Title	Potential to Increase Indigenous Biodiesel Production to help meet 2020 Targets - An EU perspective with a focus on Ireland
Authors(s)	Murphy, Fionnuala, Devlin, Ger, Deverell, Rory, McDonnell, Kevin
Publication date	2014-07
Publication information	Murphy, Fionnuala, Ger Devlin, Rory Deverell, and Kevin McDonnell. “Potential to Increase Indigenous Biodiesel Production to Help Meet 2020 Targets - An EU Perspective with a Focus on Ireland.” Elsevier, July 2014. https://doi.org/10.1016/j.rser.2014.03.046.
Publisher	Elsevier
Item record/more information	http://hdl.handle.net/10197/5671
Publisher's statement	This is the author’s version of a work that was accepted for publication in Renewable and Sustainable Energy Reviews. Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in Sustainable Energy Reviews (VOL 35, ISSUE 2014, (2014)) DOI:10.1016/j.rser.2014.03.046
Publisher's version (DOI)	10.1016/j.rser.2014.03.046

Potential to Increase Indigenous Biodiesel Production to help meet 2020 Targets – An EU perspective with a focus on Ireland.

Fionnuala Murphy[1], Ger Devlin[1*] Rory Deverell[2] and Kevin McDonnell[1]

[1]School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

[2]R&H Hall, La Touche House, Custom House Dock, IFSC, Dublin 1, Ireland

[*]Email of corresponding author: ger.devlin@ucd.ie

Tel +353 1 716 7418. Fax +353 1 716 7415

Abstract

The biofuels penetration rate target in Ireland for 2013 is 6% by volume. In 2012 the fuel blend reached 3%, with approximately 70 million litres of biodiesel and 56 million litres of ethanol blended with diesel and gasoline respectively. For January and February 2013, the blend rate had only reached 2.7%. The target of 10% by 2020 remains which equates to approximately 420 million litres. Achieving the biofuels target would require 345 ktoe by 2020 (14,400 TJ). Utilising the indigenous biofuels outlined in this paper leaves a shortfall of approximately 12,000 TJ or 350 million litres (achieving 17% of the 10% target) that must be either be imported or met by other renewables. 70% of indigenous production from one biodiesel plant is currently from TME and UCOME. If this remains for 2020 then only 30% remains equating to approximately 10 million litres indigenous production for a second biodiesel plant (30% of 21+13 million litres) which has planned capacity of 40 million litres (36 000 tonnes). In terms of the EU biofuels sustainability criteria, up to 2017, a 35% GHG emissions reduction is required compared to fossil fuels. From 2017 onwards, a 50% GHG reduction is required for existing installations and a 60% reduction for new installations.

Keywords; Biodiesel; indigenous production; Ireland resource; 2020 targets

1 Introduction

1.1 EU Biofuel Targets

In 2007, the European Union agreed new climate and energy targets- 20-20-20 by 2020 – 20% reduction in greenhouse gas emissions; 20% increase in energy efficiency and 20% of the EU's energy consumption to be from renewable sources by2020. The European Union supports the use of biofuels through two main directives: The directive on the promotion of the use of biofuels and other renewable fuels for transport (2003/30/EC) [1], also known as the biofuels directive, and the Renewable Energy Directive (2009/28/EC) [2].

1.1.1 The Biofuels Directive

The Biofuels directive entered into force in May 2003 and is primarily concerned with the promotion of the use of biofuels in the transport sector. Each member state was required to replace 5.75% of all transport fossil fuels with biofuels by 2010. The directive also set an intermediate target of 2% by December 2008. The Irish Government White Paper committed to achieving 5.75% of road and rail transport energy from renewable sources by 2010 [3] but this was later revised to 3% [4].

