricity use. Until then, alternative low emission fuels are required in order to make this transition.

The use of bioliquid blends in existing kerosene-based home heating systems is a viable way to transition away from complete reliance on kerosene oil. ***The analysis found a 50% bioliquid/kerosene blend would be optimal for the transition, in terms of attaining significant emission reductions while remaining affordable for households.***

While we acknowledge the government has signalled an end-date for fossil fuels in home heating, there is also an argument to be made to upgrade conventional boilers to condensing boilers; with significant fuel savings and emission reductions associated with that switch. Providing a total ban on kerosene use by 2030 will ensure that all replacement boilers will be compatible with pure bioliquids in the future, and will reduce incentives to continue the use of fossil fuel blends. It will encourage suppliers and others to invest in research and development to bring the cost of pure bioliquids down for consumers.

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Appendices

Appendix 1. Biomass

Biomass and Fossil Fuels

Biomass is used to generate heat by combustion. Combustion is the technical process by which a substance reacts rapidly with oxygen to give off light and heat. Biomass acts as a fuel for combustion, in this way. Biomass is used to generate energy in the same way fossil fuels are used. For this reason, biomass fuels can potentially be used in machinery that is designed to run using fossil fuels. Biomass fuels sources may be more, or less carbon-intensive than fossil fuels, when burned directly. How biomass differentiates itself from fossil fuels is that the fuel source is renewable. Biomass is a product of organic matter or waste.

Biomass from Crops

Crops can be grown on a commercial basis to produce fuels such as ethanol. These crops sequester carbon as they are grown, which is released when burned. As a result, greenhouse gas emissions released when burning fuel are offset by crops grown to replace that fuel and by the stock of that fuel available in the supply chain becoming carbon neutral.

Biomass from Waste

Waste can also be used as biomass. Organic waste releases greenhouse gas emission as it degrades over time. Burning this waste releases these emissions much more rapidly but allows society to harvest heat and light by combustion, thereby, reducing waste product which would typically be destined for landfill, to generate energy. Using waste products has a dual benefit in that additional land-area is not used to grow fuel crops, which encroaches on the farmed land area (e.g. displacing food production).

Biomass and Land-Use

Land-use considerations came into greater focus when producing the biomass. RED II and ILUC require biomass fuel derivatives to be evaluated on their whole life cost, which includes land-use. The point of having land-use values when considering bioliquids and bioliquids is to avoid indirect emissions or externalities arising from the growth of fuels crops. For example, growing more fuel crops to meet fuel demand will displace agriculture. As the demand for food does not decrease, there is increased pressure to expand farmland by cutting down forests or removing bog land for food production, which currently acts as carbon-sinks. In response, the EU has sought to develop biofuels from primary industry by-products, municipal and industrial waste which avoid these negative consequences.

Appendix 2. Assumptions and Costs used in Energy Saving Scenarios

According to the 2016 CSO Census, there are 1,697,665 households in Ireland. Approximately 686,004 of these homes are heated using kerosene. If we were to estimate the share of heating oil homes from BER statistics, a figure of roughly 510,000 would be arrived at. The discrepancy of this estimate highlights how underrepresented oil heating is in BER statistics, possibly due to the proportion of oil-heated homes which are exempt from BER ratings. The efficiency of this home is also likely to be overstated due to these sample differences.

Based on the information provided by the SEAI on energy sources and energy use, approximately 80% of the energy used in homes is directed toward the production of heat. In the absence of more detailed information, we assume that 80% of energy is used for heat across all BER categories. This is likely to overstate the energy used in heating for homes on the energy-efficient side of the BER scale and overstate the energy efficiency of heat production on the poorer end of the scale assuming these households have access to a similar quality of household appliances which account for the remaining 20% of energy use.

BER data also do not provide information on relative house sizes between BER categories or year of construction. As a result, we will assume that houses of all ratings and fuel types are equal in size.

Primary energy conversion factors adjust energy consumption for energy lost in transmission and distribution processes. These values may vary fuel to fuel[22]. **According to SEAI kerosene and biodiesel, the closest comparator to B100 and H100, have conversions factors of 1.1. They, therefore, are directly comparable in terms of transmission and distribution costs.**

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[22] It is worth noting that location-specific energy systems are currently more efficient than mains electricity due to the high carbon intensity of electricity production (.03314 kg CO_2/ kWh – 2019 Provisional) in Ireland and the high of energy in transmission and distribution (1.895605) (SEAI, 2020).

