Department
of Energy &
Climate Change

RHI Evidence Report: Bioliquids for Heat.

Assessment of the Market, Renewable Heat Potential, Cost, Performance, and Characteristics of Bioliquids for Non-Domestic Heat.

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Glossary

ACT: Advanced Conversion Technologies

AD: Anaerobic digestion

ASTM: American Society for Testing and Materials

C&I: Commercial and industrial

CAPEX: Capital expenditure

CCC: Coordination and Consistency Contractor

CfD: Contract for Difference

CFPP: Cold filter plugging point

CHP: Combined heat and power

CV: Calorific value

DD1: Deodoriser distillate

DECC: Department of Energy and Climate Change

DfT: Department for Transport

DKK: Danish krone

EC: European Commission

ECA: Enhanced Capital Allowances

EN14214: European standard that describes the requirements and test methods for **FAME** - the most common type of biodiesel

EoW: End of Waste

ETS: Emissions Trading Scheme

EU: European Union

FAME: Fatty acid methyl ester

FID: Final investment decision

FiT: Feed in Tariff

GHG: Greenhouse gas

GJ: Gigajoule

GWh: Gigawatt-hour

IEA: International Energy Agency

ILUC: Indirect land use change

IP: Intellectual property

ITT: Invitation to Tender

JRC: Joint Research Council

kWe: Kilowatt-electric

kWh: Kilowatt-hour

LC: Lignocellulosic

LCA: Lifecycle assessment

LHV: Lower heating value

MBT: Mechanical-biological treatment

MJ: Megajoule

MONG: Matter Organic Non-Glycerol

MRF: Materials recycling facility

MSW: Municipal solid waste

MW: Megawatt

MWh$_{th}$: Megawatt-hour thermal

MW$_{th}$: Megawatt thermal

odt: oven dry tonne

OECD: The Organisation for Economic Co-operation and Development

Ofgem: The Office of Gas and Electricity Markets

OPEX: Operational expenditure

OR1: Oleochemical residues

OS: Oxidation stability

PPA: Power purchase agreement

PM: Particulate matter

REA: Rapid evidence assessment

RED: Renewable Energy Directive

RHI: Renewable Heat Incentive

RO: Renewables Obligation

ROCs: Renewable Obligation Certificates

RTFO: Renewable Transport Fuel Obligation

SDE+: Stimulering Duurzame Energieproductie – Encouraging Sustainable Energy Production

SRF: Solid recovered fuel

TA: Trade association

tCO$_2$e: tonnes of carbon dioxide equivalent

tpa: tonnes per annum

TWh: Terawatt-hour

UCO: Used cooking oil

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Executive Summary

Introduction and Objectives

1. As part of its wider policy measures to reduce domestic greenhouse gas emissions (GHG) to meet UK, EU and Internationally agreed targets, the UK Government wishes to decarbonise heat generation in the UK, which is responsible for a third of UK GHG emissions. Working through the Department of Energy and Climate Change (DECC), the Government has set a target to deliver 12% of UK heat energy demand from defined renewable sources by 2020.
2. DECC has stated that it will assess the case for inclusion of a range of additional technologies that could be supported by the non-domestic RHI. One of the technologies under consideration is the use of 'heating only' bioliquids.
3. DECC needs to ensure that there are no unintended consequences of expanding the RHI and that the costs of any selected technologies deliver acceptable carbon reduction costs. By reference to 'heating only' applications, DECC means to restrict the applicability of the RHI to bioliquids that are not eligible to be used as renewable transport fuels, as supported by the Renewable Transport Fuel Obligation (RTFO).
4. DECC is interested to understand the potential for any non-food derived bioliquid feedstocks (which are suitable for heating) that are available now, or could be developed in the near future. Such feedstocks are referred to throughout this study as 'candidate' feedstocks. The first fundamental challenge of this study is therefore to determine a suitable methodology for selecting candidate feedstocks, our approach to which is described in Section 2.1.
5. It is important to note that whilst the goal of the study is to highlight candidate feedstocks that are suitable for heating, this is not to suggest that these should be ruled out for future use as transport fuels. The objective of this study is rather to provide information to help DECC in further discussions with DfT as to how Government chooses to incentivise use of such feedstocks.

Approach to Feedstock and Market Characterisation

6. The scope of the analysis undertaken for this study includes feedstock acquisition, feedstock processing and fuel conversion. This is far broader than the concurrent studies being undertaken for other 'extension' technologies, which do not rely upon feedstocks as fuels.
7. To enable the identification of candidate feedstocks for heating applications, a decision-making framework was agreed with DECC, which included a detailed set of assessment criteria. This framework included criteria relating to both heat and transport suitability, and ultimately any feedstocks which are clearly most suited (and are indeed being currently used) for transport, such as most virgin vegetable oils, were excluded from further analysis. This approach resulted in the prioritisation of the following four feedstocks:
    - Deodoriser Distillate (DD1);

- Oleochemical Residues (OR1);
- A Lignocellulosic (LC) 'Group'; and
- Solid recovered fuel (SRF) from residual waste.

8. It should be noted, however, that this analysis does not mean to suggest that other feedstocks (for example, black liquor, glycerol or tall oil pitch) do not represent candidates for support under the RHI. It is simply that the scope and budget constraints are such that they have not been given similar analysis as the priority feedstocks in this report

9. As OR1 and DD1 are processed into what is essentially the same interchangeable heating fuel, analysis of the cost and performance of these feedstocks was undertaken as if one feedstock.[1] A similar approach was applied to LC Feedstocks and SRF, which require very similar processing, with the resulting pyrolysis oil being converted in the same boiler types.

Cost and Performance Data for Prioritised Feedstocks

10. In summary, it is possible to report the following with regard to OR1 and DD1:

    - Anecdotal evidence gathered for this study suggests that both DD1and OR1 have currently very limited use as heating-only fuels in the UK, whilst more significant amounts are sent for CHP (combined heat and power), often with support from the UK Renewable Obligation (RO). At least three organisations do seem to be managing or trading these feedstocks as fuels in the UK, albeit additional volumes also appear to be exported for use overseas in boilers supplying district heating schemes.[2]
    - The limited datapoints gathered for this study suggest that the prices associated with acquiring DD1 and OR1 range from £300 to £500 per tonne (delivered at the gate). It should be noted, however, that these prices are largely supported by the CHP market, and may differ if linked to any potential future support under the RHI.
    - Whilst we have managed to gather data relating to feedstock processing costs for OR1 and DD1, all such information has been deemed by operators as commercially confidential and not for publication by DECC. This information (which wraps both CAPEX and OPEX together) has, however, been made available to DECC to inform future policy-making. We have, however, managed to gather anecdotal data relating to the costs for modifications to enable industrial boilers using gas oil to be retrofit to process bioliquids from OR1 and DD1. These are in the region of £1,500-2,000 for boiler of 1-10 MWth.

11. In summary, it is possible to report the following with regard to LC feedstocks and SRF:

    - The development of LC feedstocks for commercial use as pyrolysis oil is currently about to reach full demonstration (or 'semi-commercial' scale). Within Europe there are two main organisations which are in the process of constructing such pyrolysis facilities; the 'Empryro' project in The Netherlands (which is being developed by Treepower, with consortium partners including AkzoNobel, BTG and Stork) and the 'LignoCat' project in Finland (which is being developed by Fortum in consortium with UPM and Valmet).

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[1] It should be noted, however, that where boilers are located on same site as an oleochemicals or margarine manufacturing facility, they are more likely to have been designed to specifically process either OR1 or DD1

[2] Personal Communication, bioliquids and biofuels trading organisation, March 2014

- Based on information provided by Treepower (which includes staff costs, fixed and variable costs, along with annualised finance costs such as equity return, debt repayments and depreciation) it can be calculated that the Empyro project is forecast to produce pyrolysis oil at €265 per tonne.
- It should be noted, however, that this is not a calculation of levelised costs, which is outside the scope of this study and will be undertaken directly by DECC using this information along with its preferred approach to discounting. It should also be acknowledged that this calculation includes the significant funding from the EU the project has received along with 'soft' loans from local authorities in the Netherlands.
- Both of the Empyro and Lignocat projects are currently focused on processing woody biomass from the forestry sector. It is expected that producing pyrolysis bio-oil from S-RF would require greater costs than production from woody biomass. These costs would be associated with the processing infrastructure due to the complexities of contamination and the non-homogenous nature of residual waste. This is not to say it will not ever be commercially viable to produce pyrolysis bio-oil from SRF, but currently there are lower risk investments to be developed in the waste market, including conventional waste incineration and gasification facilities which are currently being developed by the main contractors.
- That said, the market for residual waste is very different from that of the other LC feedstocks in that waste processors earn a gate fee for accepting residual waste, rather than paying for each tonne of feedstock. Generally cement kilns charge a gate fee of £20-40 per tonne for a high specification SRF, whilst incinerators charge between £60 and £100 per tonne for a far less refined and variable feedstock, which is usually described as refuse derived fuel (RDF) or unprocessed residual waste. The economic viability of processing SRF (or residual waste) into pyrolysis oil would depend upon the balance between the additional costs associated with pre-treatment compared with woody biomass, which may be significant, and the revenue received as a gate fee. At present, there are no operating facilities, and thus no data points by which to assess this balance of costs.

Other Cost Considerations

12. Detailed assessment and recommendations as to how DECC should model hassle and risk costs is outside the scope of this study. That said, it is worth highlighting that anecdotal evidence gathered for this study suggests that the costs associated with applying and administering ongoing compliance with the RHI could be as high as £25,000 per annum for 'larger' (>10MWth) installations and thus function as a potential deterrent to new facilities to burn bioliquids.
13. The potential for cost reduction in feedstock processing and boiler conversion to heat for OR1 and DD1 appears to be very low, albeit this evidence is based on very limited data. In contrast, however, there would appear to be significant potential for cost reduction in proc]essing LC feedstocks (or SRF) into pyrolysis oil for use in heating boilers. It should be acknowledged, however, that the Empyro project has received significant funding from the EU along with 'soft' loans from local authorities in the Netherlands, and therefore financing costs would be far greater for later commercial projects.

Renewable and carbon saving credentials

14. Based on the qualitative interviews undertaken for this study, the counterfactual technology assumed for this analysis is an industrial boiler burning gas oil (also known as red diesel or '35 second' oil) to produce process heat or steam.

15. Assuming the high estimates of the current available UK arisings for the four prioritised feedstocks were converted into heating bioliquids, we have calculated that the total renewable heat potential might be as high as 63 TWh/annum whilst the associated carbon savings may be as high as 19 million tCO2e/annum.[3] The vast majority (>98%) of both these, however, are derived from the potential conversion of LC feedstocks (including SRF) into pyrolysis oil. As discussed above, this technology remains at a relatively early stage of commercial development and therefore such high annual levels of renewable heat and carbon savings are very unlikely to be achieved before 2020.

Potential Contribution of Bioliquids to 2020 Renewables Targets

16. It is therefore important to apply some further assumptions to this data to provide a more realistic picture of market potential to 2020. Whilst this will be dependent upon the level of potential RHI tariff which is put in place, based on the information and market intelligence gathered for this study, we have made an informed estimate in respect of the four prioritised feedstocks. This analysis results in a projected renewable heat output of 0.4 to 1.6 TWh per annum (and associated carbon savings of 122 to 431 $ktCO_2$), which represents between 0.9 to 3.3% of the estimated 50 TWh of heat energy that could be supplied from biomass sources by 2020, as per the central estimate of the UK Renewable Energy Roadmap.

Analysis of RHI Suitability

17. Experience with the RHI thus far (and with the RO and FiT), has shown that simply putting in place a tariff (however high, to a reasonable extent) does not bring about new infrastructure if this is dependent upon *either* relatively unproven technologies or those for which feedstock cannot simply be purchased (i.e. contracts must be won) from the market. This would suggest that such an approach may not be effective, at least for SRF and LC Feedstocks.

18. Furthermore investment in heating infrastructure is far more of a challenge than electricity infrastructure due to off-take counterparty risk. Whilst electricity revenues essentially depend upon a power purchase agreement (PPA) with a single licensed energy supplier, this is essentially backed by many unnamed users of electricity via the national grid. In contrast, aside from in the situation of wide heat networks, industrial heat off-take usually relies upon one counterparty, which if from industry, is subject to global market forces and thus may not be in business for the full pay-back period on investment. Consequently, lenders are far more reluctant to provide finance for heat-only projects. Such 'off-take counterparty' risk is therefore a major barrier to large scale renewable heating investment, and therefore shortening the RHI pay-back period to perhaps 5-10 years would be likely to bring forward greater infrastructure capacity. This would be more akin to the 7-year period of support under the domestic RHI;

19. There is also the risk of the following potential perverse outcomes:
    - Diversion of some feedstocks from existing markets, for example, pulp and paper production may lead to less desirable environmental outcomes, whereby users switch

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[3] It should be noted that our analysis indicates that it is unlikely that there will be any heating bioliquids produced from SRF prior to 2020

to alternative fuels. These could potentially be fossil fuels which would offset the carbon savings achieved; and

- Depending upon the structure of the tariff, RHI support could result in gaming by participants to maximise overall revenues from heat generation in two ways:
  - Should different banding levels be put in place for varying sizes of boiler, some participants will deliberately procure an installation at the very top of one of the tariff bands to get the higher tariff, even if they do not need that level of heating capacity; and
  - Should a 'tiered' tariff also be put in place, i.e. whereby users are rewarded with a higher tariff for a prescribed level of output (in hours, rather than MWh) and a lower tariff for any remaining output, this can also incentivise larger boilers. This is because operators seek to maximise the level of MWh they can achieve at the higher tier, and then potentially switch to an alternative fuel source after they have exhausted the related maximum number of hours.

Conclusions and Recommendations

20. The key question to address here is whether heating bioliquids and the associated boiler technologies which would convert these feedstocks into renewable heat should be provided with support under the RHI.

21. Our analysis suggests that there appears to be only limited justification for government intervention in this market on the basis of market failures. This is very feedstock specific, however, in that many of the potential feedstocks highlighted for initial (and detailed) analysis in this study are already either being used for heating (or electricity) generation or as transport fuels. Others, however, are less in demand, which could be changed via support under the RHI.

22. The potential CO_2 savings which might be delivered via support for the four priority bioliquids under the RHI may provide additional justification for intervention, but again these would need to be compared by Government with those which are delivered, or might in the future be delivered, via support under the RO and RTFO.

23. If RHI support for bioliquids was to be provided, DECC would need to very carefully design the tariff and associated policy detail to minimise the risks of:

- Directing some feedstocks away from use in electricity markets (currently supported by DECC via the RO and, under the FiT CfD regime for 'advanced' feedstocks) and transport markets (supported by the RTFO), the latter for which DfT might provide evidence to suggest they are currently more suited;
- Significant amounts of funding being allocated to manufacturing organisations operating onsite processing heating boilers converting such feedstocks as DD1, OR1 and distillation residues, which are likely to have been installed anyway;
- Exerting pressure on the overall RHI budget by providing support for a range of bioliquids, as it is understood that, due to the restrictions of the EU Renewable Energy Directive (RED), DECC is not able to 'nominate' specific fuels for varying levels of support;
- Setting the tariff at a sub-optimal level, which:

- If set too low, RHI support could provide an insufficient level of incentive for additional capacity to come forward; and
- If set too high, RHI support could lead to a situation where the marginal uptake is too great and thus DECC is compelled to quickly degress the tariff, potentially creating uncertainty in the market.

24. Achievement of such a policy design will be highly challenging. It is therefore recommended that DECC considers the following issues and related suggested tasks:

    - The research undertaken for this study suggests that the current state of the bioliquids heating market is not sufficiently mature (or with sufficient number of data points) as to provide any firm basis for tariff setting using the levelised cost approach. This study is somewhat limited in scope, however, and there may therefore be some merit in allocating further resource to assessing the suitability of some of the other eight candidate feedstocks, beyond the four prioritised in this analysis. Furthermore, additional resource allocation to the four priority feedstocks might also yield a greater volume of information to better inform tariff setting via the levelised cost method;
    - This lack of confidence in the data is the result of a nascent market, however, which suggests that a levelised cost approach to tariff setting will be extremely challenging for DECC to ‘get right’. There are lessons to be learned from the solar photovoltaic (PV) market under the FiT in this respect. It may therefore be appropriate to undertake analysis supporting the design of an approach to enable a ‘reverse auction’ of bioliquid heating capacity. This would potentially allow DECC to bring forward a prescribed level of capacity at lowest cost. Furthermore, in contrast to the solar PV market, which is dominated by a large number of small installations (of just a few kWe each), the average boiler size in this context is around 5MWth, and thus such a process would have far lower administration costs; and
    - There is still some debate between DECC and DfT as to how to determine whether a feedstock should be incentivised for transport or heating applications. One feedstock processor interviewed for this study has proposed an approach based on technical parameters (applicable to OR1 and DD1 feedstocks only), which might enable Government to make this determination.[4] Whilst we understand that DfT has commissioned research to consider whether these specific feedstocks could be used in biodiesel production, the lack of any clear alternative suggests that this technical approach is worthy of a more detailed analysis.

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[4] See Section 2.1.3 for further details of this approach

1 Introduction, Scope and Objectives

1.1 Introduction and Objectives

As part of its wider policy measures to reduce domestic greenhouse gas emissions (GHG) to meet UK, EU and Internationally agreed targets, the UK Government wishes to decarbonise heat generation in the UK, which is responsible for a third of UK GHG emissions. Under the EU Renewable Energy Directive 2009 the UK government has a commitment to increase renewable energy use to 15 per cent by 2020. Renewable heat will contribute towards meeting this commitment, but currently heat demand from renewable energy sources stands at only 2.3%. To further encourage uptake of renewable heat, DECC therefore wishes to increase deployment of renewable heat technologies. Renewable heat-only generation is supported by the Renewable Heat Incentive (RHI) scheme, currently supporting non-domestic and domestic heating applications..

At the time of writing, DECC has concluded a review of the impact of its current non-domestic RHI policy, to examine the success of the scheme and whether there is a need to revise the tariffs available. In addition, DECC has also stated that it will assess the case for inclusion of a range of additional technologies that could be supported by the non-domestic RHI. One of the technologies under consideration is the use of ‘heating only’ bioliquids.

By expanding the RHI, DECC needs to have a good understanding of the potential associated risks, such that the costs of any selected technologies deliver acceptable carbon reduction costs. By reference to ‘heating only’ applications, DECC is focusing on the applicability of the RHI to bioliquids that are not eligible to be used (or not technically or economically feasible of being used) as renewable transport fuels, as supported by the Renewable Transport Fuel Obligation (RTFO). This is in recognition of the fact that transport is the second biggest source of GHG emissions in the UK, beneath energy supply, and that the range of options for decarbonising this sector are much more limited (needs a highly energy dense, transportable fuel) and decarbonisation of the road transport sector currently relies significantly on the development of fuels from bioliquid resources. Transport has its own GHG reduction targets and diverting bioliquids away from this sector would make it difficult to achieve these, even more so when considering that transport sector has fewer alternatives available to meet its target.

The development of bioliquids for transport has also raised concerns about impacts on food prices, as a result of diverting food crops to bioliquid development, as well as impacts from changes in land use, i.e. diverting land into productive agriculture, potentially causing significant GHG emissions. As a result these impacts could negate any overall benefit in GHG reduction in the worst case scenario. In response, as part of the EU’s Renewable Energy Directive (RED), any support measure provided for bioliquids must ensure that mandatory EU biofuel sustainability criteria are met and that minimum GHG requirements are delivered.

DECC is therefore interested to understand the potential for any non-food derived bioliquid feedstocks (which are suitable for heating) that are available now, or could be developed in the near future. Such feedstocks are referred to throughout this study as ‘candidate’ feedstocks. The first fundamental challenge of this study is therefore to determine a suitable methodology for selecting candidate feedstocks, our approach to which is described in Section 2.1.

It is important to note that whilst the goal of the study is to highlight candidate feedstocks that are suitable for heating, this is not to suggest that these should be ruled out for future use as transport fuels. The objective of this study is rather to provide information to help DECC in further discussions with DfT as to how Government chooses to incentivise use of such feedstocks.

DECC is also interested in whether or not incentivising feedstocks is the correct path to take, and whether or not the RHI is the right mechanism to promote the uptake of bioliquids for heat applications. Furthermore, for each candidate feedstock, DECC would like to determine the associated costs and performance of related processing, refining and conversion processes for each of these feedstocks, such that this information can be used to guide any potential future RHI tariff setting.

1.2 Scope of Analysis

It is useful to determine the scope of the analysis required to provide this information, which can broadly be focused upon three areas (feedstock acquisition, feedstock processing and fuel conversion), as presented in Figure 1.

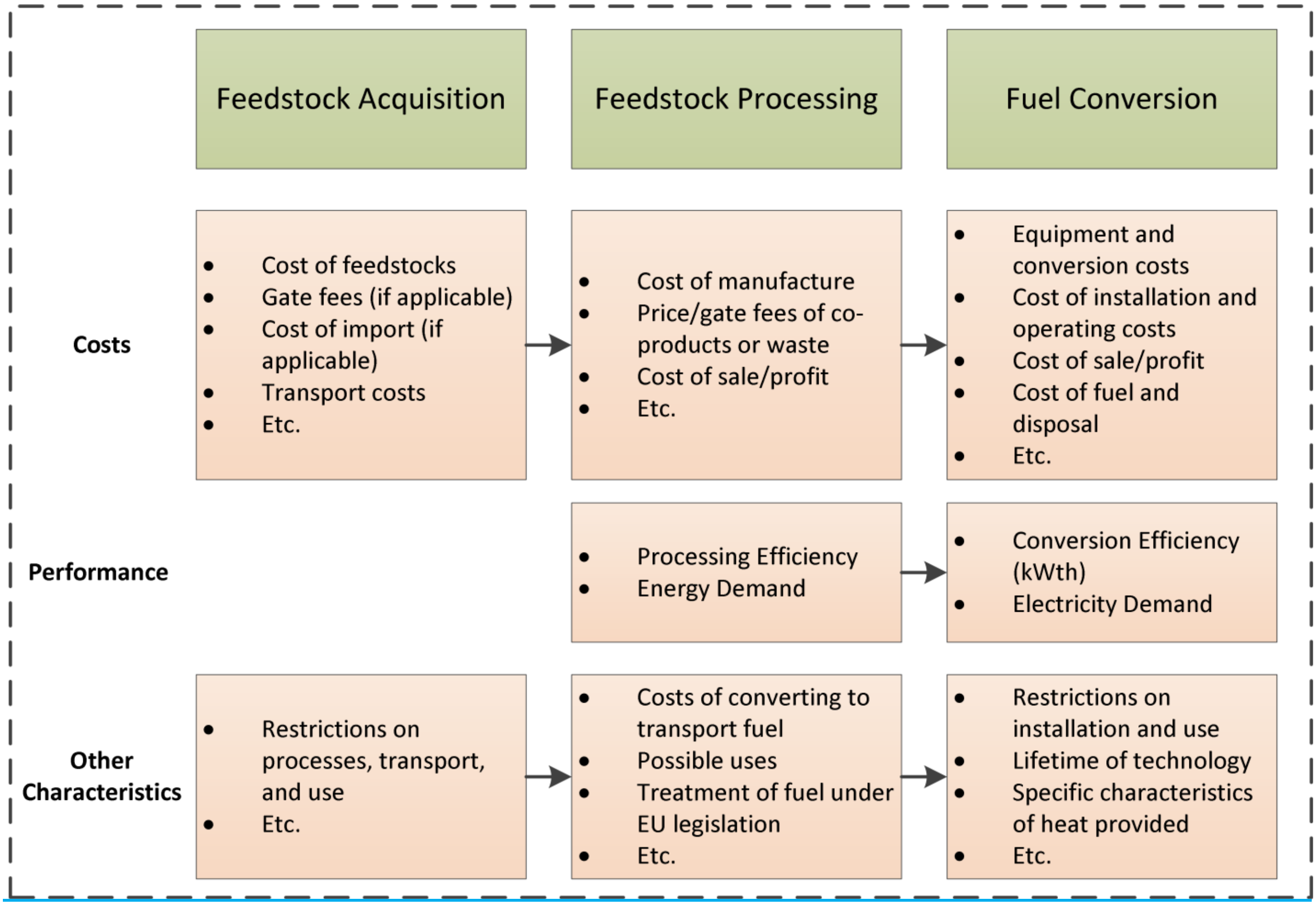

Figure 1: Overview of System Boundaries

The recent DECC consultation response on proposals to expand the RHI has highlighted two key restrictions:[5]

- Firstly, any support for bioliquids must ensure that mandatory EU biofuel sustainability criteria are met. Furthermore, whilst feedstocks which are suitable for food applications are eligible for support under the RED, only non-food feedstocks should be considered for support by DECC under the RHI;

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[5] DECC (2013) *Non Domestic Renewable Heat Incentive: Improving Support, Increasing Uptake*, December 2013

- Secondly, it is critical that added incentives for use of bioliquids in heat applications should not divert feedstocks and fuels suitable for use in transport. Therefore, analysis should be undertaken only for those fuels and feedstocks that are not appropriate for use in transport.

The focus of the analysis in this study is therefore to understand only feedstocks which fit into these constraints, such that DECC might only provide support for those which do not impact upon key adjacent markets, and thus which would appear, based on current perception, to deliver clear environmental benefits.

At present, there are many feedstocks, which might theoretically be used as heating fuels, for example, palm oil, used cooking oil (UCO) and rape seed oil. These feedstocks, however, could also be used for either food production or are eligible for transport. Consequently, competition is such that their market value is relatively high. Prior to the RTFO, the heating market, or certainly the CHP market, could compete for these feedstocks, but today without Government support akin to the RTFO, it simply cannot pay the same prices as the transport sector. Indeed, in the UK, it is understood from one fuel supplier that the CHP industry continued to use cold pressed rape seed oil until only a short number of years ago, when it became too costly due to the RTFO. As a result, many heating fuel suppliers have focused on more ‘marginal’ (or non-mainstream) fuel types, as is explored in the remainder of the study. We would expect, however, that in the absence of these constraints the most cost-effective fuels to use in the UK would be palm oil, UCO and rape seed oil, all of which are considered to be ‘food’ and/or transport-suitable feedstocks.

Taking these two issues into consideration, along with the objectives of the study, as described in Section 1.1, the range of non-food feedstocks that are that are considered in this study are summarised in Table 1.

Type of Feedstock	Examples
Energy Crops	Wheat straw, miscanthus, short rotation coppice poplar and willow
Waste	Bio-fraction of municipal and C&I waste, sewage sludge
Agricultural and Forest Residue	Straw, corn stover, animal manure, bagasse, nut shells, husks, cobs, bark, branches, leaves, saw dust and cutter shavings
Cultivated and Waste Oils	Palm oil mill effluent, tall oil pitch, crude glycerine, black and brown liquor, used cooking oil, animal fats
Algae	Micro-algae, macro-algae

Source: NNFCC (2011) Advanced Biofuels: The Potential for a UK Industry, Report for Department of Energy and Climate Change and Department for Transport, November 2011

Table 1: Overview of Non-Food Feedstocks

As described in this report, various techniques can be used to convert these non-food feedstocks into bioliquids. Thermochemical methods, which include gasification and pyrolysis, are the most common. Biochemical processes can also be used to ferment the cellulose fractions of feedstocks into alcohols.

A full list of feedstocks reviewed for this study is provided in Appendix 1, alongside their categorisation in respect of suitability for heating or transport (or both). This list is comprehensive, but not exhaustive, for example, some very obscure potential feedstocks which have only very small known arisings have been excluded from the analysis.

2 Approach and Methodology

There are a number of key phases of analysis which we have undertaken to deliver upon the objectives described in Section 1.1. These phases are summarised in Figure 2.

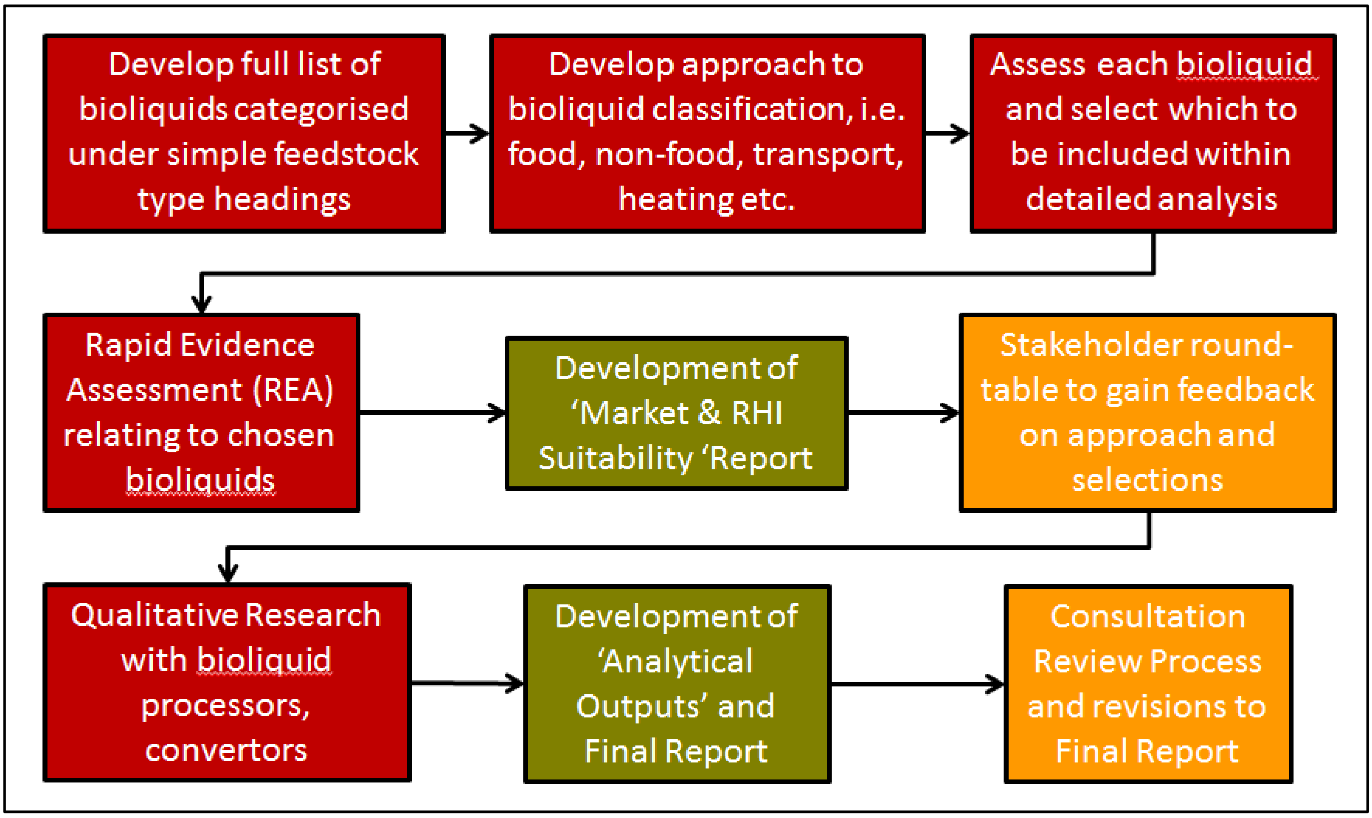

Figure 2: Overview of Study Methodology

As noted above, significant emphasis is placed on the determination of which feedstocks represent 'candidates' for support as bioliquids for heating under the RHI, i.e. those which are more suitable for use as renewable heating fuels rather than renewable transport fuels. Our approach to determining these feedstocks is based around a 'decision-making framework' which is described in detail in Section 2.1.

