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The Bioeconomy Consultants

Use of sustainably-sourced residue and waste streams for advanced biofuel production in the European Union: rural economic impacts and potential for job creation

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Executive Summary

Expansion in the use of biofuels driven by the European Union's Renewable Energy Directive (RED) has led to concerns that this may be contributing to deforestation and land use change, where land is brought into cultivation to grow food crops to compensate for lost production linked to biofuel feedstock production (the so called "indirect land use change" or ILUC impact). This has led to increased interest in the use of non-food feedstocks for biofuel production such as crop and forest residues and other waste streams.

Faced with uncertainties around the scale of any ILUC impacts associated with EU biofuels policy, the European Parliament and the Council of Ministers are currently locked in a debate on the level of biofuel production that should be supported. There are proposals to cap production of biofuels derived from food crops and to introduce a specific 'carve out' of the current RED target for transport that would be allocated to biofuels derived from non-food feedstocks.

There is currently uncertainty over the level of biofuel production that could be supported by use of non-food feedstocks, whether such biofuel production is economically feasible and the economic and job benefits that could arise through supporting the development of the associated nascent technologies.

This study analyses the potential economic viability of using crop, forest and waste residues (Refuse Derived Fuel or RDF) as feedstocks for biofuel production using a range of conversion technologies and examines the economic benefits and job creation opportunities that could arise from exploiting these resources within the EU. This analysis draws on parallel work to assess the amount of sustainably harvestable crop and forest residues and residual waste arisings in the EU that could be accessed for biofuel production without affecting other traditional markets.

NNFCC used a discounted cash-flow model to examine three advanced biofuel production pathways to determine whether it was economically feasible to use waste and residue feedstocks for biofuel production. The biofuel production pathways considered included cellulosic ethanol (biochemical fermentation) and gasification followed by either fermentation of the resulting syngas to ethanol or catalytic conversion of syngas to Fischer Tropsch diesel. These represent technologies that are currently at pilot scale development in the EU or globally.

Typical delivered cereal straw price ranges from 60-80 €/t for northern Europe, and 30-40 €/t for southern and eastern European examples. Typical costs for delivery of forest harvest residues ranged from 40-65 €/t across the EU. Refuse Derived Fuel (RDF) gate fees[1] are currently around 20€ to 40€/t in Europe.

The economic analysis indicates that at current typical feedstock costs in the most likely areas of production, advanced biofuels produced from agricultural and forest harvest residue feedstocks are likely to be more expensive to produce than current commercial biofuels. However these resources could be mobilised for use in advanced biofuel production if the appropriate incentives are made available. The incentives required in most cases are not in excess of those that have been offered as duty reductions to incentivise biofuel industry start-up in the past and currently on offer by some EU Member s States. In some cases high feedstock cost, particularly where this is in excess of €70-€ 80/tonne, may be a barrier to development. As an alternative to production support, mandating the use of such fuels would also drive their development, encouraging the most economically competitive technology solutions.

At current gate fees (ca. €20-46/tonne) it is estimated that RDF-derived biofuels can be produced at a price competitive with current biofuels. This is predicated on the assumption that receipt of RDF materials will continue to attract gate fees, even down to acceptance at zero cost by the biofuel processor, but this cannot be guaranteed as competition for such material increases. However, the feedstock is only partially renewable. Materials of biological origin can account for between 50 and 85% of the carbon content in RDF fuels. Therefore any biofuel derived from residual waste is only partially renewable and incentives are likely to be required to compensate for the anticipated lower value of the fossil-derived fuel component co-produced with the bio-derived fraction (which would have no value beyond its intrinsic fuel energy value). Again the incentives required are anticipated to be relatively small, but any incentive required to promote uptake of RDF-derived biofuels would need to be at least doubled per litre of eligible biofuel, to account for the fact that only around 50% of the output is likely to be eligible for support as a low carbon renewable fuel.

It is not possible to indicate where in the EU feedstock resources might be most effectively mobilised to rationalise how much of the available biomass resources could actually be mobilised and utilised. However, if all of the resource was used then:

- between 56 and 133 thousand additional permanent jobs would be created in the agricultural and forestry sectors; when also considering the impact of refuse derived biofuels between 4 and13 thousand additional permanent would jobs be created in the operation of the biofuel plants and a further 87

[1] 'Gate fees' are the fees demanded by waste processors or energy from waste plant operators to accept waste products for treatment or disposal. To the waste producer/handler, payment of gate fees represents an alternative to the incurred cost of disposal by landfill.

to 162 thousand temporary jobs would be created during the biofuel plant construction phase.

- a net value of between €0.2 and 5.2 billion would flow into the EU's rural agricultural economy and between €0.7 and 2.3 billion to the EU's rural forest economy.

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1 Background

The European Union's Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD) are both acting to drive the both the development and rationale for public support of biofuels. The RED mandates that 20% of EU final energy use should be derived from renewable sources and includes a sub-target that 10% of the energy used in transport should be derived from renewable sources. The FQD mandates that fuels used in road-transport and non-mobile machinery must have a 6% lower average lifecycle carbon intensity in 2020 than in 2010. Progress towards these targets has predominantly been led by use of food-derived biofuels and latterly through use of waste oils and fats.

Diversion of food crops to biofuels has one of three outcomes; either land is more intensively managed to produce more crops (intensification), more land is brought into production to compensate for the increase in demand resulting in undesirable indirect land use change (ILUC) possibly also leading to a significant net increase in greenhouse gas emissions, or less food becomes available for human consumption. Both of the latter responses have negative environmental and social consequences. It is argued that intensification is unlikely to be sufficient to meet demand of the biofuels industry and that it itself has negative consequences as land will often require increased inputs to increase yields. Such arguments thought are rather simplistic, and do not take account of the potential for reducing food waste for example.

Given the difficulties of trying to quantify the scale of the above effects and to then attempt to mitigate these by accounting for ILUC impacts within the RED's biofuel sustainability criteria, the EU has decided to adopt a cautious approach to supporting the future development of biofuels. The EC consulted in 2010 on proposals to address the ILUC impacts of its biofuel policy within the RED, from which the following proposals emerged (amongst others):

- To cap the contribution of biofuels from food-crops at 5% up to 2020
- To allow multiple counting of advanced biofuels towards meeting the RED renewable energy target for transport

The proposals also inferred that post-2020 EU policy would only support biofuels with low estimated indirect land use change impacts and proven high overall greenhouse gas savings.

The proposals are now being put to Co-Decision in the EU Council and Parliament, following significant debate and amendment by The Committee on Environment, Public Health and Food Safety (ENVI) acting as the lead Committee on the proposals and the Committee on Industry, Research and Energy (ITRE) as the associated Committee. While there is disagreement on the size of the cap that should be placed on biofuels from food crops (5% (ENVI) versus 6.5% (ITRE)), both committees support the introduction of a specific target for the contribution from advanced biofuels to the RED transport renewable energy target, though with different targets proposed; 2% (ENVI) versus 2.5% by 2020 and 4% by 2025 (ITRE), and either with (ENVI), or without (ITRE), the support of multiple counting. Industry has generally supported the proposed introduction of such specific targets for advanced biofuels as a means of supporting their development and uptake.

However, in the debate over the above targets, there is currently a lack of clarity on the level of biofuel production that could be supported by use of waste and residue feedstocks and whether such biofuel production is economically feasible. There has also been little analysis of the economic and job benefits that could arise through supporting the development of advanced biofuels

This study seeks to address these information gaps through analysis of the potential economic viability of using crop, forest and waste residues as feedstocks for biofuel production using a range of conversion technologies. It also examines the economic and job creation benefits that could arise from exploiting these resources within the EU.

This analysis draws on parallel work by the International Council on Clean Transportation (ICCT) (1) to assess the amount of sustainably harvestable crop and forest residues and residual waste arisings in the EU that could be accessed for biofuel production without affecting other traditional markets.

The project as a whole was supported and co-ordinated by the European Climate Foundation (ECF) working with the Institute for European Environmental Policy (IEEP)

2 Aims of the work

The key aims of this study are to:

- Identify the current or likely market price of agricultural residues, forest harvest residues and municipal solid waste
- Model the cost of advanced biofuel production to examine the feasibility of using waste and residues as biofuel feedstocks at current market prices
- Identify the net revenues that could flow to the rural economy, taking account of any economic trade-offs
- Identify the net additional jobs that could accrue from exploitation of the identified resources

3 Approaches

3.1 Feedstocks of interest

IEEP and work by ICCT identified three potential residue and waste feedstock groups of interest, and went on to identify the likely volumes of material that could potentially be made available within the EU for use in advanced biofuel production, without affecting, or impacting on, the sustainability of supply or competing market sectors. The feedstocks selected were:

1. Agricultural residues
2. Forestry residues (currently non-economic material left after harvesting (small branches and tops)
3. The biogenic portion of municipal waste streams

A wide range of potential agricultural residues were identified, but wheat, barley and maize accounted for 74% of the identified available resource, so this report focusses on these residues.

3.2 Current Feedstock Prices costs

The feedstock price represents a combination of the direct costs incurred in collection, storage and delivery plus the margins required to cover any recognised remedial actions (e.g. fertiliser replacement)

Data on feedstock costs were gathered from a desk based review of available information, supplemented with information received directly from industry representatives. Costs of collection and transport were derived using available literature on farm costs and forestry reviews of the costs of collection of harvest residues.

The value of the agricultural residues to farmers was calculated accounting for both its fertiliser value (see Annex 1) as well as costs of collection in order to provide a net margin. For forestry, the rates of sustainable residue removal take account of the maintenance of soil fertility, so there is no requirement for remedial nutrient applications.

3.3 Assessment of job numbers

3.3.1 Agricultural residues

Job numbers were derived from published agricultural costs, demonstrating typical rates of work for straw bailing and carting operations (2). Rates include 'low' rates for the most efficient farms, representing larger farms with larger equipment capable of delivering the highest work rates and 'high' rates for smaller farms with smaller machinery or limited access to machinery resources.

Residue loading rates of 14-28 tonne (truck or truck + trailer) were used to calculate the labour involved in straw haulage, using a haulage distance of 100km representative of around 1hrs labour with loading and unloading.

3.3.2 Forest harvest residues

In the absence of more detailed information, data on labour input rates was sourced from industry reviews of the potential for job creation in the sector.

3.4 Advanced biofuel pathways

NNFCC identified three advanced biofuel pathways for model in this study. These reflect the range of technologies currently in development or early stages of commercialisation in Europe, but which also reflect the different costs of investment required (relatively low for biochemical pathways and high for thermochemical pathways).

The pathways chosen to model were:

1. **Biochemical ethanol** - Steam explosion of biomass followed by enzymic hydrolysis and fermentation of sugars to ethanol
2. **Thermochemical & biochemical ethanol** - Thermochemical conversion of feedstocks and fermentation of resulting syngas to ethanol
3. **Thermochemical & Fischer Tropsch diesel** - Thermochemical conversion of feedstocks and catalytic reforming of syngas to drop-in fuels (Fischer Tropsch diesel (FT Diesel) plus naptha co-product)

The costs of fuel production for each of these pathways was calculated using the economic model described below.

4 Modelling biofuel production costs

4.1 Overview

NNFCC used a discounted cash flow[2] model to compare the economics of different biofuel technologies. The model calculates the Net Present Value and project Internal Rate of Return (IRR) on investment. This functionality was used with a fixed discount rate (2.5%) to ascertain the feedstock price required to yield a particular target 'IRR' rate. Investment backers in the chemical and fuels industry typically look for a return on investment of 15% or more for such high-risk commercial ventures.

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[2] Discounted cash flow analysis is an approach to value investment projects, taking account of the impact of the future passage of time on estimated cash flows to derive a net present value for future returns over a set period, compared to what otherwise might have been earned (the 'discount' rate) if the same cash was invested for example at low risk in a bank.

The model calculates costs based on:

- user-supplied base-case capital cost estimation (covering engineering, procurement and construction (EPC) costs).
- operational costs, including feedstock costs;
- process yields and conversion efficiencies
- future open-market crude oil price scenarios (to model future fuel and energy prices)[3]

Using this core data future costs and income streams were calculated, in this case over an operational plant life of 20 years. It was assumed that projects would initiate in 2013 with project build starting two years later in 2015.