Heating System Cost Comparison

Table 7: Boiler Cost Comparison

Boiler Type	Boiler Maintenance (Per annum)	Capital Cost (€)	Efficiency	Source
Conventional Gas Boiler	€120	Not applicable	70% to 80%	https://bit.ly/3kZTzfh
Condensing Gas Boiler and heating system	€120	€4,100 - €4,525	90% -92% (90% minimum)	Draft Building Regulations 2018, Technical Guidance Document L, section 1.4.1.1
Biomass Boiler and heating system	€250	€8,700 – €24,974	80% (77% Minimum)	Draft Building Regulations 2018, Technical Guidance Document L, section 1.4.2.2
Air Source Heat Pump and heating system	€100	€9,304 – €12,900	260%	https://bit.ly/3lBR4z2 https://www.iwea.com/images/files/70by30-report-final.pdf

Source: (DHPLG, 2020)

Fuel Type Comparison

Table 8: Fuel Cost Comparison

Fuel Type	kWh per TOE	Fuel Density Litres per Tonne	NCV ($kgCO_2$/ kWh)	Fuel Cost (inc. Tax)
Kerosene	€11,630	1,250	0.257	€0.85 per litre
B100 (FAME)	€11,630	1,136	0.047	€0.74 per litre
B30K (FAME)	€11,630	1,215.8	0.194	€0.82 per litre
B50K (FAME)	€11,630	1193	0.152	€0.79 per litre
H100 (HVO)	€11,630	1136	0.0357	€1.34 per litre
Electricity (2019)	-	-	0.3314	€0.188 per **kWh**
Wood Pellets	-	-	0.05	€0.0648 per **kWh**

Source: (DHPLG, 2020)

Table 9: SEAI Indicative annual CO_2 emissions and running costs for different rating bands for space and water heating

Rating	2 Bed Apartment		3 Bed Semi-D		4 Bed Semi-D		Detached House		Large House	
	Area (m^2)	75	Area (m^2)	100	Area (m^2)	150	Area (m^2)	200	Area (m^2)	300
	Tonnes CO_2	Cost (€)	Tonnes CO_2	Cost (€)	Tonnes CO_2	Cost (€)	Tonnes CO_2	Cost (€)	Tonnes CO_2	Cost (€)
A1	0.4	€140	0.5	€190	0.8	€280	1.1	€400	1.6	€600
A2	0.8	€280	1.1	€380	1.6	€560	2.2	€800	3.2	€1,100
A3	1	€350	1.4	€470	2	€700	2.7	€900	4.1	€1,400
B1	1.3	€440	1.7	€590	2.5	€900	3.4	€1,200	5	€1,800
B2	1.6	€570	2.2	€800	3.3	€1,100	4.3	€1,500	6.5	€2,300
B3	2	€700	2.7	€900	4	€1,400	5.3	€1,900	8	€2,800
C1	2.4	€800	3.1	€1,100	4.7	€1,600	6.3	€2,200	9.4	€3,300
C2	2.8	€1,000	3.7	€1,300	5.5	€1,900	7.4	€2,600	11	€3,900
C3	3.2	€1,100	4.2	€1,500	6.3	€2,200	8.4	€2,900	12.7	€4,400
D1	3.7	€1,300	5	€1,700	7.5	€2,600	10	€3,500	14.9	€5,200
D2	4.4	€1,500	5.8	€2,000	8.8	€3,100	11.7	€4,100	175	€6,100
E1	5	€1,800	6.7	€2,300	10.1	€3,500	13.4	€4,700	20.1	€7,000
E2	5.7	€2,000	7.6	€2,600	11.4	€4,000	15.1	€5,300	22.7	€7,900
F	6.8	€2,400	9.1	€3,200	13.6	€4,700	18.2	€6,300	27.2	€9,500
G	8.5	€3,000	11.3	€4,000	17	€5,900	22.7	€7,900	34	€11,900

Source: https://www.seai.ie/publications/Your-Guide-to-Building-Energy-Rating.pdf This table gives estimated annual fuel cost and CO_2 emissions on the basis of typical occupancy and heating the entire dwelling to a comfortable level.

Bioliquid Substitution

Assuming that current oil heating system users will continue to maintain their existing systems to 2030, a cost comparison was developed. In the first instance, financial costs were estimated, and in the second instance, the economic cost was calculated. Economic costs capture the costs to society rather than the individual, or rather than just through the physical monetary cost. Economic costs are constructed to take externalities (such as the cost of carbon) into account. Between both calculations, therefore, the cost for households and for society is captured.

For our calculations, we have assumed that the current user operates a heating oil system; the target market for OFTECs bioliquid proposal. For completeness, we have developed a scenario for a house with a condensing and non-condensing boiler. The cost of operating these systems was compared to the current alternatives to fossil fuels, which are Biomass (Wood Pellet) and Air Source Heat Pump (Electricity) systems. Additionally, we will benchmark these alternatives against two FAME/Kerosene blends (B30K (30/70), and B50K (50/50) and a pure Vegetable Oil alternative (H100).

Assumptions

As house sizes and their energy efficiency vary considerably, we have made some assumptions regarding a hypothetical house for our calculations. The size of this house is assumed to be 112sqm,[23] this equivalent to an average Irish home.