Following selection of these feedstocks for further analysis, for each we undertook a 'Rapid Evidence Assessment' (REA), as described in Section 2.2. For each selected feedstock, these REAs allowed us to undertake an initial 'Market and RHI Suitability' report, which focuses on any barriers to deployment as well as opportunities to overcome these barriers, along with an assessment of any potential threats to market development. These can be found:

- For the prioritised feedstocks in Appendix 3; and
- For the non-prioritised feedstocks in Appendix 4.

The analysis undertaken in the Market and RHI Suitability reports facilitated the initial 'down-selection' and exclusion of some feedstocks from further analysis. At this stage, a stakeholder 'round-table' meeting was held to gather views from industry on the methodology used to select feedstocks for detailed analysis, i.e. the decision-making framework.[6] Following this meeting, a further process of 'prioritisation' of feedstocks took place in discussion with DECC, as described further in Section 4. This resulted from the need to focus on a limited number of feedstocks due to the restricted scope and budget of study. It should be emphasised that this prioritisation *does not* mean to say that some of the other feedstocks are not suitable for RHI support, just that these are viewed as less of a priority for DECC when assessed in more detail against the key framework criteria.

All prioritised feedstocks were then subject to the development of detailed 'Analytical Outputs' (i.e. cost and performance data), which is reported in Section 6. Our approach to development of this information is detailed in Section 2.3, and is broadly based on a set of assumptions developed by DECC's Coordination and Consistency Contractor (CCC) for a range of similar RHI Assessment studies being undertaken concurrently to this one.

2.1 Approach to Feedstock Categorisation

This Section details the decision-making framework for selecting which bioliquids should be taken forward for market and RHI suitability assessment, and for those which no significant barriers have been identified via that assessment, followed by the phase of gathering of analytical outputs for heating applications.

2.1.1 Suitability of Feedstocks for Heating or Transport

DECC is keen to categorise feedstocks according to whether they are more suitable for heating or transport. Building upon the approach suggested in the Invitation to Tender (ITT), we have used the following four different descriptions by which to categorise all feedstocks:

1. **Most suitable for potential use in heating applications**

   According to the criteria within the decision-making framework and matrices set out in Section 2.1.2, the feedstock has been deemed as most suited for potential use in heating (rather than transport) applications. It has therefore been subject to a market and RHI suitability assessment, and if no significant barriers have been identified, has passed into the analytical outputs phase of the study;

2. **Most suitable for potential use in transport applications**

   Again, according to the criteria within the decision-making framework, the feedstock has been deemed as most suited for potential use in transport (rather than heat) applications. It has therefore not been the subject of further analysis in this study;

3. **Most suitable for potential use in heating OR transport applications**

   Again, according to the criteria within the decision-making framework, the feedstock has been deemed as suited for potential use in both heating and transport applications; and ultimately, based on current knowledge it cannot be determined which route would be preferable. Whilst DECC does not wish to divert feedstocks which are likely to be suitable for transport away from such applications, it is prudent to undertake further analysis of feedstocks within this category, should it be determined at a later date by the Department for Transport (DfT) that they are not suitable for transport applications. Such feedstocks have therefore been subject to analysis in this study;

4. **Not suitable for heating applications**

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[6] A list of attendees at this Stakeholder Meeting can be found in Appendix 4

Again, according to the criteria within the decision-making framework, the feedstock has been deemed as not suitable for use in heating applications. It has therefore not been the subject of further analysis in this study

2.1.2 Overview of the Decision-making Framework

An overview of the decision-making framework is provided by way of a ‘decision-tree’ in Figure 3. The framework is characterised by two main phases of analysis, which are contained within ‘heat-suitability’ and ‘transport-suitability’ matrices. Essentially each feedstock is first assessed for its suitability to the heating market, and if deemed suitable, it is assessed in terms of its suitability to the transport market. In each matrix a feedstock is assessed against a number of criteria to determine its suitability for heat or transport applications. The full detail of each matrix is provided in Appendix 2, but in summary, these criteria include analysis of:

- Theoretical Conversion Steps Required;
- Commercial Readiness of Conversion Process;
- Ability to Source Commercial Volumes;
- Cost / Gate Fee of Feedstock;
- Cost of Conversion;
- Cost of Feedstock Transport to UK (if applicable);
- Competitiveness of Potential Output Fuel at Commercial Scale;
- Sustainability Criteria;
- Techno-economic Comparison with Solid Feedstock;
- Market Comparison with Solid Feedstock; and
- Likelihood of Commercial-scale Viability pre-2020.

As shown in Figure 3 a third phase of assessment occurs to determine whether a feedstock is more suitable for either heat or transport applications. If this cannot be determined, then whilst such feedstocks have not been excluded from consideration in this study, the question of suitability is one which will be determined outside of this study by way of discussions between DECC and DfT. This issue explored further in Section 2.1.3 in the context of a specific feedstock.

There are also a number of principles which underpin some of the decision-making with regard to feedstock categorisation within this phase of the analysis. The principles can be summarised as follows:

- We assume that lignocellulosic (LC) feedstocks (which might be converted to heating bioliquids via pyrolysis) are *at least as suitable* for heating applications as for transport applications, for which gasification is required for conversion to liquid fuel. The majority of LC feedstocks have therefore been taken forward into a market and suitability assessment, as summarised in Section 4; and
- We also assume each feedstock is relatively ‘clean’, i.e. that it does not include a significant amount of contaminants or water content. This is particularly important in terms of some feedstocks which might be considered as ‘wastes’ or ‘residues’. Whilst we recognise that there might be significant variation in the overall composition of such

streams, it would not be practicable within the scope of this study to model variations in each feedstock; hence the assumption that each is relatively clean.

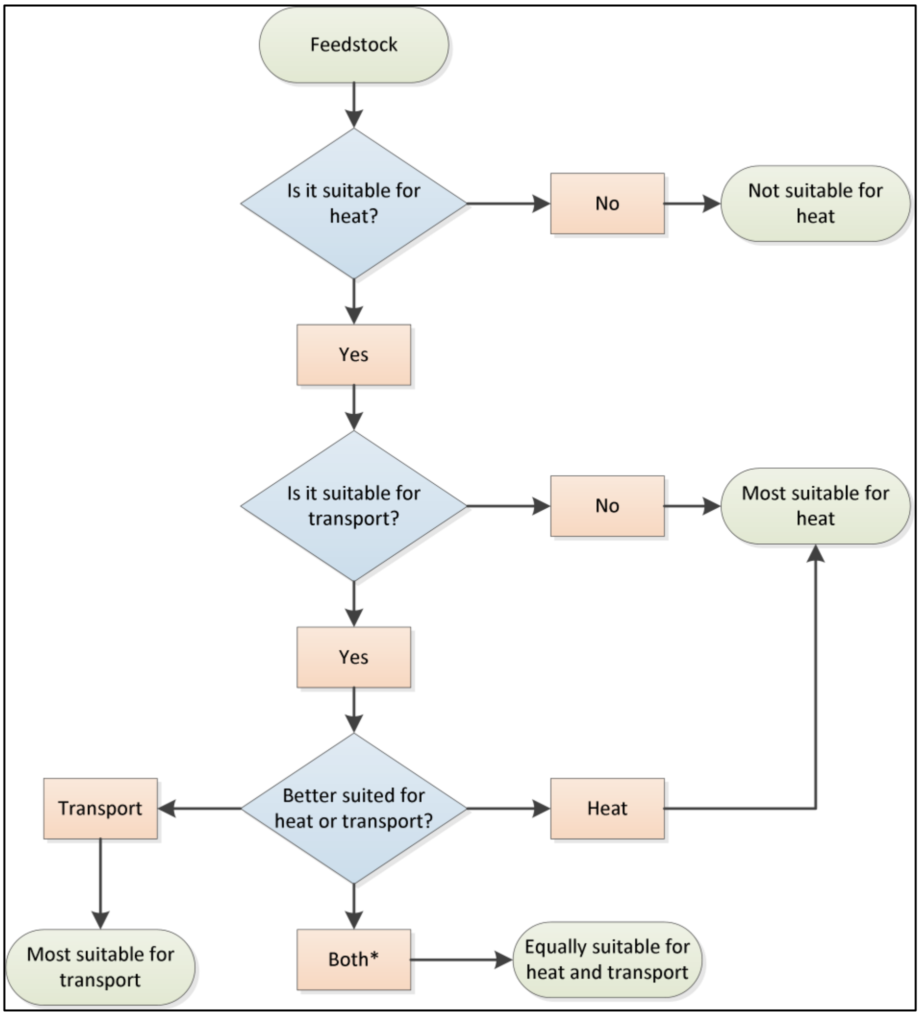

Figure 3: Decision-tree to determine Heat or Transport Suitability

2.1.3 Heat or Transport Suitability?

It is important to note that, in a policy context, it is currently very challenging to determine whether a particular feedstock is better suited to heating or transport applications. Government has committed to providing support under the RHI for new installations which are commissioned up until 2020. Consequently, it is in theory possible to rule out any feedstocks (and associated processing technologies) which we believe are not likely to be commercially feasible within this timeframe. Currently, however, such an approach is not possible for transport, as DfT may wish to provide support, in line with potential developments at European Commission (EC) level, for feedstocks to be converted to transport fuels beyond 2020. As a result, in many cases we have not been able to rule out some feedstocks in respect of their suitability for transport, even if they might appear more immediately suitable for heat. In such cases, therefore, we have chosen to provide relevant information in this study on the basis that this might be used by DECC for future analysis at such a time that DfT determines that it does not wish to support a given feedstock.

It is also worth highlighting that both during the Stakeholder Meeting described above, and as part of the qualitative interview programme (described in Section 2.3) information was provided by one attendee/interviewee in respect of a proposed technical approach to determining whether a feedstock can be used as a transport fuel.[7] In short summary, the principal behind this approach is that it is not possible via transesterification, for feedstocks such as deodoriser distillates (DD1) and oleochemical residues (OR1) to meet the requirements of EN14214 standard for road biodiesel in respect of:

- Cold Filter Plug Point (the temperature at which fuel begins to 'wax' and becomes viscous, affecting flow), for which a maximum temperature of -20°C (winter) is required; and
- Oxidation Stability (a measure of the 'shelf life' of a biofuel), for which an oxidation stability (OS) of at least 8 hours must be achieved.

DECC has received further details of this approach and alongside DfT will consider it alongside other information developed on behalf of DfT, which has not been published. Our analysis of this information suggests that this represents an area where further research is required.

2.2 High-level Rapid Evidence Assessment

The approach taken to reviewing the available evidence for this study can *broadly* be defined as a REA. An REA can be described as a systematic and documented process of searching for evidence, setting exclusion and inclusion criteria and data extraction from the materials found. This approach maximises our ability to review a large volume of data, as comprehensively as possible, within the constraints of the timetable and budget.[8] This will include analysis of data drawn from journal articles, government and consultancy reports and industry grey literature. By drawing on our experience we will be able to critically appraise where such data is of sufficient quality and relevance for inclusion within the study.

As part of this REA process, using our existing network, we have made contact with trade associations (TAs) and research networks in order to understand the extent of externally available literature, reports and analyses. This stage allows us to establish the extent of current work on this topic, and therefore facilitates identification of gaps in understanding that will require further targeted data collection for the gathering of information to support the Analytical Outputs phase of the study.

As part of the REA, we also conducted a brief review of schemes in other EU Member States which provide financial support for heating bioliquids. This allowed for a high-level assessment of any lessons that could be learned for the UK, and provision of insight as to whether any incentives offered by other Member States might affect potential markets for bioliquids for heating in the UK. This review is provided in Section 3.

2.3 Approach to Development of Analytical Outputs

The quantitative data relating to the costs and performance of bioliquid feedstocks and conversion processes was drawn from both secondary data and from a series of telephone interviews with industry, both in the UK and in other EU Member States.

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[7] This information was provided by Refuel Energy

[8] Civil Service (2013) *Rapid Evidence Assessment Toolkit* Index, Accessed 9th January 2014, http://www.civilservice.gov.uk/networks/gsr/resources-and-guidance/rapid-evidence-assessment

These interviews were semi-structured in nature and were based around a ‘topic guide’ to ensure each relevant area was addressed by the interviewer, even if not in the exact order of the guide. During interviews, field notes were taken by interviewers and this information was synthesised with secondary data to inform the findings of this study. All such datasets were also combined to produce a spreadsheet of analytical outputs for submission to DECC, which will be used to inform any decision-making relating to support for bioliquids under the RHI.

It should be noted that the number of interviews undertaken was somewhat limited by the limited number of organisations actually involved in heating bioliquid production and use in both the UK and wider EU. Furthermore, much information was considered to be commercially confidential, and thus whilst some of this has been permitted for submission to DECC to inform its further consideration for RHI support, it has not been possible to publish this data.

3 Other Support Schemes for Bioliquids

The use of bioliquids within the UK and other EU Member States is primarily driven by the Renewable Energy Directive (RED), whilst other policy measures, such as the EU Emissions Trading Scheme (EU ETS), may also impact upon the attractiveness of such applications. In this section we set out a brief analysis of bioliquid incentive schemes in other EU Member States and in the UK which may have an impact upon the potential development of bioliquid heating markets in the UK.

It is important to acknowledge that we have not provided analysis of the support mechanisms which might exist in other Member States for biofuels *for transport*. Whilst such mechanisms might also impact upon the availability of some feedstocks for use as heating fuels in the UK, such analysis is considered to be outside the scope of this study.

3.1 Renewable Heating Incentives in Other Member States

The RHI is often regarded as the world's first long-term financial support programme for renewable heat, and the research undertaken for this study does indicate that there are only a limited number of other schemes in other EU Member States which provide similar support to renewable heating technologies.[9] Whilst a number of schemes do provide some form of fixed support per unit of renewable heat produced (as per the RHI), the vast majority do not include any specific support for heating from bioliquids, albeit many provide support for heating from solid biomass and biogas. To demonstrate the scope of financial support for renewable heat within the EU, these schemes are listed in Table 2.

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[9] Department of Energy & Climate Change (2014) *Increasing the Use of Low Carbon Technologies,* 24th January 2014, Accessed 27th February 2014, https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/renewable-heat-incentive-rhi

Member State	**Scheme Characterisation**	**Eligible Technologies**	**Method of Support**	**Amount or Calculation of Support Level**
Belgium (Flanders)	Quota system (CHP certificates)	Biogas, biomass	CHP producers are eligible for CHP certificates	The amount of CHP certificates granted for 1,000 kWh of primary energy saved in a qualitative CHP-facility compared to a situation in which the same quantity of electricity or heat were produced separately is multiplied with the respective banding factor.
Denmark	Per unit output support	Biogas	Provision of a premium tariff for each GJ of biogas used	Two tariffs: DKK 26 (€3.5) per GJ_{biogas} DKK 10 (€1.34) per GJ_{biogas}
Finland	Per unit output support	Biomass and biogas	CHP plants burning biogas or wood fuel receive a fixed 'heat bonus'	The bonus is fixed at € 50 per MWh for CHP plants burning biogas, and at €20 per MWh for CHP plants burning wood fuel
Italy	Per unit output support ('Conto Termico')	In place for 'small' renewable heating sources, including aerothermal, hydrothermal, biomass, geothermal and solar thermal	Incentive is granted for a period varying between 2 and 5 years.	Incentives vary depending on the type, the source, the capacity and the location of the installation
Lithuania	Per unit output support	Biogas, biomass, geothermal, solar thermal	Utilities have a priority purchase obligation for renewable heat generated by independent producers.	Prices are either regulated by the …. Or are freely defined by independent heat producers.
Luxembourg	Per unit output support	Biogas	A feed-in tariff for producers that inject biogas into the natural gas network	Tariff levels differ depending on the timing of first injection and on the nature of the owner of the plant.

Source: RES Legal, Accessed 9th March 2014, www.res-legal.eu/

Table 2: Incentive Schemes in EU Member States for Technologies Other than Bioliquids

3.2 Support for Heating or Electricity from Bioliquids

3.2.1 Support for Heating from Bioliquids in other Member States

Within the scope of this study, we have only identified one Member State, the Netherlands, which provides support to bioliquids for heating under a similar scheme to the RHI. This scheme is known as the SDE+ (Stimulering Duurzame Energieproductie – Encouraging Sustainable Energy Production).[10]

The SDE+ scheme is essentially an operating incentive provided to non-domestic producers of renewable energy (electricity, gas, heat and CHP), with the aim of providing compensation for the difference between the cost price of fossil energy and that of renewable energy, i.e. it has very similar goals to the RHI. Financial assistance is provided for periods of 5, 12 or 15 years, depending on the relevant technology. The financial support is granted in six subsidy 'rounds' (phases), in which the amount of funding increases with each phase. Facilities under Round 1, therefore, receive a lower tariff than facilities which are granted funding during one of the rounds. The amount of support provided also differs according to the technology and plant size. Table 3 details the financial assistance provided by the SDE+ scheme for the production of heat (and electricity via CHP) from bioliquids.

Energy type	Technology	Capacity	Tariff range (€/GJ)[11]	Max. full load hours per year	Max. subsidy period (years)
Heat only	Boiler liquid biomass	≥ 0.5 MW_{th}	9.6 – 10	7,000	12
CHP	Solid and liquid biomass	> 10 and ≤ 100 MW_e	12.2 – 15.5	7,500	12
CHP	Solid and liquid biomass	≤ 10 MW_e	11.1 – 32.6	4,241	12

Table 3: Support Provided to Bioliquids for Heat Applications under the SDE+ Scheme

The scheme requires heat producers to prove that the bioliquids used comply with the EU sustainability criteria.[12] This is verified by means of certification through one of the many available voluntary biofuel sustainability schemes approved by the EC.[13] Data recently published by the Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland) suggests that 8 projects have received accreditation for funding under the scheme.[14] This will

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[10] Ministry of Economic Affairs (2013) *SDE+ 2013,* February 2013, *http://english.rvo.nl/sites/default/files/2013/11/English_brochure_SDE%2B_2013_%28kleur_version%29_0.pdf*

[11] The SDE+ tariff is calculated according to the following formula: SDE+ contribution = base amount – correction amount, where the base and correction amounts are equivalent to the estimated cost price for renewable and fossil energy respectively.

[12] Ministry of Economic Affairs (2013) *SDE+ 2013,* February 2013, *http://english.rvo.nl/sites/default/files/2013/11/English_brochure_SDE%2B_2013_%28kleur_version%29_0.pdf*

[13] European Commission (2013) *Biofuels – Sustainability Schemes,* 19th July 2011, Accessed 27th February 2014, http://ec.europa.eu/energy/renewables/biofuels/sustainability_schemes_en.htm

[14] See http://english.rvo.nl/

equate to a total of €364 million over the various different periods of support and it is suggested that nearly 26 TWh of associated heat (or electricity) will be delivered. It is not clear, however, how many of these projects are heat-only.

3.2.2 Support for Electricity from Bioliquids in Other Member States

Support for bioliquids used in electricity generation in the EU falls mainly under two types of scheme, these are:

i. **Fixed support per unit of renewable electricity produced**. This definition covers both feed-in-tariff schemes and quota schemes, both of which guarantee producers a minimum price for each unit of electricity produced.

ii. **Investment grants and loans.** These are schemes in which renewable energy production is incentivised through investment grants and loans, mainly to support the capital costs of developing new facilities.

This latter scheme-type is fairly common within other EU Member States, and some form of monetary grant or loan scheme is provided by the majority. Due to the widespread nature of these schemes, and the fact that few of these schemes are targeted specifically at bioliquids (most are aimed at incentivising all types of renewable technology), it is unlikely that these will have a significant effect on bioliquid markets in the UK. As such, they have been included as being relevant for analysis within the scope of this study.

A small number of countries, including France and Ireland, also incentivise renewable energy through tax regulation mechanisms. These generally consist of tax reductions on capital investments in renewable technologies - similar to the system of Enhanced Capital Allowances (ECAs) in the UK. These schemes effectively reduce capital costs in a similar manner to investment grants and loans, and are therefore, for the reasons listed above, not considered relevant to the aims of this analysis.

Schemes providing fixed support per unit of renewable electricity produced are less common. These schemes, however, arguably have a greater capacity to support renewable energy by providing generators with ongoing financial support over a defined period. Further detail on the scope of financial support from such schemes for renewable electricity from bioliquids within the EU can be found in Appendix 5.

3.2.3 Support for Bioliquids for Electricity and Transport in the UK

3.2.3.1 Renewables Obligation and Electricity Market Reform

Under the Renewables Obligation, generating stations accredited by Ofgem are eligible to receive Renewables Obligation Certificates (ROC) in respect of electricity generated from bioliquids. ROCs are tradable across all licensed electricity suppliers obligated under the RO. Suppliers which don't fulfil their obligation either by trading or production must pay the buy-out price, which has been set by Ofgem at £43.30 per ROC for 2014/15, and may be higher than the market price of a ROC.

The number of ROCs a bioliquid station receives depends upon which of the biomass bands it is operating in. For example, a station that is co-firing in the 'low range' co-firing band is eligible for 0.3 ROCs/MWh, while a bioliquids station operating in the dedicated biomass band will receive 1.5 ROCs/MWh. Furthermore, stations which generate combined heat and power or use energy crops as their feedstock are eligible for 2 ROCs/MWh.

Whilst these latter levels of support might be sufficient to promote use of bioliquids for electricity generation, DECC has stated that at these support levels, it expects very little standard co-firing with CHP or co-firing of regular bioliquids to be accredited during 2013/17 under the RO. At the same time DECC has put in place a specific cap on the amount of standard bioliquids capacity which will be supported under the RO.[15] This limit on support for standard bioliquids does not apply to ‘advanced’ (or ‘second generation’) bioliquids, which might come from pyrolysis processes. Indeed, from 2014/15, under the new regime following electricity market reform (EMR), eligible bioliquids will be able to receive Contracts for Difference (CfDs) under the strike price for ACT (Advanced Conversion Technologies).

Consideration of the extent to which the feedstocks selected for analysis in this study are currently being, or in the future might be used as bioliquids under the RO or CfDs is challenging. In terms of the feedstocks identified as priorities for this study, within the scope of this study it is not possible to disaggregate any related publicly available data on bioliquids fired under the RO to determine their overall level of use. At the same time, it is too early to determine the potentials impact on the market from the future support from CfDs.

3.2.3.2 Renewable Transport Fuel Obligation

Biofuels are supported in the UK through the Renewable Transport Fuel Obligation (RTFO). The RTFO obligates road transport fuel suppliers (who supply at least 450,000 litres a year) to show that a specified percentage of their fuels for road transport in the UK comes from renewable sources.

The RTFO includes a certificate trading mechanism to increase the efficiency of compliance. One certificate is awarded for each litre of biofuel supplied (two RTFCs for biofuels made from wastes). Trading certificates provide potential financial support for the production of biofuels. The value of RTFCs is determined by the market.

At the end of the obligation period, suppliers demonstrate compliance with the RTFO by redeeming the appropriate number of RTFCs to demonstrate that the required volume of biofuel was supplied or, as per the RO, suppliers which don’t fulfil the obligation either by trading or production are exposed to a far higher annually fixed ‘buy-out’ price.

The RTFO came into effect in April 2008, with an obligation level of 2.5% in the first year. For 2013/14 the obligated level (or target) is 4.75%. Given concerns over the sustainability of biofuels, the UK Government has been cautious in increasing targets for the supply of biofuels. It has argued in the EU for effective measures to address indirect land use change (ILUC) and assure the sustainability of biofuels, including through supporting a cap on crop-based biofuels. ILUC negotiations began in 2012, and it is hoped that the European Council of Ministers will agree a position at the Energy Council on June 13th 2014. If it does, final adoption may be completed before the end of 2014.

In December 2011, following several consultations, the RTFO was amended to allow implementation of most of the transport-specific elements of the RED. This included the introduction of sustainability criteria for eligible fuels, and the award of an additional RTFC for each litre of biofuel produced from specific materials, i.e. what are known as ‘second generation’ feedstocks, which includes biofuel produced from wastes, residues, non-food cellulosic material and lignocellulosic material.

3.3 Potential Impacts upon UK Heating Bioliquids Market

There is potential for other support schemes for bioliquids, whether in other Member States or in the UK to impact upon the success of potential RHI support for heating bioliquids. Both the RO

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[15] DECC (2012) *Renewables Obligation Banding Review for the period 1 April 2013 to 31 March 2017: Government Response to further consultations on solar PV support, biomass affordability and retaining the minimum calorific value requirement in the RO*, December 2012

and the RTFO currently provide higher prices than the heating market could support, and it is likely the same is the case for the SDE+ scheme in The Netherlands, given its relatively close proximity to the UK for ease of transport of feedstocks between the two EU Member States. Consideration and modelling of the economics of each scheme compared with the RHI is not within the scope of this study, and would also be very feedstock and project specific. It is useful here, however, to explore some of the risks associated with effectively having support mechanisms which might be considered competitive. It is also important to acknowledge that the criteria for selection of feedstocks for analysis in this study (as described in Section 2.1.2) have been developed to focus on those less suited to transport. That said, such feedstocks are probably equally suited to the electricity and CHP applications, and thus the RO does function as a competing mechanism.

Without further detailed analysis, it is challenging to comment on the potential magnitude or nature of any impacts, albeit the following potential issues have been highlighted to provide context for any further analysis which might be undertaken by DECC in the future as part of further work to determine the likely effects of provision of support for bioliquids under the RHI:

- Critically, the fact that there are competing support mechanisms in the EU and more importantly in the UK, is such that potential investors in new feedstock processing and boiler conversion plant face greater uncertainty. Assessment of feedstock risk is a critical component of any due diligence undertaken on such projects, and the impact of the RTFO and RO would be taken into consideration as part of a wider investment decision;
- As highlighted above, however, the emphasis of this study is upon feedstocks which are not suitable for transport. That said, whilst some waste feedstocks might not currently appear to be suitable for conversion to transport fuels, there is some debate, as discussed in Section 2.1.3, as to whether this might be possible in the near future, particularly as DfT is keen that such feedstocks are not excluded from the transport sector. This, again provides uncertainty for investors;
- At the same time, if the supply-demand balance of bioliquids available on European markets results in a lack of feedstock availability, then increased demand in Member States such as The Netherlands could lead to higher bioliquid prices as well a shortfall in the quantities available to UK markets;
- Conversely, however, such developments could have more indirect, but beneficial impacts on any future UK heating bioliquids market. High levels of use in other Member States may drive down the costs of feedstock production in the UK as a result of greater economies of scale achievable through higher production volumes. For some waste-derived feedstocks, for which overall volumes are relatively low, however, this is unlikely to be the case;

Ultimately, the inclusion of bioliquids under the RHI will require careful consideration of other UK and European market interactions to ensure efficient allocation of resources and optimum affordability for UK non-domestic consumers.

4 Feedstocks Prioritised for Initial and Detailed Analysis

As outlined in Section 2.1, using our decision-making framework, we drew up an initial list of feedstocks, which represented clear candidates for further analysis. These 12 feedstocks (or feedstock 'groups') and their relevant properties are shown in Table 4.

Feedstock Selected for Initial Market Analysis	Energy Content (GJ/tonne)	Moisture Content (%)	Volumetric Density (kg/m^3)
Black and Brown Liquors	12	25	1,400
Tall Oil Pitch	38	0.2	950
Deodoriser Distillate (DD1)	32 – 42	<0. 1	890
Oleochemical Residues (OR1)	32 – 42	0.08	890
Distillation Residues (from Biodiesel Production)	40	Variable	Variable
Glycerol (from Biodiesel Production)	14.2 – 19	10 – 18	1,200
Gums (including those from oleochemical production)	Highly Variable	Highly Variable	Highly Variable
Matter Organic Non-Glycerol (MONG) (from production of distilled Glycerol)	Highly Variable	Highly Variable	Highly Variable
Sugar Beet Pulp[1]	1.5	80	561
Vinasse	6.93	96	1,300
Lignocellulosic (LC) 'Group'[2]	15 – 16	24	1,200
Solid recovered fuel (from residual waste)[1]	15 – 16	24	1,200

Note:

1. The figures in this table relate to raw, unprocessed sugar beet pulp
2. Figures quoted relate to pyrolysis oil produced by a fast pyrolysis process rather than to the input LC feedstocks

Table 4: Candidate Feedstocks and Relevant Properties

As described in Section 2.1, at this stage, a stakeholder 'round-table' meeting was held to gather views from industry on the methodology used to select feedstocks for detailed analysis, i.e. the decision-making framework.[16] Following this meeting, due to the restricted scope and budget of study, a further process of 'prioritisation' of feedstocks took place in discussion with

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[16] A list of attendees at this Stakeholder Meeting can be found in Appendix 4

DECC. This prioritisation exercise focused upon the following four core criteria, which are mostly drawn from the initial decision-making criteria:

1. Commercial viability pre-2020;
2. Renewable heat potential from UK/EU feedstock (MW_{th} capacity) – based on current arisings and CV;
3. Substitution impacts resulting from drawing in feedstocks from other existing markets; and
4. Availability of (feedstock price and processing/conversion) cost and performance data.

This exercise resulted in a list of four ‘prioritised’ feedstocks (or feedstock ‘groups’), for which we have gathered data, as shown in Table 5. Again, it should be emphasised that this prioritisation *does not* mean to say that any of the other initially selected feedstocks are not suitable for RHI support, just that these are viewed as less of a priority for DECC when assessed in more detail against the key framework criteria. It may well be that DECC decides to undertake subsequent analysis of the feedstocks which have not been prioritised here. Towards this goal, we have included analysis of the market for each ‘de-prioritised’ feedstock in Appendix 4.