4.2 Capital costs

The data on capital costs associated with each of the modelled plant types was based on the following reference plants:

Reference plants	**Biochemical ethanol**	**Thermochemical & biochemical ethanol**	**Thermochemical & Fischer Tropsch diesel**
Year	2007	2011	2006
Location	Europe	Europe	Europe
Capacity	200 kt/annum	25 kt/annum	200 kt/annum
ISBL[4] of reference plant	114 million$	97 million $	388 million $
OSBL of reference plant	8 million $	32 million $	131 million $
ISBL + OSBL	121 million $	130 million $	519 milion $

These figures are derived from plants working at large scale on production of fossil-derived fuels (e.g. coal gasification plants) or represent pilot-scale plants. It is recognised that there are costs benefits from increased scales of production. In the case of smaller plants these can be scaled to represent likely costs for larger commercial plants using industry scaling factors as follows:

$$\frac{Cost\ 2}{Cost\ 1} = \left(\frac{Scale\ 2}{Scale\ 1}\right)^{SF}$$

Cost 1 is the cost of base case installation (from data above), Cost 2 the cost of scaled up (or down) installation, Size 1 the size of the base case installation, Size 2

[3] NNFCC used estimates derived by the UK's Department of Energy and Climate Change (DECC)
[4] ISBL = Inside battery limits (costs for all equipment and buildings within the plant perimeter fence) OSBL = outside battery limits (costs for additional infrastructure upgrading etc required outside the plant gates)

the size of scaled up installation and SF the scale factor. A scale factor of 0.65 was used in modelling this study as typical of values used in the sector.

It is assumed that costs are incurred at the following rates: 20% in year 1 of building; 50% in year 2 of building and the balance in year 3 of building. A loan equivalent to 70% of the capital is assumed with an interest rate of 8%. Straight line depreciation over 10 years has been assumed for the ISBL capital costs and 20 years for the OSBL capital costs.

4.3 Operating costs

4.3.1 Feedstock costs

Within the model, feedstock costs are inflated annually except in the case of wastes. Across the EU there is likely to be a progression to lower waste resource availability over time and therefore gate fees are expected to reduce accordingly. As this is not something that is easily predictable, waste 'gate fees' were not increased in line with inflation, reflecting a decreasing relative cost over time.

The costs of ash disposal for thermochemical technologies were also calculated and ash landfill costs were assumed to be €3/tonne.

4.3.2 Process chemicals and utilities

Data available from NNFCC's own commissioned work on advanced conversion technologies and from commercial plants as well as from reference cases has been used to estimate costs of processing raw material inputs.

4.4 Process efficiencies

Process energy efficiencies will be variable according to process design. Fischer Tropsch processes are reported to have energy conversion efficiencies (energy in product versus energy in feedstock) in the range 40-50% (to naphtha and diesel). Data on syngas fermentation process efficiency is extremely difficult to source. NNFCC has access to commercial data which indicates that it would again be expected to be in the range 40-50%. In both cases we assume efficiencies of 45%.

For the hydrolysis and fermentation process, we have assumed 42% energy efficiency from biomass to ethanol. Although Abengoa and others have reported that there are plans to extract sugars from municipal solid wastes for fermentation to ethanol, which have gone so far as to develop demonstration scale facilities[5], we consider that the heterogenous nature of wastes will make this highly challenging. As such this will not be considered further in this study.

[5] http://www.biofuelsdigest.com/bdigest/2013/07/01/abengoa-completes-waste-to-biofuels-demo-plant-in-spain/

Feedstock energy contents were assumed to be 12.5 GJ/t for forest and agricultural residues and 11.5 GJ/t for refuse derived fuel.

4.5 Fuel prices

Future fuel prices have been estimated using future crude oil scenarios[6], for which there are low, central or high options. Following discussions with industry experts, the central scenario has been used in this study because fuel industry experts expect future crude oil prices to remain at or around the $100/barrel level (in 2013 value).

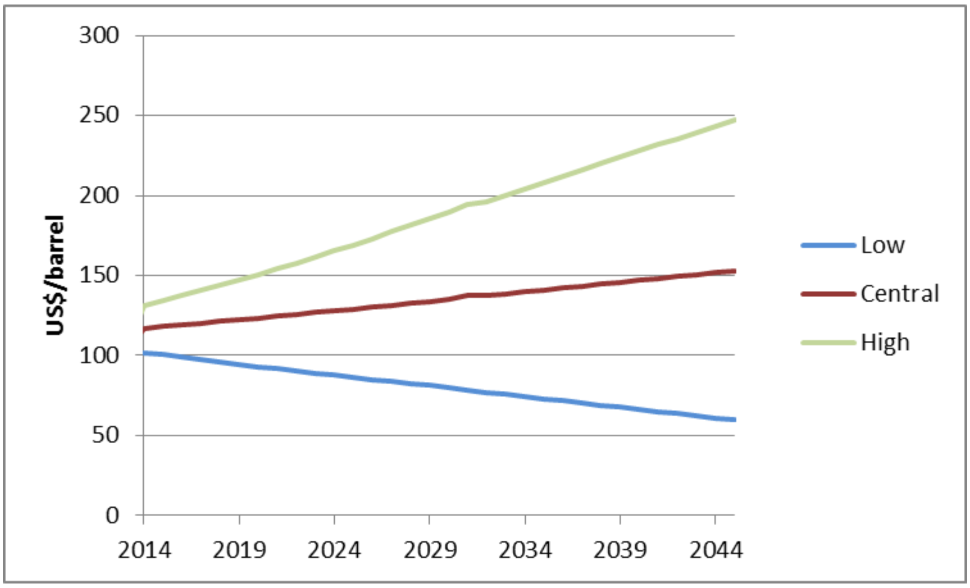

Figure 1. Future crude oil price scenarios

From the future crude oil prices, future diesel and petrol prices were calculated using a consistent diesel/crude and petrol/crude ratio. FT diesel prices were derived by adjusting the diesel prices for density and cetane value to provide an equivalent €/GJ cost. Future ethanol prices were derived by multiplying crude oil prices by the historic ethanol/crude price ratio[7]. These calculated biofuel prices were taken as the competitive likely market price for these fuels for comparison with the outputs from scenario modelling.

4.6 Approaches to economic analysis

An initial set of scenarios were explored using fixed feedstock costs to identify the optimum size of plant (see Annex 2), recognising that larger plants can deliver better economies of scale. From this analysis, plant sizes of 150,000 tonnes fuel/annum for biochemical ethanol and 300,000 tonnes of fuel per annum for thermochemical

[6] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65698/6658-decc-fossil-fuel-price-projections.pdf

[7] It is assumed that this would remain a valid approach, assuming future ethanol prices do not reduce significantly relative to the price of fossil crude.

pathways were used as the reference case for further economic analysis. These scales represented a compromise between optimising cost efficiency while ensuring that feedstock supply tonnages were manageable (and economical) within a reasonable transport distance of the plant.

At the chosen plant size, the impacts of rising feedstock cost on the returns on investment were examined targeting IRR’s of 10, 15 and 20%, representing low, average and relatively good returns for industrial investments.

The additional incentive (in €/litre) required to achieve the target IRR’s was calculated, which represents the premium or subsidy required, over and above the returns achieved from selling biofuel at the anticipated competitive market price to drive investment and development of the sector.

5 Feedstock costs

5.1 Wheat and barley straw residues

Wheat and barley straw are commonly traded in Europe for use in animal bedding (mainly wheat straw) and for inclusion in livestock diets as roughage (primarily barley). Small amounts are also used in mushroom production and applied to soil as a mulch to protect root crops and bulbs from frost damage. While straw is a relatively low bulk density product (around 100-140 kg/m^3), making it relatively expensive to transport, this does not preclude inter- European trading, which has involved transport of significant tonnages (circa 500k tonnes from UK to mainland Europe) in the past (3).

In areas of high livestock demand, straw can be collected on up to 80% of the barley area, while in contrast wheat straw is collected on around 60% of the wheat area. If not collected and removed, it is typically ploughed back into soil.

5.1.1 Factors affecting the price of straw residues

As a tradable commodity, with markets throughout Europe, there are a number of issues that affect the price of agricultural straw residues. Many of these relate to its relative availability within existing markets, but the advent of energy markets and associated feedstock supply contracts is also having an influence.

Some of the issues that affect price include:

- barley straw tends to trade at a premium to wheat straw (and corn straw) in the livestock sector as it has a higher nutritional value and better palatability than wheat and corn straw when used in livestock diets).
- distance from supply and area of production has a very significant impact on the price, due to the impacts of its low bulk density on transport costs

- the relative availability of straw in the market place and concerns over weather impacts on the future ability to secure straw can lead to significant speculation and price rises in the straw market as buyers compete to secure their requirements
- the types of bale and degree of handling required (smaller bales demand a small premium)

There is a very limited window of opportunity to collect wheat and barley straw after harvest. Where farmers intend to collect straw, it is allowed to pass through combines without chopping and left to lie in lines of piled straw (swath). If these swaths become wet, the weight of the wet straw pushes the straw down onto the soil surface and prevents the effective use of baling machines. In very wet seasons collection can be abandoned. Straw also needs to be stored year round to serve year round energy markets demanding storage space on farm or at collecting points.

5.1.2 Wheat and barley straw prices

In the current market situation, straw price typically rises from September to November as livestock farmers compete to secure their winter feed and bedding requirements. However, poor weather conditions can lead to significant spikes in prices in the open market. As an example, Figure 2 shows the variability in wheat straw costs experienced in the UK in recent years.

Wheat and barley straw prices also vary significantly between EU Member States (Table 1). Cereal straw is scarce in the Netherlands (to meet demands in the livestock and horticultural sector) and straw prices are high (110-120 €/t) reflecting that most is imported. Straw can be sold in the swath (in field) at very low prices (e.g. see Denmark), where the buyer is then expected to collect and bale. Prices in eastern and southern Europe also tend to be lower. This reflects lower labour costs and to some extent the reduced 'value' placed on straw, in terms of recognising its fertiliser value and/or the compensation required to compensate for additional handling, storage and inconvenience.

5.1.3 Impact of energy contracts

Where straw for heat and power applications have developed this has had an impact on the contracted straw price. To protect developers from market volatility, power generators have developed long-term supply contracts with growers, offering some longer-term security to farmers. The price on offer is currently 20-30 €/t below that currently on the open market, but contracted suppliers are expected to deliver to the generator which adds roughly 12-14 €/t to costs.

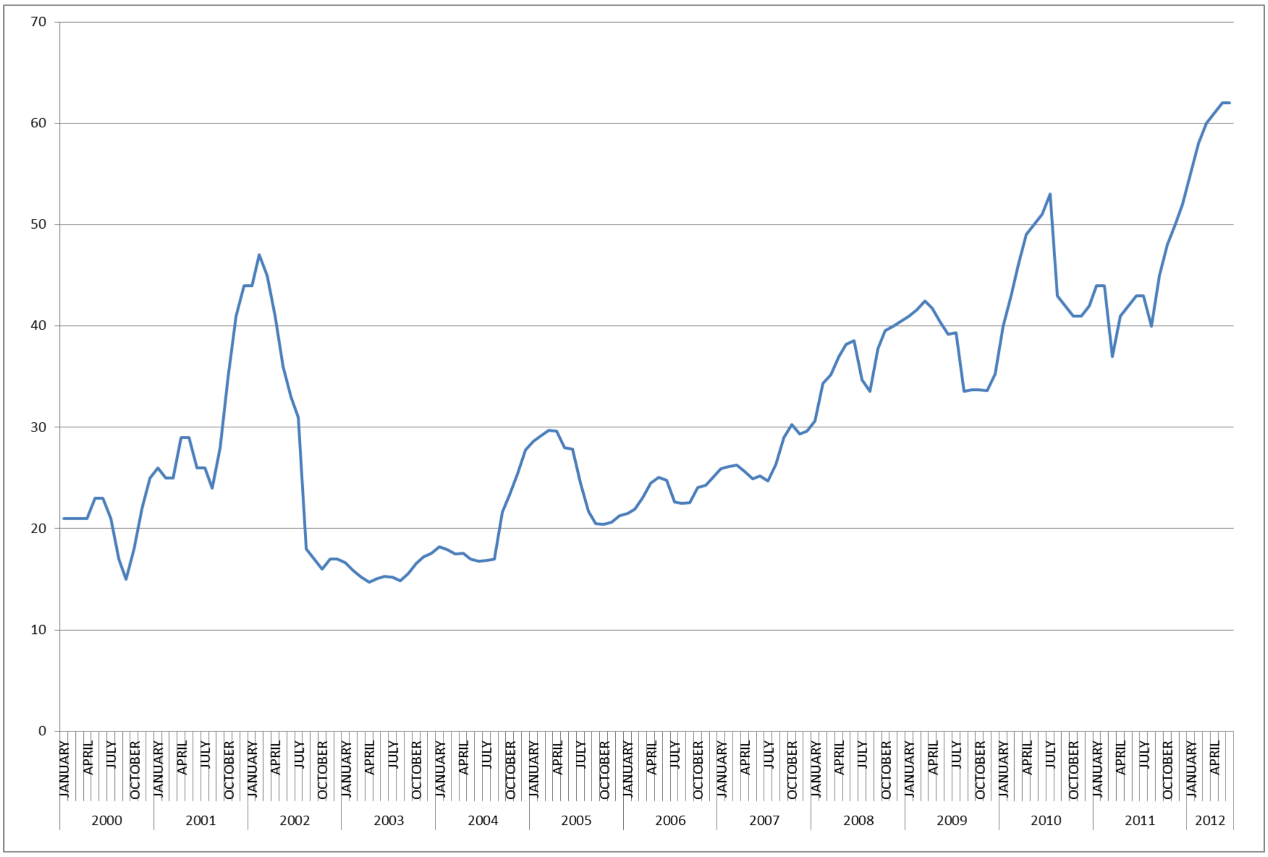

Figure 2. Seasonal and annual variation in UK big bale wheat straw average price (£/t ex farm, good quality) (source: UK Hay and Straw Traders Association)[8]

[8] The surge in straw price in autumn 2001 was caused by the foot and mouth epidemic and subsequent restrictions on cattle movement, leading to farmers having to buy in additional straw to keep animals longer prior to slaughter or moving on to other farms.