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[23] http://www.surveyorsjournal.ie/index.php/the-true-cost-of-building-a-house/

The energy efficiency of the hypothetical house is a D1 Rating, which is the average rating for an oil-heated home according to the BER certs; although overstated for sampling reasons as previously identified. A D1 rated house needs between 226 -260 kWh/m^2/yr, according to BER standards. We will assume a central value of 243 kWh/m^2/yr. As outlined earlier in the report, 80% of energy usage is required for the heating of space and water. This means that the average annual heating requirement for an oil-heated house is 194.4 kWh/m^2/yr. For our hypothetical house means an average yearly consumption of 21,772.8 kWh per home.

Emissions were calculated using Net Calorific Value figures (kgCO$_2$/kWh) contained within this report. These emissions captured final energy consumption and were converted to total primary energy consumption to capture total emissions. The total primary energy consumption factor for electricity is 1.895605 (SEAI, 2020). For all other fuels compared in this section, a value of 1.1 is used as per SEAI conversion factors.

Baseline Costs: Kerosene

Taking an oil-heated house fitted with a condensing boiler (90% efficient) as an example, the house would need to generate 24,192 kWh of energy per annum to account for efficiency losses. Using (SEAI, 2020) estimates for kerosene oil equivalent and fuel density, kerosene can produce 9.3 kWh per litre, meaning a total supply of 2,600 litres are required per year. As a typical oil tank contains 1,000L – 1,350L in Ireland, this is the equivalent to 2 -2.5 refills per year. The cost of kerosene was found to range between 77.4c/l to 85.0c/l,[24] meaning the annual price of kerosene was between €2,013 to 2,213 per annum. Boiler maintenance would cost an additional €120 per annum according to (DHPLG, 2020), bringing the annual heating cost to €2,130 to €2,333 per annum for a 90% efficient boiler. As discussed previously, less efficient boilers have higher running costs, and these are presented in Table 10.

Table 10: Costs associated with different boiler efficiencies

	Boiler Maintenance	Fuel Cost High	Fuel Cost Low	Annual Cost High	Annual Cost Low	Emissions (kgC0$_2$ eq./yr	Carbon Cost per Annum (€)	Carbon Cost per Annum Discounted (€)
Minimum Condensing Boiler Efficiency (90%)	€120	€2,213	€2,015	€2,333	€2,135	6839	428	335
Maximum Conventional Boiler Efficiency (80%)	€120	€2,703	€2,490	€2,823	€2,610	7693	481	377
Minimum Conventional Boiler Efficiency (70%)	€120	€3,089	€2,846	€3,209	€2,966	8793	550	430

Source: AECOM analysis

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[24] https://www.cheapestoil.ie/heating-oil-prices/Republic

Alternatives: Wood Pellets and Air Source Heat Pumps

The cost of wood pellets can vary significantly from source and by the size of the delivery, bulk deliveries being cheaper. According to a report by the SEAI,[25] the price of wood pellets ranges between 6.48 c/kwh and 7.53 c/kwh. The typical efficiency of a biomass boiler is 80%. An energy efficiency rating of 80% means that the house would need to burn 24,192 kWh of wood pellets per annum to account for efficiency losses. Assuming SEAI cost estimates are correct, the annual cost of heating an average home would be €1,251 to €1,442 per annum.

For our electrical heating example, AECOM has assumed the same heat output requirements as for the oil heated home. 21,772.8 kWh. However, as Air Source Heat Pumps have an energy efficiency rating of 260%, the total energy requirement of these homes is 8,374 kWh. The cost of electricity varied significantly from provider to provider depending on standing charges etc. Electric Ireland's standard unit price of 18.81c/kwh was used, which results in a cost of €1,575 per annum.

Table 11: Existing alternatives to oil heating systems

	Boiler Maintenance	Fuel Cost High	Fuel Cost Low	Annual Cost High	Annual Cost Low	Emissions (KG C0$_2$) p.a	Carbon Cost per Annum (€)	Carbon Cost per Annum Discounted (€)
Biomass (Wood Pellet)	€250	€1,567	€1,822	€1,817	€2,072	1,496.88	94	73
Air Source Heat Pump	€100	€1,575		€1,675		5,260.67	329	258

Source: AECOM calculations, based on current (2020) industry estimates of bioliquid fuel costs

Proposal: Biofuels

Table 12: Estimation of annual costs for biofuels B30K (FAME), B50K (FAME), and H100 (HVO)

	Boiler Maintenance	€ per litre (2020 value, including VAT)	Fuel Cost Low 90% efficiency, discounted over 10 years	Emissions (Tonne C0$_2$ Equivalent), per annum	Carbon Cost per Annum (€)	Carbon Cost per Annum Discounted (€)
B30K (FAME)	120	0.52	€16,683	5.162	341	253
B50K (FAME)	120	0.58	€15,877	4.044	253	198
H100 (HVO)	120	0.96	€25,669	0.95	59	47

Source: AECOM calculations, based on current (2020) industry estimates of bioliquid fuel costs

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[25] https://www.seai.ie/publications/Domestic-Fuel-Cost-Comparison.pdf

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