As described in Section 2.1.3, it is important again to note here that, whilst we have determined that these feedstocks are suitable for heating, we *are not* at the same time suggesting that they are ruled out for use as transport fuels. The objective of this study is rather to provide information to help DECC in further discussions with DfT as to how Government chooses to incentivise use of such feedstocks.

Feedstock Selected for Initial Market Analysis	**Prioritisation for Detailed Analysis**	**High-level Rationale for Prioritisation or De-prioritisation**
Black and Brown Liquors	No	Potential large environmental impacts from fuel substitution in paper mills in Europe which needs to be investigated further
Tall Oil Pitch	No	Potential large environmental impacts from fuel substitution in paper mills in Europe which needs to be investigated further
Deodoriser Distillate (DD1)	Yes	Currently being used as a fuel for CHP in the UK and offers potential for use as heating fuel with only limited equipment retrofit
Oleochemical Residues (OR1)	Yes	Currently being used as a fuel for CHP in the UK and offers potential for use as heating fuel with only limited equipment retrofit
Distillation Residues (from Biodiesel Production)	No	Already used at source as a CHP fuel at biodiesel production facilities. Support under RHI may mean substitution of fossil alternatives, but this should be investigated further
Glycerol (from Biodiesel Production)	No	Support could have impacts on current use in anaerobic digestion (AD) in the UK and EU. Emissions mean that challenging for use in most heating boilers, although current use as CHP fuel merits further analysis

Feedstock Selected for Initial Market Analysis	Prioritisation for Detailed Analysis	High-level Rationale for Prioritisation or De-prioritisation
Gums (including those from oleochemical production)	No	Lack of commercial development, largely due to the need to blend with other fuels to reduce viscosity, which means there is very limited availability of relevant data
Matter Organic Non-Glycerol (MONG) (from production of distilled Glycerol)	No	Lack of commercial development means very limited availability of relevant data. Also very limited feedstock volumes as it is dependent upon glycerol production
Sugar Beet Pulp	No	Currently almost exclusively used as animal feed in the UK, and therefore substitution impacts require further research
Vinasse	No	Very limited volumes, which are dependent upon ethanol production. Also very low CV, which limits renewable heat potential
Lignocellulosic (LC) 'Group'	Yes	Fast pyrolysis processes to produce pyrolysis oil currently at demonstration scale in other EU Member States. Large volumes available in UK and overseas
Solid recovered fuel (from residual waste)	Yes	Fast pyrolysis processes for LC group (above) are applicable to SRF, albeit with modification. Large volumes available in UK at negative cost (i.e. gate fee)

Table 5: Initial Feedstock Selection and Prioritisation for Detailed Analysis

5 Renewable and Carbon Saving Credentials of Bioliquids

5.1 Characterisation of Boilers which might Convert Bioliquids to Heat

5.1.1 Analysis of Counterfactual Fuels and Boiler Efficiencies

Ultimately, our research indicates that bioliquids will only be taken up in the non-domestic sector, whereby these are more cost-effective, and in some cases, more ‘hassle free’ than the use of fossil fuels. The counterfactual fuels and technologies that bioliquids would replace are likely to be oil boilers. These might vary in size and sophistication, but will generally be in the industrial sector providing process heat.[17]

The counterfactual fuel in this case will be gas oil (also known as red diesel or ‘35 second’ oil). This is different to Kerosene (‘25 second oil’) which is lighter and generally used in domestic or commercial space (rather than process) heating boilers. Some very large commercial boilers are able to use ‘heavy fuel oil’, which is cheaper but has a higher firing temperature and is generally unsuited to most boilers. Boilers designed for gas oil (the vast majority of non-domestic boilers) cannot burn heavy fuel oil. Table 6 details the properties of the assumed counterfactual fuel and boiler, and Box 1 details the calculation of the counterfactual carbon output per unit of heat produced.

In limited cases, there might also be the replacement of natural gas boilers, albeit this would depend on the level of the RHI, with a relatively high tariff likely being required to displace gas at the present time. In very limited cases, coal might be replaced in such processes as cement manufacture, albeit unless direct heating, i.e. without the raising of steam in a boiler becomes eligible for RHI (as is currently being considered by DECC in a concurrent study), this does not represent a relevant counterfactual.

Gas Oil / Boiler Properties	Value
Carbon Factor (tCO_2e/MWh) LHV	0.2688[18]
Energy Content (GJ/t_{fuel})	42.7[19]
Boiler Efficiency	89%[20]

Table 6: Counterfactual - Gas Oil and Boiler Properties

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[17] Personal communication with two bioliquid handling organisations in the UK

[18] Defra, *Greenhouse Gas Conversion Factor Repository*, http://www.ukconversionfactorscarbonsmart.co.uk/

[19] Ibid

[20] DECC (2012) *Spreadsheet with Calculations Used to Derive Tariffs for the Non Domestic RHI Scheme,*

$$CO_2\ Output\ (t_{CO2}\ per\ MWh_{th}) = \frac{Carbon\ Factor}{Boiler\ Efficiency} = \frac{0.2688}{89\%} = 0.30202$$

$$Heat\ Output\ \left(GJ\ per\ t_{fuel}\right) = Boiler\ Efficiency\ x\ Energy\ Content = 89\%\ x\ 42.7 = 38.0$$

$$Heat\ Output\ \left(MWh_{th}\ per\ t_{fuel}\right) = \frac{Heat\ Output\ \left(GJ\ per\ t_{fuel}\right)}{3.6} = \frac{38.0}{3.6} = 10.6$$

Box 1: Calculation of Counterfactual CO_2 Emissions and Energy Generation

Therefore for each MWh_{th} energy generated through the use of a bioliquid feedstock for heating that displaces gas oil there will be a carbon saving of 0.325 tCO_2e.To displace one tonne of gas oil, 10MWh_{th} of heat would need to be generated by a bioliquid feedstock.

This counterfactual is used in Sections A3.1 to A3.4 of Appendix 3 in the calculation of the carbon saving potential for each of the prioritised feedstocks.

5.1.2 Potential Size of Industrial Boilers

Anecdotal evidence from boiler suppliers and reviews of product lists undertaken for this study suggest that the most common size of boiler suited to use with gas oil, which is currently being marketed by manufacturers is between 1MW_{th} and 10MW_{th}. To test this assumption, we have also undertaken a brief ‘top-down’ modelling exercise using data from the UK National Atmospheric Emissions Inventory (UK NAEI).[21]

This provides data on carbon emissions from all industrial processes, from which we calculated the size of each installation using a range of assumptions including:

- Fuel use, based on the emissions factors for both gas or oil as the fuel source, as set out in Section 5.1.1;
- A load factor of 70% as discussed further in Section 5.1.4;
- A ratio of 8.5:1.5 for gas:oil usage, based on Dukes’ data for energy consumption for industrial applications.[22]

This data was then placed in 1MW_{th} ‘bins’ between 0-40MWth to determine the distribution. At the same time, the data was reviewed to remove point sources which would be unlikely to be relevant (i.e. offshore, refineries, power stations, CHP, gas let-down stations, etc.) where either the application was not likely to be a simple boiler, or there was an obvious existing fuel. Furthermore, all public sector data points were removed, as these would not represent boilers producing process heat or steam.

This approach resulted in the most number of units within the <1MW_{th} category, but with the distribution suggesting that 5MW_{th} represents probably the best assumption as a ‘central’ case for modelling within this study, with 1MW_{th} and 10MW_{th} representing the ‘low’ and ‘high’ cases. It is recognised that this approach relies on a number of uncertain assumptions, but allied with the ‘bottom-up’ data collected via interviews and other secondary research, it appears to provide a reasonable estimate for a study of this nature.

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[21] See www.naei.org.uk/reports.php

[22] See Dukes 2010, Table 1.09

5.1.3 Interchangeability of Bioliquids within Industrial Boilers

It is first necessary to clarify what might be meant by interchangeability, which could refer to both:

- A particular bioliquid vs. different (fossil) liquid fuels; and/or
- A particular bioliquid vs. other bioliquids.

In the context of this study, we think it is necessary to consider both of these issues, as the first considers the extent to which a bioliquid might be a 'drop-in' fuel and the second considers the level of flexibility of boilers which might burn bioliquids, which affects the attractiveness to operators of switching to such fuels. These issues are explored in Sections 5.1.3.1 and 5.1.3.2 in the context of the specific feedstocks (or output fuels) reviewed for this study, i.e. heating oil derived from OR1 or DD1, and pyrolysis oils from woody biomass or SRF. The former issue is also considered further in Section 6 in the context of how this adds to capital (i.e. boiler conversion) costs.

5.1.3.1 Heating Oils from OR1 or DD1

Interviews undertaken as part of this study with two organisations which produce bioliquids for industrial heating boilers and CHP engines suggest that fuels derived from OR1 and DD1 (or indeed fish oils, which appear to be an equally common feedstock) are fully interchangeable.[23] This is because the product that is sold as bioliquid (assuming this meets the main requirements of the EN 14214 standard) is the same, irrespective of whether it is derived from OR1, DD1 or fish oils.[24] It is therefore understood that such fuels are wholly interchangeable in this context. It should also be noted that the modifications to the boiler do not prevent it from using the fuel for which it was originally designed, i.e. gas oil.

The producers of such fuels are keen to emphasise that this type of product represents a drop-in fuel, which requires very little boiler modification and only limited adaptation (if any) of storage tanks. This issue is discussed in more detail in Section 6.1.2. It is useful to highlight here, however, that the users of such fuels who have direct access to such fuels are likely to be within the biodiesel or oleochemical industries and therefore in a position to install bespoke boilers and auxiliary equipment. At the same time, any organisation without links to these sectors is likely to be motivated to source such fuels via a dedicated producer or broker to ensure fuel specification and consistency (probably to EN 12414) and maximise fungibility. Such organisations would potentially seek to undertake any burner (or other equipment) modifications in conjunction with the fuel supplier in order to transfer risk.

5.1.3.2 Pyrolysis Oils from Woody Biomass or SRF

As discussed in Section 6.2, at present the only (demonstration scale) projects being undertaken currently are based on woody biomass feedstocks. The use of other feedstocks, including SRF, is likely to result in more challenging chemistry and thus have not been attempted at any scale.

The key issue to consider here, therefore, is the interchangeability with fossil fuels, which is best considered in the context of the changes which would be needed to enable a boiler which has been processing pyro-oils to be able to process more conventional fuels. This might be a boiler

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[23] Personal Communications, Refuel Energy and Fleetsolve, May 2014

[24] See Section 2.1.3 for further discussion of issues relating to use of this standard for heating bioliquids

which has been converted for use with pyro-oils or one which has originally been designed for such use.[25]

The main issues which may impact upon interchangeability in this context include, but are not limited to:

- Ignition characteristics and ongoing combustion stability;
  - The lower ignition point could present issues with start-up, so a support fuel is likely to be necessary. The change in flame characteristics will also change the thermal profile in the boiler, with implications with regard to efficient heat transfer;
- Fuel properties including ash content and viscosity;
  - The ash/solids as well as viscosity in the fuel will have different atomisation characteristics, and so would necessitate a new burner configuration. For example, a burner configuration utilising compressed air, and potentially different water tube layout for optimum heat extraction. In reality, changing these to optimise performance with gas oil or natural gas would not be economically feasible and thus the efficiency and potentially emissions performance of the boiler be degraded;
- Water vapour;
  - Due to higher water content, the plume from using pyrolysis oil would be more prevalent and thus a switch to fossil fuels may require a redesign of any flue gas treatment; and
- Emissions control;
  - Both SO_x and NO_x emissions are likely to be lower than for gas oil, the latter primarily due to lower combustion temperatures. At the same time, however, this is likely to lead to potentially higher levels of particulate matter (PM). Optimisation of the set up for control of these emissions would be required if switching between pyrolysis and conventional oils.

The above analysis demonstrates that pyrolysis oils are far from being a ‘drop-in’ fuel for gas oil, and careful consideration is therefore required of any organisation considering switching between such fuels.

5.1.4 Load factor of Industrial Boilers

The load factor of industrial boilers is influenced by many considerations, but primarily these relate to whether a manufacturing process is continuous or ‘batch’. For continuous processes, even if there are limited shifts (i.e. a production facility is not manned 24/7), then the boiler is unlikely to cease operating aside from during times of planned (and unplanned) maintenance. For batch processes, however, there is often a significant load at start-up as equipment and process materials are heated to temperature (albeit there are latent heat issues in many applications), and potentially a long ‘tail’ at lower heat inputs as temperature is maintained. Furthermore, batch processes are affected by cycle times, which can also be linked to shift patterns.

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[25] As discussed in Section 6.2, however, it appears that both current pyrolysis oil projects for which information has been gathered for this study intend, to a large extent co-fire with conventional fuels

Availability is also a key consideration, particularly with pyrolysis oil in the early months or years of operation. Higher planned maintenance can be managed through scheduling, but unplanned outrages could result in lower load factors with process reliability implications for users.

Given these potential variances across different boilers, identifying one load factor applicable to all processes is very challenging. For simplicity, we have therefore used a figure of 70%, which is drawn from a recent study focused on heat recovery from industry undertaken on behalf of DECC[26]. Whilst this load factor is not related to heating boilers fuelled by gas oil or bioliquids, in the absence of a more specific data point, it is appropriate for use in a study of this nature.

5.2 Wider Lifecycle Emissions from Production and Transport of Bioliquids

Wider lifecycle emissions from the use of bioliquids for heating will vary across feedstocks and applications, depending upon the level of fossil emissions from the cultivation (if applicable), processing and transport of each feedstock. This variation is significant in terms of the differences in emissions between what might be considered agricultural feedstocks (or ‘energy crops’), which require energy (with resulting emissions) to assist cultivation, and feedstocks which are considered to be wastes or residues, which essentially do not require any energy inputs until the point of transport or processing.

In this context, it should be acknowledged that bioliquids are already incentivised for electricity generation under the Renewable Obligation (RO). The eligibility of bioliquids under the RO is dependent upon each individual feedstock meeting a set of detailed sustainability criteria, which have been developed by Ofgem.[27] Those seeking to claim Renewable Obligation Certificates (ROCs) must demonstrate compliance with both ‘land’ and greenhouse gas criteria.

The majority of the initial list of twelve feedstocks highlighted in Section 4 are wastes or residues, and thus, as shown Table 7, are largely exempt from needing to demonstrate compliance with the land criteria under the RO, albeit these would still apply to some residues. More importantly in the context of carbon savings, the greenhouse gas (GHG) emission calculations which would apply to many feedstocks for bioliquids which are given further analysis in this study would usually exclude any emissions prior to the point of collection for processing. Consequently, it is very likely that the majority would meet any GHG criteria developed to determine eligibility for support under the RO. For each of the four priority feedstocks, however, we have undertaken high-level analysis of lifecycle carbon emissions in Appendix 3. In respect of this analysis, however, it should be acknowledged that:

- Available data is very limited for some elements of the supply and processing chains and thus we have either used generic information, or limited the system boundaries to exclude elements upon which we have not been able to gather suitable information; and
- Much of the data is very project specific, and relevant only to the specific locations in which the plant from which data has been gathered are located.

Consequently, this high-level analysis should not be used to make any judgements in respect of whether such feedstocks are likely to meet any future associated sustainability requirements.

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[26] DECC (2013) *The potential for recovering and using surplus heat from industry*, Element Energy et al on behalf of DECC, March 2014

[27] Ofgem (2011) *Renewables Obligation: Sustainability criteria for bioliquids*, December 2011

Whilst one might expect GHG criteria for heating bioliquids to vary slightly from those for electricity generation (largely as a result of alternative counterfactuals), any such criteria could be broadly similar to the manner in which waste and residues are considered. The development by DECC of sustainability criteria for the use of solid biomass under the RHI are not dissimilar in many essential respects to those used under the RO.[28] The RHI GHG criteria require that conversion of feedstocks to heat result in a maximum of 125.28kg CO_2 equivalent (CO_2e) per MWh of heat generated. RHI recipients will soon be required to demonstrate they have met the lifecycle emissions savings to be eligible for RHI payments.

It should also be noted that Ofgem has released a Carbon Calculator for calculating GHG emissions from bioliquids under the RO.[29] This tool, however, appears to be largely focused on bioliquid feedstocks which are suitable for transport, and thus is of very limited use for this study.

Fuel Category	**Land Criteria**	**GHG Criteria**	
		Emissions up to the process of collection	**Emissions from the process of collection**
Waste	✗ Exempt	✗ Exempt	✓
Residues (excl. residues from processing, fisheries, forestry, aquaculture and agriculture)	✗ Exempt	✓	✓
Processing residues	✗ Exempt	✗ Exempt	✓
Residues from agriculture	✓	✗ Exempt	✓
Residues from forestry	✓	✓	✓
Residues from aquaculture	✓	✓	✓

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[28] DECC (2013) *Non-Domestic Renewable Heat Incentive: A Government Response to 'Providing Certainty, improving performance' July 2012 Consultation*, February 2013

[29] See https://www.ofgem.gov.uk/publications-and-updates/uk-bioliquid-carbon-calculator

		GHG Criteria	
Fuel Category	**Land Criteria**	**Emissions up to the process of collection**	**Emissions from the process of collection**
Products / co-products	✓	✓	✓

Source: Ofgem (2011) Renewables Obligation: Sustainability criteria for bioliquids, December 2011

Table 7: Sustainability Requirements for Bioliquids under the RO

5.3 Bioliquids with Fossil Content

In line with the principles set out previously, all but two of the feedstocks proposed for detailed analysis can be considered to be 100% biogenic.

Solid recovered fuel (SRF), following mechanical-biological treatment (MBT) contains fossil fuels within the proportion of plastics present within the feedstock. The level of plastics in SRF varies according to the type of MBT process which is undertaken to prepare the input waste as a fuel or feedstock for bioliquid production. Currently, under the RHI for solid biomass, such feedstocks are deemed to be 50% fossil unless proven otherwise. It is therefore likely that ‘tonne for tonne’ SRF will deliver far lower carbon savings than other feedstocks.

Furthermore, waste wood may also contain fossil fuels within plastics or treatments, albeit these will be far lower than for SRF, and may fall below any thresholds required for consideration in any future GHG calculations relating to bioliquids for heating.

5.4 Analysis of Counterfactual Costs

The analysis of counterfactual costs for heat generation from bioliquids requires consideration of both the costs of the industrial oil boilers which would be displaced, as well as the costs of the oil used to fuel them. For the purpose of this study we assume that gas oil (i.e. red diesel) will be the fuel displaced by bioliquids.

Data relating to both elements can be drawn from information published by DECC, as is set out in Table 8. Furthermore, it is also worth highlighting some semi-quantitative data from boiler (and burner) manufacturers. This suggests that CAPEX and OPEX costs are around 50% of the prices indicated by DECC, and depend greatly on the size of the unit being built, with benefits being earned from economies of scale.[30] It is likely that the true cost of a boiler system lies somewhere in between.

The data relating to fuel costs is in line with the market price of gas oil, which, depending on the quantities being purchased can range from £56 – £70 per MWh.[31]

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[30] Personal communication with Riello Burners, April 2014

[31] Personal communication with Refuel Energy, April 2014

	Costs
CAPEX (£/MW)[1]	£34,000
OPEX (£/MW/year)[1]	£37
Fuel Cost (£/MWh)[2]	£62

Sources:

1. DECC (2012) *Spreadsheet with Calculations used to Derive Tariffs for the Non Domestic RHI Scheme, 2012*
2. DECC (2013) *Updated energy and emissions projections: 2013*, September 2013, https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2013

Table 8: Counterfactual Costs of Industrial Gas Oil Heating Infrastructure

6 Cost and Performance Data for Prioritised Feedstocks

The embryonic state of the use of bioliquids for heating, particularly in the UK, is such that there is relatively little data available, even on those feedstocks which are most advanced in terms of either commercial development of related conversion technologies or their suitability as a 'drop-in' fuel for existing applications. Of the four feedstocks selected for further analysis, it is relevant to put these into two groups. This is because one of the cost and performance datasets gathered is applicable to both DD1 and OR1, whilst another is relevant to both SRF and the wider LC group.

In Sections 6.1 and 6.2 we explore the current status of feedstock processing and use in the UK (and other EU Member States) along with cost parameters and issues relating to the performance of related processing and fuel conversion technologies.

In Appendix 3, we have provided broader analysis of the market dynamics relating to each of these four key feedstocks, along with similar reviews, in Appendices 4, of each of the other 'long-listed' feedstocks highlighted for initial analysis in Section 4. These reviews include information relating to:

- Feedstock composition and origins;
- Size of the opportunity;
- Barriers to deployment; and
- Impact on existing RHI applications (i.e. solid biomass markets).

6.1 DD1 and OR1

6.1.1 Current Status of Feedstock Processing and Use

Anecdotal evidence gathered for this study suggests that DD1and OR1 have currently very limited use as a heating-only fuels in the UK, with larger amounts being sent for CHP, often driven by the incentive provided by the RO. At least three organisations do seem to be handling these feedstocks as fuels in the UK, albeit additional volumes also appear to be exported for use overseas in boilers supplying district heating schemes.[32]

The organisation most prominent in this sector is Refuel UK ('Refuel'). Refuel currently refines a range of feedstocks, with a primary focus on DD1 and OR1 (alongside fish oils). The resulting bioliquid is used in both their own and others' CHP engines, along with very limited volumes going to heating-only boilers. Another organisation, Fleetsolve, also handles both feedstocks, but as it stands (i.e. without support from the RHI), is solely focused on the CHP market, for which it also designs and builds its own engines.

Refuel has stated that their production capacity (for all feedstocks including DD1 and OR1) by end 2014 will be 25 million litres per annum. The company has also stated that in response to an appropriate level of support under the RHI, it could potentially increase production to 100 million litres per annum within 12 months. Fleetsolve also processes around 25 million litres per

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[32] Personal Communication, MBP Group, March 2014

annum of a range of fuels, which are largely sourced directly from producers. In 2012, the UK consumed approximately 6 billion litres of gas oil. Consequently, the quantity of bioliquid that might be supplied by these two companies by the end of 2014 would equate to under 1% of the total UK demand for gas oil.

6.1.2 Cost Parameters

Refuel produces its fuels (derived from both DD1 and OR1) to the specification of EN14214 (for road biofuels).[33] This is such that it undertakes processing and testing activities to refine the fuel to meet this standard. As Fleetsolve designs its own CHP engines, it does not need to meet such requirements, as users do not need to comply with manufacturer warranties for engines which are not designed for conversion of bioliquids.

6.1.2.1 Feedstock Acquisition

Data relating to the costs (or prices) of feedstocks, prior to any processing, is usually considered to be commercially confidential. Estimates gathered for this study, however, suggest that the costs associated with acquiring DD1 and OR1 range from £300 to £500 per tonne (delivered at the gate). This depends upon whether these come directly from a margarine or oleochemical manufacturer, or via a feedstock/materials trader; the latter adding their own ‘margin’ to the overall price. It should also be noted that these prices are largely supported by the CHP market, and may differ if linked to any potential future support under the RHI.

6.1.2.2 Feedstock Processing

Whilst we have managed to gather data relating to feedstock processing costs, all of this information has been deemed by operators as commercially confidential and not for publication by DECC. This information (which wraps both CAPEX and OPEX together) has, however, been made available privately to DECC to inform future policy-making. It is possible to say within this report, however, that these costs do not appear ‘significant’ in that they are somewhat lower (per tonne) than the price of input feedstocks.

6.1.2.3 Fuel Conversion to Heat

Information gathered as part of this study suggests that existing installations require some modification to enable the use of DD1 and OR1. These include:

- Specialised new seals and filters to avoid corrosion; and
- Trace heating for fuel tanks, which is provided via application of electric pads.

One interview respondent (a feedstock supplier) suggested that such modifications would cost no more than £1,500 per installation to implement. If the trace heating for fuel tanks is not put in place, there may be the need for additional pumping equipment as the fuel could become ‘waxy’ within the tank. Furthermore, if copper piping is in use, this may need to be replaced with steel.

A burner manufacturer, which had recently trialled such feedstocks, also suggested that there might also be modifications required to the burner, such that a new burner may be required, and that this might be 25-50% more expensive than ‘standard’ prices.[34]

As described in Section 5.1.3.1, it is understood that DD1 and OR1 and interchangeable within industrial boilers.[35] This is because the product that is sold as bioliquid (assuming this meets the

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[33] With the exception of CFPP – cloud point (low temperature at which fuel starts to wax/solidify) and oxidation stability (measure of the shelf life – the likely elapsed time before the fuel may start to become rancid (and so be un-useable). These are both criteria, which the company has suggested should be used to determine whether a fuel is transport-suitable or not as discussed in Section 2.1.3

[34] Personal Communication, Riello Boilers, 2nd April 2014

main requirements of the EN 14214 standard) is the same, irrespective of whether it is derived from OR1, DD1 (or fish oils).[36]

6.1.3 Performance of Processing and Fuel Conversion Technologies

It is understood from Refuel that there are very few losses which take place in the feedstock processing phase. Evidence gathered as part of this study suggests that the efficiency of a purpose built boiler burning bioliquids is unlikely to be dissimilar to that for a boiler designed to burn gas oil. Where investment is made in retrofitting the equipment to existing boilers, as identified in Section 6.2.2.4, however, our research suggests that the efficiency of heating boilers burning heating bioliquids produced from DD1 or OR1 will decrease slightly due to the different burning characteristics of the fuel. For the purposes of this model, we have therefore used a thermal efficiency of 80% At the same time, although it might be assumed that there would be a greater amount of down-time for maintenance for such retrofitted boilers, we have modelled a 70% load factor, which is the same as the counterfactual for boilers burning gas oil. We have provided information relating to load factors and efficiencies for the counterfactual (gas oil boilers) in Section 5.1.

6.2 LC Group and SRF

6.2.1 Current Status of Feedstock Processing and Use

The development of LC feedstocks for commercial use as pyrolysis oil is currently about to reach full demonstration (or ‘semi-commercial’ scale). Within Europe there are two main organisations which are in the process of constructing such pyrolysis facilities; the ‘Empyro’ project in The Netherlands (which is being developed by Treepower, with consortium partners including AkzoNobel, BTG and Stork) and the ‘LignoCat’ project in Finland (which is being developed by Fortum in consortium with UPM and Valmet), and a further project by another organisation in Canada (Ensyn).[37]

Our qualitative interviews, as part of this study, with both Treepower and Fortum suggest that virgin wood will be the core feedstock for both processes, albeit other LC feedstocks will be explored at later dates. Whilst residual waste is generally viewed as having potential for conversion into pyrolysis oil, the higher cost of processing, due to its non-homogenous nature (and plastics content), is such that it is likely to be one of the later candidate feedstocks in this sense.

Both the Empyro and LignoCat projects require that feedstock moisture content be reduced to very low levels (similar to oven-drying of wood). For SRF produced from residual waste, at present, no organisation in the UK (or to our knowledge in the EU) is producing a feedstock that would be sufficiently dry, albeit in theory this would be possible.

Furthermore, our qualitative interviews with Fortum and Treepower suggest that the feedstock material would need to have a small particle size of around 6-8mm for the pyrolysis process to convert the feedstock effectively. This is readily achievable (although not standard practice for tradable wood chip) for virgin wood, so would require further processing with bespoke

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[35] This does not apply to boilers which are located ‘on-site’ at oleochemicals or biodiesel production sites. Such boilers will be designed or retrofitted to process a less refined feedstock produced directly by the manufacturing plant and are unlikely to be able to accept external fuels

[36] See Section 2.1.3 for further discussion of issues relating to use of this standard for heating bioliquids

[37] See www.empyroproject.eu/index.php; www.fortum.com/en/mediaroom/pages/fortum-upm-and-valmet-are-jointly-developing-technology-to-produce-advanced-biomass-based-fuels.aspx

equipment on site, Current production of SRF cement kiln applications is currently only usually to <30mm, and therefore whilst such a particle size might theoretically be achievable, it is not proven on such materials, and would also add greater costs (from additional shredding equipment) to current practices. It is therefore unlikely that any future support for conversion of SRF to bioliquids would directly pull fuels, which are already being produced to a specification, away from the cement industry.

To provide confidence in this emerging market, ASTM International has developed a standard for pyrolysis oils produced from biomass feedstocks (ASTM D7544 – 12).[38] The standard sets out two grades, D & G. Grade D is intended for use in commercial/industrial burners and requires lower levels of both solids content and ash content, whereas Grade G is intended for use in larger industrial burning applications. This standard is summarised in Table 9.

Property	Grade D	Grade G
Gross Heat of Combustion (MJ/kg)	15	15
Water Content (%)	30	30
Pyrolysis Solids Content (%)	0.25	2.5
Kinematic Viscosity at 40ºC (mm^2/s)	125	125
Density at 20ºC (kg/m^3)	1,100 – 1,300	1,100 – 1,300
Sulphur Content (%)	0.05	0.05
Ash Content (%)	0.15	0.25
Flash Point – min (ºC)	45	45
Pour Point – max (ºC)	-9	-9

Table 9: ATSM Standard for Biomass Pyrolysis Oil

As shown in Table 9, ash content is also an important factor, as significant levels of ash can create difficulties when burning the fuel, which could be a problem for feedstock such as straw, albeit Treepower claims to have tested this at a previous pilot facility.

There is also a large degree of uncertainty as to whether pyrolysis oil from SRF would be able to meet the ASTM standard. This is because, as discussed in Appendix 3, it is not likely reach End of Waste (EoW) status, and will also contain significant levels of fossil carbon content in the form of plastic waste. Without a full review of the published standard, which is outside the scope of this analysis, it is not possible to make a definitive judgement in this respect. Furthermore, meeting the ASTM standard is not a prerequisite to any fuel being used in the market, albeit this would be a helpful step towards securing demand.

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[38] ASTM International, *Standard Specification for Pyrolysis Liquid Biofuel – ASTM D7544 – 12*, http://www.astm.org/Standards/D7544.htm

6.2.2 Cost Parameters

6.2.2.1 Feedstock Acquisition – LC Feedstocks

The feedstocks used by Treepower and Fortum are mainly ‘woody’ biomass, generally residues from wood processing activities. The prices paid for such feedstocks are considered commercially confidential, albeit data obtained on the Empyro project suggests that these are around €80 per oven dry tonne (odt). For both projects, it is notable that there is greater ease of access to biomass than in the UK. There are significant volumes of woody biomass grown in Finland, whilst Rotterdam is the main port for import and export of biomass products in Europe.