Table 1. Straw prices for forage and energy contracts around Europe

Straw type and source country		€/t	Reference year	Data source
WHEAT STRAW				
Denmark	**(energy)**	80-87	2012	Heating and power markets (ref (3))
		74-80	2012	Local district heating markets (ref (3)) (reflects shorter transport distance)
	(forage)	27 to 34 (in field)		Cost of baling and collection to be borne by buyer (ref (3))
France	**(forage)**	95	2012	French Entrée farmers forum
Hungary		24	unknown	Ref (3) (not clear if farm gate price only)
Netherlands		110-120 (typically > 100/tonne	2012	Ref (3) (note generally imported)
Serbia		30-40	2012	Ref (4)
UK	**(forage)**	71-83 (delivered)	2012	Peacocks of Thirsk, UK straw traders (personal communication)
	(energy)	47.5-53 + delivery	2012	Peacocks of Thirsk, UK straw traders (personal communication) and ref (3)
	(energy)	59 + delivery	2012	Northern Straw UK straw traders (personal communication)
BARLEY STRAW				
UK	**(forage)**	73	2013	Ref (3) citing UK Defra statistics
		88	2013	Farming Forum Discussion group
		81-87	2013	Farming UK (www.farminguk.com)

5.1.4 Typical contract terms in the straw for energy sector

Agricultural residue supply chains are typically comprised of a number of relatively small scale regional operators, supplying straw to both local and national markets. The development of large scale outlets for crop residues, leads to opportunities to develop new supply chains, supplying reliable markets and offers opportunities to reduce costs and to negotiate deals on longer term supply of straw. This helps to insulate from the typical seasonal variation seen in straw costs on the open market.

Current straw for energy (power) contracts typically include;

- Contract durations of 8-12 years, possibly with break options (typically at 4-6 years respectively) that vary between contracts
- Minimum supply tonnages of 250-300t and fixed tonnage to be supplied each year (typically it is the contracted suppliers responsibility to meet contracted tonnage in all years)

- An agreed price for supply based on meeting specific quality parameters, such as moisture content.

5.1.5 Typical cereal straw costs

Based on the above a typical straw price of 60-80 €/t (delivered) is reasonable for northern Europe, and 30-40 €/t would be more typical of southern and eastern Europe.

5.1.6 Costs incurred in straw provision – the net value of straw to the rural economy

Farmers incur additional direct costs in collecting and collating straw residues into on-farm storage (Table 2) and may be required to pay for onward delivery to the end user. While there are some energy savings to be made from negating the need to chop straw on the combine, there is a direct cost to the farmer in bailing and collecting straw of around 17€/t, plus any onward transport cost. These costs are likely to be at the upper end of the estimate and more reflective of extensive northern European farming conditions with economies of scale seen in larger more commercially oriented farms.

What tends to be less well recognised by farmers is the nutrient value of the straw removed (see Annex 1). Straw contains valuable phosphate and potash, that if removed should be replaced within the recommended fertiliser additions to following crops. The value of the fertiliser forgone is estimated at between 19 and 14 €/t at current fertiliser prices. This value is not always appreciated or recognised, particularly by farmers on relatively fertile land.

Table 2. Estimation of the direct and indirect cost incurred in straw collection and transport

	€/t fresh straw
Bailing (2)	15.02
Collection and carting to on-farm storage	2.14
Transport to plant	14.00
Saving on straw chopping (2)	-8.16
Total costs of collection and delivery	23.00
Fertiliser value of straw (see annex 1)	9 to 14
Cost of straw provision (direct and indirect)	32 to 37

Taking all these issue into account and when excluding the fertiliser value forgone the actual margin on cost of supply is likely to be only a few euro up to €10 at a straw price of €30-40/t. At a straw price of €60-80/t this margin rises to €28-43/t even when accounting for the fertiliser value of straw. It is worth remembering that this margin must be attractive enough to compensate for the additional complications that straw collection imposes on farmers, in terms of managing equipment and manpower at the busiest time of the year.

5.2 Corn/Maize straw

Finding data on the use and costs of maize straw proved more difficult.

The European grain maize harvest is relatively late in the autumn and it can be difficult to dry straw in the field. As a result, gain maize straw moisture levels tend to be high which can lead to spoilage during storage.

In contrast forage maize is commonly harvested earlier in the year while still 'green' and ensiled (wrapped in bales or in sheeted silos) to preserve it for use as overwinter forage (as an alternative to ensiled grass, hay or straw). Forage maize is commonly grown for use in anaerobic digestion systems, as the sole or as a supplementary feedstock. However, such feedstocks are not compatible with the objectives of this study of looking at 'no regrets' residue feedstocks which do not compete with food production or other existing market uses for residues.

The bulk of the remaining analysis for agricultural feedstocks therefore focuses on data for wheat and barley straw where there is more information available.

5.3 Forest harvest residues

Forest harvest residues includes bark, tops and branches, and in some cases tree stumps, which in most cases are left in the forest after felling and therefore represent an underutilised resource in the forest biomass sector.

Bark, tops and branches harvested straight from the forest have a relatively high moisture content, similar to a tree, of 40% or more, this makes transport costly.

With the exception of Scandinavian countries where harvest residues are collected at the time of harvesting to reduce collection costs, tops and branches are typically left to dry naturally for several months before use to allow time for the moisture content to decrease to around 20-30%. In this case most of the leaves will have been lost, adding to soil carbon and nutrients (5). Harvest residues are typically collected in large bundles and then chipped either at the roadside or at a central reception plant to ease onward transport.

In Scandinavian Member States, the value of these residues has been recognised. Collectable forest harvest residues can amount to 35-45% of the biomass volume of felled roundwood. While removal from some sites will be excluded or limited (i.e. from soils with low nutrient status or steep slopes where there is a risk of erosion if removed), the potential resource is significant. The ICCT (1) estimates the sustainably harvestable resource could amount to 40 million tonnes in the EU.

The ECF (6) estimates that only around 3% of forest residues are currently collected in the EU. Hence, with the exception of experience in Scandinavian countries, there is little data available on the market price of such materials, beyond that provided in studies that have estimated the potential costs of supply. However a price index (PIX Bioenergy Forest Biomass Index) has been developed based on recent Finnish market trades in forest residues.

The largest reserves of forest residue resources are to be found in Finland, Sweden, Germany, France, Poland and Spain. However, with the exception of Finland and Sweden, these residues are not collected currently. Where costs have been estimated, these tend to be higher in Northern Europe reflecting the mechanised approach adopted for collection. Costs tend to be lower in Eastern Europe with lower labour costs.

The key issues affecting uptake and use of forest residues are harvesting and handling costs, as collection is highly mechanised. It is also uneconomic to transport chipped forest residues more than 200km (UPM personal communication).

In Scandinavia, residues are collected with a mechanical grab and bundled into bales of around 0.5 tonne in weight. Clear felling of 1ha of softwood produces around 100-150 bundles at the rate of about 20-30 per hour. Collection at the time of harvesting reduces costs, but moisture content is higher (circa 40% moisture). Bundles are collected by a self-propelled transporter with a mechanical grab (Forwarder) and moved to the road side for storage and onward transport on standard timber trucks.

Where transport routes are short, and more commonly in Finland for example, bundled material may be chipped at the roadside and carried as chips from the forest to reduce handling costs. This approach is better suited to small operations as speeds of operation are relatively slow compared to large centralised chipping operations. Large chipping operations store bundles on-site, to help dry residues, but also to provide large volumes of year round feedstock supply.

The different production techniques and handling options lead to wide variation in estimates of cost.

5.3.1 Costs of forest harvest residues

Table 3 shows the prices for forest residues calculated by industry or forestry researchers, examining costs for a range of locations in Europe. In addition the table includes the latest costs from the PIX Bioenergy Forest Biomass index, based on real material trades in Finland. One difficulty in compiling such comparisons is the plethora of units used in reporting (€/m^3, €/MWh, €/GJ, €/t), commonly without provision of key data on the relevant applicable moisture contents, wood densities or calorific values. This therefore required some assumptions to be made to enable use of standard conversion factors.

Much of the data relates to estimates for Scandinavia, where the practice of collection is more developed, and given the highly mechanised and relatively high costs of labour involved in such regions is likely to represent the upper end of the supply price range. The PIX cost of 62.5 €/t is in line with the more academic estimates of cost for Scandinavian countries.

Transport of forest residues adds around 8-12 €/t to the delivered price (for ca. 30-100km trip) (7). This gives a range of costs for delivery to plant of around 40-65 €/t, a wide range which covers the majority of the estimates found in the literature. This wide range reflects the structural, social and transport distance issues highlighted above, and the fact that this is a relatively undeveloped sector currently, which would benefit from more detailed analysis in areas outside Scandinavia.

These prices are in line with current market prices for industrial wood chips of around 59-65 €/t (8).

5.3.2 The net value of forest residues to the rural economy

Most of the data presented in Table 3 is typically built up from individual operation costs that include individual margins required by each operator in the chain, so it is more difficult to identify the net margin on costs in the absence of more granular data. However, UPM[9] provided the typical breakdown costs structure for forest residue supply chains (Figure 3). The majority of costs are associated with harvesting and transport of materials, which will include an element for salary costs that will flow into the rural economy. This data suggest that around 10% of the purchase price will accrue to forest owners, the rest will cover direct operational and capital costs associated with processing and supply.

In contrast to cereal residues, where forest residues are secured sustainably, there is deemed to be no net detrimental impact on soil nutrient status that would otherwise require remediation through application of fertiliser. So no additional indirect costs are anticipated where forest harvest residues are exploited.

[9] UPM are an international forest industry company, with interests in papermaking, biomass energy and biorefining of forest resources

Table 3. Prices for forest residues (branches and tops left after harvest)

source country	€/t[10]	Reference year	Data source
Forest harvest residues			
Belgium	33-51	2003	Ref (9)
Finland (energy)	62.5 (18 €/MWh) (chipped & delivered)	2013	FOEX, PIX Bioenergy Forest Biomass index (trade vaules for forest residues and wood industry by-products) (note widescale use of biomass for heating in Finland and includes local domestic delivery) (www.foex.fi)
	54-60	2013	Estimates by VTT for marginal costs of supply of logging residues (ref (10))
	33-38	2010	Ref (11) Cost estimate of supply
Ireland	27.3/odt (chipped but excluding transport)	2010	Ref (12) Estimated costs form small trials
Scandinavia	60-66 (20-22 euro/m^3)	2012	Ref (13) cited by ref (3) Chipped material delivered to site typically for energy generation
Germany, Sweden, Poland, Greece, UK and Ireland	24.7-60.8, typically 47.5 (per dry tonne)[11]	2008	Ref (14) (RENEW project)calculated costs for collection chiping and delivery to 1st central collection point
Czech Republic, Finland, France, Hungary, Poland, Slovakia, Spain, UK	22.6-62 (average of 37.9) chipped and delivered	2008	Ref (15) figures represent calculated marginal costs of supply to plants

[10] Where data was presented in references as euro/m^3, the conversion factor of 250kg/m^3 of chips at 30% moisture was used, or 680kg/m^3 for oven dry chips. Also assumed 1m^3 of wood chip equates to 1MWh, and 3MWh/t of chips at 30% moisture.