1.1.2 The Renewable Energy Directive (RED)

The European Union has committed to reduce greenhouse gas emissions under the Kyoto Protocol [5]. In order to reach the 8% binding target on 1990 levels between 2008 and 2012 and to develop a sustainable energy plan for Europe, a renewables directive came into force in 2009. The directive outlines targets to be achieved by 2020; 20% of total energy to come from renewable sources, a 20% reduction in GHG emissions and a 20% increase in energy efficiency [6]. Each member state was assigned specific targets in order to achieve the overall target. Ireland's target is set at 16% by 2020 [2]. A 10% target is set for all member states to be achieved in the transport sector from renewable sources. Due to concerns regarding food security and land use change, the European Commission decided to limit the contribution of food-based biofuels to 5% of the overall transport target [7]. Any fuel above this target must not be based on food crops. The directive also outlined sustainability criteria for biofuels that monitor how and where they are produced. All biofuels must achieve at least 35% GHG emissions reduction by 2017 in comparison to conventional fossil fuels. These factors are further discussed in the section 'Policy constraints' below.

1.2 National Biofuel Targets

The government first outlined its commitment to reaching the 2020 targets in the Government White Paper on Energy in 2007 [3]. It set national targets, in line with the EU targets, committing to a 20% target to be achieved across all energy sectors by 2020. In the transport sector renewables would account for 5.75% of all road transport by 2010 and 10% by 2020. The National Climate Change Strategy 2007 to 2012, set out further measures in which Ireland would meet its Kyoto commitments and enable Ireland to meet the 2020 targets [8]. A national biofuels obligation was set at 5% by 2010 for all fuel suppliers [3]. However in 2008 it was lowered to 4% by 2010 due to concerns with the impact of biofuels on food prices [9].

According to the NORA statistics, only 2.2% target was met in 2010. The fuel blend reached 3% in 2012. In 2012, approximately 70 million litres of biodiesel and 56 million litres of ethanol were blended with diesel and gasoline respectively [10].

The Irish government outlined its commitment to sustainable energy production in the publications mentioned above and it introduced various policy support schemes and mechanisms.

1.2.1 Mineral Oil Tax Relief Scheme (MOTR)

The Mineral Oil Tax Relief Scheme (MOTR) was introduced in 2005 and granted motor tax relief to approved biofuel suppliers. It was designed to incept a national biofuels industry by offering tax incentives whereby producers could sell the biofuels without excise duty, thus making it cheaper than the conventional fossil fuel alternative. This was mostly targeted towards captive transport fleets that their own fuel tanks on site or in the truck or bus depots. The total excise derogation would stand to the cost the tax payer €205 million. It was modified in 2006 and replaced by MOTR II and ran until 2010. As a scheme it failed to reach the desired results and outcome as; 1) Only 16 companies (mainly PPO projects) were granted a place in the scheme, with larger suppliers being favoured over smaller ones; 2) Many companies did not have facilities that were required to produce biofuels, thus although they were under the scheme, they did not produce anything; 3) changing market conditions and the availability of cheaper imported alternatives made it difficult to compete in the commercial market. The uptake of MOTR II was slow, with less than 28% of the relief used by the end of 2009 [4]. Although this scheme was always going to be temporary, and the sector would have had to survive on its own in the commercial market, without the exemption from the excise duty, producing biofuel at competitive market prices is proving difficult.

1.2.2 Biofuels Obligation Scheme 2010

In 2010 when MOTR II scheme ended, the Biofuels Obligation Scheme was introduced. A subsidy scheme was replaced by an obligation scheme, under which all road transport fuel suppliers are obliged to use biofuel in the fuel mix (4 litres of biofuel in every 100 litres of transport fuel) to ensure that a certain percentage is represented in the annual sales [11]. The scheme is administered by the National Oil Reserve Administration (NORA). The starting penetration rate is 4% per annum and will be increased over time. If a supplier fails to meet his obligations (does not provide enough certificates), a penalty of 40 or 45 cent per litre must be paid [11]. The share of transport energy from biofuels has increased from 1 ktoe in 2005 (0.03%) to 92 ktoe in 2010 (2.4% in energy terms) [12].While this scheme has so far increased the use of biofuels, it has not necessarily increased the production of indigenous biofuels as pre-blended fuels are imported at more competitive prices. Overall the scheme has resulted in major fuel companies bypassing smaller indigenous producers. Furthermore, the value of the biofuel certs issued to biofuel producers cannot be determined until the end of the year [13].