Data gathered as part of this study suggests that there can be a significant cost associated with purchasing LC feedstocks, ranging from £3 to £97 per tonne, with empty palm fruit branches at the lower end of the scale and husks at the upper end.[39] Conversely, waste wood usually attracts a gate fee, which varies according to the quality and consistency of the feedstock.[40]

Due to the volumes required, and the limited nature of domestic supplies, large scale biomass generators in the UK use a majority of imported virgin feedstock, including both woodchips and pellets. The price of woodchip varies depending both on the moisture content of the feedstock and the volumes which are purchased, i.e. a high volume industrial buyer would receive a lower price than a smaller purchaser. Generally, for low moisture content feedstocks, prices of £100 - £200 per tonne delivered can be expected and one would suspect this to apply to feedstock purchased for use for conversion to bioliquids in the UK. This is based on published information for 2011, and while the market has changed since 2011, we believe the ranges presented remain reasonably accurate for the purposes of this analysis.[41]

6.2.2.2 Feedstock Acquisition – SRF

The market for residual waste is very different from that of the other LC feedstocks, such that a waste processor earns a gate fee for accepting residual waste. For residual waste going to a MBT facility a gate fee of £70-£100 per tonne would be expected. The residual waste must then be processed into SRF, and then be moved on for thermal processing (unless this takes place at the same site).

The processor of SRF will also charge a gate fee, the scale of which depends on the quality of the feedstock. Generally cement kilns charge a gate fee of £20-40 per tonne for a high specification SRF, whilst incinerators charge between £60 and £100 per tonne for a far less refined and variable feedstock, depending upon a range of market factors, as described in Appendix 3. Depending on the level of processing available on site, any facility seeking to process SRF for bioliquids would need to compete with these gate fees.

6.2.2.3 Feedstock Processing

Due to the semi-commercial nature of the two pyrolysis facilities in Europe (i.e. they are supported by grant funding) there is a greater level of publically available data on costs associated with processing LC feedstocks, as compared to a number of other feedstocks. The CAPEX and output of pyrolysis oil for each facility is summarised in Table 10. Based upon the assumptions set out in Section 5.1, the feedstock output from these two facilities could be used to potentially replace the use of gas oil in 10 industrial boilers of 5MWth output capacity.

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[39] E4tech (2013) Advanced Biofuel Feedstocks - An Assessment of Sustainability, Report for Department for Transport, December 2013

[40] WRAP (2013) *Gate Fees Report 2013*, August 2013, http://www.wrap.org.uk/content/wrap-gate-fees-report-2013

[41] Carbon Trust (2012) Biomass fuel procurement guide, March 2012, http://www.carbontrust.com/media/88607/ctg074-biomass-fuel-procurement-guide.pdf

	Empyro	**Fortum**
Output Capacity (tpa)	26,250	50,000
CAPEX (€)	16,000,000 – 18,000,000	30,000,000

Table 10: CAPEX and Output Capacity of two Pyrolysis Facilities

Other than feedstock purchasing costs, small quantities of natural gas are used to heat up the production process to the required temperature from a cold start. The Empyro project, however, has been designed such that both heat for fuel drying and steam for electricity are both provided by the pyrolysis process itself. Operating costs are largely therefore restricted to staff costs along with other miscellaneous fixed and variable costs. These are summarised, alongside annualised finance costs (including equity return, debt repayments and depreciation) in Table 11.

	Proportion of Cost (%)	Annual Costs (€)[1]
Feedstock	43	€ 3,000,000
Personnel costs	10	€ 698,000
Finance costs (incl. equity and depreciation)	42	€ 2,930,000
Other fixed cost minus income from sales co-products	2	€ 140,000
Other variable costs	3	€ 209,000
Total	100	€ 6,977,000

Notes:

1. Costs rounded to nearest thousand

Source: BTG (2014) *Presentation: Market introduction of Fast Pyrolysis Technology*, March 2014

Table 11: Annualised Costs Associated with the EMPYRO Project (26 ktpa output capacity)

Forecast costs per tonne of fuel produced by the Empyro project, based on the information provided in Table 11 and an assumed plant output of 26 ktpa, can be calculated to be €265 per tonne of pyrolysis oil produced. It should be noted, however, that this is not a calculation of levelised costs, which is outside the scope of this study and will be undertaken directly by DECC using this information along with its preferred approach to discounting. It should also be acknowledged that this calculation includes the significant funding from the EU the project has received along with ‘soft’ loans from local authorities in the Netherlands. The impact of this means that financing costs would be far greater for later commercial projects, and consequently this value of €265 per tonne might increase for subsequent projects. That said, there may be some potential for cost reduction, as discussed further in Section 7.2.

It is expected that producing pyrolysis bio-oil from SRF would require greater costs than production from woody biomass. These costs would be associated with the processing infrastructure due to the complexities of contamination and the non-homogenous nature of residual waste. This is not to say it will not ever be commercially viable to produce pyrolysis bio-oil from SRF, but currently there are lower risk investments to be developed in the waste market, including conventional waste incineration and gasification facilities. SITA has also recently commissioned a commercial-scale pyrolysis facility to produce fossil diesel from waste plastics in Avonmouth, Bristol and although the company has no current plans to focus on producing heating bioliquids from SRF, support from the RHI, if sufficiently high, could stimulate more interest in such projects.[42]

6.2.2.4 Fuel Conversion to Heat

Discussions with Treepower and Fortum suggest there are two main routes for utilising pyrolysis oil in heat applications:

- Retrofitting of existing burners and boilers;
- Bespoke designed burners and boilers.

For both the Empyro and LignoCat projects, it is planned to use the former option, with the pyrolysis oil from the Empyro project to be used alongside (30%) natural gas in a commercial dairy manufacturing site. Due to the high acidity of pyrolysis oil, auxiliary infrastructure, such as piping and the storage tank must be modified to ensure they do not corrode. Modifications to the burner must also be made.

Discussions with stakeholders as part of this study suggest that a purpose-built boiler could be between 50% - 150% more costly than a standard gas oil boiler.[43] That said, in future, it is hoped that standard diesel boilers might be used, albeit pyrolysis oil seems to be some way from being considered as a ‘drop-in’ fuel.

As discussed in Section 5.4, cost estimates of a gas oil fired burner depend on the size of the unit, but are generally in the range of £2,000 to £3,000 per MW.[44] Therefore, this cost could increase to £3,000 to £7,000 per MW, depending on the size of unit required. Cost estimates for a packaged gas oil boiler are in the range of 3 to 5 times the cost of the burner, such that for a purpose built boiler for pyrolysis oil, the cost could be between £9,000 to £35,000 per MW.[45] This can be compared with data from DECC (see Section 5.4), which suggests that costs for gas oil boilers are on the upper end of this range. However, as noted above anecdotal evidence gathered as part of this study suggests that costs for packaged gas oil boilers are likely to be considerably lower.

6.2.3 Performance of Processing and Fuel Conversion

As described in Appendix 3, our research indicates that there is around a 70% conversion factor for the production of pyrolysis oil from oven-dried LC feedstocks. By way of example, the Empyro project hopes to produce 26,250 tpa of pyrolysis oil from around 37,500 tpa of input feedstock.

Our research suggests that the efficiency of heating boilers burning pyrolysis oil is likely to be significantly lower than for those using gas oil. We’ve therefore assumed a decreases to 80%, from 89% for gas oil, primarily as a result of the different burning characteristics of pyrolysis oil. This efficiency, however, is likely to increase as boiler manufacturers become more familiar with

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[42] Personal Communication major UK waste management contractor, April 2014

[43] Personal Communication, Treepower, March 2014

[44] Personal Communication, Riello Burners, April 2014

[45] Ibid.

the burning characteristics of pyrolysis oil.[46] There may also be additional maintenance required in comparison to a gas oil boiler, which would reduce overall annual load factors.

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[46] Based on discussions with boiler manufacturers, March to April 2014

7 Other Cost and Commercial Considerations

7.1 Consideration of Hassle Costs and Risk Premium

Aside from capital and operational costs, which need to be taken into consideration by DECC in potentially attempting to set RHI tariffs for heating bioliquids, thought also needs to be given to what are termed ‘hassle’ costs and ‘risk premium’.

Hassle costs are those associated with the time input required for project identification, appraisal, and commissioning of new renewable heating systems, which might be applicable over and above those associated with the counterfactual. Risk premium refers to any additional incentive which is required to convince businesses to switch to less proven technologies or feedstocks.

A range of documentation, which has been developed by DECC or on behalf of DECC, towards setting RHI tariffs (using the levelised cost method) appears to take into consideration a range of different types of hassle and risk costs, albeit apparently using slightly different approaches.[47] In some cases, these include both ‘upfront’ hassle costs, such as those listed above, but also ‘ongoing’ hassle costs, which might refer to any additional ongoing maintenance and administration required over and above that for the counterfactual. It appears, therefore, that DECC has some established principles, which are used to model such costs.

Detailed assessment and recommendations as to how DECC should model hassle and risk costs is outside the scope of this study. That said, it is worth highlighting relevant findings from the qualitative interview programme in this respect, which can be summarised as follows:

- Two respondents suggested that the costs associated with applying and administering ongoing compliance with the RHI could be significant and function as a potential deterrent to new facilities burning bioliquids;
- One of these respondents suggested that this is apparently already the case for some facilities which currently use bioliquids as a CHP fuel, and have not attempted to gain accreditation and payments under the RO;
- The same respondent suggested that these costs might be in the region of £25,000 per annum for ‘larger’ (>10MWth) installations, in terms of administration and auditing required by Ofgem; and
- Another respondent suggested that a supplementary support of 5p / litre would be needed to compensate for the overall risk and admin burden.

It may therefore be prudent for DECC to take these comments into consideration in its wider methodology for any potential levelised cost modelling relating to bioliquids.

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[47] DECC (2009) *The UK Supply Curve for Renewable Heat*, AEA and NERA on behalf of DECC, July 2009; DECC (2012) *RHI Phase II – Technology Assumptions: Key Technical Assumptions for Selected Technologies,* AEA on behalf of DECC, February 2012; DECC (2013) *Research on Costs of Heating and Cooling Technologies*, Sweett Group on behalf of DECC, February 2013

7.2 Potential for Cost Reduction

In the Impact Assessment for the RHI extension undertaken in 2013, DECC states that by supporting renewable heat deployment it expects that costs will reduce and performance may increase over time.[48] It does not, however, seek to quantify these benefits in any way. Similarly, this is not the goal of this study, albeit it is necessary to provide commentary on the potential for such cost reductions.

As presented in Section 6, the volume of cost data available to support this study is somewhat limited by the relative lack of activity in respect of bioliquid production for heating (and power) in the UK. This applies to both of the markets upon which the analysis is focused:

1. Refining of DD1 and OR1 into a heating bioliquid for use in existing gas oil boilers without significant modification; and
2. Fast pyrolysis of solid LC feedstocks or SRF to produce a pyrolysis oil, which either requires significant retrofit of boilers or potential investment in a new boiler.

That said, the dynamics and technologies associated with these two markets are also very different, as described in Sections A3.1 and 0 of Appendix 3.

7.2.1 Potential Future Cost Reduction in OR1 or DD1 Processing and Use

Based on discussions with fuel suppliers, there does not appear to be significant potential for reducing the costs associated with processing DD1 or OR1 into a bioliquid for heating (or CHP). Furthermore, as any associated required boiler (or auxiliary equipment) modifications are likely to be very limited, there are unlikely to be significant opportunities for future cost reduction in respect of converting such bioliquids to heat. That said, there is currently very limited available production and use of such bioliquids, and therefore confidence in this information may be considered to be relatively low.

7.2.2 Potential Future Cost Reduction in Production and Use of Pyrolysis Oils

Fast pyrolysis processes, such as those described above are not only currently at a semi-commercial scale of development, but also require bespoke or retrofitted boilers to burn the output pyrolysis oils. This would suggest the potential for significant cost reductions over time. The extent to which such cost reductions might take place in the future, however, will depend upon the success of these two (and other similar) projects, and the potential wider proliferation of the technology (potentially supported by the RHI).

Any wider roll-out of the technology might bring about both economies of scale in manufacturing and lower cost finance resulting from reduced technology risk. In the context of the latter, however, it should be acknowledged that the two current projects in Finland, operated by Fortum, and in The Netherlands, operated by Treepower, have been facilitated either by significant EU or National Government grant funding, along with low cost loans from local authorities in the case of the latter. Consequently, subsequent facilities immediately following potential successful demonstration of the technology may not necessarily produce pyrolysis oils at a lower cost.

7.3 Intellectual Property Issues

Both Fortum and Treepower (alongside BTG) have invested significant time and resources into developing the two fast pyrolysis demonstration facilities cited in this study. As a result, it is not

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[48] DECC (2013) *Impact Assessment - RHI Tariff Review, Scheme Extensions and Budget Management*, September 2013

likely that the technology (and associated ‘know how’) will be freely available to project developers. That said, the conditions associated with the funding provided by both the EU and the Finnish Government may be such that some intellectual property must be shared with wider communities. These conditions, however, are commercially confidential and have not been provided to inform this study.

We would also expect that, rather than constraining development of projects to their own teams or technology partners, both Fortum and Treepower will license the technology to other organisations in the UK and beyond. The extent to which these agreements represent a facilitator or constraint upon take-up of the technologies will depend upon the capability (and financial backing) of the organisations which take up these licenses.

To a lesser extent, there is also be intellectual property (IP) ‘tied up’ in the ‘Resin Catalyst’ process developed by Refuel Energy for production of heating bioliquids from OR1, DD1 (and fish oils). Subject to demand for heating bioliquids it is possible that the company might seek to licence the technology, but as there are likely to be competitors who can quickly develop similar approaches, it is more likely it would seek to use this IP to try to quickly develop a significant market share.

7.4 Bioliquids Infrastructure Lead Times

Lead times for all infrastructure depend as much upon the periods required to gain planning permission and to reach final investment decision (FID), as upon the periods for construction and commissioning. Furthermore, reaching financial close will also depend upon securing appropriate contracts for feedstock input.

The lead time for facilities designed for processing of DD1 and OR1 is likely to be far shorter than that for fast pyrolysis processes. This is largely due to the lower level of finance and thus risk associated with the technology, along with greater ease of gaining planning consent, albeit this may depend upon the types of feedstock used for pyrolysis.[49]

From project conception, information provided by Refuel Energy suggests that significant additional operational fuel processing capacity could be added to an existing site within 12 months. For a new site without planning consent, however, we might expect total lead time to be 1-3 years, whilst for a new pyrolysis facility; this period could probably be extended to 3-6 years from project conception.

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[49] It is generally more challenging to gain planning consent for facilities processing waste feedstocks than for those processing non-waste biomass

8 Potential Contribution of Bioliquids to 2020 Renewables Targets

The UK Renewable Energy Roadmap published in 2011 states that for a central estimate, up to 50 TWh per annum of non-domestic heat energy could be supplied by biomass sources by 2020.[50] The goal of this section is, therefore, to provide a high-level view as to the proportion of this estimated 50TWh that may be delivered by heating bioliquids.

In Appendix 3, for the four prioritised feedstocks, we set out the theoretical potential of each feedstock in terms of renewable heating output, assuming 100% of available feedstock was utilised. It is important here to apply some further assumptions to this data to provide a more realistic picture of market potential to 2020, assuming adequate support from the RHI comes into place.

In the absence of any historic data upon which to base this analysis, in Table 12 we have used the following assumptions to model renewable heat output which might become operational prior to 2020 from the four prioritised feedstocks given detailed analysis for this study:[51]

- 5% to 25% of OR1 and DD1 produced in the EU is diverted for use as an RHI-accredited heating fuel in existing gas oil boilers in the UK; and
- The feedstock from two to five new commercial-scale fast pyrolysis facilities (either located in the UK or other EU Member States), fuelled by virgin wood feedstocks, each with an output of 30 ktpa of pyrolysis oil.

It should be noted that these assumptions represent illustrative examples only. In part, and particularly for DD1 and OR1, the amount of capacity which comes online will be dependent upon the tariff which is put in place. This analysis does provide a basis, therefore, for any further modelling of this potential by DECC should further evidence become available. It should also be acknowledged that this potential excludes consideration of any use of bioliquids that might have happened regardless of the RHI. Furthermore, with regard to the carbon savings shown in Table 12, it is also important that these are not viewed in isolation of the 'system boundaries' we have used within high-level life-cycle assessments for each feedstock in Appendix 3.

The information presented in Table 12 shows that, in respect of the *examples* for these two bioliquid 'groups', the renewable heat output could be between 394 to 1,656 GWh per annum. This equates to 0.4 to 1.7 TWh of heat energy, which represents between 0.8 to 3.4% of the estimated 50 TWh of heat energy that could be supplied from biomass sources, as suggested in the UK Renewable Energy Roadmap. Whilst this level might appear modest, it should be further acknowledged that these are only two feedstock groups which were selected for detailed analysis in this study.

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[50] DECC (2011) *UK Renewable Energy Roadmap*, July 2011, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48128/2167-uk-renewable-energy-roadmap.pdf

[51] As described in Section 4, there are eight additional feedstocks, which represent candidates for support under the RHI, and therefore this is an underestimate of total likely potential renewable heat from all bioliquids which are suitable for heating

Feedstocks	**Heating Bioliquid Used (tonnes)**		**Renewable Heating Output (GWh_{th})**		**Carbon Savings (tCO_2e)**	
	Low	**High**	**Low**	**High**	**Low**	**High**
DD1 / OR1	18,750	128,500	152	1,045	46,096	315,912
LC Group	60,000	150,000	240	600	72,485	181,213
Total	78,750	278,500	394	1,656	127,971	537,822

Table 12: Potential Annual Contribution of Bioliquids to 2020 Renewables Targets[52]

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[52] It should be noted that our analysis indicates that it is unlikely that there will be any heating bioliquids produced from SRF prior to 2020

9 Analysis of RHI Suitability

The focus of this section is upon presenting a case for whether (or not) the RHI is a suitable policy mechanism for incentivising the development of infrastructure to produce renewable heat from bioliquids. This analysis set out in Sections 9.1 to 9.5 has been framed within the scope of several key supporting questions from the ITT for this study. It is intended that the evidence presented below will help inform DECC policy makers as to whether there is a case for support of different bioliquids through the RHI or, if not, possibly via a different mechanism.

9.1 Is Government Intervention Necessary?

Primarily it is necessary to ask whether Government intervention is necessary, i.e. has there been some kind of significant 'market failure' whereby resources could have been used to generate more efficient (in this case economic and environmental) outcomes? In some respects, our analysis indicates that this is not the case; for example, many paper mills, biodiesel producers and oleochemical manufacturers appear to be using their own process residues to generate combined heat and power. In other respects, feedstocks which might have value as a heating fuel are not being captured for such use, or are being exported for use in other EU Member States.

In respect of LC feedstocks and SRF, to the extent that these are not instead being used as solid fuels for heating and power applications (or as transport fuels), this does represent market failure. Many other policy mechanisms, however, such as the RO, small-scale Feed-in Tariff (FiT), forthcoming FiT Contract for Difference (CfD), RTFO and more indirectly, the Landfill Tax, have all been designed to move such feedstocks into energy-related applications. These have met with limited success, and therefore, as discussed below, it is necessary to consider whether the RHI, which in many ways is similar to the RO, FiT and FiT CfD is the right mechanism with which Government might intervene to influence the market.

9.2 If so, is the RHI the right mechanism for support?

In asking this question, it is also sensible to respond simultaneously to another closely related research question from the ITT which seeks information on what modifications might be made to the RHI to enhance the impact of support.

An important initial consideration to note here in respect of both questions is that, in contrast to most other renewable heat technologies supported by the RHI (aside from solid biomass), by providing the financial support to the end user of the bioliquid, i.e. the entity producing renewable heat from a boiler, this is not necessarily the point in the value chain where direct support is most required. That is to say that unless the feedstock supplier also has a stake in the ownership of the boiler the RHI relies upon the passing down of additional revenues from the end user to those involved in producing, sourcing and processing of feedstocks, such that these organisations are incentivised to change behaviour. Our research indicates that at present, in some current cases, it does appear to be the case that the feedstock processor either owns or at least operates the related boiler(s), albeit this cannot be considered to be the norm for the future. The anecdotal evidence gathered for this study does suggest, however, that there is sufficient engagement along the supply chain to allow sufficient pass-through of any RHI tariff, with this likely to be driven by feedstock suppliers, which would be able to seek higher prices for bioliquids from potential users, with this additional value coming from the user's return from RHI payments.

A further consideration is that we understand that the provisions of the RED are such that DECC is not able to nominate specific bioliquid feedstocks for support. It would not therefore be in a position to exclude from support feedstocks which might be more suitable for transport, which could be problematic, as discussed in Section 2.1. We also understand, however, that there may be flexibility to name specific *solid* feedstocks for support, and to allocate variable tariffs to such feedstocks, much as is the case for solid biomass under the RO and small-scale FiT. It should be noted that it is currently unclear from our analysis of the RED whether conversion of solid LC feedstocks into pyrolysis oil would be considered to be a *solid* or *liquid* feedstock. To provide a clearer steer on this issue would potentially require a legal opinion, or engagement with the European Commission, which is outside the scope of this study.

Perhaps the most important consideration is the potential limited impact of the RHI in the absence of accompanying policy mechanisms. Experience with the RHI thus far (and with the RO and FiT), has shown that simply putting in place a tariff (however high, to a reasonable extent) does not bring about new infrastructure if this is dependent upon *either* relatively unproven technologies or those for which feedstock cannot simply be purchased (i.e. contracts must be won) from the market. A clear example of this is the gasification of wastes, which has been eligible for two Renewable Obligation Certificates (ROCs) per MWh for some years. Issues associated with technology risk and feedstock sourcing are such that there has been practically zero development of such facilities thus far.

Furthermore investment in heating infrastructure is far more of a challenge than electricity infrastructure due to off-take counterparty risk. Whilst electricity revenues essentially depend upon a power purchase agreement (PPA) with a single licensed energy supplier, this is essentially backed by many unnamed users of electricity via the national grid. In contrast, aside from in the situation of heat networks, industrial heat off-take usually relies upon one counterparty, which is subject to global market forces and thus may not be in business for the full pay-back period on investment. Consequently, lenders are far more reluctant to provide finance for heat-only projects, which therefore must usually be backed by wider securities. An exception to this, and an example of where the RHI is starting to gain traction, is in the market for AD gas-to-grid applications. Not only does the gas grid represent a solid off-take counterparty (as per the electricity grid), but AD is a proven technology, and thus the only real constraint on this market is feedstock concerns.

Another important issue in this respect relates to the current duration of support under the RHI. Our experience of engagement with developers, both as part of this study, and in the wider market, suggests that a 20 year pay-back period is far too long as to stimulate investment in major new bioliquid fuel supply and industrial boiler infrastructure. As discussed above, off-take counterparty risk is a major barrier to large scale renewable heating investment, and therefore shortening the pay-back period to perhaps 5-10 years would be likely to bring forward greater infrastructure capacity. This would be more akin to the 7-year period of support under the domestic RHI.

It is also worth mentioning that whilst it appears that new State Aid rules will not have a significant impact upon the RHI, DECC will need to consider how any support for bioliquids (or any other technology) will comply with the clause on annual updating of production costs.[53]

Finally, if it is not determined that the RHI is an appropriate mechanism for supporting bioliquids for heating, a far simpler and more radical approach (in theory), and one which would largely eradicate the hassle costs outlined in Section 7.1, would be to apply greater taxation to gas oil, as there is only currently very low duty (11.1p/litre) applied compared with that for road diesel

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[53] European Commission (2014) *COMMUNICATION FROM THE COMMISSION, Guidelines on State aid for environmental protection and energy 2014-2020,* April 2014

(58p/litre). This rate for gas oil is the same as that applied to biodiesel for non-road use, albeit this is refundable if it can be proven that it has been used to generate electricity or CHP in a qualifying station.[54] Ultimately, most EU Member States have similar taxation regimes for fuel use by industry, and although this is in conflict with recommendations from the EC, it is unlikely that the UK (or any other Member State) will change this approach without EC-led legislation, for fear of making domestic industry uncompetitive.

9.3 If so, do the likely outcomes justify the likely administration costs?

Both low and high potential roll-out scenarios are presented in Section 8 for the four prioritised feedstocks subject to detailed analysis in this study. Should either of these potential roll-out scenarios represent the total renewable heat from bioliquids driven by the RHI, it is possible that such outcomes would not be sufficiently material as to justify putting in place support for bioliquids under the RHI. As described in Section 4, however, there are eight additional feedstocks, which are candidates for support under the RHI, and therefore the modelling in Section 8 represents an underestimate of total likely potential renewable heat from all bioliquids which are suitable for heating. As described above, as it appears that DECC is not able to identify specific feedstocks for support under the RHI, it is not possible within the scope of the current study to answer this question to any great depth, as to some extent, all bioliquids would be supported.

9.4 What would be an appropriate process for tariff setting?

The RHI has an annual budget allocation, and although this is, to some extent, controlled by the degression mechanism, it would be important for DECC to set any tariff at the right level to stimulate any ‘desired’ level of uptake. This is because:

- If set too low, RHI support could provide an insufficient level of incentive for additional capacity to come forward, whilst providing support to existing facilities, which would have been using bioliquids regardless; and
- If too high, RHI support could lead to a situation where the marginal uptake is too great and thus DECC is compelled to quickly degress the tariff, potentially creating uncertainty in the market.

The information provided in this report goes some way towards providing an evidence base for tariff setting, albeit the market as a whole, with perhaps the exceptions of DD1 and OR1, is not currently at sufficient state of development to support any ‘accurate’ approach in this respect.

It is also worth commenting here as to whether using a levelised cost approach to tariff setting is the most sensible approach support of bioliquids (or any other technology). Is rewarding the least efficient technologies with the most support the right approach? The principal behind the levelised cost approach is that by providing support in this way, it will allow technologies to become more widely adopted and proven, thus reducing their cost, such that they become more competitive with traditional forms of energy. Whilst we have seen significant cost reductions for both solar photovoltaics and wind energy supported by the RO and FiT during the last decade, there is perhaps less scope for cost reduction for bioliquids production and conversion, which for some feedstocks uses relatively established technologies, i.e. existing boilers. In determining levels of support, it is therefore necessary to consider and compare the marginal costs of carbon abatement for each technology, which is outside the scope of this study.

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[54] See http://www.hmrc.gov.uk/rates/hydro-oils.htm accessed 16th April 2014

An alternative approach, in theory, would be to put in place some kind of competitive tendering (or ‘reverse auction’) process, akin to that which DECC will be using for electricity generation for some technologies under the FiT CfD. This would solve any issues relating to tariff setting, as bidders would be forced to keep prices low to win contracts. Furthermore, it would also reduce the need for degression, as bidders would be provided with the support they need, rather than anything over and above. In practice, however, this may not be a sound solution for the nascent heating bioliquids market. There are currently few players as to make such an auction process fully competitive, whilst those which would be required to bid, i.e. the end users generating heat from bioliquids (unless feedstock processors or suppliers themselves), would have low market knowledge of feedstock costs, and thus would be unlikely to be sufficiently confident to bid. It is, however, perhaps a consideration for the future, which would allow DECC to efficiently bring forward a prescribed level of capacity at lowest cost.

9.5 Could RHI support lead to any perverse outcomes?

As described in Appendix 3 in respect of OR1 (to some extent), and in Appendix 4 with regard to a range of feedstocks including tall oil pitch, distillation residues (from biodiesel production, black and brown liquor, provision of support for some bioliquids under the RHI risks diverting feedstocks which are already being used as fuels for heating (and power) in existing markets. Subject to further, more detailed research for some of these feedstocks, this may lead to less desirable environmental outcomes, whereby users switch to alternative fuels, which might result in higher carbon emissions (or other greater environmental impacts), even if these are also biomass fuels.

Depending upon the structure of RHI support, this could result in gaming by participants to maximise overall revenues from heat generation. Anecdotal evidence relating to the RHI for solid biomass suggests this might happen in the following two ways:

- Should different banding levels be put in place for varying sizes of boiler, some participants will deliberately procure an installation at the very top of one of the tariff bands to get the higher tariff. This is exemplified by a large amount of installations of 199kW operating in the solid biomass heating market, and packaged boilers of this size being marketed by installers; and
- Should a ‘tiered’ tariff be put in place, i.e. whereby users are rewarded with a higher tariff for a prescribed level of output (in hours, rather than MWh) and a lower tariff for any remaining output, this can also incentivise larger boilers. This is because operators seek to maximise the level of MWh they can achieve at the higher tier, and then potentially switch to an alternative fuel source after they have exhausted the related maximum number of hours.

In any tariff design for bioliquids, therefore, DECC should take these risks into consideration.

Furthermore, it should be noted that some biodiesel plant and oleochemicals facilities are already using distillation residues and OR1 respectively to generate heat and power. DECC should therefore be mindful that any support provided under the RHI does not support an activity that would have happened anyway, i.e. that the outcomes of the policy are additional.

10 Conclusions and Recommendations

The key question to address here, based on the various elements of analysis above, but particularly the discussion in Section 9, is whether heating bioliquids and the associated boiler technologies which would convert these feedstocks into renewable heat, should be provided with support under the RHI.

Our analysis suggests that there appears to be only limited justification for government intervention in this market on the basis of market failures. This is very feedstock specific, however, in that many of the potential feedstocks highlighted for initial (and detailed) analysis in this study are already either being used for heating (or electricity) generation or as transport fuels. Others, however, are less in demand, which could be changed via support under the RHI.

The potential CO_2 savings which might be delivered via support for the four priority bioliquids under the RHI may provide additional justification for intervention, but again these would need to be compared by Government with those which are delivered, or might in the future be delivered, via support under the RO and RTFO.

If RHI support for bioliquids was to be provided, DECC would need to very carefully design the tariff and associated policy detail to minimise the risks of:

- Directing some feedstocks away from use in electricity markets (currently supported by DECC via the RO and, under the FiT CfD regime for 'advanced' feedstocks) and transport markets (supported by the RTFO), the latter for which DfT might provide evidence to suggest they are currently more suited;
- Significant amounts of funding being allocated to manufacturing organisations operating onsite processing heating boilers converting such feedstocks as DD1, OR1 and distillation residues, which are likely to have been installed anyway;
- Exerting pressure the overall RHI budget by providing support for a range of bioliquids, as it is understood that, due to the restrictions of the EU Renewable Energy Directive (RED), DECC is not able to 'nominate' specific fuels for varying levels of support;
- Setting the tariff at a sub-optimal level, which:
    - If set too low, RHI support could provide an insufficient level of incentive for additional capacity to come forward; and
    - If set too high, RHI support could lead to a situation where the marginal uptake is too great and thus DECC is compelled to quickly degress the tariff, potentially creating uncertainty in the market.