[11] Assuming CV of 12.5 GJ/t for wood chips at 30% moisture

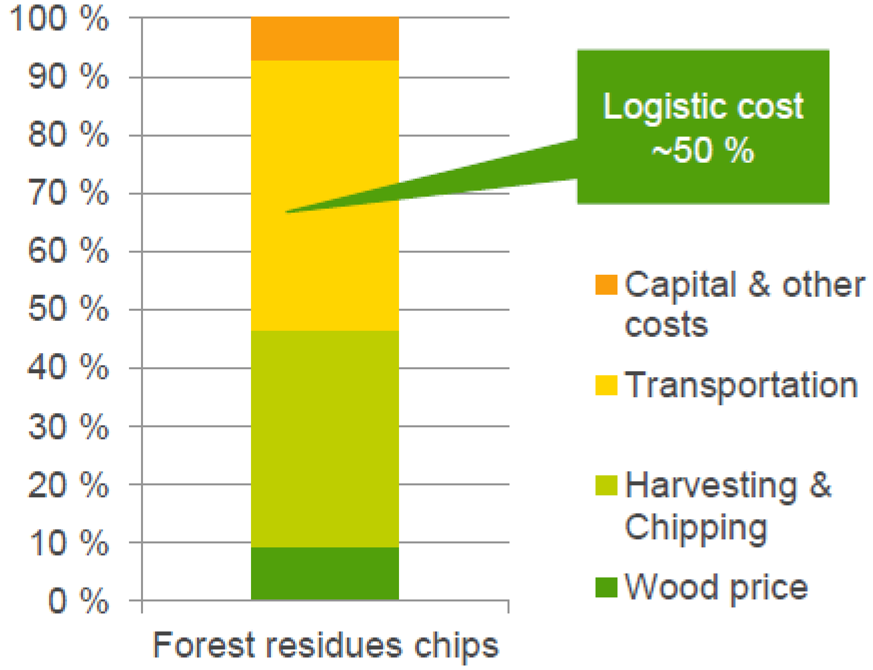

Figure 3. Typical cost structure for forest residue supply chain to end user (CHP Plant in this case). Data from UPM, Finland

5.4 Municipal Solid Waste (MSW)

While there are a number of different waste streams arising from construction, industrial and commercial activities, providing a range of resources that could be used for energy generation, much of this resource is now being recycled, or in the case of food wastes directed towards anaerobic digestion to generate heat and power.

However MSW arising primarily from households and green-waste collections is a resource with significant potential for conversion into biofuels. The EU Landfill Directive[12] is actively discouraging the disposal of biodegradable wastes by burial. In addition, the EU Waste Framework Directive[13] also sets out a hierarchy for waste treatment, encouraging recycling and reuse over disposal, which includes use for energetic applications, to ensure the most efficient use of resources and minimise lifecycle GHG emissions.

The biodegradable fraction of MSW can vary significantly, ranging between 25 and 71% for different countries (16). Unsorted MSW is not particularly suited to use with advanced biofuel technologies, given the wide range of contaminants that may be present. Such plants therefore would typically rely on refuse derived fuels (RDF))

[12] Council Directive 99/31/EC
[13] Directive 2008/98/EC

derived from waste that had passed through a Materials Recycling Facility to pull out metals, glass and other recyclates as well as other materials (see Figure 4).

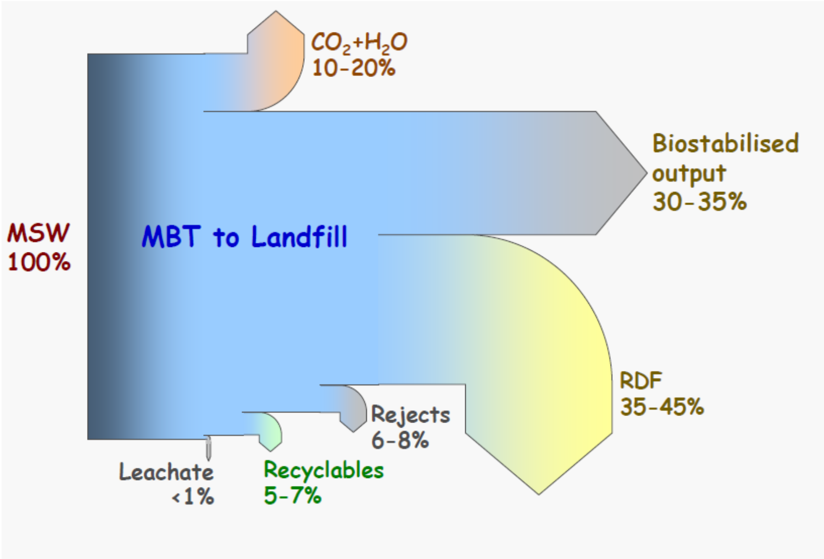

Figure 4. Example conversion rates (mass balance) for RDF from MSW via a mechanical and biological treatment (MBT) waste handling plant (17) (biostabilised output represents composted or digested material typically sent to landfill or used for land reclamation)

Depending on the type of MBT plant, materials of biological origin can account for between 50 and 85% of the carbon content in RDF fuels. Recycling and sorting conversion efficiencies will vary between plants, but the data in Figure 4 provides a reasonable starting point or further analysis.

It should be noted that energy derived from residual waste is only partially renewable, due to the presence of fossil-based carbon in the waste. Only the energy contribution from the biogenic portion is counted towards renewable energy targets and only this element is eligible for renewable financial incentives. Depending on the level of treatment this can be as high as 90% for some waste treatment processes (though with added cost to achieve this).

As part of the EU-RED requirements, Member States have to regularly report to the European Commission on how they estimate the share of biodegradable waste in wastes rewarded for renewable energy production. For example in the UK, if not actually recorded by an approved procedure and subject to appropriate evidence provision, the renewable fraction of wastes is permitted to be deemed at 50% within the Renewables Obligation designed to support large-scale renewable power generation (18).

Based on Eurostat figures, in the EU27[14] 218 million tonnes/annum of household waste has been produced in recent years. If processed this would provide between 76 and 98 million tonnes of RDF based on the separation values in Figure 4. This material would be compatible with advanced conversion processes utilising thermochemical conversion, but less so with those relying purely on biochemical conversion, due to its heterogeneity and possible contamination issues.

As RDF is still classed as a waste, a fee (gate fee) would currently be demanded by the biofuel plant for its acceptance; ostensibly to cover for the additional environmental requirements and procedures that the receiving biofuel plant has to put in place to comply with waste handling and combustion regulations. The waste processor would otherwise incur a charge to dispose of the material, most probably via landfill. The gate fee for biofuel plants has to be more competitive than disposal via landfill (or other disposal routes) for biofuel plants to secure this feedstock.

As an example, RDF gate fees are currently around 45.6 €/t in the UK power sector. However, it anticipated that these will fall in the future as the value of energy to wastes streams is recognised and better exploited. Gate fees in northern Europe are reported at 20€ to 40€/t, the lower end of this range is associated with areas of high energy-from-waste power capacity (Karen Andrews, Senior Advisor at the UK Environment Agency[15]).

6 Feedstock cost tolerance in advanced biofuel production processes

6.1 Agricultural and forest residues

The results of economic modelling for agricultural and forest harvest residues are shown in Figures 5 to 7 for bioethanol via biochemical, bioethanol via thermochemical and biochemical and FT diesel via thermochemical production chains respectively. As identified in the approaches section, it should be noted that the incentives referred to represent the additional support that would be required to make these advanced fuels competitive with the anticipated market price of each respective biofuel (that in turn for bioethanol reflects the costs of bioethanol production from sugar or starch feedstocks and for FT diesel represents the anticipated market value based on its calorific and cetane value).

[14] http://ec.europa.eu/environment/waste/compost/pdf/econanalysis_finalreport.pdf

[15] http://www.ciwm.co.uk/web/FILES/SouthWestCentre/3_-_Regulatory_Developments_in_the_Export_of_RDF-_Karen_Andrews,_EA.pdf

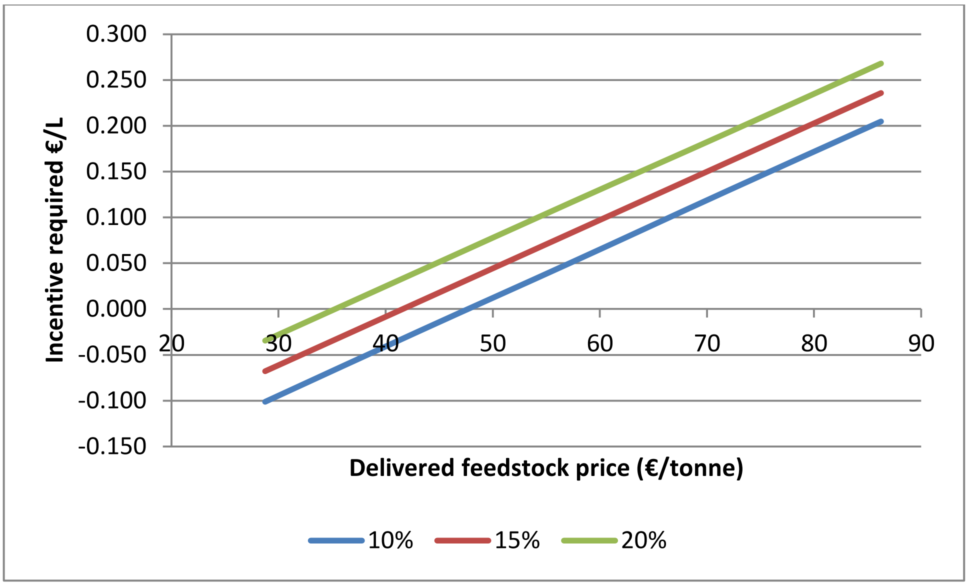

Figure 5. Effect of biomass feedstock price (€/t) on the incentive required over and above the anticipated base fuel ethanol market price, to deliver project IRR's of 10, 15 or 20% for a 150 tpa biochemical ethanol plant

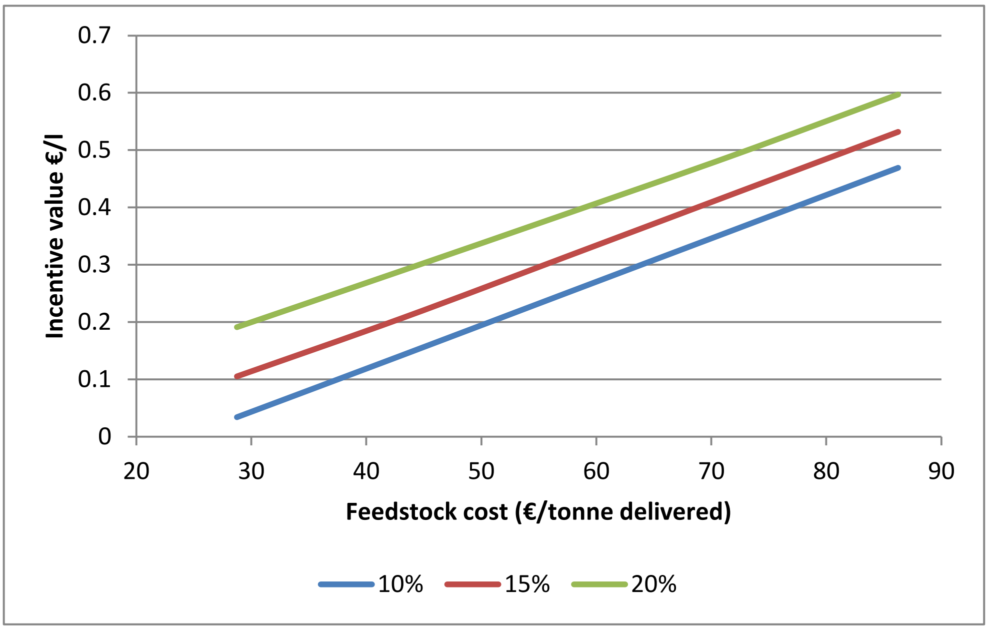

Figure 6. Effect of biomass feedstock price (€/t) on the incentive required over and above the anticipated base fuel ethanol market price, to deliver project IRR's of 10, 15 or 20% for a 300 tpa thermochemical and biochemical ethanol plant

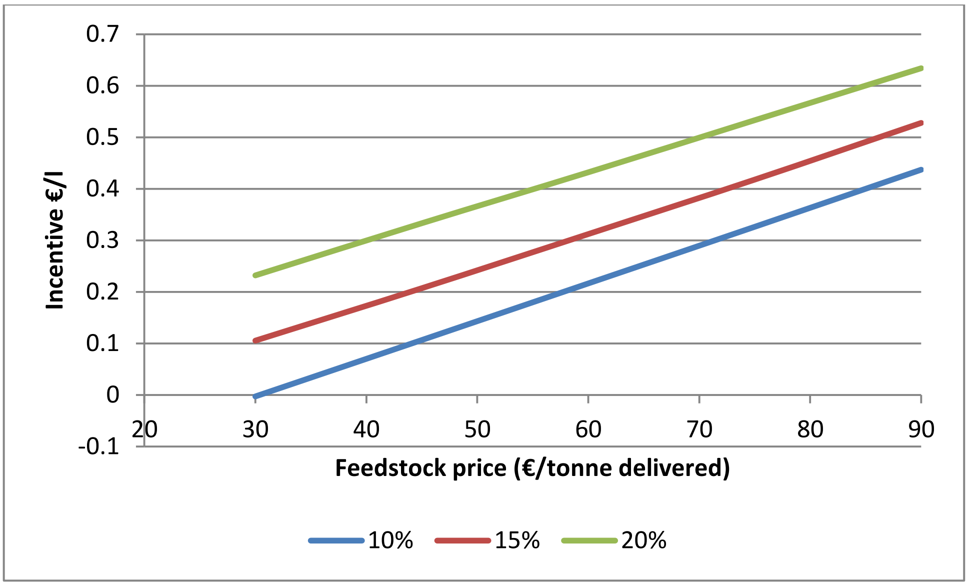

Figure 7. Effect of biomass feedstock price (A) €/t, (B) €/GJ on the incentive required over and above the anticipated base market price for synthetic diesel fuel to deliver a project IRR of 10, 15 or 20% for a 300 tpa thermochemical FT diesel plant

Reading between these figures emphasises the higher production costs of thermochemical approaches (i.e. a greater incentive is required per litre of output), though there is little difference between the costs of biofuel production for syngas fermentation to ethanol and catalytic conversion of syngas to FT diesel. The higher cost of thermochemical systems is balanced by its greater tolerance for variability in feedstock quality than biochemical approaches.