1.2.3 Vehicle registration and annual motor tax change

Under the Kyoto Protocol, Ireland is legally bound to meet its set target of 13% reduction in GHG emissions above 1990 levels in the period 2008 to 2012 [14]. Transport is the largest CO2 emitting sector, in 2010 CO2 emissions were 129% higher than in 1990 (4.2% average annual growth rate), falling for the first time in 2008 by 1.8%. In the 2008 Budget it was announced that the vehicle registration (VRT) and annual motor tax (AMT) systems would base the tax rates on the specific CO2 emissions (grams of CO_2 per kilometre – g/km) rather than engine size. This incentive came into effect in July 2008 and is aimed at encouraging the consumer to purchase more fuel efficient vehicles with lower GHG emissions [14].

1.3 Policy constraints

1.3.1 EU Sustainability criteria

The increased use of biomass for biofuel production has led to concerns regarding the sustainability of this practice. Concerns surround the methods of cultivating and producing biofuels, particularly in regard to actual greenhouse gas emissions reductions in comparison with fossil fuels, and in concerns with land use change due to increased demand for arable land for biomass production. In order to ensure the sustainability of biofuel used to achieve the targets in the EU, the European Commission proposed a set of sustainability criteria in the Directive 2009/28/EC on the promotion of the use of energy from renewable sources. The sustainability criteria consist of the following main points [2]:

- The directive lays out certain greenhouse gas emissions reductions to be achieved from the use of biofuels. In the case of biofuels and produced by installations that were in operation on 23 January 2008, GHG emissions savings must be at least 35% from 2013. This figure rises to 50% in 2017, and further to 60% for biofuels produced in installations in which production started on or after January 2017.

- The raw materials sourced for biofuel production, from within the EU or from third countries, should not be obtained from land with high biodiversity value, land with a high carbon stock, or land that was peatland in 2008.

These criteria, while undoubtedly good for the sustainable production of biofuels, may restrict growth of the biofuel production industry in Ireland as biofuels must meet certain minimum criteria.

1.4 Proposed indirect land-use change (iLUC) directive

Recent concerns have developed that rising demand for feedstocks for biofuel production has resulted in increased indirect land-use change. iLUC is the phenomenon by which crops grown to make biofuels indirectly generate additional greenhouse gas emissions due to clearing of other land (especially forested land) to grow food crops. As EU biofuel policies require increasingly vast amounts of biomass, the iLUC effects of these policies are likely to be considerable.

On 17th October 2012, the European Commission published a proposed methodology to address iLUC. The aim of the proposed directive is to limit global land conversion for biofuel production, and raise the climate benefits of biofuels used in the EU. The use of food-based biofuels to meet the 10% renewable energy target of the Renewable Energy Directive will be limited to 5% [7].

The proposal aims to;

- Limit the contribution that conventional biofuels (with a risk of ILUC emissions) make towards attainment of the targets in the Renewable Energy Directive to 5%
- Improve the greenhouse gas performance of biofuel production processes (reducing associated emissions) by raising the greenhouse gas saving threshold for new installations subject to protecting installations already in operation on 1st July 2014
- Encourage a greater market penetration of advanced (low-ILUC) biofuels by allowing such fuels to contribute more to the targets in the Renewable Energy Directive than conventional biofuels.