Achievement of such a policy design will be highly challenging. It is therefore recommended that DECC considers the following issues and related suggested tasks:

- The research undertaken for this study suggests that the current state of the bioliquids heating market is not sufficiently mature (or with sufficient number of data points) as to provide any firm basis for tariff setting using the levelised cost approach. This study is somewhat limited in scope, however, and there may therefore be some merit in allocating further resource to assessing the suitability of some of the other eight candidate feedstocks, beyond the four prioritised in this analysis. Furthermore, additional resource allocation to the four priority feedstocks might also yield a greater volume of information to better inform tariff setting via the levelised cost method;

- This lack of confidence in the data is the result of a nascent market, however, which suggests that a levelised cost approach to tariff setting will be extremely challenging for DECC to ‘get right’. There are lessons to be learned from the solar photovoltaic (PV) market under the FiT in this respect. It may therefore be appropriate to undertake analysis supporting the design of an approach to enable a ‘reverse auction’ of bioliquid heating capacity. This would potentially allow DECC to bring forward a prescribed level of capacity at lowest cost. Furthermore, in contrast to the solar PV market, which is dominated by a large number of small installations (of just a few kWe each), the average boiler size in this context is around 5MWth, and thus such a process would have far lower administration costs; and
- There is still some debate between DECC and DfT as to how to determine whether a feedstock should be incentivised for transport or heating applications. One feedstock processor interviewed for this study has proposed an approach based on technical parameters (applicable to OR1 and DD1 feedstocks only), which might enable Government to make this determination.[55] Whilst we understand that DfT has commissioned research to consider whether these specific feedstocks could be used in biodiesel production, the lack of any clear alternative suggests that this technical approach is worthy of a more detailed analysis.

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[55] See Section 2.1.3 for further details of this approach

Appendix 1 – Decision Making Frameworks

A1.1 Heat-suitability Matrix

The core question to be determined via use of this matrix can be summarised as:

Is the feedstock suitable for use as a bioliquid for heating?

To determine the answer to this question, each feedstock is assessed according to each of the parameters set out in Table 13. As noted above, whilst a feedstock might be determined as being ‘heat-suitable’, this does not necessarily mean that it is taken forward into a market and RHI suitability assessment, as it may be subsequently be determined that it is ‘most suitable’ for transport applications.

Parameter	Description	Defined Options for Selection (if applicable)
Theoretical Conversion Steps Required	A summary of the theoretical steps required to take the feedstock to a bioliquid which meets quality required for heating applications.	n/a (qualitative commentary)
Commercial Readiness of Conversion Process	A description of the current stage of development of the conversion process required for heating applications.	**Fully Commercial** – more than one commercial reference plant operating in the UK **Semi-commercial** – at least one commercial reference plant operating in the UK or more than one overseas **Demonstration** – at least one demonstration plant operating in the UK, or more than one overseas **Pilot** – at least one pilot plant operating in the UK, or more than one overseas **Bench Scale** – lowest level of commercial readiness; has been tested in a laboratory environment only
Ability to Source Commercial Volumes	A relative scale measure of the ease of accessing of sufficient volumes of the feedstock to enable commercial scale operation (assuming that price is not a factor).	**High** – There is sufficient feedstock available in a transparent market **Medium** – there appear to be sufficient quantities of the feedstock available, but challenges exist, e.g. geographical or contractual, in accessing this material **Low** – there are insufficient quantities of feedstock available on the market

Parameter	Description	Defined Options for Selection (if applicable)
Cost / Gate Fee of Feedstock	Costs associated with procuring the feedstock for conversion into a bioliquid for transport applications. Cost data will be provided where readily available, but focus will be upon a relative scale measure.	**High** – the cost (of commercial scale volumes) is above average relative to other feedstocks **Medium** – the cost (of commercial scale volumes) is close to the average cost of all feedstocks **Low** – the cost (of commercial scale volumes) is below average relative to other feedstocks **Negative** – a gate fee is paid for management of the feedstock
Cost of Conversion	Costs associated with converting the feedstock to a bioliquid for heating applications. Cost data will be provided where readily available, but focus will be upon a relative scale measure.	**High** – the cost (of converting commercial scale volumes) is above average relative to other feedstocks **Medium** – the cost (of converting commercial scale volumes) is close to the average cost of all feedstocks **Low** – the cost (of converting commercial scale volumes) is below average relative to other feedstocks
Cost of Transport to UK (if applicable)	Costs associated with transporting a converted bioliquid to the UK for consumption. Cost data will be provided where readily available and applicable.	Cost data relative to likely source of feedstock / bioliquid.
Competitiveness of Potential Output Fuel at Commercial Scale	A combination of the above two cost criteria, coupled with 'expert opinion' on the likely competitiveness at *different potential* levels of subsidy.	n/a (qualitative commentary)
Sustainability Criteria	Identification of any issues with regard to meeting RHI sustainability criteria, i.e. can support be justified given any sustainability concerns?	n/a (qualitative commentary)
Other Considerations	Identification of any other considerations, for example, the potential impact of an incentive on existing markets for the feedstock, including existing boilers which are already supported by the RHI	n/a (qualitative commentary)
Techno-economic Comparison with Solid Feedstock	If applicable, a high-level analysis of the techno-economic comparison of using the feedstock as a bioliquid in heat applications, or as a solid biomass fuel.	n/a (qualitative commentary)

Parameter	Description	Defined Options for Selection (if applicable)
Market Potential Comparison with Solid Feedstock	If applicable, a high-level analysis of the market potential for the feedstock as a bioliquid for RHI-eligible heat, as compared to the market potential for the feedstock as a solid biomass fuel.	n/a (qualitative commentary)
Likelihood of Commercial-scale Viability pre-2020	If applicable (i.e. the related feedstock conversion process is not defined as ‘Fully Commercial’ above), high-level analysis of the likelihood of this process becoming ‘Fully Commercial’ ahead of 2020, such that the feedstock might be supported by the RHI.	n/a (qualitative commentary)
Summary	A summary of the key pros and cons associated with using the feedstock to produce a heating fuel.	n/a (qualitative commentary)

Table 13: Decision Making Framework for Feedstocks for Heat Applications

A1.2 Transport-suitability Matrix

The core question to be determined via use of this matrix can be summarised as:

Is the feedstock most suitable for use as a bioliquid for transport?

To determine the answer to this question, each feedstock is assessed according to each of the parameters set out in Table 14.

Parameter	Description	Defined Options for Selection (if applicable)
Theoretical Conversion Steps Required	A summary of the theoretical steps required to take the feedstock to a bioliquid which meets quality required for transport applications.	n/a (qualitative commentary)
Commercial Readiness of Conversion Process	A description of the current stage of development of the conversion process required for transport applications.	**Fully Commercial** – more than one commercial reference plant operating in the UK **Semi-commercial** – at least one commercial reference plant operating in the UK or more than one overseas **Demonstration** – at least one demonstration plant operating in the UK, or more than one overseas **Pilot** – at least one pilot plant operating in the UK, or more than one overseas **Bench Scale** – lowest level of commercial readiness; has been tested in a laboratory environment only
Ability to Source Commercial Volumes	A relative scale measure of the ease of accessing of sufficient volumes of the feedstock to enable commercial scale operation (assuming that price is not a factor).	**High** – There is sufficient feedstock available in a transparent market **Medium** – there appear to be sufficient quantities of the feedstock available, but challenges exist, e.g. geographical or contractual, in accessing this material **Low** – there are insufficient quantities of feedstock available on the market
Cost / Gate Fee of Feedstock	Costs associated with procuring the feedstock for conversion into a bioliquid for transport applications. Cost data will be provided where readily available, but focus will be upon a relative scale measure.	**High** – the cost (of commercial scale volumes) is above average relative to other feedstocks **Medium** – the cost (of commercial scale volumes) is close to the average cost of all feedstocks **Low** – the cost (of commercial scale volumes) is below average relative to other feedstocks **Negative** – a gate fee is paid for management of the feedstock

Parameter	Description	Defined Options for Selection (if applicable)
Cost of Conversion	Costs associated with converting the feedstock to a bioliquid for transport applications. Cost data will be provided where readily available, but focus will be upon a relative scale measure.	**High** – the cost (of converting commercial scale volumes) is above average relative to other feedstocks **Medium** – the cost (of converting commercial scale volumes) is close to the average cost of all feedstocks **Low** – the cost (of converting commercial scale volumes) is below average relative to other feedstocks
Competitiveness of Potential Output Fuel at Commercial Scale	A combination of the above two cost criteria, coupled with 'expert opinion' on the likely competitiveness *at current levels of subsidy.*	n/a (qualitative commentary)
Sustainability Criteria	Identification of any issues with regard to meeting RTFO sustainability criteria, i.e. can any greater level of support be justified given any sustainability concerns?	n/a (qualitative commentary)
Other Considerations	Identification of any other considerations, for example, the potential impact of an incentive on existing markets for the feedstock.	n/a (qualitative commentary)
Likelihood of Commercial-scale Viability pre-2020	If applicable (i.e. the related feedstock conversion process is not defined as 'Fully Commercial' above), high-level analysis of the likelihood of this process becoming 'Fully Commercial' ahead of 2020, such that the feedstock might be supported by the RHI.	n/a (qualitative commentary)
Summary	A summary of the key pros and cons associated with using the feedstock to produce a transport fuel.	n/a (qualitative commentary)

Table 14: Decision Making Matrix for Transport-suitability of Bioliquid Feedstocks

Appendix 2 – Results from Feedstock Assessment

Table 15 summarises all the feedstocks examined via the decision-making framework for potential suitability for conversion to a bioliquid for heat applications. Information relating to the ‘category’ within which they have been placed, and the rationale behind this, is also provided.

Feedstocks	Category	Rationale for Categorisation
Acid Ester	Most suitable for use in transport applications	Already in use as a transport fuel.
Acid Oils	Most suitable for use in transport applications	Already in use as a transport fuel.
Animal Fats Cat I & II	Most suitable for use in transport applications	Already in use as a transport fuel.
Black & Brown Liquor	Most suitable for use in heating applications	Feedstock is suitable for use a bioliquid for heat applications with minimal refinement; however conversion to a transport grade bioliquid is likely to be cost prohibitive. This feedstock already appears to be a viable heating fuel but impacts on use in onsite applications needs to be considered via comparative analysis.
Brown Grease	Most suitable for use in transport applications	Already in use as a transport fuel.
Deodoriser Distillate (DD1)	Most suitable for use in heating applications	Feedstock theoretically suitable for use a bioliquid for heat applications, either in its current state, or with minimal refinement, however, conversion to a transport grade bioliquid is likely to be cost prohibitive.
Distillation Residues	Most suitable for use in heating applications	As a by-product of the bio-diesel refining process this feedstock is unsuitable for transport applications; however it is suitable as a bioliquid for heat applications.
Fatty Acid Methyl Esters	Most suitable for use in transport applications	Already in use as a transport fuel.
Food Waste (MSW / C&I)	Not suitable for heating applications	Not suitable for conversion to a bioliquid for heat or transport applications due to current uses, and complexities in converting the feedstock, primarily the high moisture content. Already being diverted to AD.

Feedstocks	Category	Rationale for Categorisation
Glycerol	Most suitable for use in heating applications	This feedstock is already used in AD facilities as a catalyst, up to 10% of input. The feedstock can also be used in its original state as a heating fuel, but can also be refined should a better quality bioliquid be required.
Gums	Most suitable for use in heating applications	Feedstock theoretically suitable for use a bioliquid for heat applications, either in its current state, or with minimal refinement, however, conversion to a transport grade bioliquid is likely to be cost prohibitive.
High Oleic Acid Rape Seed Oil	Most suitable for use in transport applications	Already in use as a transport fuel.
Lignocellulosic Materials	Most suitable for potential use in heating or transport applications	Feedstock is suitable for conversion to a bioliquid for heat applications; however, this feedstock category is also suitable for use as a solid biomass fuel, or conversion to a transport suitable bioliquid. The cost-benefits of which route is preferred in terms of economics and GHG benefits will have to be examined in greater detail.
Macro-algae	Not suitable for heating applications	Feedstock has high moisture content and is better suited to AD. Can theoretically be converted to a bioliquid for heat applications; however the high cost of conversion would be prohibitive. The feedstock is already incentivised under the RHI through AD.
Manure	Not suitable for heating applications	Feedstock is already sent to AD. The high moisture content of feedstock would make converting to a bioliquid a complex, costly process.
Matter Organic Non-Glycerol (MONG)	Most suitable for use in heating applications	Feedstock theoretically suitable for use a bioliquid for heat applications, either in its current state, or with minimal refinement, however, conversion to a transport grade bioliquid is likely to be cost prohibitive.
Meal from Virgin Oil Production	Not suitable for heating applications	Current uses of feedstock rule it out as suitable for conversion to a bioliquid for heat
Meat & Bone Meal (MBM)	Not suitable for heating applications	The feedstocks high ash content prohibits its conversion to a suitable bioliquid.
Micro-algae	Most suitable for use in transport applications	Best suited to a transport fuel.
Oleochemical Residues (OR1)	Most suitable for use in heating applications	Feedstock theoretically suitable for use a bioliquid for heat applications, either in its current state, or with minimal refinement, however, conversion to a transport grade bioliquid is likely to be cost prohibitive.

Feedstocks	Category	Rationale for Categorisation
Palm Fatty Acid Distillate	Most suitable for use in transport applications	Already in use as a transport fuel.
Palm Processing Residues (Palm Oil Effluent (POME))	Not suitable for heating applications	Feedstock has high moisture content and is better suited to AD.
Palm Processing Residues (Palm Stearin)	Most suitable for use in transport applications	Best suited to a transport fuel.
Refinery Fatty Acids	Most suitable for use in transport applications	Already in use as a transport fuel.
Residual Waste - Post MBT (MSW / C&I)	Most suitable for use in heating applications	If output heating bioliquid achieves 'end of waste' status, this feedstock could present a cost-effective route compared with solid feedstock route. There would also be little impact on existing markets due to the high availability of the feedstock.
Sewage Sludge	Not suitable for heating applications	Feedstock is already sent to AD. The high moisture content of feedstock would make converting to a bioliquid a complex, costly process.
Sugar Beet Pulp / Vinasse	Most suitable for use in heating applications	Feedstock theoretically suitable for use a bioliquid for heat applications, either in its current state, or with minimal refinement, however, conversion to a transport grade bioliquid is likely to be cost prohibitive.
Tall Oil Pitch	Most suitable for use in heating applications	Feedstock is suitable for use a bioliquid for heat applications with minimal refinement; however conversion to a transport grade bioliquid is likely to be cost prohibitive. This feedstock already appears to be a viable heating fuel but impacts on use in onsite applications needs to be considered via comparative analysis.
Tallow	Most suitable for use in transport applications	Best suited to a transport fuel.
Used Cooking Oil (UCO)	Most suitable for use in transport applications	Best suited to a transport fuel.
Virgin Vegetable Oils (Palm / Rape / Soy / Sunflower)	Most suitable for use in transport applications	Already in use as a transport fuel.
Yellow Grease	Most suitable for use in transport applications	Best suited to a transport fuel.

Table 15 – Summary of Feedstocks Analysed

Appendix 3 – Market Dynamics for Prioritised Feedstocks

A3.1 Oleochemical Residues (OR1) – Market Analysis

A3.1.1 Feedstock Composition and Origins

Oleochemicals are chemicals that have a wide variety of uses in industry, ranging from animal feed, to electronics, to healthcare, to food, to manufacturing. Oleochemicals are derived from vegetable and plant oils as well as animal fats.

Oleochemicals are analogous to petrochemicals, which are derived from fossil fuels.

Oleochemical residues (OR1) are produced during the production of oleochemicals and are known as the 'bottom of the reactor residues'. OR1 contains high levels of fatty acids (c. 44%).

A3.1.2 Size of the Opportunity

A3.1.2.1 Feedstock Arisings

Global vegetable oil production was estimated to be around 155 million tonnes in 2012, and is expected to increase to almost 200 million tonnes by 2022.[56] The main use of vegetable oil is for foodstuffs, but in recent years there has been a marked increase in demand for biodiesel which has created greater levels of demand for vegetable oils. It is estimated that current global use of vegetable oils for oleochemical production is 20 to 30 million tpa.[57]

It is difficult to estimate the exact quantity of oleochemical production in the EU, but for two sectors of production, fatty acid and detergent alcohol production, Europe has almost 2 million tpa of production (output) capacity, approximately 17% of the world's production capacity.[58] We estimate, therefore, that Europe consumes 17% of the global vegetable oil demand for oleochemical production. This results in a requirement for 3.4 to 5.1 million tpa of vegetable oils for oleochemical production in Europe.

It is unclear as to the exact quantity of OR1 that arises from oleochemical production. Anecdotally, research undertaken for this study suggests an arising rate of between 1% and 2% for every tonne of vegetable oil processed into oleochemicals. Consequently, European arisings of oleochemical residues from vegetable oil processing are likely to be in the range of 54,000 to 108,000 tpa. This, however, represents an underestimate of arisings, as we have not been able to similarly quantify the processing of animal fats for oleochemical use. At the same time, further anecdotal evidence gathered for this study suggests that arisings of oleochemical residues within the UK and Europe is in the region of 8-10,000 tpa and approximately 80,000 tpa respectively.[59] This broadly fits with our estimates above for the European market of OR1.

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[56] OECD-FAO (2013) *Agricultural Outlook 2013 - 2023*, 2013

[57] IEA Bioenergy (2009), *A global overview of vegetables, with reference to biodiesel*, June 2009, http://www.bioenergytrade.org/downloads/vegetableoilstudyfinaljune18.pdf

[58] ICIS (2011) *Oleochemicals rebound but outlook cautious for 2011*, Accessed 15 April 2014, http://www.icis.com/resources/news/2011/01/24/9427112/oleochemicals-rebound-but-outlook-cautious-for-2011/

[59] Personal Communication, Feedstock Supplier, April 2014

A3.1.2.2 Renewable Heat Potential and Carbon Savings

To determine the total renewable heat potential and carbon savings it is necessary to define the boundaries of the system. As shown in Figure 4, we have included the same stages as those required under the RED.

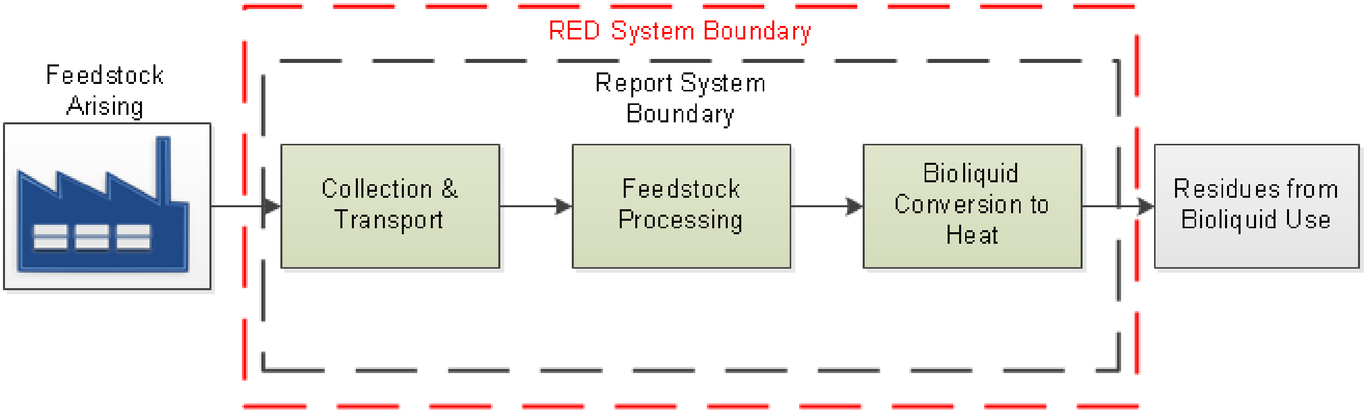

Figure 4: System Boundary of CO_2 Emissions Associated with Production and Consumption of OR1-based Bioliquids

Figure 4 shows that the following elements have been excluded from the analysis:

- Feedstock Arising:
    - The feedstock is a residue of a production process and is therefore deemed to have zero carbon emissions associated with it at this point;
- Residues from Bioliquid Use;
    - We do not have any relevant data by which to make any estimates as to the impacts from process residues, albeit we would surmise that these are again very small.

Based on the tonnages of feedstock highlighted above as arising in the UK, and upon an assumed average CV of 37 GJ/tonne (based on a CV range of 32-42 GJ/tonne, as set out in Section 4 of the main report) the renewable heat and carbon saving potential of bioliquids derived from OR1 is set out in Table 16.

To calculate the renewable heat potential and carbon savings we also assume the following:

- Carbon emissions factor for the ‘Collection & Transport’ and ‘Feedstock Processing’ stages of 0.014 tCO_2/GJ (14 gCO_2/MJ) of bioliquid. This factor was provided by one bioliquid fuel supplier as being the accepted ‘default value’ associated with biodiesel produced from waste oils;[60]
- Feedstock to bioliquid conversion efficiency of 99%;
- The use of a retrofitted boiler with a thermal efficiency of 80%; and

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[60] . It was suggested as a conservative value (i.e. over-estimate) to use in terms of the carbon emissions associated with their production process, which is likely to result in lower emissions due to it being the less energy-intensive stage of ‘Feedstock Processing’ compared to biodiesel production from waste oils

- As noted in Section 5.1.1 of the main report, the CO_2 displacement factor for the counterfactual fuel (gas oil) is 0.302 tCO_2/MWh thermal (which is calculated based on a boiler with an efficiency of 89%).

This shows that assuming all OR1 generated within the UK was burned in industrial heating boilers, between 65,100 and 81,400 MWh of renewable heat would be generated per annum, displacing between 15,600 and 19,500 tCO_2e per annum. Similarly for Europe, assuming all OR1 generated was utilised, between 439,600 and 879,100 MWh of renewable heat would be generated per annum. This would displace between 105,100 and 210,100 tCO_2e per annum from boilers which would have been burning gas oil.

Parameter	UK	Europe
Feedstock Arisings (tpa)	8,000 – 10,000	54,000 – 108,000
Renewable Heat Potential (MWh_{th}/annum)	65,100 – 81,400	439,600 – 879,100
Carbon Savings (tCO_2e/annum)	15,600 – 19,500	105,100 – 210,100

Table 16: Total Theoretical Renewable Heat and Carbon Saving Potential of OR1

As per Section 5 of the main report, to determine the number of boilers this could supply, we have assumed an average boiler size of $5MW_{th}$ that operates with an average load factor of 70%. Therefore, based on UK feedstock arisings, there would be sufficient bioliquid to supply fuel to 2 boilers. Taking into account European feedstock arisings, between 14 and 28 boilers could be supplied with sufficient bioliquid fuel. This is detailed in Table 17, including a low and high sensitivity range (boiler capacities of $1MW_{th}$ and $10MW_{th}$ respectively).

	Low ($1MW_{th}$)	Central ($5MW_{th}$)	High ($10MW_{th}$)
UK	10 to 13	2	1
Europe	71 to 143	14 to 28	7 to 14

Table 17: Theoretical No. of Boilers That Could be Supplied by OR1

A3.1.3 Barriers to Deployment under RHI

A3.1.3.1 Future Feedstock Availability

Oleochemical residues are ultimately sourced from vegetable oils and animal fats. The market for vegetable oils is currently very stable; however, due to increased demand for vegetable oils for biodiesel production, the OECD forecasts that the oleochemical industry will not be able to compete against the demand from biodiesel, and its share of the vegetable oil market will decrease from 20 to 30 million tpa to 10 million tpa over the next 10 years.[61] Whether this is an accurate forecast remains to be seen, as there are likely to be a range of factors which influence the attractiveness of biodiesel in the coming years, and particularly in the EU beyond the current period to 2020.

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[61] OECD-FAO (2013) *Agricultural Outlook 2013 - 2023*, 2013

A3.1.3.2 Feedstock Sustainability – Indirect Impacts

Any uptake of oleochemical residues as a bioliquid for non-domestic heating is likely to divert this feedstock away from existing uses (i.e. on site CHP). In this situation, the production facilities may replace these feedstocks with other fuels such as gas oil. The increased use of gas oil would likely offset any direct GHG savings achieved via the use of the feedstock as a heating fuel in the UK.

Some oleochemical production uses virgin vegetable oils. In the context of the overall supply chain, however, oleochemical production accounts for a small fraction of the total quantity of global vegetable oil arisings, and therefore it is highly unlikely that any increased demand for OR1 (which represents a very small fraction of the input stream) would result in increased cultivation of virgin vegetable oil crops.

A3.1.4 Impact on Existing RHI Applications

OR1 is a liquid feedstock which is not currently supported by the RHI, and therefore provision of support as a bioliquid would not impact on current RHI applications. It should be noted, however, that this feedstock is eligible for support under the RO, and we are aware anecdotally of limited tonnages being burned in CHP boilers. However, the higher value of fuels to the CHP market (which benefits from both heat and electricity sales) is such that support under the RHI is very unlikely to impact upon this existing market. At the same time, it appears that the relatively low price of gas is such that demand for OR1 for CHP is unlikely to increase significantly in the short term (without a spike in the price of gas), thus leaving feedstock available for heating-only applications.

A3.2 Deodoriser Distillate – Market Analysis

A3.2.1 Feedstock Composition and Origins

Deodoriser distillates (commonly known as DD1) can be defined as the by-product of deodorisation, which is the last step in the refining process of vegetable oil to produce margarine or other edible oils. This refining process, often called ‘deodorised distillation’ is required to make such products suitable for human consumption. The calorific value of DD1 is likely to be in the range of 32 to 42 GJ/tonne.[62]

The feedstock comprises of a mixture of free fatty acids, glycerol, as well as sterols, tocopherols, hydrocarbons, and a number of other components.[63] Raw deodoriser distillate contains a number of further useful compounds, such as phytosterols and squalene, which can be extracted and utilised in other markets, including that for food additives, as well as the pharmaceutical and cosmetic industries.

A3.2.2 Size of the Opportunity

A3.2.2.1 Feedstock Arisings

As mentioned above, deodoriser distillate is a by-product of the vegetable oil refining process to produce margarine or other edible oils. As such its availability is linked directly to the quantity of margarine (and edible vegetable oils) produced. Publicly available data shows that global margarine production totalled 9.4 million tonnes per annum in 2012, as detailed in Table 18.[64] Data is also available split by the geographical location of production.

Region	Margarine Production in 2012 (thousand tonnes)
UK	321
EU	2,119
Global	9,374

Source: International Margarine Association of the Countries of Europe (2012) Statistics, http://www.imace.org/about-margarine/statistics-1/

Table 18: Global Margarine Production in 2012

The distillation process mainly functions to reduce the composition of unsaponifiable matter (e.g. plant sterols, tocopherols and squalene) and free fatty acids in the refined oil. By comparing the average composition of these components in typical crude and refined vegetable oils, we can estimate that deodoriser distillate is produced at a rate of between 1,550 and 1,950

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[62] Personal Communications, two feedstock suppliers/handlers, April 2014

[63] Ramamurthi, S., and McCurdy, A. (1993) Enzymatic pretreatment of deodorizer distillate for concentration of sterols and tocopherols, *Journal of the American Oil Chemists’ Society*, Vol.70, No.3, pp.287–295

[64] International Margarine Association of the Countries of Europe (2012) *Statistics*, http://www.imace.org/about-margarine/statistics-1/

tonnes for every 100,000 tonnes of vegetable oil processed, which equates to a production ratio of 1.55-1.95%.[65]

Calculation of output deodoriser distillate from margarine production also requires an understanding of the average vegetable oil content of margarine, which can be assumed to be 80%.[66] We have used this ratio and percentage to estimate the quantity of deodoriser distillate produced globally, in EU Member States and in the UK. It is estimated that 118,000 to 149,000 tpa is currently produced globally, of which 27,000 – 34,000 tpa comes from EU Member States and 4,000 to 5,000 tpa arises in the UK, as shown in Table 19.

Whilst the above analysis appears to show that DD1 production in the UK is relatively small, it should be noted that this only includes that which comes from margarine production and therefore not that which arises from wider refining of edible vegetable oils. There is currently around 1.7 million tpa of vegetable oil processing which takes place in the UK, with a further 20.4 million tpa in other EU Member states (assuming all crude vegetable oil undergoes refining).[67] As detailed in Table 19, assuming the same ratio of production of DD1, this would result in 26,000 to 33,000 tpa in the UK and 321,000 to 406,000 tpa in the EU from all vegetable oil refining processes (including margarine production).

Region	Feedstock Supply (tonnes per annum)		
	From Margarine Production	From Other Vegetable Oil Refining	Total
UK	4,000 – 5,000	22,000 – 28,000	26,000 – 33,000
EU	27,000 – 34,000	294,000 – 372,000	321,000 – 406,000

Table 19: Current Tonnage of DD1 from Vegetable Oil Refining

Furthermore, anecdotally, ‘availability’ of DD1 in the UK has been estimated by one feedstock supplier at 100,000 tpa.[68] This figure seems somewhat high in terms of what is actually produced in the UK, and more in line with what might be available if significant quantities of DD1 are imported from Europe.

A3.2.2.2 Renewable Heat Potential and Carbon Savings

To determine the total renewable heat potential and carbon savings it is necessary to define the boundaries of the system. As shown in Figure 4, we have included the same stages as those required under the RED.