For the cheapest feedstocks (at €30-40/tonne) it is estimated that ethanol could be produced via cellulosic fermentation routes at a comparable cost to the anticipated market price of bioethanol (from more conventional sources) while providing adequate returns on investment. The key issue affecting deployment is large scale demonstration of the technical capabilities of such approaches to stimulate investor confidence.

In contrast, even with the cheapest feedstocks, fuels derived from thermochemical-based technologies (both bioethanol and FT diesel) would require an additional incentive to facilitate their deployment and to ensure their costs were competitive with more conventional sources of the same fuels (bioethanol) or fuel industry estimates of their relative energy value. The incentive required increases with increasing feedstock cost, but at the highest feedstock cost and at an investment IRR of 20%, this is estimated to be a maximum of €0.56/litre. In most cases it could be considerably lower.

To aid comparison, Table 4 shows the incentives estimated to be required to derive investment IRR's of 15% for each residue feedstock and for each biofuel production technology. Note that these incentives would only bring advanced technologies to fuel price parity with other potential sources of the same biofuel, for which additional incentives (financial or otherwise) may be required to stimulate their uptake by fuel suppliers.

Table 4. Indicative additional incentive range (€/l of fuel produced) required to deliver a minimum project IRR of 15%

Feedstock		Biofuel production pathway		
	Typical price range (delivered to plant)	Cellulosic ethanol	Syngas fermentation to ethanol	Syngas to FT diesel
Agricultural residue – S&E Europe	€30-40/t	€-0.07-0.01	€0.11-0.19	€0.11-0.18
Agricultural residue - C&N Europe	€60-80/t	€0.08-0.22	€0.33-0.49	€0.31-0.44
Forest harvest residue	€40-65/t	€0-0.14	€0.19-0.38	€0.18-0.34

Throughout Europe, development of the biofuel market has relied on mandated volumes of biofuel included in total fuel sales in order to drive the market demand, coupled with other incentives to reduce the financial burden on industry. The latter has typically included reductions in duty (tax) levied on biofuels, which has in some cases been banded to encourage biofuels derived from particular feedstocks.

At the EU level, the EU Renewable Energy Directive allows for biofuels derived from designated 'waste' feedstocks to contribute twice their energy content towards meeting individual Member States transport renewable energy targets. The Commission has proposed that 'advanced fuels' (including those based on the feedstocks considered in this study) can be mandated and could count four times towards these targets. Such policy approaches could encourage Member States to offer additional financial support for such biofuels.

The opportunity to introduce different tiered levels of support for different fuels to deliver specific objectives is therefore established in the EU. However, the introduction of any such incentives and the specific means of delivery is left to individual Member States, leading to a plethora of different possible support options. The range of duty reduction incentives currently or that have been on offer in the recent past for a range of EU member States are demonstrated below (Table 5).

These figures demonstrate that the levels of incentive required to encourage the commercial development of advanced biofuels for the majority of feedstocks considered are not dissimilar from the range of support that either is, or has recently been on offer from Member State Governments.

These represent the minimum levels of support that would be required for the most expensive production processes. However, additional mandating of use or additional support would most likely be needed to encourage uptake by fuel suppliers to drive the market demand for these fuels.

Table 5. Example duty reductions offered for biofuels by different EU Member States either currently or in recent years. Source: derived from IEA Bioenergy Task 39 (19)

Country	Fuel duty reductions currently in place or offered in recent years for biofuels (€/litre)
Belgium	0.62 for ethanol, 0.35 biodiesel
Denmark	0.03 'biofuels'
France	0.08 to 0.38
Germany	0.47 BTL fuels, 0.65 ethanol and 2nd generation ethanol
Ireland	0.36 biodiesel to 0.44 ethanol (demonstration plants)
Netherlands	0.365 biodiesel – 0.50 ethanol (demonstration plant only)
Spain	0.278-0.37
UK	Was 0.298, now obligation worth up to 0.18/l (or double this for fuels from wastes (0.36/l))

6.2 Refuse derived waste

The results of economic modelling of the impact of gate fees on the costs of thermochemical ethanol and FT diesel production from wastes are shown in Figure 8 and 9 respectively. In all cases at current gate fees (ca. €20-46/tonne) and even in the absence of such fees, the bio-derived ethanol or FT diesel produced should be cost competitive with the anticipated market price of these fuels (based on price trends for current commercial biofuel processes or on their equivalent fuel energy value). This is predicated on the assumption that receipt of RDF materials will continue to attract gate fees, but this cannot be guaranteed as competition for such material increases.

However, as identified in section 5.4, RDF is only partially renewable. Materials of biological origin can account for between 50 and 85% of the carbon content in RDF fuels. Therefore any biofuel derived from residual waste is only partially renewable. Only the energy contribution from the biogenic portion can be counted towards renewable energy targets and be eligible for renewable financial incentives.

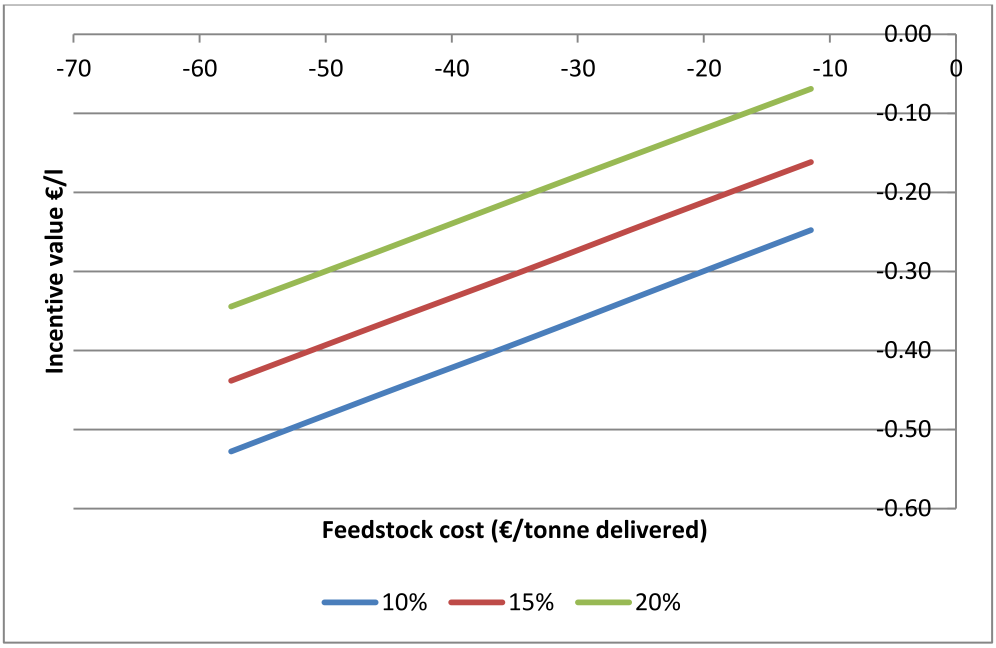

Figure 8. Effect of waste gate fee (€/t) on the difference in the price of bioethanol produced, relative to the anticipated base fuel ethanol market price, required to deliver project IRR's of 10, 15 or 20% for a 300 tpa thermochemical and biochemical ethanol plant

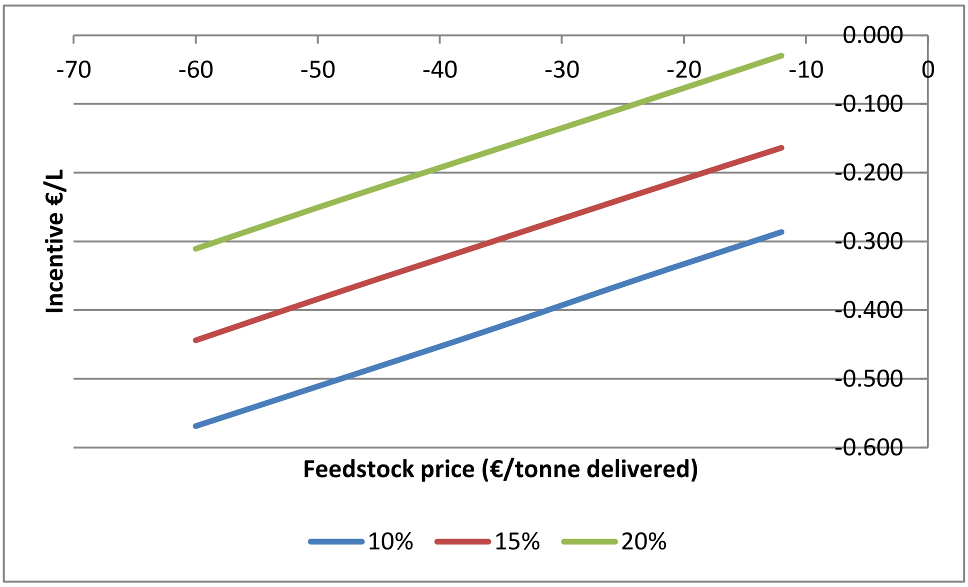

Figure 9. Effect of waste gate fee (€/t) on the difference in the price of synthetic diesel, relative to the anticipated base market price, required to deliver project IRR's of 10, 15 or 20% for a 300 tpa Thermochemical FT diesel plant.

Discussions with developers of advanced bioethanol production plants (Ineos Bio) suggest that the equivalent 'fossil derived portion ' of the ethanol output from the process will retail at prices significantly below that for bio-ethanol[16]. In contrast, fossil-derived FT diesel, because of its higher energy concentration may not be so significantly affected, however, it is still likely to require discounting to ensure price compatibility with regular diesel costs on a €/GJ basis. In the case of both fuels, the fossil-derived fuel output places a financial burden on the economics of the plant that must be recouped from returns on the biofuel output. This creates the need for additional reward on the bio- fraction for such waste-derived fuels.

Member States have to report to the European Commission on how they plan to estimate (and reward) the renewable energy contribution from wastes with variable renewable energy content. Following RED guidance that the energy content of waste-derived fuels can count twice towards delivery of Member States renewable fuel energy target, the UK has deemed that biofuels from 'wastes' are eligible for double reward (2 Renewable Transport Fuel Certificates per litre) which helps to compensate for the lower value of the fossil–derived fuel fraction in RDF derived fuels.

6.3 Summary of the economic modelling

The identified biomass resource can be mobilised for use in advanced biofuel production <u>if</u> the appropriate incentives are made available. The incentives required in most cases to encourage exploitation of agricultural and forest residue biomass resources for biofuel s are not in excess of those that have been offered as duty reductions to incentivise biofuel industry start up to date.

In some cases feedstock cost, particularly around €70-€80/tonne, may be a barrier to development if these cannot be reduced. The development of energy contracts offering long term supply and development of larger and more efficient supply chains may help to reduce such costs.

For the waste sector, no specific cost barrier to development was identified assuming the incentives available adequately compensate for the anticipated lower value of the fossil-derived fuel component that would typically be co-produced with the bio-derived fraction where RDF was used as a feedstock. The fact that most of the advanced thermochemical biofuel demonstration plants in development are predicated on use of waste feedstocks supports this conclusion. The issues affecting development are primarily confidence in the presence of a long-term supportive policy framework.

[16] The fossil-derived ethanol generated by large-scale conversion of wastes to transport fuels would swamp the lower value but relatively small industrial ethanol market, so is most likely that it would be bought by fuel retailers as a petrol additive at discount prices reflecting its relative fuel energy value.

7 Job creation in the rural economy

7.1 Direct employment in agricultural residue collection

Based on typical agricultural work rates for agricultural residue collection and transport to on-farm storage, the number of jobs involved was estimated for small and large farms, representing both low and high levels of labour use efficiency respectively (Table 6). With the addition of estimates of labour costs for haulage (transporting either 14 or 28 tonnes per load over 100km), this gives labour hours of 1.01 to 1.44/tonne of agricultural residue delivered to the biofuel processor, equivalent to 0.47-0.68 Full Time Employees (FTE)/1000 tonnes of agricultural residue, based on 2112 available working hours per year.

Table 6. Person hours involved in agricultural residue collection and transport

	Person hrs/tonne fresh straw		Person hrs/1000 t fresh straw	
	low	**high**	**low**	**high**
Straw baling	0.23	0.37	229	371
Carting	0.74	*1.00*	743	1000
sub total	0.97	1.37	971	1371
haulage (ca 100km)	0.04	0.07	36	71
total	1.01	1.44	1007	1443
FTE:			0.47	0.68

7.2 Direct employment in forest harvest residue collection

Finding disaggregated data on the number of jobs likely to be created in the collection and transport of forest harvest residues is challenging. However Paananen (2005) (20) based on a case study for central Finland collecting forest residues, estimated that production of 5,600MWh of wood chip would provide the equivalent of a 1 person year of employment (1 FTE), equivalent to 0.62 FTE per 1,000 tonne of wood chip.

The EUwood project (21), estimated the potential for development of EU forests, including the potential for use of sustainably-harvested forest residues. In its modelling of the potential resource availability, it estimated that between 113 and 252 million m^3 of forest residues and stumps could be mobilised for use in its medium and high use scenarios, generating 22,000 to 54,000 additional jobs in the wood collection and transport sector. This equates to between 0.34 and 0.37 FTE per 1000 tonnes, lower than in Paananen (2005).

These studies both represent or draw on Scandinavian experiences, representing highly mechanised supply chains. As a result they probably represent conservative estimates of the potential for job creation. The variability in the estimates also highlights the need for more detailed studies.

The range from 0.34 to 0.62 FTE/1000 tonnes was used in scaling up to assess the potential for rural employment in the forest sector

7.3 Employment at advanced biofuel plants

There is little information available in the public domain on the direct number of jobs created in the plant construction phase. This is estimated at 2,000 person years of time over the duration of the build, or the equivalent of 1,000 FTE for 2 years. There is evidence in support of this figure in that the Vivergo wheat–to-ethanol plant, which recently opened in the UK and is capable of producing 420 million litres (330 thousand tonnes) of fuel per annum, created 1,000 jobs in its construction phase.

The number of individuals required to run an advanced fuel plant is relatively small by comparison and is not significantly affected by plant size in part due to automation and increased store, treatment or fermentation capacity which does not have a concomitant increased labour demand.

The US National Renewable Energy Laboratory (NREL) in 2002 estimated the number of FTEs in a cellulosic ethanol plant at 77 (Table 7). Again this shows commonality with a staffing rate of 80 FTE per annum for the Vivergo ethanol plant referred to above.

Table 7. Estimated FTE in a 69 m gallon (204 thousand tonne)/year cellulosic ethanol plant (source: NREL)

Role	
Plant manager	1
Plant Engineer	1
Maintenance supervisor	1
Laboratory manager	1
Shift supervisor	5
Maintenance technician	8
Shift operators	20
Yard employees	32
General manager	1
Clerks and secretaries	5
Total:	77

In contrast, work by Black and Veatch for NNFCC in 2008 identified slightly lower FTE staffing rate for a cellulosic ethanol plant, as well as FTE staffing rates for other plant types of interest (Table 8)

Table 8. Estimates by Black and Veatch for NNFCC of employees required in a range of advanced biofuel plants

Plant type	Number of FTE
Biochemical (lignocellulosic)	55
Thermochemical	54
Hybrid (thermochemical plus biochemical)	80

In 2012, Novozymes announced its plans to partner with Chemtex in a cellulosic ethanol plant in North Carolina, with plans to employ 65 staff in its operation. Enerchem announced in August 2013 that its advanced biofuels from waste plant under construction in Alberta, Edmonton will "employ 30 staff and create more than 200 jobs in construction". In previous work by NNFCC it was estimated that a 150,000 tonne per annum (tpa) thermo-biochemical ethanol plant, a 50,000 tpa BTL aviation fuel plant and a 200,000 tpa waste gasification to synthetic diesel plant would each employ 60 FTE in their operation.

Looking at the range of numbers in the literature the number of full time employees employed in advanced biofuel plants is likely to range between 30 and 80, though most estimates lie towards the mid to upper end of this range. Therefore a range of 50-80 FTE per plant was taken as representative for further scenario modelling.

7.4 Impacts on employment potential at the EU level

To model the EU-scale impacts of utilising the identified waste and residues for biofuel production on rural jobs and financial impacts, estimates of the resource available were taken from work by ICCT (1).

To reiterate ICCT identified the likely volumes of material that could potentially be made available within the EU for use in advanced biofuel production, <u>without affecting, or impacting on, the sustainability of supply or competing market sectors.</u> Therefore the employment figures and net revenues calculated from these figures represent the potential real net additional effects that could be delivered from exploiting these resources for biofuel production without significantly impacting on the environment or resource availability for other competing sectors for the resource.

It is assumed that all of the agricultural and forest residue resource identified by ICCT (see Table 9) could be mobilised for use to assess the maximum potential impact.

The ICCT work on wastes focussed on industrial and commercial waste arisings in the EU (primarily waste wood, paper and food and garden waste). However, in this work we focussed on Municipal Solid Waste arisings and the fraction that would otherwise go to landfill. This fraction is estimated at 76-98 million tonnes in the EU (see section 5.4). These figures were used to represent the 'low' and 'high' availability levels for this resource.

Table 9. Agricultural and Forest harvest residue resources identified by ICCT and RDF resources derived in this study used for scenario modelling

	'low' resource potential	'high' resource potential
Agricultural residues	91 million tonnes (wheat, barley and maize straw only (the most likely target residues)	122 Million tonnes (all potential crop residues identified by ICCP)
Forest harvest residues	40 million tonnes (50% of the total available, viewed as sustainable)	80 million tonnes (total harvestable resource available)
Refuse derived fuel	76 million tonnes	98 million tonnes

The number of jobs created per unit of residue delivered to the plant (employment indices) (Table 10) were used to estimate the number of FTE that would be created in the feedstock supply chain and sustained on an annual basis if all the feedstock available was used.

As collection of MSW and conversion to RDF fuels is something that would have happened in the absence of a biofuel market, driven by legislation to reduce use of landfill, it is assumed that the development of an advanced fuels stream would not provide additional jobs in the resource collection and waste processing sector up to the point of delivery to a biofuel plant.

The temporary direct employment generated in building these plants and the more permanent employment generated in operating these plants was calculated using the indices in Table 10.

Table 10. Employment indices used in scaling employment estimates for 'low' and 'high' scenarios

	'low' scenario	'high' scenario
FTE's in feedstock collection	0.47 FTE/1000 tonne agricultural residue 0.34 FTE/1000 tonne forest harvest residue	0.68 FTE/1000 tonne agricultural residue 0.62 FTE/1000 tonne forest harvest residue
FTE's in plant construction and operation	50 FTE's in plant operation 1000 FTE/plant in construction	80 FTE's in operation 1000 FTE/plant in construction

The conversion factors used in the fuel chain cost modelling (feedstock requirement per tonne of fuel output) were used to convert the above feedstock resource arisings into potential total biofuel yield (Table 11).

Table 11. Potential EU employment that could be generated from exploitation of the identified, exploitable EU agricultural residue, forest harvest residue and MSW residue resource

Feedstock type	Fuel chain	Feedstock resource availability in EU (million tonnes)		Tonnes of feedstock/ tonne fuel output	Potential biofuel production (million tonnes)		FTE's directly employed in feedstock supply chain (thousand)		FTE's directly employed in operation of biofuel plants (thousand)	
	Feedstock potential:	low	high		low	high	low	high	low	high
	Employment potential:						low	high	low	high
Agricultural residues	Biochem ethanol Themochem drop in	91	122	8.19 7.28	11.11 12.50	14.90 16.76	42.77	82.96	3.70 2.08	7.94 4.46
Forest harvest residues	Biochem ethanol Themochem drop in	40	80	8.52 7.58	4.69 5.28	9.39 10.55	13.60	49.60	1.56 0.88	5.01 2.81
Refuse derived fuel	Themochem drop in of which 'renewable'[17]	76	98	9.26	(8.21) 4.10	(10.58) 5.29	N/A	N/A	1.36	2.82
Total biofuel potential	Biochem ethanol Themochem drop in				15.81 21.88	24.29 32.60	56.37	132.56	5.26 4.33	12.95 10.10

[17] As the RDF contains both fossil and bio-derived materials it is nominally deemed to have a minimum 50% renewable energy content

The number of plants that would be required to deliver these total biofuel volumes (Table 12) was calculated based on the number of 300 ktpa thermochemical plants or 150 ktpa celulosic ethanol plants that would be supported. This data was used to calculate the employment in plant operation (Table 11) and the temporary employment created in their construction (Table 12)

It was assumed that use of RDF as a feedstock would only generate additional employment at the biofuel processing plant itself, at rates similar to those utilising other feedstocks (in fact they could be one and the same plant in the case of thermochemical conversion plants).

Table 12. Number of advanced biofuel plants that would be supported by the available resource and temporary FTE's created during plant construction

Feedstock type	**Fuel chain**	**Number of plants supported (300 ktpa thermochem, 150 ktpa biochem)**		**Temporary FTE's involved in plant construction (thousand)**	
	Feedstock potential:	low	high	low	high
Agricultural residues	Biochem ethanol	74.07	99.31	74.07	99.30
	Themochem drop in	41.67	55.86	41.66	55.86
Forest harvest residues	Biochemical ethanol	31.30	62.60	31.29	62.60
	Themochemical drop in	17.59	35.18	17.59	35.18
Refuse derived fuel	Themochemical drop in	27.36	35.28	27,35	35.28
Total	biochemical ethanol			105.37	161.91
	thermochemical			86.62	126.32

It was calculated that utilising all of the identified available waste residues could generate between 15.8 and 24.3 million tonnes of bioethanol (equivalent to 3-7% of EU road transport energy demand), or 21.8 to 32.6 million tonnes of FT biodiesel (equivalent to 8-11% of EU road transport energy demand). This is assuming all of the identified resource could be collected, with little or no competition from other potential energetic uses of biomass.

In reality there will inevitably be competition from different energetic uses, and reasons why some material cannot be accessed, therefore the 'real' potential will be smaller than these maximum values.

The development of an industry at these maximum values would create between 56 and 133 thousand new jobs in the rural economy in the agricultural and forestry sectors. In the case of collection of agricultural residues, much of this would be seasonal during the autumn field collection phase.

In addition, it is estimated that this would create between 4,300 and13,000 new jobs in the operation of the biofuel plants, dependant on resource availability. This includes creating between 1,300 and 2,800 additional jobs in the biofuel from RDF waste processing plants. These job numbers would be affected by the optimum plant sizes actually adopted.

A further 87,000 to 162,000 temporary jobs would be created during the construction phase, typically 2-3 years. In both cases, many of these would be high value technical jobs, delivering higher than average wages.

In total if all the available resource could be utilised, this would create between 147,000 and 307,000 additional full time jobs in the EU, 38-43% of which would be primarily in the rural community and associated logistics companies.

These represent only the direct employment associated with feedstock collection, transport and processing. Additional indirect employment would flow though machinery suppliers, fuel suppliers and other ancillary industries and through training and development and other support services, significantly increasing the overall impact in the EU.

8 Revenue flows to the rural economy

If all the available sustainable agricultural and forest harvest resource could be utilised at the range of resource prices identified (€40-80/tonne for agricultural residues[18] and €40-65/tonne for forest harvest residues) then between 1.6 and 9.7 billion euros could flow into the European rural economy, depending on the amount of sustainable resource that could be accessed. This would flow back through the whole feedstock supply chain, including the supporting logistics operators, machinery suppliers and contacted equipment suppliers etc.

The development of waste to energy plants, and the likely impacts on the market value placed on waste-derived feedstocks could help to reduce the costs for waste processors, when compared to the increasing costs of disposal by use of landfill,

[18] It was assumed that agricultural residues available at €30-39/tonne failed to recognise the replacement fertiliser value of the resource

helping to stimulate the development of such facilities more widely, improving waste recycling and re-use rates.

Table 13. Revenue to the rural economy

	Resource (million tonnes)		Total value (€ millions)		Net value (€ million)	
Feedstock potential:	low	high	low	high	low	high
resource price:			low	high	low	high
Agricultural Residues	91	122	3640	9760	273	5246
Forest harvest residues	40	80	1600	5200	720	2340

It is more difficult to ascertain the net revenues that would flow back to individual land owners, but if the costs of replacement fertiliser and transport are accounted for and assuming all labour and costs for straw collection are borne by the land owner then a net of between 0.2 and 5.2 € billion would flow into the EU's rural agricultural economy annually. Accepting the data presented earlier on forest cost breakdown (Figure 3) up to 45% of the resource value is earned by forest owners and those harvesting the material. In this case the net return to the EU's rural forest economy would be between 0.7 and 2.3 billion €. This represents total net revenue to agriculture and forestry land owners of between 0.9 and 7.5 billion Euros.

9 Concluding remarks

This analysis highlights that it is feasible to develop a biofuel industry based on use of agricultural and forest residues as these would require little (in the case of the cheapest available sources) or only a modest additional incentive to stimulate production of biofuels with no land use change impacts at a price comparable to that capable of being delivered by current biofuel technologies using crop feedstocks.