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[65] T.L. Mounts (1981) Chemical and Physical Effects of Processing Fats and Oils, *Journal of the American Oil Chemists’ Society*, Vol.58, No.1, p.51A–54A

[66] Soy Info Center (2007) *History of Soy Oil Margarine*, 2007, http://www.soyinfocenter.com/HSS/margarine1.php

[67] SCOPA (2014) *About SCOPA*, 2014, http://www.scopa.org.uk/

[68] Personal Communication with feedstock supplier, 8th April 2014

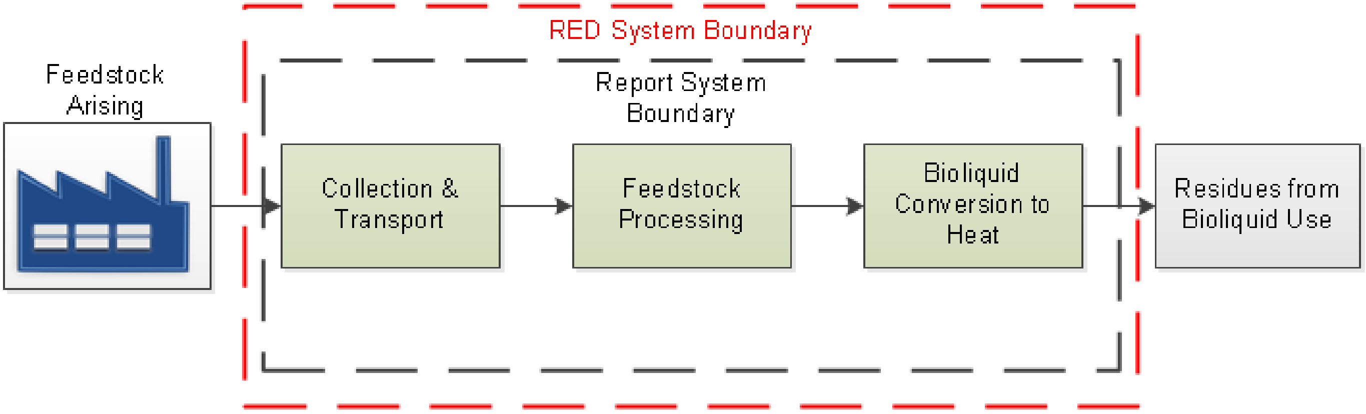

Figure 5: System Boundary of CO_2 Emissions Associated with Production and Consumption of DD1-based Bioliquids

Figure 4 shows that the following elements have been excluded from the analysis:

- Feedstock Arising:
  - The feedstock is a residue of a production process and is therefore deemed to have zero carbon emissions associated with it at this point;
- Residues from Bioliquid Use;
  - We do not have any relevant data by which to make any estimates as to the impacts from process residues, albeit we would surmise that these are again very small.

Based on the tonnages of feedstock highlighted above as arising in the UK, and upon an assumed average CV of 37 GJ/tonne (based on a CV range of 32-42 GJ/tonne, as set out in Section 4 of the main report) the renewable heat and carbon saving potential of bioliquids derived from OR1 is set out in Table 16.

To calculate the renewable heat potential and carbon savings we also assume the following:

- Carbon emissions factor for the ‘Collection & Transport’ and ‘Feedstock Processing’ stages of 0.014 tCO_2/GJ (14 gCO_2/MJ) of bioliquid. This factor was provided by one bioliquid fuel supplier as being the accepted ‘default value’ associated with biodiesel produced from waste oils;[69]
- Feedstock to bioliquid conversion efficiency of 99%;
- The use of a retrofitted boiler with a thermal efficiency of 80%; and
- As noted in Section 5.1.1 of the main report, the CO_2 displacement factor for the counterfactual fuel (gas oil) is 0.302 tCO_2/MWh thermal (which is calculated based on a boiler with an efficiency of 89%).

This shows that assuming all DD1 generated within the UK was burned in industrial heating boilers, between 211,600 and 268,600 MWh of renewable heat would be generated per annum. This would displace between 50,600 and 64,200 tCO_2 per annum from boilers which would

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[69] . It was suggested as a conservative value (i.e. over-estimate) to use in terms of the the carbon emissions associated with their production process, which is likely to result in lower emissions due to it being the less energy-intensive stage of ‘Feedstock Processing’ compared to biodiesel production from waste oils

have been burning gas oil. Similarly for Europe, assuming all DD1 generated was utilised, between 2,613,000 and 3,305,000 MWh of renewable heat would be generated per annum. This would displace between 624,600 and 789,900 tCO_2e per annum from boilers which would have been burning gas oil.

Parameter	UK	EU
Feedstock Arisings (tpa)	26,000 – 33,000	321,000 – 406,000
Renewable Heat Potential (MWh/annum)	211,600 – 268,600	2,613,000 – 3,305,000
Carbon Savings (tCO_2e/annum)	50,600 – 64,200	624,600 – 789,900

Table 20: Total Theoretical Renewable Heat and Carbon Saving Potential of DD1

As per Section 5 of the main report, to determine the number of boilers this could supply, we have assumed an average boiler size of 5MW_{th} that operates with an average load factor of 70%. Therefore, based on UK feedstock arisings, there would be sufficient bioliquid to supply fuel between 6 to 8 boilers. Taking into account European feedstock arisings, between 85 and 107 boilers could be supplied with sufficient bioliquid fuel. This is detailed in Table 21, including a low and high sensitivity range (boiler capacities of 1MW_{th} and 10MW_{th} respectively).

	Low (1MW_{th})	Central (5MW_{th})	High (10MW_{th})
UK	34 to 43	6 to 8	3 to 4
Europe	426 to 538	85 to 107	42 to 53

Table 21: Theoretical No. of Boilers That Could be Supplied by DD1

A3.2.3 Barriers to Deployment under RHI

A3.2.3.1 Future Market Potential

Global vegetable oil markets are currently very stable, and any future risks to this market are unlikely to impact significantly on overall supply trends. The quantities of deodoriser distillate available are effectively determined by the amount of margarine and edible oil production in the UK and EU. We are not aware that these markets are currently exposed to any significant risk, and therefore it is likely that availability of deodoriser distillate should remain relatively stable.

A3.2.3.2 Feedstock Sustainability – Indirect Impacts

Deodoriser distillate arises from the processing of virgin vegetable oils into margarine and edible oils, for which concerns about indirect land use change (ILUC) impacts are well documented. In the context of the overall supply chain, margarine production accounts for a small fraction of the total quantity of vegetable oil arisings, and therefore it is highly unlikely that any increased demand for deodoriser distillate (which represents a very small fraction of the input stream) would result in increased cultivation of virgin vegetable oil crops. Furthermore, our research indicates that DD1 is not being used in any alternative market, which might result in a more carbon intense alternative. The use of DD1 as a heating fuel is therefore unlikely to have significant indirect environmental impacts.

A3.2.4 Impact on Existing RHI Applications

Deodoriser distillate is a liquid feedstock which is not currently supported by the RHI, and therefore provision of support as a bioliquid would not impact on current RHI applications. It should be noted, however, that this feedstock is eligible for support under the RO, and we are aware anecdotally of limited tonnages being burned in CHP boilers. However, the higher value of fuels to the CHP market (which benefits from both heat and electricity sales) is such that support under the RHI is very unlikely to impact upon this existing market. At the same time, it appears that the relatively low price of gas is such that demand for DD1 for CHP is unlikely to increase significantly in the short term (without a spike in the price of gas), thus leaving feedstock available for heating-only applications.

A3.3 Lignocellulosic ‘Group’ – Market Analysis

A3.3.1 Feedstock Composition and Origins

Lignocellulosic (LC) feedstocks are those which comprise of cellulose, hemicellulose and lignin based polymers. There is a vast array of feedstocks that can be classified as LC materials, and as such, as discussed in Section 4 of the main report, for the purposes of this study we have grouped these feedstocks into a single general LC group. This is such that the focus of cost and performance information for fast pyrolysis processes used to convert LC feedstocks into pyrolysis oils (see Section 6 of the main report) relates to a ‘generic’ tonne of ‘oven-dried’ (i.e. 0% moisture content) of LC material. We therefore assume that all feedstocks within the LC group have a CV of 17-19 GJ/tonne.[70]

In Table 22, we have presented the LC feedstocks to be taken forward as candidates for support under the RHI. As discussed in Section 4 of the main report, it should be noted that only very wet feedstocks, which are more suited to support under the RHI for anaerobic digestion, were excluded from the LC group, along with one feedstock which is currently used as animal feed. As shown in Table 22 we have also further divided all selected feedstocks into two sub-categories; ‘LC Energy Crops’ and ‘LC wastes and residues’.

Whilst the majority of LC feedstocks have the same characteristics and properties when oven dried, there are a small number of feedstocks that present certain difficulties when attempting to convert the feedstock into a bioliquid, for example, straw has a high alkaline content, which can be problematic. Therefore, although we examine a generic LC feedstock for conversion to a bioliquid, we have also sought to identify and explore issues which relate to particular feedstocks within this overall context.

LC Energy Crops	**LC ‘wastes’ and residues**
Miscanthus	Arboricultural Residues[1]
Short Rotation Coppice	Cobs
Short Rotation Forestry	Husks
	Nut Shells
	Palm Processing Residues (Empty Palm Branches / Empty Fruit Bunch, Fibre and Shell from Palm Oil Production)
	Saw dust & cutter shavings

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[70] Biomass Energy Centre, *Calorific Value vs. Moisture Content*, www.biomassenergycentre.org.uk, accessed 16th April 2014

	Straw
	Waste Wood
	Molasses
	Bagasse
	Corn stover

Note:

1. Includes small round-wood, bark, branches, leaves

Table 22: Categorisation of Lignocellulosic Feedstocks

A3.3.2 Size of the Opportunity

A3.3.2.1 Feedstock Arisings

Of the listed feedstocks, various datasets can be combined to suggest that there could be as much as 22.7 million tpa of LC feedstocks (excluding MSW or C&I wastes, which are discussed in Section A3.4 of this Appendix) currently arising in the UK.[71] [72] Globally, it is estimated that there is over 2,750 million tpa of LC feedstock arisings, with straw and small-round wood contributing the vast majority.[73] This level is forecast to increase to almost 3,000 million tpa.[74] In Europe, it is estimated there is over 575 million tpa arising. The UK therefore accounts for a very small fraction of LC feedstock arisings.

As mentioned above, feedstocks within this LC group arise from two main sources, they are either a residue (or ‘waste’) from a process, or are grown specifically to meet a demand. Currently, the majority (around 22.5 million tonnes) of LC material that arises in the UK falls into the ‘wastes and residues’ category, and as such, the availability of this material is dependent on the activity of the various related markets. For example, saw dust and cutter shavings arise as a residue from the furniture manufacturing industry, and therefore the quantity available depends on a large number of factors, including, but not limited to, increased household construction, as well as, to a degree, disposable income.

In contrast, energy crops can be grown in response to demand, and therefore potentially represent a more flexible opportunity for use as a feedstock for bioliquids. That said, with many such feedstocks, there are likely to be concerns as to the real carbon benefits and over the sustainability of such practices, as discussed in Section 5 of the Main Report.

Unlike the majority of feedstocks analysed as part of this project, LC feedstocks are a solid material that require converting into a useable fuel through pyrolysis. However, prior to the pyrolysis process the feedstock must be oven-dried to remove moisture content, which we assume reduces the weight of the feedstock by 30%. Following oven-drying, bioliquid is

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[71] DEFRA (2012) *Wood Waste: A Short Review of Recent Research*, July 2012, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82571/consult-wood-waste-researchreview-20120731.pdf;

[72] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

[73] Ibid

[74] Ibid

produced from the pyrolysis of the oven-dried LC feedstock. Anecdotal evidence from a pyrolysis oil producer suggests that 3.5 tonnes of pyrolysis oil is produced from every 5 tonnes of oven-dried feedstock, which equates to a conversion efficiency of 70%.

Therefore from a starting point of 22.7 million tpa of LC feedstock arising in the UK and 575 million tpa in Europe, if all of this feedstock were oven dried, there could be as much as c.15.9 million tpa of useable feedstock arising in the UK, and c.403 million tpa in Europe. Which, if the entirety of this were to be converted to a pyrolysis oil, there could be as much as c.11.1 million tpa available in UK, and c.282 million in Europe.

A3.3.2.2 Renewable Heat Potential and Carbon Savings

To determine the total renewable heat potential and carbon savings it is necessary to define the boundaries of the system. As shown in Figure 6, those modelled for this study are more narrow than is required for reporting under the RED.

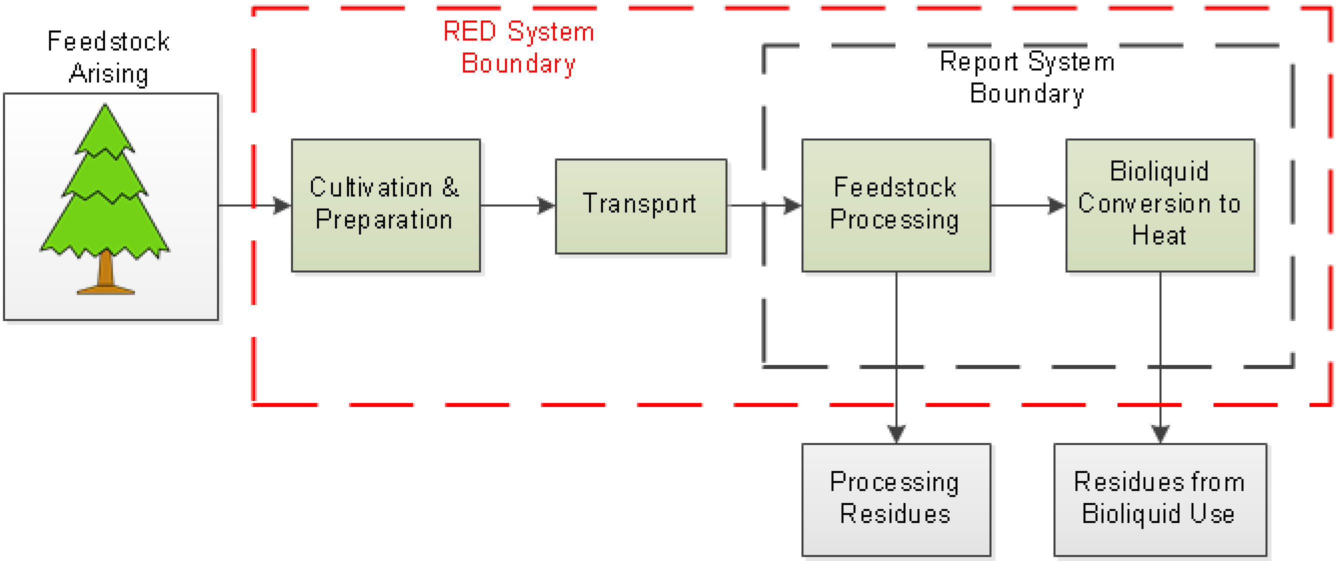

Figure 6: System Boundary of CO_2 Emissions Associated with Production and Consumption of LC-based Pyrolysis Oil

Figure 6 shows that only the feedstock processing and bioliquid to heat conversion elements are included within the system boundary. This is for the following reasons:

- Cultivation and Preparation:
    - The feedstock might either be a purpose grown crop, which will require energy inputs for cultivation, or residues from forestry management or timber products manufacture. As each might have very different associated carbon emissions, these have been excluded from the analysis;
- Transport;
    - Due to the variable nature of transport of the feedstock from range of potential different sources this part of the chain has again been excluded;
- Residues from feedstock processing;
    - Due to a lack of available data, any emissions resulting from the management of residues from this process have been excluded;

- Residues from bioliquid conversion to heat;
  - Again, due to a lack of available data, any emissions resulting from the management of residues from the boiler have been excluded.

Therefore, based on the tonnages of feedstock highlighted above as arising in the UK, and upon an assumed CV of 16 GJ/tonne (based on a CV range of 15-16 GJ/tonne, as set out in Section 4 of the main report) the renewable heat and carbon saving potential of LC-based pyrolysis oil is set out in Table 25.

To calculate the renewable heat potential and carbon savings we also assume the following:

- Feedstock to bioliquid conversion efficiency of 70%;
- The use of a retrofitted boiler with a thermal efficiency of 80%; and
- As noted in Section 5.1.1 of the main report, the CO_2 displacement factor for the counterfactual fuel is 0.302 tCO_2/MWh thermal (which is calculated based on a boiler with an efficiency of 89%).

This shows that assuming all LC feedstocks arising within the UK were converted by pyrolysis into pyrolysis oil (which is assumed to have a CV of 16 GJ/tonne) and were burned in industrial heating boilers, up to 39,550 GWh of renewable heat could be generated per annum. This would displace up to 11.9 million tCO_2e per annum from boilers which would have been burning gas oil. Similarly for Europe, assuming all LC feedstocks were utilised, up to 1,002,000 GWh of renewable could be generated per annum, displacing up to 302.5 million tCO_2e per annum.

As noted in Section A3.3.2 of this Appendix, the arising figures are for the total estimated amount of LC material currently arising in the UK and the EU and it is therefore to be taken only as the upper limit in terms of feedstock availability and carbon savings. Realistically, the proportion of this material that could be utilised depends on a number of market factors, as well as any level of future incentive, and is likely to be significantly lower.

Parameter	UK Upper Limit	Europe Upper Limit
Potential Fuel Availability (tpa)	11,123,000	281,799,000
Renewable Heat Potential (GWh_{th}/annum)	39,550	1,002,000
Carbon Savings ($ktCO_2e$/annum)	11,900	302,500

Table 23: Total Theoretical Renewable Heat and Carbon Saving Potential of LC-based Pyro-Oil

As per Section 5 of the main report, to determine the number of boilers this could supply, we have assumed an average boiler size of $5MW_{th}$ that operates with an average load factor of 70%. Therefore, as per above, assuming that all LC feedstock is converted into bioliquid, based on UK feedstock arisings, there would be sufficient bioliquid to supply fuel c.1,290 boilers. Taking into account European feedstock arisings, the number of boilers that could be supplied increases to c.32,680. This is detailed in Table 24, including a low and high sensitivity range (boiler capacities of $1MW_{th}$ and $10MW_{th}$ respectively).

	Low ($1MW_{th}$)	Central ($5MW_{th}$)	High ($10MW_{th}$)
UK	6,550	1290	645

Europe	163,400	32,680	16,340

Table 24: Theoretical No. of Boilers That Could be Supplied by LC-based Pyrolysis Oil

A3.3.3 Barriers to Deployment under RHI

A3.3.3.1 Uncertainty over Future Support Levels

Current perceived uncertainty surrounding long-term government policy has led to a number of high-profile solid biomass facilities being cancelled, for example, RES's biomass power station in North Blyth.[75] This has the potential to damage confidence in the Government's long-term support for the use of LC feedstocks as a means of reducing carbon emissions from energy generation. This issue needs to be carefully managed to ensure market confidence is sufficient to invest in commercial scale processing infrastructure for heating bioliquids.

A3.3.3.2 Challenges associated with specific Feedstocks

As highlighted above, whilst the majority of the feedstocks are suitable for conversion to bioliquids, there are a number which may be less suited. One example is straw, which is primarily challenging due to its high ash content, which adds another level of complexity to the conversion (pyrolysis) process. Some progress is being made on this issue, however, with a company in Finland claiming that they have tested conversion of straw into a heating bioliquid at semi-commercial scale.[76]

A3.3.3.3 Feedstock Sustainability – Indirect Impacts

An increase in demand for LC feedstocks as bioliquids for non-domestic heating has the potential for fuel substitution impacts, whereby they are already used (in solid form) in onsite heating applications, for example at saw-mills. Due to the historic value of many materials, the use of such fuels by producers is usually relatively limited, for example, to space rather than process heating, and therefore any switch of feedstock away to bioliquid markets is likely to have only very limited impacts in terms of greater use of heating oil or other sources of fossil heating.

At the same time, however, significant incentives for LC energy crops could result in a range of indirect land use change (ILUC) impacts. It is expected, however, that these would be managed effectively via a very similar regime currently being put in place by DECC such that fuels need to meet defined sustainability criteria to receive support under the RHI for heat generation from solid biomass.[77]

A3.3.4 Impact on Existing RHI Applications

LC feedstocks in solid biomass form are currently eligible under the RHI, and as such, should they be incentivised towards conversion into bioliquids for heat, there is uncertainty as to the impact this would have on existing RHI applications.

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[75] RES (2014) *RES stops work on £300M North Blyth Power Station*, Accessed 13 March 2014, http://www.northblythproject.co.uk/news/announcement.aspx

[76] Personal Communication, Fortum, 5th April 2014

[77] DECC (2013) *Non-Domestic Renewable Heat Incentive – A Government Response to 'Providing Certainty, improving performance' July 2012 consultation*, February 2013, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/128679/Gov_response_to_non_domestic_July_2012_consultation_-_26_02_2013.pdf

There is likely to be less impact on solid biomass markets where current feedstock supply agreements have been secured through long-term contracts. This is particularly relevant for energy crops, for which the lead time between contract agreement and cultivation also is a constraining factor. LC feedstocks which are wastes and residues (aside from MSW or C&I wastes), however, are generally not contracted in the long-term. Consequently, any significant new demand from future incentives for bioliquids could result in some feedstocks, for example, arboricultural residues, being drawn away from existing solid biomass heating markets. This could result in some existing users of such fuels switching to fossil alternatives, and therefore any new incentive would need to be carefully managed.

A3.4 Solid Recovered Fuel – Market Analysis

A3.4.1 Feedstock Composition and Origins

Solid recovered fuel (SRF) is derived from residual waste, which is generated by households, as well as commercial and industrial premises through consumption and economic activity. Residual waste is the fraction of waste that remains when any materials (which have value) in the waste stream have been captured for reuse, recycling, composting, or AD. Materials capture systems, however, usually rely upon human intervention, and thus are often far from perfect. Residual waste, therefore, generally comprises of a number of key materials; plastics (both dense plastics and plastic film), metals, glass, paper/card and other biomass, such as food and wood.

As described in Section 5.3 of the main report, SRF is usually produced in a process known as mechanical-biological treatment (MBT), but can also be produced via a residual materials recycling facility (MRF) or via large-scale autoclaving processes, which include mechanical separation. The level of sophistication of such processes depends upon the desired use, which can range from combustion of a fairly rudimentary, variable and low CV feedstock in moving grate incinerators, to production of a refined, high CV fuel, to specification, for cement kilns. It is the latter, which is likely to be the focus of this analysis, but essentially fuels can, to some extent, be produced to demand, albeit this depends on the input composition of wastes. All such processes are often also designed to capture additional materials for recycling from the input waste stream.

The level of plastics in SRF is a key variable. Whilst plastics are desirable to raise the CV of the fuel, in the case of cement manufacture, they are not ‘renewable’ and therefore this fraction would not be supported by the RHI. As discussed in Section 5.3 of the main report, currently, under the RHI for solid biomass, MSW (and SRF) is deemed to be 50% fossil content unless proven otherwise. Falling levels of food, wood and paper within the residual waste are such that this is probably a reasonable assumption to make for this study. We have also assumed that moisture content is reduced to zero in line with our analysis of LC feedstocks in Section A3.3 of this Appendix, which is brought together in terms of analysis of costs and performance of fast pyrolysis processes, as per Section 6 of the main report.

A3.4.2 Size of the Opportunity

A3.4.2.1 **Feedstock Arisings**

As mentioned above, residual waste is the fraction of waste that remains after other waste materials have been sent for reuse, recycling, composting, or AD. In terms of the quantity of residual waste that arises each year in the UK, this is estimated to be around 28.2 million tonnes in 2012-13.[78].

The amount of residual waste being landfilled has decreased steadily over the last decade as the ‘standard’ (non-inert) rare of Landfill Tax has increased dramatically (to £80/tonne from April

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[78] Eunomia (2013) *Residual Waste Infrastructure Review – Version 5*, November 2013. http://www.eunomia.co.uk/product.php/113

2014), making alternatives, such as incineration, more economically viable. Residual waste managed by local authorities (MSW) is generally contracted to specific facilities on a long-term basis, whilst residual waste from commercial and industrial (C&I) sources is generally managed on much shorter treatment contracts.

The long term local authority contracts are such that the actual quantity of residual waste which might be available for processing into SRF for pyrolysis into bioliquids, is somewhat smaller than that which is not currently recycled or sent to composting/AD. Whilst C&I wastes are usually available to those offering the lowest gate fee (outside of 1-2 year contracts), we have assumed the fraction which is currently available as that which is currently sent to landfill at the standard rate. In 2012-13, this was 18.8 million tonnes.

Therefore, if all of this residual waste were to be processed into SRF, there could be between 11.3 and 13.2 million tpa of SRF available as a feedstock, assuming a mass loss of between 30 to 40% for moisture loss, and additional recyclable material recovered.

If all this SRF were to be converted to a useable pyrolysis oil through pyrolysis, based on a similar process to that for LC feedstocks (as described in Section A3.3 of this Appendix) where anecdotal evidence suggests a feedstock to pyrolysis oil conversion efficiency of 70%, we estimate there could be as much as 7.9 to 9.2 million tonnes of pyrolysis oil generated.

It should be noted, however, that the residual waste treatment market is becoming ever more competitive, not only as more treatment facilities come online within the UK, but as demand for residual waste from European incinerators increases in response to a situation of overcapacity in Member States such as Germany, The Netherlands, Sweden and Denmark. In theory, there is likely to be sufficient levels of feedstock available to 2020, however, the key factor is being able to continue to operate in the market at a competitive gate fee.

A3.4.2.2 Renewable Heat Potential and Carbon Savings

To determine the total renewable heat potential and carbon savings it is necessary to define the system boundaries. As shown in Figure 7, those modelled for this study are more narrow than is required for reporting under the RED.

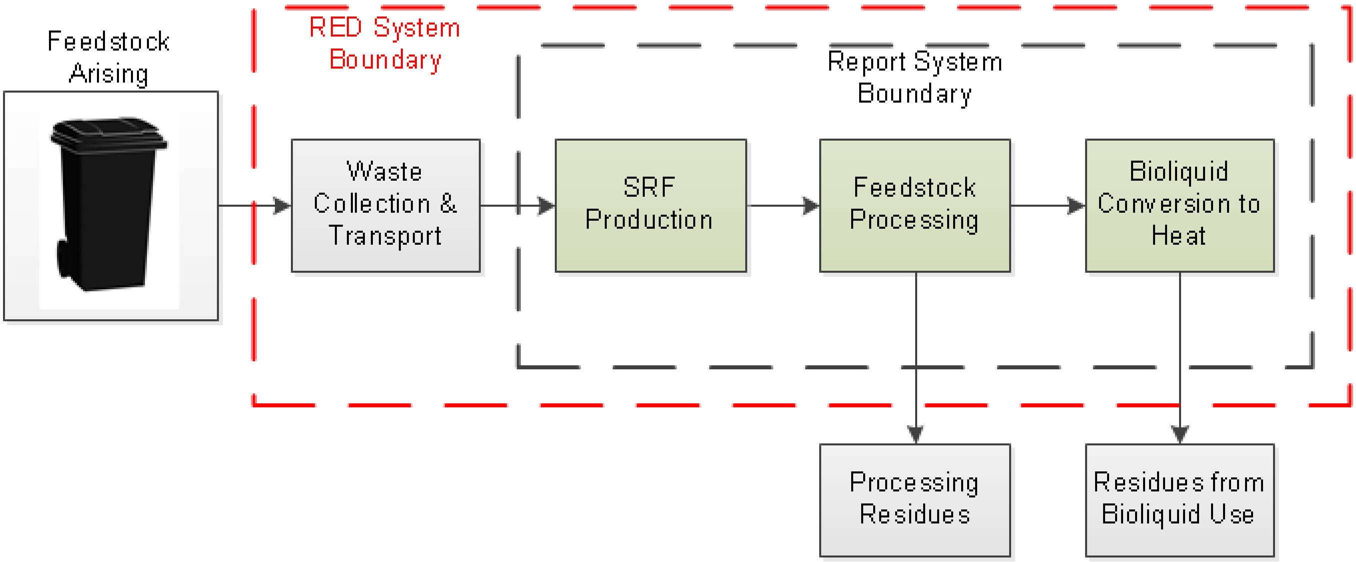

Figure 7: System Boundary of CO_2 Emissions Associated with Production and Consumption of SRF-based Pyrolysis Oil

Figure 7 shows that several elements are excluded from the system boundary. This is for the following reasons:

- Waste Collection & Transport:
  - Due to the variable nature of waste collection and transport, the carbon emissions associated with this aspect of the chain have been excluded;
- Residues from feedstock processing:
  - Due to a lack of available data, any emissions resulting from the management of residues from this process have been excluded;
- Residues from bioliquid conversion to heat:
  - Again, due to a lack of available data, any emissions resulting from the management of residues from the boiler have been excluded.

Therefore, based on the tonnages of feedstock highlighted above as arising in the UK, and upon an assumed CV of 16 GJ/tonne (based on a CV range of 15-16 GJ/tonne, as set out in Section 4 of the main report) the renewable heat and carbon saving potential of SRF is set out in Table 25.

To calculate the renewable heat potential and carbon savings we also assume the following:

- Associated carbon emissions of 0.9 $kgCO_2$ per tonne of SRF produced for the 'SRF Production' stage;[79]
- Feedstock to bioliquid conversion efficiency of 70%;
- Biomass content of feedstock of 50%;
- The use of a retrofitted boiler with a thermal efficiency of 80%; and
- As noted in Section 5.1.1 of the main report, the CO_2 displacement factor for the counterfactual fuel is 0.302 tCO_2/MWh thermal (which is calculated based on a boiler with an efficiency of 89%).

This shows that assuming all residual waste was processed into SRF, and all this SRF was converted to pyrolysis oil, and was subsequently burned in industrial heating boilers, between 14,000 and 16,400 GWh of renewable heat could be generated per annum. This would displace between 4.2 and 4.9 million tCO_2e per annum from boilers which would have been burning gas oil.

As noted above, the arising figures are for the total estimated amount of available SRF currently arising in the UK and the EU and it is therefore to be taken only as the upper limit in terms of feedstock availability and carbon savings. Realistically, the proportion of this material that could be utilised depends on a number of market factors, as well as any level of future incentive.

Parameter	Low	High
Potential Fuel Availability (tpa)	7,896,000	9,212,000
Renewable Heat Potential (GWh_{th}/annum)	14,037	16,377
Carbon Savings ($ktCO_2e$/annum)	4,225	4,929

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[79] Prior to being processed into pyrolysis oil, residual waste must first undergo a form of pre-treatment to produce SRF. For the purposes of this study, we assume this pre-treatment is an MBT 'biodrying' process

Table 25: Total Theoretical Renewable Heat and Carbon Saving Potential of SRF-based Pyro-Oil

As per Section 5 of the main report, to determine the number of boilers this could supply, we have assumed an average boiler size of 5MW$_{th}$ that operates with an average load factor of 70%. Therefore, assuming that all SRF was converted into bioliquid, this would be sufficient fuel to supply between 515 to 600 boilers. This is detailed in Table 26, including a low and high sensitivity range (boiler capacities of 1MW$_{th}$ and 10MW$_{th}$ respectively).