Similarly refuse derived biofuels could be a cost competitive source of such biofuels as long as feedstocks continue to attract gate fees or are available at little or no cost. However, some support would be required to compensate for the lower returns anticipated for the fossil-derived co-produced fuels. Until such fossil co-product fuels are produced at scale and their market value is more clearly identified it is difficult to clearly quantify how much additional support would be required to stimulate commercial development. Current business plans in this segment are based on the RDF-derived fuel output being sold wholesale into the transport fuel market, with the requirement for double reward on the renewable component to make it economically feasible (i.e. assuming a minimum of 50% renewable carbon content). Such support would also promote the development of more efficient waste processing facilities to increase the biobased content of waste streams that can be separated and screened for use in refuse derived low-carbon fuels, with potential to improve the GHG saving of the resulting fuels.

Utilising all of the available identified waste and residue resource has potential to deliver against a significant proportion of EU fuel energy demand, up to 11% of current EU fuel demand was estimated in this study. However this is clearly an over estimate and in actuality will be significantly less due to difficulties in accessing and mobilising the whole resource identified at reasonable cost.

In terms of where uptake is more likely to occur, other studies have attempted to identify on a more regional basis where surplus straw resources exist, for example see Figure 10 derived from the Renew project (14).

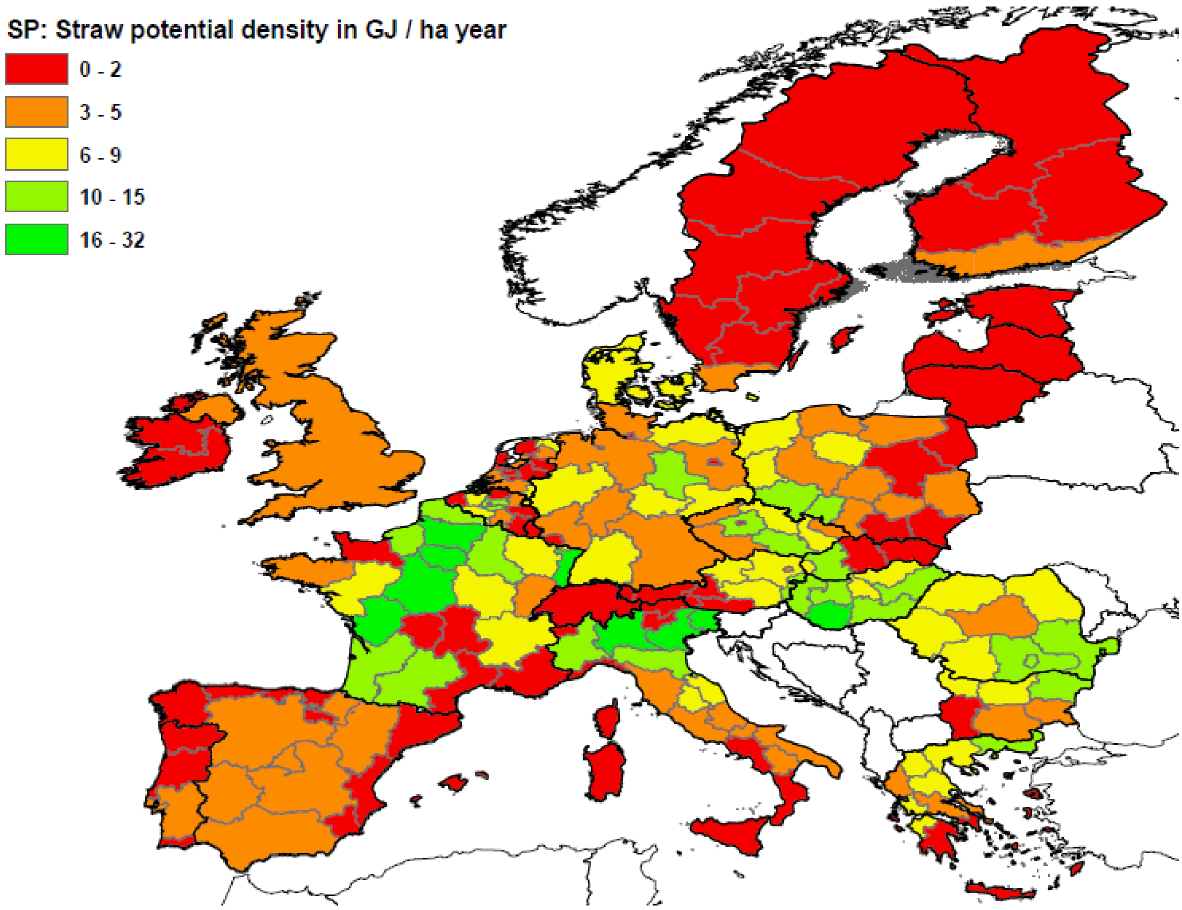

Figure10. Agricultural residue potential in GJ/year/ha of land area (Source: Renew project Final Report 2008 "Renewable fuels for advanced powertrains" (14))

This identifies the high agricultural straw resource concentrations in central, Eastern and Northern Europe.

The EuWood (21) and Biomass Futures[19] projects have analysed the regional potential for forest harvest residues, demonstrating the very high potential resource levels in Northern Europe, but also the widespread lower resource availability throughout Central and Southern Europe (Figure 11).

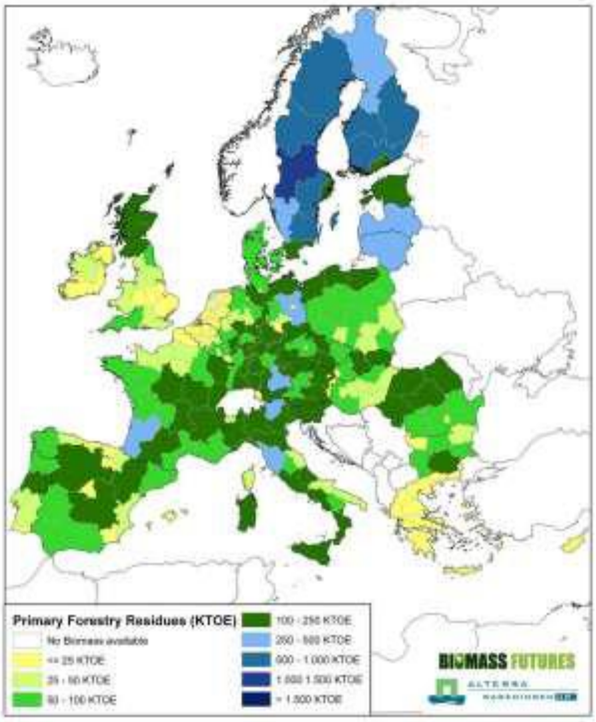

Figure 11. Forest harvest residue resource in EU (as KTonne Oil Equivalent)

Clearly such concentrations in both cases indicate where advanced fuel biorefinery developments are more likely to be sited, focusing on large volumes of localised supply.

While utilising all of the available resource may be optimistic, achieving just 2% of current EU road transport fuel use would secure up to an additional 38,000 permanent jobs in the rural economy and 3,700 more in biofuel refineries, with the potential to return up to €1.1 - 2.4 billion in net revenues to the agricultural and forestry sectors.

19 http://www.biomassfutures.eu/public_docs/final_deliverables/WP3/D3.3%20%20Atlas%20of%20technical%20and%20economic%20biomass%20potential.pdf

10 Annex 1 – Fertiliser value of agricultural residues

The fertiliser value of agricultural residues was calculated based on typical reported nutrient content and the cost of fertiliser required to replace the nutrients removed in a tonne of fresh straw.

Table 14. Fertiliser value of agricultural residues

Straw type	Nutrient	Typical nutrient content in fresh weight straw (kg/t straw)	Value of individual nutrients (€/kg)	Fertiliser value of nutrients contained in 1 tonne of fresh straw (€)	Total nutrient value/tonne of fresh straw (€)
Wheat	P_2O_5	1.2	0.97	1.17	
	K_2O	9.5	0.93	8.83	11.09
	MgO	1.3	0.84	1.09	
Barley	P_2O_5	1.5	0.97	1.46	
	K_2O	12.5	0.93	11.62	14.09
	MgO	1.2	0.84	1.01	
Maize	P_2O_5	1.2	0.97	1.17	
	K_2O	6.8	0.93	6.32	9.30
	MgO	2.16	0.84	1.81	

Sources of data

Nutrient content of wheat and barley straw (22)

Fertiliser prices (2)

Corn stover potash and magnesium content (23)

Corn stover phosphate content (24)

11 Annex 2 – Examination of optimum scale of biofuel plant

Biochemical ethanol

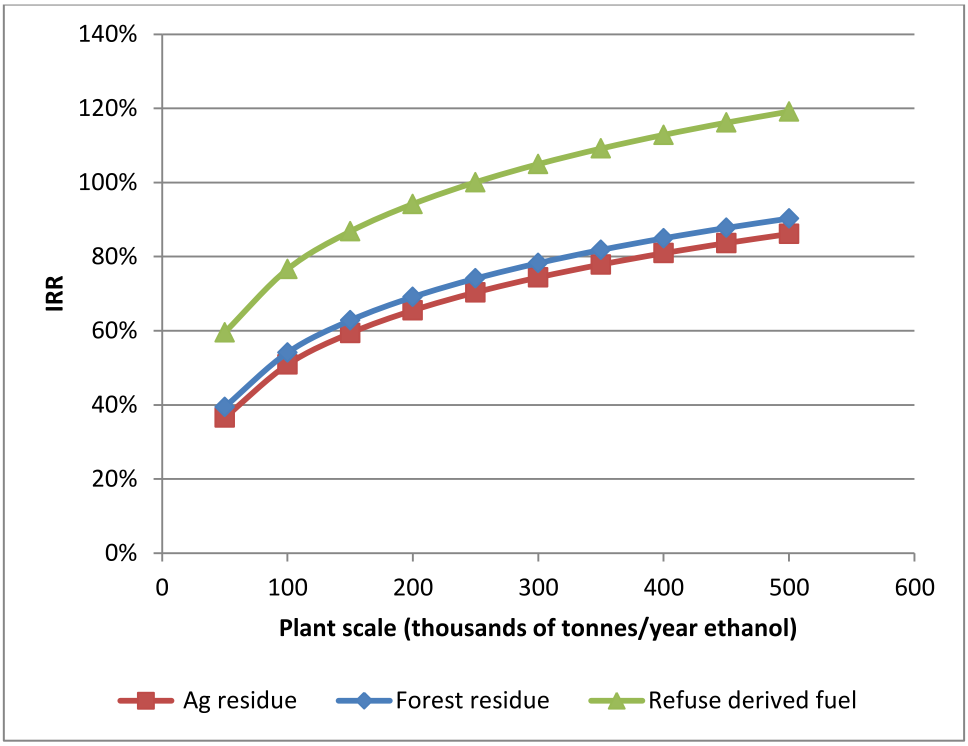

Figure 12. Impact of plant scale on IRR for cellulosic bioethanol plant

- Includes 0.47€/litre subsidy for ethanol
- Agricultural residues £28/t at farm gate plus 100km transport to plant
- Forest residues at £28/t at forest edge and 100km transport to plant
- Refuse derived fuel at gate fee of £38/tonne delivered (with no inflation for gate fee)

Thermochemical & biochemical ethanol

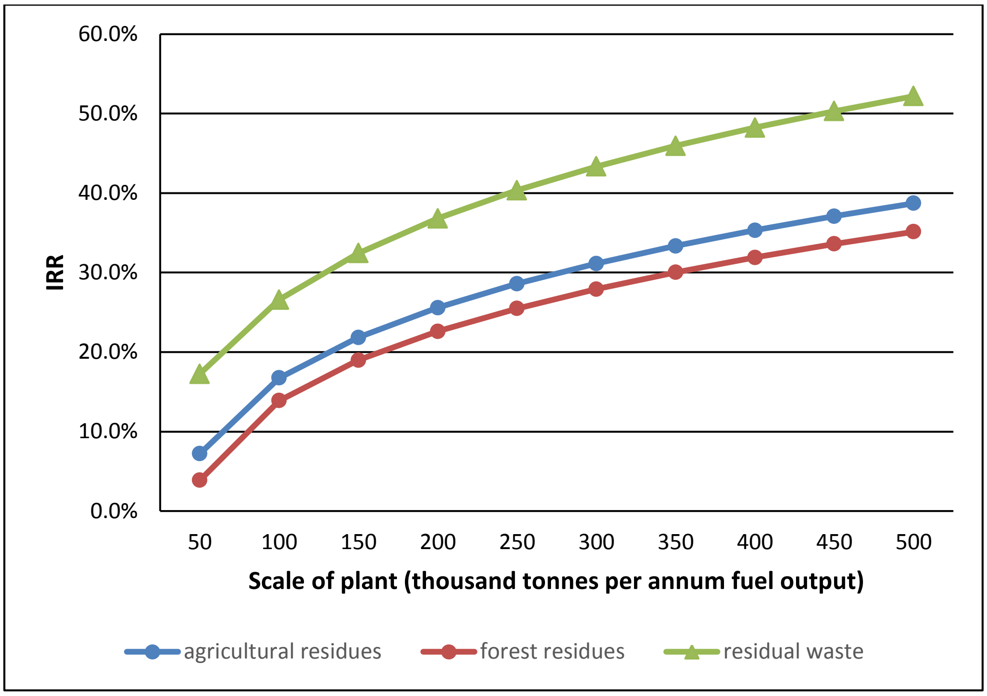

Figure 13. Impact of plant scale on IRR for syngas fermentation to bioethanol plant

- Includes 0.47€/litre subsidy for ethanol
- Agricultural residues £28/tonne at farm gate plus 100km transport to plant
- Forest residues at £28/tonne at forest edge and 100km transport to plant
- Refuse derived fuel at gate fee of £38/tonne delivered (with no inflation for gate fee)

Thermochemical FT diesel

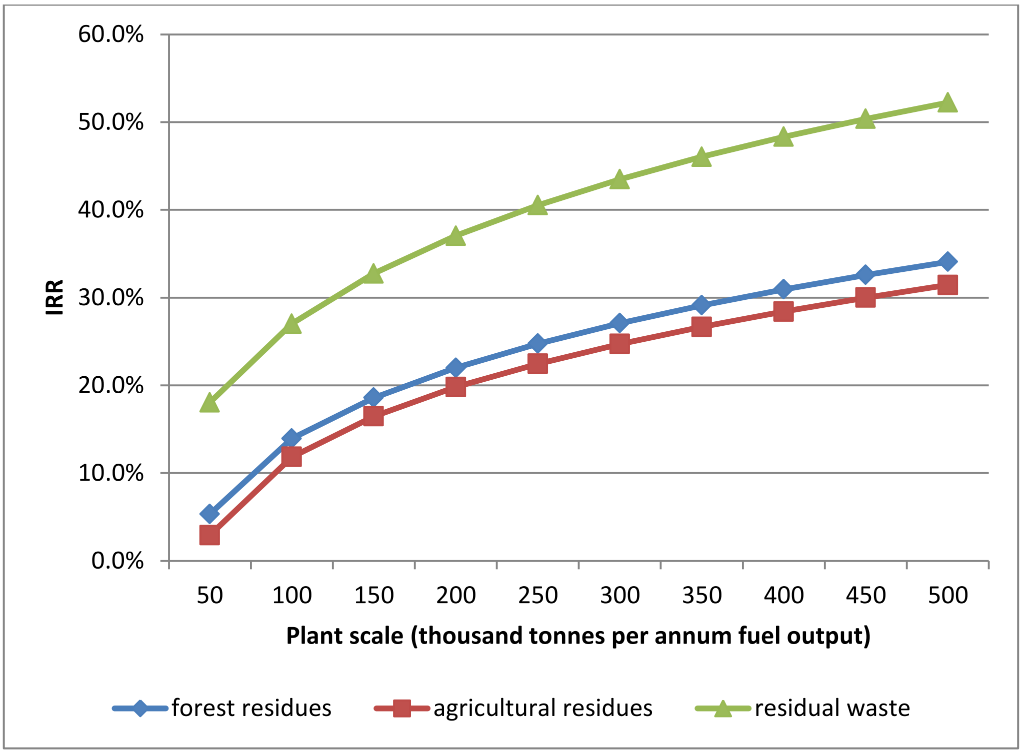

Figure14. Impact of plant scale on IRR for syngas to FT diesel plant

- Includes 0.47€/litre subsidy for ethanol
- Agricultural residues £28/t at farm gate plus 100km transport to plant
- Forest residues at £28/t at forest edge and 100km transport to plant
- Refuse derived fuel at gate fee of £38/tonne delivered (with no inflation for gate fee)

12 Annex 3 – Modelled impacts of feedstock price (€/GJ) on the additional incentive (€/litre biofuel) required to deliver project IRR's of 10-20% for advanced biofuel processes

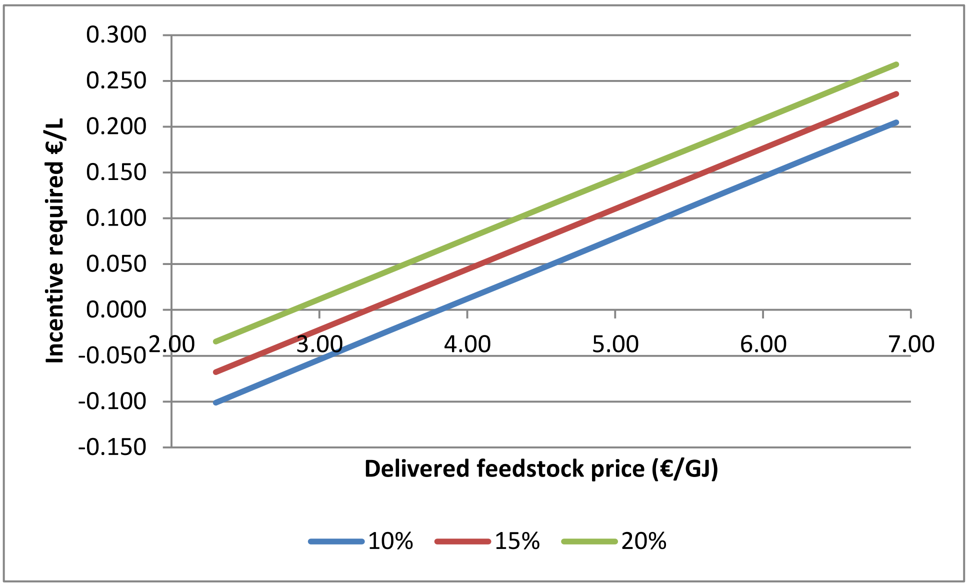

Figure 15. Effect of virgin biomass feedstock price €/GJ on the incentive required over and above the anticipated base fuel ethanol market price, to deliver project IRR's of 10, 15 or 20% for a 150 tpa biochemical ethanol plant

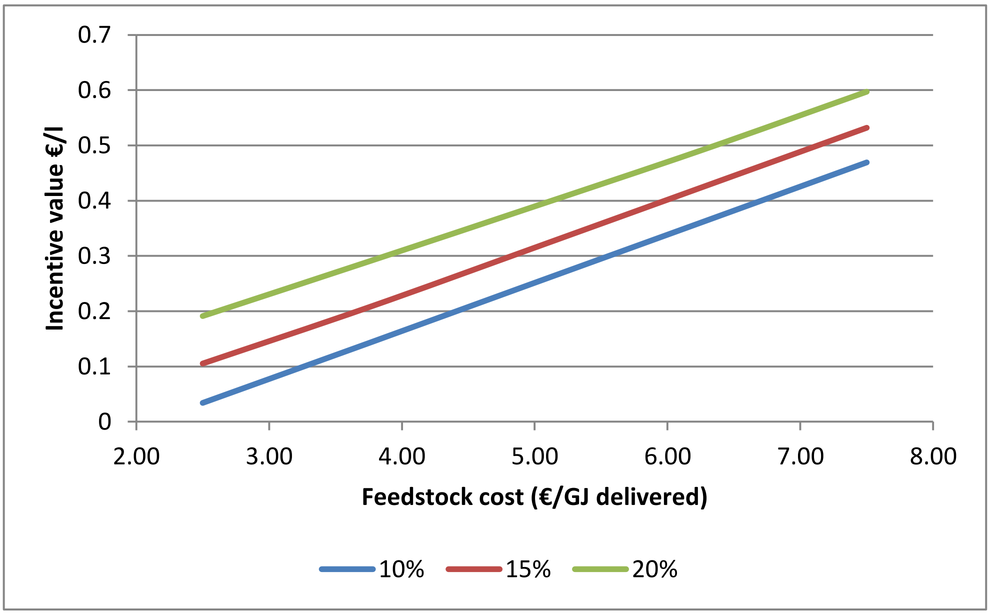

Figure 16. Effect of virgin biomass feedstock price (€/GJ) on the incentive required over and above the anticipated base fuel ethanol market price, to deliver project IRR's of 10, 15 or 20% for a 300 tpa thermochemical and biochemical ethanol plant

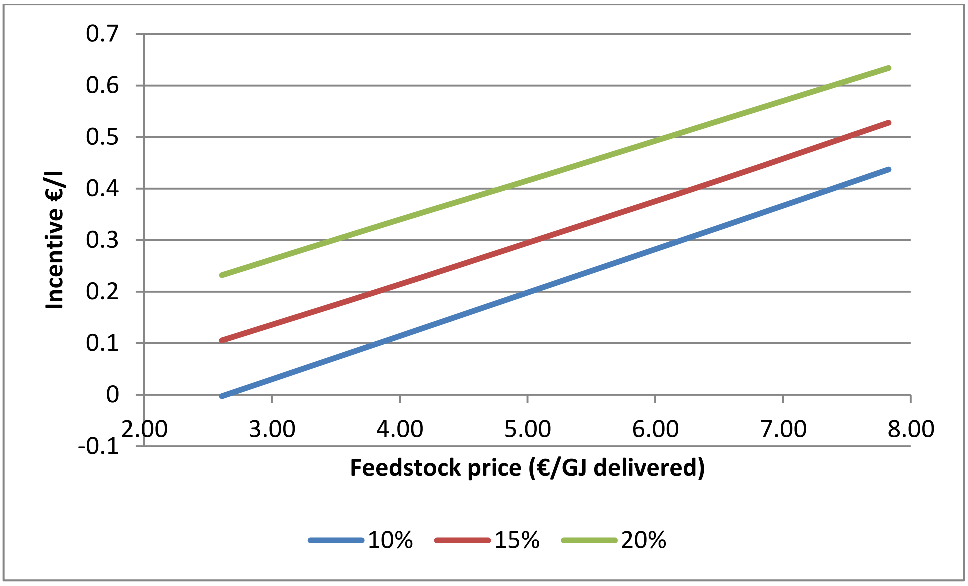

Figure 17. Effect of virgin biomass feedstock price (€/GJ) on the incentive required over and above the anticipated base market price for synthetic diesel fuel to deliver a project IRR of 10, 15 or 20% for a 300 tpa thermochemical FT diesel plant

13 Annex 3 – Modelled impacts of waste gate fee (€/GJ) on the additional incentive (€/litre biofuel) required to deliver project IRR's of 10-20% for advanced biofuel processes

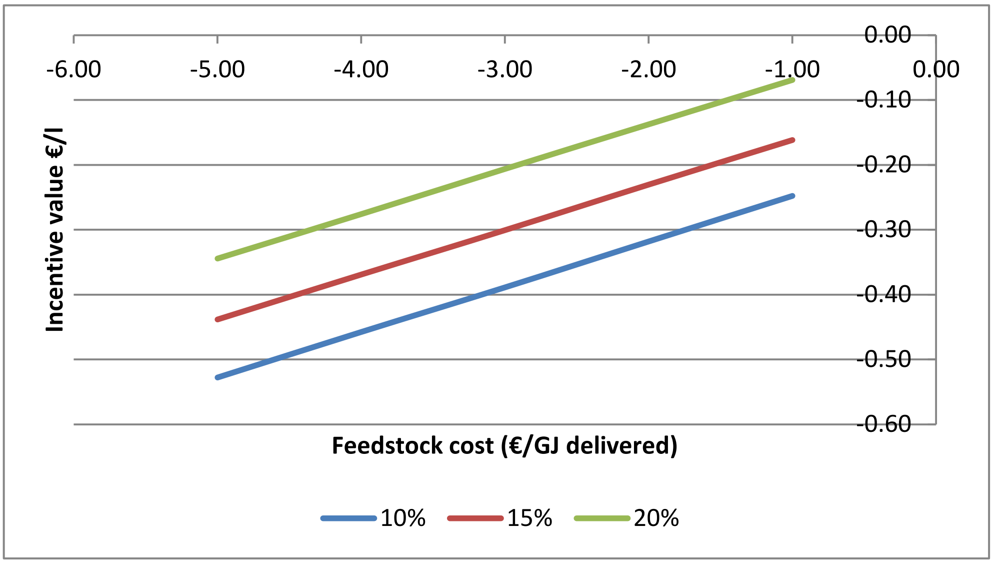

Figure 18. Effect of waste gate fee (€/GJ) on the difference in the price of bioethanol produced, relative to the anticipated base fuel ethanol market price, required to deliver project IRR's of 10, 15 or 20% for a 300 tpa thermochemical and biochemical ethanol plant

Figure 19. Effect of waste gate fee price (€/GJ) on the difference in the price of synthetic diesel, relative to the anticipated base market price, required to deliver project IRR's of 10, 15 or 20% for a 300 tpa thermochemical FT diesel plant.

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