	Low (1MW$_{th}$)	Central (5MW$_{th}$)	High (10MW$_{th}$)
UK – Low Estimate	2,575	515	257
UK – High Estimate	3,004	600	300

Table 26: Theoretical No. of Boilers That Could be Supplied by SRF-based Pyrolysis Oil

A3.4.3 Barriers to Deployment under RHI

A3.4.3.1 Competitive Market

As described above, much residual waste is contracted in the long-term, whilst there is a significant amount of competition over gate fees to attract waste into treatment facilities, both in the UK and in other EU Member States. This is such that any pyrolysis plant will need to compete for tonnage on an ongoing basis, as contracts for C&I waste usually are only 1-2 years in duration.

Furthermore, whilst disposal to landfill sits at the bottom of the ‘waste hierarchy’, there remains a significant amount of investment in landfill void in the UK, upon which operators, in many cases large waste management companies, which control much of the waste collection market, would like to see a return. Consequently, it can be a challenge to secure tonnage, even when, in terms of overall gate fees, a facility might appear to represent the most attractive option.

A3.4.3.2 Additional Costs of Compliance with Waste Permitting

Wastes are subject to waste management permitting and licensing, which place additional limits and restrictions on any organisation handling them. Whilst some (single stream) materials have managed to achieve ‘end of waste’ (EoW) status, such that they are no longer bound by waste management licensing, SRF from residual waste is very unlikely to achieve such status in the short to medium term, albeit it is considered as a candidate for consideration for EoW status by the EU Joint Research Council (JRC).[80] Facilities using pyrolysis to convert SRF to pyrolysis oil for heating, therefore, would be bound by waste management licensing, which would result in additional costs incurred by the operator.

Furthermore, similarly a pyrolysis oil converted from SRF, would also remain classed as a waste, unless it can be proven that it has reached End-of-Waste status. If End-of-Waste was not achieved, then any heating boiler using the oil would be subject to a number of waste management controls, including those contained within the EU Waste Incineration Directive (2000/76/EC), which includes requirements to adhere with strict emissions thresholds. This can result in significant additional costs, which may result in conversion routes being prohibitively expensive.

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[80] EU Joint Research Council (2010) *Study on the selection of waste streams for end-of-waste assessment, 2010* http://ftp.jrc.es/EURdoc/JRC58206.pdf

It should be noted that whilst an ATSM standard does exist for pyrolysis oil, as discussed further in Section 6.2.1 of the main report, this does not represent EoW status if the oil has been derived from a waste feedstock.[81]

A3.4.4 Feedstock Sustainability – Indirect Impacts

There is a small risk, should bioliquids from SRF receive too great a level of support under the RHI, that current waste treatment facilities in the UK, which do not have long-term contracts guaranteeing them supply of feedstock, might not be able to source sufficient feedstock as to remain operational. This is a worst-case scenario, however, and would only occur if the market for residual waste based bioliquids grew to a considerable size.

A3.4.5 Impact on Existing RHI Applications

Residual waste is already incentivised under the RHI where it is sent to CHP-enabled (or, in theory, heat only) incineration or gasification facilities. It should be noted, however, that there is a distinct lack of CHP-enabled facilities in the UK, primarily due to the high costs associated with developing a heat network, and the difficulty to guarantee a long-term heat off-take contract. Therefore it is unlikely that incentivising residual waste based bioliquids would impact on current RHI applications, rather it could impact on facilities currently supported by the RO or in future by Feed-in Tariff Contracts for Difference (FiT CfDs).

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[81] ASTM D7544 - 12 : *Standard Specification for Pyrolysis Liquid Biofuel*. See http://www.astm.org/Standards/D7544.htm, accessed 15th April 2014

Appendix 4 – Non-Prioritised Feedstocks

As described in Section 4 of the main report, these 'non-prioritised' feedstocks are those which, based on our analysis, are suitable for use as bioliquids in heat-only applications, but which, due to constraints in scope and budget, when compared with other feedstocks against a further set of criteria, have not been prioritised.

A4.1 Black & Brown Liquor – Market Analysis

A4.1.1 Feedstock Composition and Origins

Black and brown liquors are process residues from the production of paper pulp from pulpwood. Black liquor results from the 'kraft process' where lignin, hemicelluloses and other extractives are removed from the wood to free the cellulose fibres. Brown liquor is the equivalent spent cooking liquor in the 'sulfite process' (also known as red liquor, thick liquor and sulfite liquor). Along with tall oil, black and brown liquor are the main by-products of pulp and paper manufacturing, and as such, the key regions of arising are Northern Europe (principally Scandinavia), Northern America, East Asia and Brazil.[82]

Black and brown liquor are suitable for burning as heating fuels with minimal further refinement, and are already used as heating fuels in the (primarily Scandinavian) pulp and paper mills where they are produced as a residue. A biofuel CHP system supplier informed us that this fuel is also burnt within the UK, albeit, they are only aware of two UK sites currently using this fuel: a CHP facility and a biomass plant.[83]

A4.1.2 Size of the Opportunity

As mentioned above, black and brown liquor are process residues of the pulp and paper industry, and therefore production volumes are directly determined by demand for paper.

A recent study on behalf of DfT estimated the current and future quantities of black and brown liquor available.[84] As detailed in Table 27, this study estimates that current global supply is around 200 million tonnes per annum (tpa), which is anticipated to increase to around 426 million tpa by 2020. This future growth forecast is relatively consistent with anticipated growth in paper and board demand of 2.3% a year to 2030.[85]

The methodology within the DfT study acknowledges, however, that whilst the data points were considered to be of high quality for the UK and EU, they are less accurate with regard to the global figure, which is estimated on the basis of total wood residue production data.

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[82] NNFCC (2011) *Evaluation of Bioliquid Feedstocks and Heat, Electricity and CHP Technologies*, Report for Department of Energy and Climate Change, April 2011

[83] Personal communication, Fleetsolve, April 2014

[84] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

[85] OECD (2008) *OECD Environmental Outlook to 2030,* Accessed 6th March 2014, http://www.keepeek.com/Digital-Asset-Management/oecd/environment/oecd-environmental-outlook-to-2030_9789264040519-en#page403

Region	Feedstock Supply (Mt/year)	
	Current	2020
UK	0.28	0.28
EU	66	72
Global	200	246

Source: E4tech (2013) Advanced Biofuel Feedstocks - An Assessment of Sustainability, Report for Department for Transport, December 2013

Table 27: Current and Future Tonnages of Feedstock Available

A4.1.3 Barriers to Deployment under RHI

A4.1.3.1 Lack of Market Price

As noted above, black and brown liquor are predominantly used for on-site heat and power in the paper and pulp mills at which they arise, and as such, they are rarely, if ever, transported and traded. Whilst these feedstocks have a value to paper and pulp mills, therefore, they do not have a visible or real market price. Instead they are valued as savings by pulp and paper mills on the costs that would be associated with other fuel sources. The aforementioned DfT report estimates, based on energy values, that potential market prices would fall between £0 and £175 per tonne.[86] This wide range reflects the significant amount of uncertainty that results from attempting to calculate market prices via such an approach.

A4.1.3.2 Suitability for Transport Fuel Applications

In a 2007 study, a consortium headed by the Joint Research Centre of the EU Commission suggested that both black and brown liquor could be converted to a transport fuel via gasification, with potentially high conversion efficiencies.[87] In recent years, this conversion route has been further developed by a collaborative research group in Sweden. At this stage, two gasification plants are in operation: (1) a commercial scale plant in North Carolina, USA, with a nominal capacity of 330 tonnes per day; (2) a development scale plant in Pitea, Sweden, with a nominal capacity of 20 tonnes per day.[88]

A4.1.3.3 Low Calorific Value

Black and brown liquor have a relatively low calorific value (CV) of 12 GJ/tonne (LHV), and as most of these feedstocks arise outside the UK, the impact of their importing as a heating fuel could have considerable impacts (in both cost and environmental terms).[89]

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[86] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

[87] EUCAR, CONCAWE, and The Joint Research Centre of the EU Commission (2007) *Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context*, March 2007, http://ies.jrc.ec.europa.eu/uploads/media/WTW_Report_010307.pdf

[88] Chemrec (2014) *Chemrec plants*, 2014, www.chemrec.se/Chemrec-plants.aspx

[89] Calorific value (LHV) of 12.0 GJ/tonne

A4.1.3.4 Low Availability and Inelastic Supply

The supply of black and brown liquor is very inelastic, as even large increases in the price paid for such materials would be unlikely to result in significant increases in supply. This is because of the value of the feedstock (above and beyond its value as a fuel) to pulp and paper mills and the fact that it is a *residue* from a manufacturing process, i.e. additional demand for black and brown liquor will not drive additional paper and pulp manufacturing.

A4.1.3.5 Lack of Suitable Existing Burners within the UK

It is likely that very few existing boilers in the UK would be suited to burning black or brown liquor without significant modification. As a result, unless the feedstock was refined to meet current heating fuel standards, the likelihood of significant market penetration is somewhat low.

A4.1.3.6 Feedstock Sustainability – Direct Impacts

Discussions with a biofuel CHP system supplier inform us that, while black and brown liquor are available in significant quantities, these feedstocks are fairly 'dirty' fuels, which can't be used in urban areas due to high ash and heavy metal content.[90] This suggests that flue gas treatment equipment would need to be installed to boilers burning black and brown and liquor in order to meet environmental standards.

A4.1.3.7 Feedstock Sustainability – Indirect Impacts

Any uptake of black and brown liquor as a bioliquids for non-domestic heating is likely to divert these feedstocks away from existing uses (i.e. on site heat and power in pulp mills). In this situation, the mills are likely to replace these feedstocks with other fuels such as fuel oil and wood chip. The increased use of fuel oil would likely offset any direct GHG savings achieved via the use of the feedstock as a heating oil in the UK, whilst the use of woodchip might result in greater environmental impacts, such as reduced biodiversity and soil degradation.[91]

A4.1.3.8 Displacement of By-products from Combustion

Another factor in the determining the economics of utilising black and brown liquor in on-site CHP is that during burning of these feedstocks, the mills capture and recover a number of important chemicals that are then put back into the paper and pulp production process.[92] Therefore, should black and brown liquor be transported off-site for other heat applications, the impact this would have on the paper and pulp production process must be considered in terms of efficiencies and raw material costs.

A4.1.4 Impact on Existing RHI Applications

Black and brown liquor are broadly liquid feedstocks which are not currently supported by the RHI, and therefore provision of support as bioliquids would not impact on current RHI applications. It should be noted, however, that they could be eligible for support under the RO, albeit we are not aware of any such actual use at present.

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[90] Personal communication, Fleetsolve, April 2014

[91] As described in Section 4, modelling of the direct lifecycle emissions from the use of different bioliquids is outside the scope of this study, albeit certain principles apply to all feedstocks

[92] Honghi Tran, and Esa K. Vakkilainnen (2008) *The Kraft Chemical Recovery Process*, 2008, http://www.tappi.org/content/events/08kros/manuscripts/1-1.pdf

A4.2 Tall Oil Pitch – Market Analysis

A4.2.1 Feedstock Composition and Origins

Tall oil pitch is a highly viscous residue from the distillation of crude tall oil. Crude tall oil is derived from crude sulphate soap, which is (along with black and brown liquors) obtained as a co-product of the process of pulp and paper manufacturing.[93] Key regions of production are Northern Europe (principally Scandinavia), Northern America, East Asia and Brazil.[94] [95]

Tall Oil Pitch is suitable for burning as a heating fuel with minimal further refinement, and is already a proven cost effective fuel for certain heat applications. For example, tall oil pitch is primarily used for on-site process heat and power at the pulp and paper mills at which it is produced.[96] It is also used as a bioliquid fuel in district heating systems in Scandinavia and for co-firing with coal/oil in UK Power stations.[97]

A4.2.2 Size of the Opportunity

There is a relatively limited supply potential for tall oil pitch. As tall oil pitch is a process residue of the pulp and paper industry, production volumes are directly determined by demands for pulp and paper. A recent study on behalf of DfT estimated the current and future quantities of tall oil pitch available, with figures derived from crude tall oil production and a residue factor. As detailed in Table 27, this study estimates that current global supply is around 0.57 million tonnes per annum (tpa), which is forecasted to increase to 0.70 million tpa by 2020. Due to the geographically specific nature of the pulp and paper industry (discussed in Section A4.2.1 of the main report), the vast bulk of these arisings are outside the UK. This future growth forecast is relatively consistent with anticipated growth in paper and board demand of 2.3% a year to 2030.*[98]*

Region	**Feedstock Supply (Mt/year)**	
	Current	**2020**
UK	0.001	0.001
EU	0.16	0.19

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[93] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

[94] NNFCC (2011) *Evaluation of Bioliquid Feedstocks and Heat, Electricity and CHP Technologies*, Report for Department of Energy and Climate Change, April 2011

[95] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

[96] Ibid

[97] NNFCC (2011) *Evaluation of Bioliquid Feedstocks and Heat, Electricity and CHP Technologies*, Report for Department of Energy and Climate Change, April 2011

[98] OECD (2008) *OECD Environmental Outlook to 2030,* Accessed 6th March 2014, http://www.keepeek.com/Digital-Asset-Management/oecd/environment/oecd-environmental-outlook-to-2030_9789264040519-en#page403

Global	0.41	0.51

Source: E4tech (2013) Advanced Biofuel Feedstocks - An Assessment of Sustainability, Report for Department for Transport, December 2013

Table 28: Current and Future Tonnages of Feedstock Available

A4.2.3 Barriers to Deployment under RHI

A4.2.3.1 Market Competition

Multiple competing uses, such as process heat for the pulp and paper industry, already exist for tall oil pitch feedstocks and associated bioliquids. Furthermore, the resource potential for tall oil pitch is only rising slowly, due to the fact that it is a *residue* from a manufacturing process, i.e. additional demand for tall oil pitch will not drive additional paper and pulp manufacturing. Deployment under the RHI is therefore likely to increase competition for this resource and could lead to price rises in the face of high demand and relatively inelastic supply. This could decrease the cost-effectiveness of subsidies and raise costs for producers and consumers.

A4.2.3.2 Suitability for Transport Fuel Applications

Significant development of commercial scale production of biodiesel from tall oil pitch and tall oil is currently underway. Two specific examples are known of, these are:

1. Tall oil pitch has recently been tested by Neste Oil in commercial refinery operations, and has been deemed suitable for processing into transport fuel, although it is unclear as to whether commercial scale production is underway.[99]
2. A biorefinery capable of producing 100,000 tonnes of biodiesel per annum from crude tall oil (the unrefined precursor to tall oil pitch) is currently being constructed by UPM in south-eastern Finland. Construction is due to be completed by 2014.[100]

A4.2.3.3 Future Market Uncertainty

Tall oil pitch is just one of a number of products produced through further refining of crude tall oil. These other products include tall oil fatty acids, rosin acids and sterols. Currently, about two thirds of the global supply of crude tall oil undergoes further refining, while the remainder is directly burnt in boilers at pulp mills.[101] This fraction will be significantly determined by the demand for these distillation products. This presents a potential future risk to the tall oil pitch market: if demand for these other distillation products should decrease then less refining of tall oil pitch would take place. In this scenario the feedstock volume available will decrease even if global production of tall oil continues to increase as predicted.

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[99] Neste Oil (2013) *Neste Oil Uses Tall Oil Pitch to Produce Traffic Fuel*, April 2013, http://www.nesteoil.com/default.asp?path=1,41,540,1259,1260,20492,20993

[100] UPM (2014) *UPM Biofuels*, 2014, http://www.upm.com/en/media/press-kits/business/Biofuels/Pages/default.aspx

[101] Silvex Energy (2010), *AB Presentation to DECC,* October 2010

A4.2.3.4 Lack of Suitable Existing Burners within the UK

It is likely that very few existing boilers in the UK would be suited to burning tall oil pitch without significant modification. As a result, unless the feedstock was refined to meet current heating fuel standards, the likelihood of significant market penetration is somewhat low

A4.2.3.5 Feedstock Sustainability – Indirect Impacts

The limited supply of tall oil pitch means that increased uptake of this bioliquid for non-domestic heating is likely to divert this feedstock away from existing uses (e.g. on site heat and power in pulp mills). In this situation, these consumers are likely to replace tall oil pitch feedstocks with other fuels such as fuel oil and wood chip. The impacts of increased fuel oil use could offset any direct GHG savings achieved via the use of the feedstock as a heating oil in the UK. Potential negative impacts of substituting for wood fuel are reduced biodiversity and soil degradation due to increased deforestation.[102]

A4.2.4 Impact on Existing RHI Applications

Tall Oil Pitch is a broadly liquid feedstock which is not currently supported by the RHI, and therefore provision of support as a bioliquid would not impact on current RHI applications. It should be noted, however, that they could be eligible for support under the RO, albeit we are not aware of any such actual use at present.

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[102] As described in Section 4, modelling of the direct lifecycle emissions from the use of different bioliquids is outside the scope of this study, albeit certain principles apply to all feedstocks

A4.3 Distillation Residues (from biodiesel production) – Market Analysis

A4.3.1 Feedstock Composition and Origins

The production of biodiesel includes a number of steps, one of which is 'distillation' to ensure that the biodiesel complies with the transport fuel standard (EN14214). This process removes unreacted oil components, including mono-, di- and triglycerides, metals, catalyst, salts and pigmentation.[103] This produces a by-product called 'distillation residues'.

Defra notes that distillation residues are suitable for use in on-site boilers, or by third parties (subject to environmental legislation).[104] Other research and discussions with industry suggest that on-site use of the distillation residues appears to be common for on-site heat and steam production.[105]

A4.3.2 Size of the Opportunity

The distillation process is increasingly included as part of biodiesel production to ensure that fuels comply with biodiesel standards, and as such distillation residues are being produced in greater quantities.

Total world biodiesel production is increasing rapidly in response to rising demand for sustainable transport fuels, and is set to increase from 24 billion litres in 2012 to 41 billion litres in 2022, an increase of 70% in 10 years.[106] Non-distilled biodiesel contains between 1 to 5 % 'distillation residues' by weight. If all biodiesel produced were to include a distillation process, global arisings of distillation residues would range from 0.21 to 1.1 million tonnes at current levels of biodiesel production (assuming densities meet EN 14214 specifications). By 2022, global arisings of distillation residues could range from 0.35 to 1.9 million tonnes.

The UK production of FAME biodiesel in the first three quarters of 2013 totalled 612 million litres.[107] We can use this data to estimate that 631 to 661 thousand tonnes of biodiesel were produced in 2013 (assuming densities meet EN 14214 specifications). Assuming a similar potential for distillation residues as quoted above (1 to 5% by weight), this suggests that around 7-37 thousand tonnes of distillation residues are currently produced in the UK. However, this calculation assumes that all biodiesel produced in the UK undergoes a distillation process, and it should be noted that it is thought that very few UK biodiesel plant have distillation equipment installed. From further discussions with the company responsible for this facility, we found that

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[103] Raj Mosali (2012) *The Final Treatment*, http://www.biodieselmagazine.com/articles/8477/the-final-treatment

[104] Department for Environment, Food and Rural Affairs (2013) *Biodiesel*, http://www.defra.gov.uk/ahvla-en/disease-control/abp/biodiesel/

[105] UIC GmbH (2010) *Biodiesel Distillation*, 2010, http://www.uic-gmbh.de/images/UIC_Downloads/Applications/Biodiesel/Biodiesel1.pdf

[106] OECD-FAO (2013) *Agricultural Outlook 2013 - 2023*, 2013, http://www.keepeek.com/Digital-Asset-Management/oecd/agriculture-and-food/oecd-fao-agricultural-outlook-2013_agr_outlook-2013-en#page116

[107] Department for Transport (2013) *Biofuel Statistics*, February 2014, Accessed 14th March 2014, https://www.gov.uk/government/collections/biofuels-statistics#obligation-year-5-biofuels-data

3-4 thousand tonnes of distillation residues are produced per annum at this site, from a total annual output of c.55 thousand tonnes of biodiesel.[108]

A4.3.3 Barriers to Deployment under RHI

A4.3.3.1 Feedstock Availability

The literature does not provide an indication of the availability and cost of distillation residues. Similar to tall oil pitch, however, distillation residues are already used in on-site process heating boilers and are not commonly traded on global markets. Further market analysis will be required to assess whether this feedstock could be more readily traded in the future, without additional environmental impacts from fuel substitution.

A4.3.3.2 Future Markets

Distillation residues are a by-product of the biodiesel refining process, and as such the quantity that arises is linked directly to the biodiesel industry. While biodiesel production is expected to increase significantly through to 2020, driven by the RED which encourages greater demand for sources of renewable transport fuel, growth beyond this period is challenging to predict. Policy support at EU level for some forms of transport biofuel may not continue beyond 2020, and therefore the amount of biodiesel production could actually fall in future. That said future market development is further dependent on a number of other variable external factors, such as the level of crude oil prices, and the continuation of national biofuel policies at Member State level, all which give rise to some uncertainty over future markets.[109]

A4.3.3.3 Lack of Suitable Existing Burners within the UK

It is likely that very few existing boilers in the UK would be suited to burning distillation residues without significant modification. As a result, unless the feedstock was refined to meet current heating fuel standards, the likelihood of significant market penetration is somewhat low.

A4.3.3.4 Handling Difficulties

Distillation residues are corrosive and difficult to handle. Discussions with industry indicate that, while some biodiesel plants do use distillation residues in on site CHP applications, with efficiencies similar to a gas oil boiler, other plants dispose of them as wastes due to the high ongoing costs associated with using distillation residues for on-site heating. Heated tanks are also required for storage of distillation residues prior to feed-in to burners.[110]

A4.3.3.5 Feedstock Sustainability – Indirect Impacts

Distillation residues are the result of the biodiesel refining process, and a major feedstock source for biodiesel production is from virgin vegetable oils, for which concerns about indirect land use change (ILUC) impacts are well documented. In the context of the overall supply chain, however, distillation residues can be regarded as a minor by-product of the biodiesel refining process, of which a proportion is sourced from virgin vegetable oils, and therefore it is extremely unlikely that any increased demand for distillation residues would result in increased cultivation of virgin vegetable oil crops. It is very unlikely, therefore, that bioliquids produced from distillation residues will not have any significant indirect environmental impacts.

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[108] Personal communication, Argent Energy, March 2014

[109] OECD-FAO (2011) *Agricultural Outlook 2011-2020*, 2011, http://www.oecd.org/site/oecd-faoagriculturaloutlook/48202074.pdf

[110] Personal communication, Argent Energy, March 2014

A4.3.4 Impact on Existing RHI Applications

Distillation residues are a liquid feedstock which is not currently supported by the RHI, and therefore provision of support as bioliquids would not impact on current RHI applications. It should be noted, however, that this feedstock could be eligible for support under the RO, albeit we are not aware of any such actual use at present.

A4.4 Glycerol – Market Analysis

A4.4.1 Feedstock Composition and Origins

Crude glycerol is a by-product of biodiesel production and the processing of animal and vegetable fats and oils. Biodiesel production yields around 10 per cent crude glycerol output, for each tonne of input vegetable oil.[111] Glycerol can also be synthesised, but due to the large current oversupply produced via non-synthetic routes, very little is currently produced in this way. Key production locations exist both across the EU and US, where the majority of FAME biodiesel plants are located.

The composition of crude glycerol is highly variable and primarily depends on the feedstock used for biodiesel production. For example, a typical crude glycerol from a tallow biodiesel plant is composed of c.76% glycerol, c.18% water, c.5% MONG, and a minor ash component.[112]

Glycerol is used in a large number of applications, including in the biofuel, food, pharmaceutical, chemical and animal feed industries. It is also commonly mixed with other fuels and used for process heat in biodiesel facilities.[113] A number of companies are also developing technologies to enable the burning of glycerol as a pure fuel for heat applications. A few small-scale CHP facilities utilising glycerol are currently in operation, with more announced, and obvious potential for further expansion in this sector.[114] [115] [116]

A4.4.2 Size of the Opportunity

There is a significant quantity of glycerol arising globally. World markets are currently facing an oversupply due to increasing biodiesel production. This oversupply is likely to continue into the future, fuelled by the rapid growth of the biodiesel industry, which is forecast by the IEA to increase production volumes to around 40 billion litres in 2022.[117] Given these oversupply issues, it is feasible that large quantities of glycerol could be made available for use in heating applications.

A recent study on behalf of DfT estimated the current and future quantities of glycerol available. These figures are calculated from FAME biodiesel production data using a 'residue factor'. As detailed in Table 29, this study estimates that current global supply of glycerol is around 3.9

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[111] Fangxia Yang, Milford A Hanna, and Runcang Sun (2012) Value-added uses for crude glycerol--a byproduct of biodiesel production, *Biotechnology for Biofuels*, Vol.5, No.13

[112] Personal communication, Argent Energy, March 2014

[113] Lawong, W., and Shuriyapha, C. (2012) Capital Cost Comparison of Heat Energy obtained from Glycerine Fuel and Cooking gas used for Bio-diesel Production Process, *ISEEC*, Vol.32, No.0, pp.449–454

[114] Aquafuel (2014) *Glycerine CHP*, 2014, http://www.aquafuelresearch.com/glycerine-chp.html

[115] Combined Heat & Power Association (2012) *Biofuels Of The Future: Glycerol-Fuelled CHP Station Plans Unveiled*, November 2012, http://www.chpa.co.uk/biofuels-of-the-future-glycerol-fuelled-chp-station-plans-unveiled_1072.html

[116] William L. Roberts (2012) *Crude Glycerol as Cost-Effective Fuel for Combined Heat and Power to Replace Fossil Fuels, Final Technical Report*, Report for US Department of Energy, October 2012, http://www.osti.gov/scitech/biblio/1053951

[117] OECD-FAO (2013) *Agricultural Outlook 2013 - 2023*, 2013, http://www.keepeek.com/Digital-Asset-Management/oecd/agriculture-and-food/oecd-fao-agricultural-outlook-2013_agr_outlook-2013-en#page116

million tpa, with the majority of feedstock originating from outside the UK. This is forecasted to increase to approximately 6.3 million tpa by 2020.[118]

The current UK supply of glycerol is around 30,000 tpa, and this is forecasted to increase to 40,000 tpa by 2020. The main production sites for glycerol are biodiesel producers, and, within the UK, there are three major facilities of this type: Greenergy, based in Immingham, Harvest Energy, based in Seal Sands, and Argent Energy, based in Mothwerwell. In 2013, the biodiesel sector alone accounted for 22,000 tonnes of the total glycerol produced.[119]

Region	Feedstock Supply (Mt/year)	
	Current	2020
UK	0.03	0.04
EU	1.0	1.4
Global	2.9	4.9
Total	3.93	6.34

Source: E4tech (2013) Advanced Biofuel Feedstocks - An Assessment of Sustainability, Report for Department for Transport, December 2013

Table 29: Current and Future Tonnages of Feedstock Available

A4.4.3 Barriers to Deployment

A4.4.3.1 Future Feedstock Availability

As mentioned above, whilst many competing uses exist for crude glycerol, the apparent large oversupply of this feedstock means that sourcing sufficient quantities to meet increased demand is unlikely to pose any issues at present. The extent of current oversupply of this feedstock was quantified in previous work on behalf of DfT.[120] It was estimated that current glycerol applications currently require around 1.2 million tpa of feedstock, compared to total production volumes of 3.9 million tpa. This study also provided estimates of the current quantities of glycerol used by other applications, which can be summarised as follows:

- C.0.1 million tpa - heat and power use (via biogas);
- c.0.3 million tpa - low value sales into animal feed and waste water treat;
- c.0.56 million tpa - upgraded for chemical, food and pharmaceutical markets; and
- c.0.2 million tpa - used to make bio-methanol.

In response to this oversupply issue, research into alternative uses for glycerol has intensified in recent years. There is a minor risk that such developments will lead to the discovery of

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[118] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

[119] Personal communication, European Biodiesel Board, April 2014

[120] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

alternative, thereby increasing global demand and potentially impacting on the future availability of this feedstock for heating, but at present, this seems somewhat remote.

A4.4.3.2 Production Cost Uncertainty

As little processing is required to convert this feedstock to a heating fuel, we anticipate that processing costs should be minimal, bringing the overall cost of production down. Further market assessment is required to better determine the price of glycerol for heating applications and therefore the potential competitiveness of this feedstock compared to alternatives.

A4.4.3.3 Feedstock Sustainability – Indirect Impacts

Previous work on behalf of DfT suggested that glycerol should not be supported for biofuel production, as there are multiple competing uses with high risks of detrimental indirect impacts.[121] Given the large oversupply of glycerol, which is projected to continue into the future, however, it seems unlikely that increased use as a fuel for heating would lead to shortages for other applications. That said, should a shortage occur due to use of glycerol in heating markets, the following impacts might take place:

- Chemical and food markets would be likely to replace glycerol with fossil-derived glycerine or propylene glycol, with significant GHG emissions impacts;
- An incentive (via the RHI) might increase the profitability of FAME biodiesel production (via the value paid to FAME process operators), and hence have a knock-on impact on indirect land use change (ILUC) via greater virgin vegetable oil consumption;[122]
- It might be replaced by corn, starch and sugar crops for the animal feed market. This would require new arable land to be set aside for crop production, unless farming output is improved to provide the additional substitute resources without additional land use.

As mentioned above, however, the current level of global oversupply is such that we would expect that the influence of any support mechanism for heat would be relatively minimal in these respects.

A4.4.3.4 Difficulties in Combustion Process

Glycerol is commonly mixed with other fuels before use in heating and CHP applications. Clean combustion of glycerol is difficult due to its high viscosity, salt content, alkalinity and concerns of hazardous emissions.[123] A key issue is that combustion of glycerol at insufficiently high temperatures can lead to the formation of acrolein, an aldehyde which is a thermal decomposition product of glycerol and is toxic at very low concentrations.[124]

A4.4.3.5 Suitability for Transport Fuel Applications

Any incentive (via the RHI) for glycerol in heat applications should take account of the significant current and future potential for converting this feedstock to biofuels suitable for

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[121] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

[122] Kretschmer, B., Allen, B., Kieve, D., and Smith, C. (2013) *The sustainability of advanced biofuels in the EU: Assessing the sustainability of wastes, residues and other feedstocks set out in the European Commission's proposal on Indirect Land Use Change (ILUC)*, Report for Institute for European Environmental Policy, March 2013, http://www.ieep.eu/assets/1173/IEEP_2013_The_sustainability_of_advanced_biofuels_in_the_EU.pdf

[123] Personal communication, MBP Group, March 2014

[124] Personal Communication, Green Fuels, April 2014

transport applications. The major pathway for transport biofuel production from glycerol is via gasification to bio-methanol; this is mixed with petrol and used as a ‘drop-in’ fuel for motor vehicles. A recent study on behalf of DfT stated that crude glycerol is the only feedstock to have reached commercial scale development for transport fuel production via this pathway.[125]

Within the UK, discussions with a leading biodiesel manufacture suggest that the majority of crude glycerol is used as a catalyst in anaerobic digestion facilities, and that the proportion of glycerol going to this route is likely to increase in the future.[126] The bio-methane produced during this process also has significant potential to be utilised in the transport sector.

A4.4.4 Impact on Existing RHI Applications

Glycerol is not currently supported by the RHI (liquid feedstocks are not currently supported under this scheme) or by any other UK government schemes, and therefore provision of support as bioliquids would not impact on current RHI applications. It should be noted, however, that glycerol could be eligible for support under the RO, albeit we are not aware of any such actual use at present.

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[125] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

[126] Personal communication, Argent Energy, March 2014

A4.5 Gums – Market Analysis

A4.5.1 Feedstock Composition and Origins

Gums are a by-product of the vegetable oil refining process. While the chemical nature of these products has been relatively difficult to determine, we now know that gums consist mainly of phosphatides and a minor component of entrained oil and meal particles.[127] Through physical or chemical refining (degumming), these phosphatides can either be recovered for their by-product value through water degumming, or can be treated as waste products.

Gums are commonly further processed to produce lecithin. This has a large number of applications, including in the pharmaceutical industry, in animal feed, in the paint industry, and in plastics manufacturing. If further processing of the crude gums is not economically feasible, due to insufficient plant scale or market demand, the crude gums can be added-back to the vegetable oil meal to enhance bulk and caloric value.[128] Alternatively, where no clear market exists, some producers choose to send gums to landfill.

A4.5.2 Size of the Opportunity

As mentioned above, current global demand for lecithin (the primary use for hydrated gums) is low, and as such gums are frequently disposed of as wastes. This indicates that a significant proportion of total feedstock arisings could potentially be available for heating fuel applications.

A review of the literature did not yield any information relating to the current global production of gums, or the volume of gums produced during the degumming process. Further primary data gathering would be required in order to assess the tonnage of feedstock available.

A4.5.3 Barriers to Deployment under RHI

A4.5.3.1 Lack of Technological Development

Heating technologies using refined gums as fuels are currently only at a pilot stage, and given the non-standard composition of gums compared to most other bioliquids it is likely that very few existing boilers in the UK would be suited to burning gums without significant modification. As a result, unless the feedstock was refined to meet current heating fuel standards, the likelihood of significant market penetration is somewhat low.

A4.5.3.2 Future Feedstock Availability

Gums are ultimately sourced from vegetable oils. These markets are currently very stable, and any future risks to this market are unlikely to impact significantly on overall supply trends.[129] The availability of gums is also dependent on the proportion of vegetable oil processers that employ degumming during vegetable oil refinement. While there is no evidence to suggest that these numbers will decrease in the future, this factor will be significant in determining the future supply of gums.

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[127] Richard D. O'Brien (2010) *Fats and Oils: Formulating and Processing for Applications, Third Edition*, CRC Press

[128] Soy 20/20 (2005) *Lecithin Information*, April 2005, http://www.soy2020.ca/pdfs/LecithinInformation.pdf

[129] OECD-FAO (2013) *Agricultural Outlook 2013 - 2023*, 2013, http://www.keepeek.com/Digital-Asset-Management/oecd/agriculture-and-food/oecd-fao-agricultural-outlook-2013_agr_outlook-2013-en#page116

A4.5.3.3 Feedstock Sustainability – Indirect Impacts

Gums are ultimately sourced mainly from virgin vegetable oils, for which concerns about indirect land use change (ILUC) are well documented. However, in the context of the overall supply chain, gums can be regarded as a minor by-product of the vegetable oil refining process. Accordingly, it is extremely unlikely that increased demand for these feedstocks following deployment would impact on vegetable oil markets. Bioliquids produced from gums will not therefore have significant indirect environmental impacts.

A4.5.4 Impact on Existing RHI Applications

Gums are not currently supported by the RHI, or by any other UK government schemes. The provision of support to bioliquids produced from gums will not therefore impact on current RHI applications.

A4.6 Matter Organic Non-Glycerol (MONG) – Market Analysis

A4.6.1 Feedstock Composition and Origins

Matter organic non-glycerol (MONG) is a minor component of crude glycerol. In addition to MONG, glycerol typically contains a mixture of methanol, water, inorganic salts (catalyst residue), free fatty acids, unreacted mono-, di-, and triglycerides and methyl esters in varying quantities, which depend on the feedstock and chemical process used. The standard accepted method for calculating MONG is:

MONG = 100 – (glycerol content, % + water content, % + ash content, %)[130]

In order to produce a commercially viable product, crude glycerine is further refined to comply with the technical standards required by the consumer industry. Depending on the purity required, MONG is mostly or almost completely removed from the crude glycerol during the refining process.[131]

A4.6.2 Size of the Opportunity

Previous studies have shown that the MONG content of crude glycerol is highly variable (1.0 – 57.0 %), although the majority of crude glycerol samples measured by these studies had MONG compositions of 1 - 20%.[132] [133] Further research may enable a more detailed understanding of how common such compositional variation is during glycerol production.

A recent study on behalf of DfT estimated the current and future quantities of glycerol available. These figures were calculated from FAME biodiesel production data using a residue factor, and are determined by this study to be of a high overall quality. By applying estimates of the MONG composition of glycerol (discussed above) to this data, it is possible to estimate the total quantity of MONG available worldwide, however it should be noted that our calculations assume that all crude glycerol does undergo further refinement to remove the MONG component. Our final estimates are presented in Table 30.

Region	Feedstock Supply (Mt/year)	
	Current	2020

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[130] ISO (2002) *ISO 2464:1973*, May 2002, http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?ics1=71&ics2=080&ics3=60&csnumber=7379

[131] Nicholas Carels, Mulpuri Sujatha, and Bir Bahadur(2012) *Jatropha, Challenges for a New Energy Crop: Volume 1: Farming, Economics and Biofuel*, Springer

[132] A. A. Nik Nor Aziati, and A. M. Mimi Sakinah (2011) *Review: Glycerol Residue and Pitch Recovered from Oleo Chemical and Biodiesel Waste Industries*, Report for University of Malaysia Pahang, 2011, http://umpir.ump.edu.my/2728/1/aziati_full_text.pdf

[133] Hansen, C.F., Hernandez, A., Mullan, B.P., Moore, K., Trezona-Murray, M., King, R.H., and Pluske, J.R. (2009) A chemical analysis of samples of crude glycerol from the production of biodiesel in Australia, and the effects of feeding crude glycerol to growing-finishing pigs on performance, plasma metabolites and meat quality at slaughter, *Animal Production Science*

UK	0.0003 – 0.006	0.0004 – 0.008
EU	0.01 – 0.2	0.01 – 0.3
Global	0.03 – 0.6	0.05 – 0.1
Total	0.04 – 0.8	0.06 – 1.3

Table 30: Current and Future Tonnages of Feedstock Available

A4.6.3 Barriers to Deployment under RHI

A4.6.3.1 Lack of Feedstock Availability

As detailed in Table 30, somewhere on the region of 300 to 6000 tonnes of MONG are currently produced in the UK per annum. Furthermore, these estimates assume that all glycerol undergoes further refining to extract MONG and other contaminants. This is clearly not the case, and therefore the actual tonnages available are likely to be lower than indicated here.

A4.6.3.2 Lack of Commercial Development

Any current development of cost-effective pathways for bioliquid production from MONG is at a very early stage – none of the businesses contacted during this study were using MONG as a heating fuel.

Significant research is therefore required to determine the suitability of this product for heating applications and the heating technologies required for optimal combustion. However, with such small quantities available, it is unlikely that industry will invest significantly in the development of these bioliquids as heating fuels. Furthermore, we would assume that few existing boilers in the UK would be suited to burning MONG without significant modification. As a result, unless the feedstock was refined to meet current heating fuel standards, the likelihood of significant market penetration is somewhat low.

A4.6.3.3 Future Market Risks

Continued supply of MONG is largely dependent on the glycerol market. Significant quantities of glycerol (>60% of total glycerol demand) are further refined for the chemical, food and pharmaceutical markets, and to make bio-methanol.[134] Due to the current oversupply of glycerol, and the likelihood for this to continue into the future, it is unlikely that the supply of MONG would be threatened on a short to mid-term basis. However, glycerol production is largely dependent on a single industry, that is, biodiesel production. The growth of this industry is somewhat uncertain and dependent on a number of unpredictable external factors, and therefore some volatility will continue to remain in glycerol markets.[135]

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[134] E4tech (2013) *Advanced Biofuel Feedstocks - An Assessment of Sustainability*, Report for Department for Transport, December 2013

[135] OECD-FAO (2013) *Agricultural Outlook 2013 - 2023*, 2013, http://www.keepeek.com/Digital-Asset-Management/oecd/agriculture-and-food/oecd-fao-agricultural-outlook-2013_agr_outlook-2013-en#page116

A4.6.3.4 Feedstock Sustainability – Indirect Impacts

The indirect impacts of burning MONG as a heating fuel would be minimal. Essentially, MONG is regarded as a waste product of glycerol refining, which is itself a by-product of biodiesel production. Increased demand for MONG will not therefore have any impacts through indirect land use change (ILUC) or other concerns relating to virgin vegetable oils. Furthermore, we are not aware competing uses for MONG. Increased demand for this feedstock is therefore unlikely to lead to any fuel swapping issues.

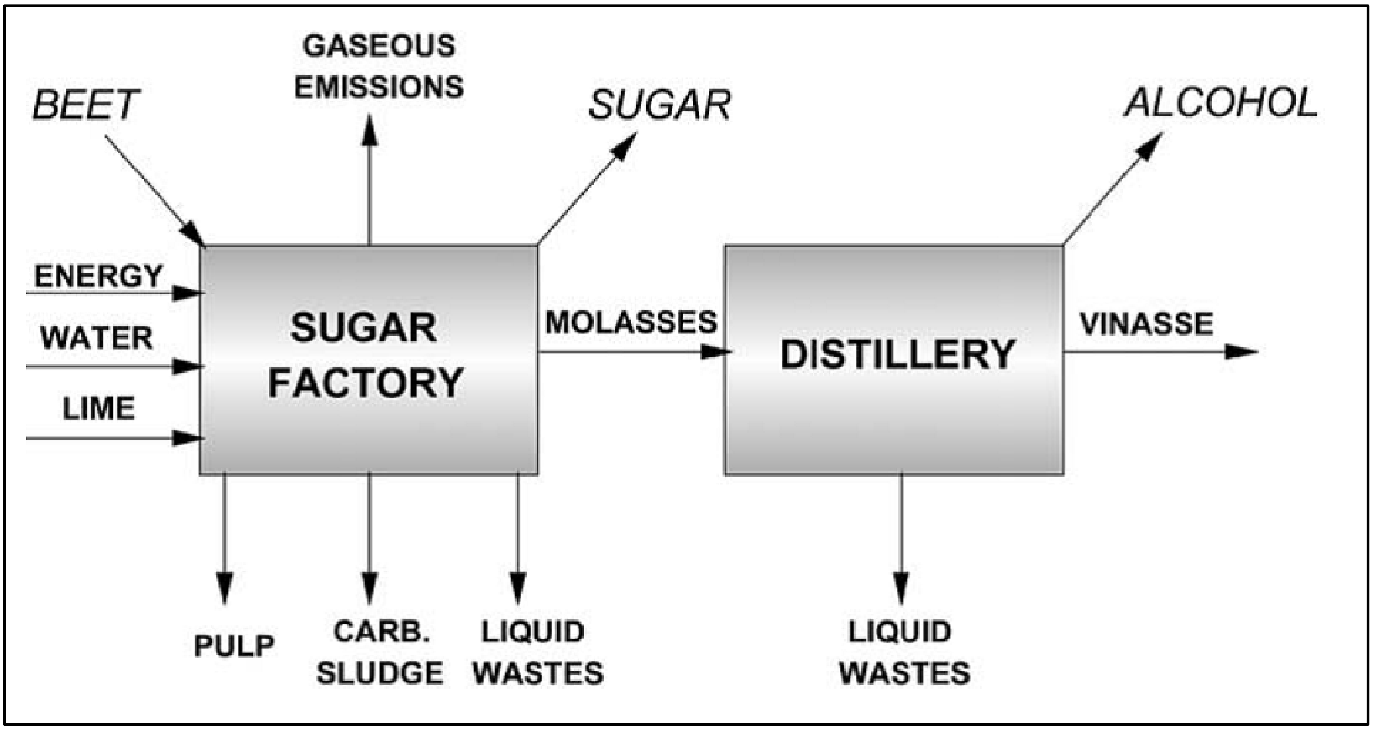
A4.6.4 Impact on Existing RHI Applications

MONG is not currently supported by the RHI, or by any other UK government schemes. The provision of support to MONG will not therefore impact on current RHI applications.

A4.7 Sugar Beet Pulp – Market Analysis

A4.7.1 Feedstock Composition and Origins

Sugar beet pulp is a by-product of sugar beet processing and the sugar crop-based ethanol industry. Figure 8 shows the position of this product within the overall sugar and bioethanol supply chain. Beet pulp is the fibrous matter that remains after sugar beet is crushed as part the juice extraction process. It is chemically composed of roughly equal proportions of cellulose, hemicellulose and pectins, with minor proteins, insoluble ash, lignin and sugar components.[136]



Source: *Vaccari, G., Tamburini, E., Sgualdino, G., Urbaniec, K., and Klemeš, J. (2005) Overview of the environmental problems in beet sugar processing: possible solutions, Journal of Cleaner Production, Vol.13, No.5, pp.499–507*

Figure 8: Streams in the Sugar Factory/Distillery

Sugar beet pulp is mainly sold to the animal feed market, and it is clear from discussions with industry that this is the main market for this feedstock within the UK. Sugar beet pulp also goes to anaerobic digestion and could potentially be used for paper production.[137] [138]

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[136] Vaccari, G., Tamburini, E., Sgualdino, G., Urbaniec, K., and Klemeš, J. (2005) Overview of the environmental problems in beet sugar processing: possible solutions, *Journal of Cleaner Production*, Vol.13, No.5, pp.499–507

[137] M. Hutnan, M. Drtil, J. Derco, L. Mrafkova, M. Hornak, and S. Mico (2001) Two-Step Pilot-Scale Anaerobic Treatment of Sugar Beet Pulp, *Polish Journal of Environmental Studies*, Vol.10, No.4

[138] Vaccari, G., Tamburini, E., Sgualdino, G., Urbaniec, K., and Klemeš, J. (2005) Overview of the environmental problems in beet sugar processing: possible solutions, *Journal of Cleaner Production*, Vol.13, No.5, pp.499–507

A4.7.2 Size of the Opportunity

In 2013, global sugar beet and sugar cane production totalled 252 million tpa and 1,704 million tpa respectively. By 2022, world sugar production is forecasted to increase to around 273 million tpa for sugar beet and approximately 1,996 million tpa for sugar cane.[139]

The processing of 1 ton of sugar beet produces about 250kg of exhausted pressed pulp, with a water content of approximately 75-80%.[140] This amount can be converted into 70kg of exhausted dried pulp, with about 10% water content. Comparing this information against global sugar beet production data, this suggests that 17.6 million tonnes of dry pulp were produced in 2013, with potential for this to rise to around 19.1 million tpa by 2022.

The UK's sole sugar beet producer estimated that between 0.5 and 1.0 million tonnes of sugar beet pulp, containing 17% dry fibre, is produced per year in the UK.[141] This is equivalent to around 85-170 thousand tonnes of dry pulp production per annum.[142]

A4.7.3 Barriers to Deployment under RHI

A4.7.3.1 Availability of Feedstock

Sugar beet pulp is produced in relatively small quantities, and, as far as we are aware, the majority of this feedstock is sold to animal feed markets. Further research is required to understand whether significant quantities of these feedstocks could be sourced at relatively low cost; this will be determined by the extent of current market competition for these feedstocks.

A4.7.3.2 Potential for Use in Transport Applications

The potential for conversion of sugar beet pulp to bio-ethanol has been demonstrated in lab-scale studies. The material characteristics of sugar beet pulp make it particularly suitable for this process, namely, low lignin contents mean that pre-treatment costs should be low, while high sugar contents will translate to higher ethanol yields.[143] However, at this stage we are unaware of any move towards commercial scale development of this production pathway. Under current market conditions, the most feasible production route to a transport fuel is via anaerobic digestion to biomethane.

A4.7.3.3 Feedstock Sustainability – Indirect Impacts

Increased demand for sugar crops following RHI support would require new arable land to be set aside for crop production, unless farming output is improved to provide the additional substitute resources without additional land use. However, in the context of the overall supply chain, sugar beet pulp can be regarded as a minor by-product of the sugar production process. Accordingly, it is extremely unlikely that increased demand for this feedstock following deployment would impact on sugar crop production. Bioliquids produced from sugar beet pulp are therefore unlikely to have indirect environmental impacts.

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[139] OECD-FAO (2013) *Agricultural Outlook 2013 - 2023*, 2013, http://www.keepeek.com/Digital-Asset-Management/oecd/agriculture-and-food/oecd-fao-agricultural-outlook-2013_agr_outlook-2013-en#page116

[140] Hutnan, M., Drtil, M., and Mrafkova, L. (2000) Anaerobic biodegradation of sugar beet pulp, *Biodegradation*, Vol.11, No.4, pp.203–211

[141] Personal communication, AB Sugar, April 2014

[142] Ibid

[143] Stefan Kühnel, Henk A Schol, and Harry Gruppen (2011) *Aiming for the complete utilization of sugar-beet pulp: Examination of the effects of mild acid and hydrothermal pretreatment followed by enzymatic digestion*, 2011, http://www.biotechnologyforbiofuels.com/content/pdf/1754-6834-4-14.pdf

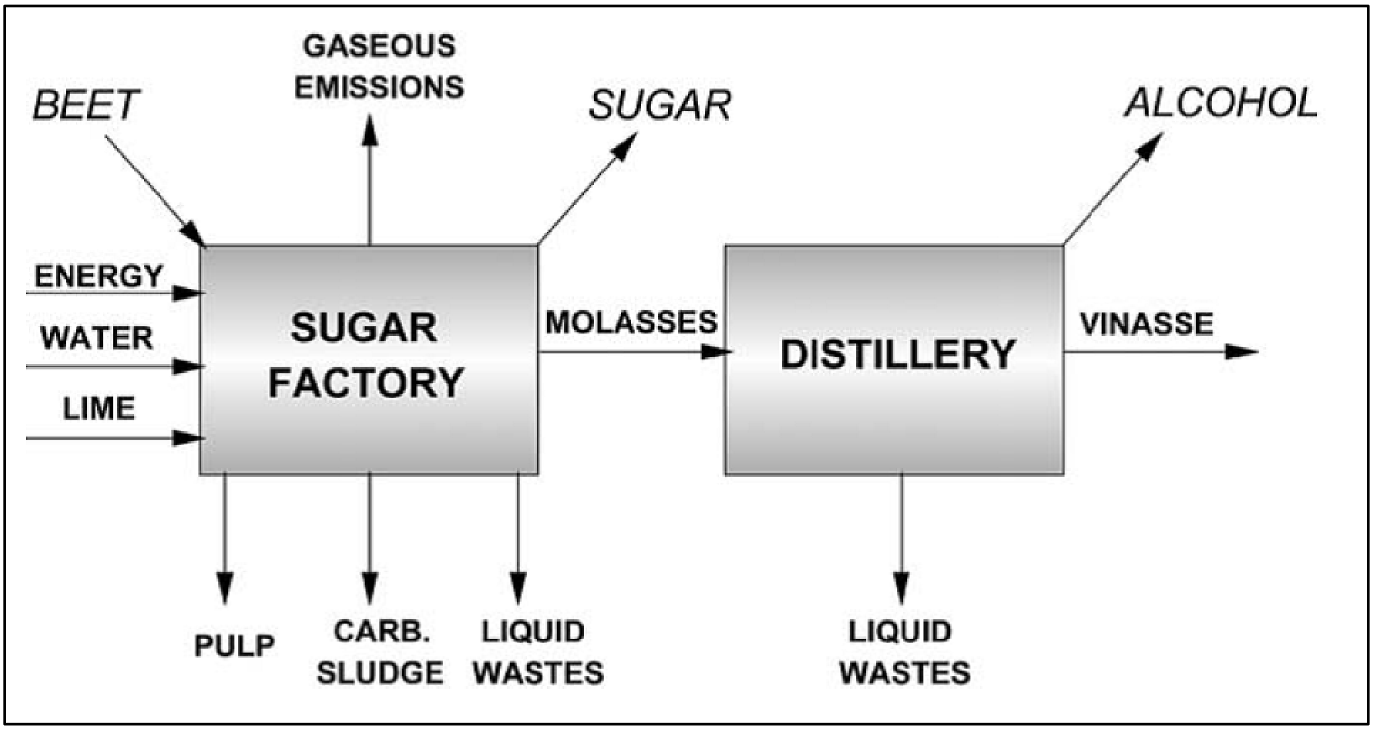
A4.7.4 Impact on Existing RHI Applications

Sugar beet pulp is a form of biomass, and therefore currently eligible under the RHI. We are not aware of any existing use of this feedstock as a fuel for direct combustion. As such it is unlikely that support for bioliquids derived from sugar beet pulp would have on existing RHI applications.

A4.8 Vinasse – Market Analysis

A4.8.1 Feedstock Composition and Origins

Vinasse is a by-product of the sugar crop-based bio-ethanol industry. Figure 9 shows the position of these by-products within the overall sugar and bioethanol supply chain.



Source: *Vaccari, G., Tamburini, E., Sgualdino, G., Urbaniec, K., and Klemeš, J. (2005) Overview of the environmental problems in beet sugar processing: possible solutions, Journal of Cleaner Production, Vol.13, No.5, pp.499–507*

Figure 9: Streams in the Sugar Factory/Distillery

Vinasse is produced, along with bio-ethanol, during the fermentation of sugarcane or sugar beet molasses by yeast, and has a viscosity similar to molasses.[144] Vinasse is largely used as a fertilizer in sugarcane cultivation. An alternative use, and one more prevalent within the UK, is biomethane production via anaerobic digestion. Vinasse can also go to animal feed markets and can be used as a feedstock for microalgae cultivation to produce biodiesel.[145]

A4.8.2 Size of the Opportunity

The UK's sole sugar beet processor produces 70 million litres of bio-ethanol per year.[146] While bio-ethanol may also be produced in the UK from imported sugar beet, it is likely that this figure represents the bulk of the UK sugar beet bio-ethanol market. Further discussions with this processor informed us that 0.44 tonnes of vinasse is produced per tonne of bioethanol

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[144] Ashok Pandey, Duu-Jong Lee, Yusuf Chisti, and Carol R. Soccol (2013) *Biofuels from Algae*, Newnes

[145] Ibid

[146] Personal communication, AB Sugar, April 2014

produced. Assuming a maximum density of 791.5 kg/m^3 for bio-ethanol, this suggests that around 24,400 tonnes of vinasse are produced per year in the UK.[147]

Sugar crops share of global world ethanol production should increase from 24% to 27% between 2012 and 2022. Total world ethanol production stood at 100 billion litres in 2012, and is forecasted to increase to 167 billion litres per annum by 2022.[148] Using the same assumptions as discussed above, this suggests that around 8.4 million tpa of vinasse are currently produced worldwide, forecasted to increase to around 15.7 million tpa by 2022.

A4.8.3 Barriers to Deployment under RHI

A4.8.3.1 Availability of Feedstock

Vinasse is generally disposed of as a waste or sold on as low-value products. Vinasse can contribute to land and water pollution, due to its high chemical and biological oxygen demand and potential for polluting soil and groundwater.[149]

Our assumption is that there is relatively little market competition for this resource. Furthermore, supply is likely to increase in the future as global sugar and bioethanol production continue to expand, mainly driven by policies promoting increased use of biofuels.[150] These relatively stable markets present minimal risk to the future supply of vinasse. However, further research is required to understand whether significant quantities of these feedstocks could be sourced at relatively low cost, that is, the extent of current market competition for these feedstocks.

A4.8.3.2 Lack of Commercial Development

We are not aware of any existing research or pilot schemes exploring the potential for using these feedstocks as fuels for heating applications. Significant development would be required before conversions processes and heating technologies using these feedstocks could become commercially viable.

A4.8.3.3 Low Calorific Value

Vinasse has a very low calorific value (CV) of 6.930 GJ/tonne.[151] This suggests that further processing and/or significant modification of burners/boilers would be required to use this feedstock in heat applications. Furthermore, due to the low quantities of this feedstock arising in the UK, imports of this feedstock may be required to meet demand following RHI support. The feasibility of importing this feedstock needs to be considered against the potential for high costs and negative environmental impacts (on a per unit basis) associated with the transportation of a low energy density feedstock.

A4.8.3.4 Feedstock Sustainability – Indirect Impacts

As previously discussed for sugar beet pulp, in the context of the overall supply chain, vinasse can be regarded as a minor by-product of the sugar production process. Accordingly, increased

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[147] ITEC Refining and Marketing Company Ltd. (2011) *Specifications for Anhydrous Fuel Ethanol,* November 2011, http://www.itecref.com/pdf/Fuel_alcohol_comparison_ASTM_ANP_EN_%28ITEC%29_Nov_2011.pdf

[148] OECD-FAO (2013) *Agricultural Outlook 2013 - 2023*, 2013, http://www.keepeek.com/Digital-Asset-Management/oecd/agriculture-and-food/oecd-fao-agricultural-outlook-2013_agr_outlook-2013-en#page116

[149] Ashok Pandey, Duu-Jong Lee, Yusuf Chisti, and Carol R. Soccol(2013) *Biofuels from Algae*, Newnes

[150] OECD-FAO (2013) *Agricultural Outlook 2013 - 2023*, 2013, http://www.keepeek.com/Digital-Asset-Management/oecd/agriculture-and-food/oecd-fao-agricultural-outlook-2013_agr_outlook-2013-en#page116

[151] Personal communication, AB Sugar, April 2014

demand for this feedstock following deployment is unlikely to lead to further conversion of land to sugar cane/sugar beet plantations. The use of bioliquids produced from vinasse is therefore unlikely to lead to environmental impacts associated with indirect land use change.

A4.8.4 Impact on Existing RHI Applications

Vinasse is not currently supported by the RHI, or by any other UK government schemes. The provision of support to bioliquids produced from vinasse will not therefore impact on current RHI applications.

Appendix 5 – EU Incentive Schemes

Member State	Scheme Characterisation	Eligible Bioliquid Technologies	Method of Support	Amount or Calculation of Support Level
Austria	Per unit output support	Liquid biomass	A feed-in tariff for all renewable energy plants. For biomass plants eligibility is conditional on the plant reaching an efficiency of at least 60%.	Liquid biomass is supported at a rate of 57.4 per MWh in 2013
Belgium (Flanders)	Quota system	Liquid Biomass	CHP producers are eligible for CHP certificates. These can be sold on to other electricity producers and suppliers to enable them to meet their quota requirements. One certificate is earned for each MWh of energy produced.	From 1 January 2013 onwards, the minimum price per certificate is €93. In May 2013, the average certificate market price was €95.23.
Croatia	Per unit output support	Liquid biomass	A feed-in tariff for all renewable energy plants.	The tariff is based on the average electricity price.
Netherlands	Per unit output support	Liquid biomass	The SDE+ scheme grants a premium on top of the market price to the producers of renewable energy in order to compensate for the difference between the wholesale price of electricity from fossil sources and the price of electricity from renewable sources. For CHP applications, the scheme only provides support for a limited number of full load hours.	The support is made available in 6 stages and is allocated on a ‘first come, first serve’ basis. Depending on the stage, plant size, and if the boiler is being used in a CHP configuration or not, the effective tariff (after the correction amount is applied) for liquid biomass used in CHP applications can vary from €10. - €32.60 per GJ.

Member State	**Scheme Characterisation**	**Eligible Bioliquid Technologies**	**Method of Support**	**Amount or Calculation of Support Level**
Romania	Quota system	Liquid biofuels for energy generation that were produced from biomass and are not used in the transport sector	Renewable energy producers are entitled to certificates for each MWh of electricity generated. These can be sold on to other electricity producers and suppliers to enable them to meet the quota requirements. Two certificates are provided per MWh of electricity generated from liquid biofuels.	The amount of subsidy corresponds to the price per certificate achieved in the market. During the years 2008-2025 the transaction value of one green certificate will be at least €27 and up to a maximum of €55.
Slovakia	Per unit output support	Bioliquids	The feed-in tariff consists of two parts: the price of electricity for losses (market price) and a surcharge. The market price is paid for all electricity supplied from renewable energy facilities up to a support limit of 125 MW. The surcharge is billed by the plant operator for the electricity generated, less the internal technological consumption of electricity.	Bioliquids are currently supported at a rate of €94.36 per MWh.

Source: RES Legal, *Accessed 9th March 2014, www.res-legal.eu/*

Netherlands Enterprise Agency (2014), *SDE+ 2014 Instructions on how to apply for a subsidy for the production of renewable energy*, February 2014, http://english.rvo.nl/sites/default/files/2014/04/Brochure%20SDE%2B%202014.pdf

Table 31: Incentive Schemes in EU Member States for Electricity Generation from Bioliquids

Appendix 6 – Attendees at Stakeholder Roundtable Meeting

Organisation	Attendee
DECC	Fraser Allan
	Ruhi Babbar
	Philip Sargent
DfT	Tom Barrett
	Matthew Ford
AB Sugar	Richard Stark
MBP Group	Joe Platt
Refuel Energy	Andrew Monaghan
	John Neild
Greenergy	Patrick Lynch
Eunomia	Adam Baddeley
	Chris Cullen
	Laurence Elliott
NNFCC	Jeremy Tomkinson
Progressive Energy	Chris Manson-Whitton
Ecofys	Sacha Alberici

Table 32: Attendees at Stakeholder Meeting

Department of Energy & Climate Change
3 Whitehall Place
London SW1A 2AW
www.gov.uk/decc
URN 14D/392