- Feedstocks whose contribution towards the targets shall be considered to be twice their energy content include;
    - Used cooking oil.
    - Animal fats classified as category I and II in accordance with EC/1774/2002 laying down health rules concerning animal by-products not intended for human consumption.
    - Non-food cellulosic material.
    - Ligno-cellulosic material except saw logs and veneer logs.
- Feedstocks whose contribution towards the targets shall be considered to be four times their energy content include;
    - Algae
    - Biomass fraction of mixed municipal waste, but not separated household waste
    - Biomass fraction of industrial waste
    - Straw
    - Animal manure and sewage sludge
    - Palm oil mill effluent (POME) and empty palm fruit bunches
    - Tall oil pitch
    - Crude glycerine
    - Bagasse
    - Grape marcs and wine lees
    - Nut shells
    - Husks

Table 1 illustrates the estimated GHG emissions from land use change which will be added to the GHG emissions calculated for biofuel production using these feedstocks for the purposes of complying with the RED. The addition of these GHG emissions will compromise the ability of these conventional biofuels to meet the emissions reduction required by the RED.

Table 1 – Estimated indirect land-use change emissions from biofuel and bioliquid feedstocks Biodiesel Feedstocks [7]

Feedstock group	Estimated indirect land-use change emissions (gCO_2-eq/MJ)
Cereals and other starch rich crops	12
Sugars	13
Oil crops	55

Tallow and recovered vegetable oil (RVO) or used cooking oil (UCO) are two commonly used feedstocks for biodiesel production in Europe. The high calorific values of these feedstocks make them ideal for use as biodiesel.

Tallow refers to the inedible animal fats produced as a by-product to the slaughtering industry and produced by the rendering process. Recovered vegetable oil is a waste product of the food industry. Tallow has traditionally been used in producing animal feed however; EU regulations have come in to force restricting its use. As such, use of tallow for biodiesel production offers an alternative disposal route for producers to deal with any surplus. As both RVO and tallow can be classified as waste products, providing alternative uses for these feedstocks will result in less risk of surpluses being dumped illegally and will minimise high waste disposal fees.

Oilseed rape, a crop grown for its high oil yield, is one of the primary feedstocks or biodiesel production in Ireland.

1.5 Saturated fatty acid (SFA) content

In biodiesel production one mole of triglyceride reacts with three moles of alcohol (molar ratio of methanol to vegetable oil of 3:1) to form one mole of glycerol and three moles of the respective fatty acid alkyl esters [15]. There are two types of fatty acids, saturated (SFA), and unsaturated fatty acids. Fatty acids that have no double bonds are termed ‘saturated’, these fatty acid chains contain the maximum number of possible hydrogen atoms per atom of carbon. Stearic acid is an example of a saturated fatty acid. Fatty acids that have double bonds are termed unsaturated. Linoleic acid is an unsaturated fatty acid [16]. The fuel properties of biodiesel, such as cetane number, cold flow, viscosity and oxidative stability, are influenced by the fatty acid profile of the biodiesel. In general, the cetane number, heat of combustion and melting point decrease with increasing saturation [17]. Cold flow properties of biodiesel are influenced by the SFA content, biodiesels with high SFA content exhibit poor cold flow behaviour [18]. Tallow methyl ester (TME) and used cooking oil methyl ester (UCOME) tend to have a higher content of saturated fatty acids than virgin vegetable oil biodiesel [19].

1.6 Free fatty acid content

Waste fats and oils can contain low to moderate quantities of free fatty acids (FFA) which can affect conversion to biodiesel. Animal fats naturally contain 5–30% FFAs and RVO contains 2–7% FFAs and respectively [20]. The presence of high FFAs in the feedstocks causes difficulty in processing to biodiesel. During transesterification, high FFA feedstocks easily undergo saponification reaction leading to soap formation. Soap formation results in reduced biodiesel yields, in particular when alkaline catalyst is used [21]. However, it is reported that this can be minimised through the utilisation of alternative processing techniques using heterogeneous catalysts such as solid and enzyme catalysts [22].

1.7 Transesterification methods

The choice of technology employed in biodiesel production is generally dependant on the FFA content of the oils [22]. Transesterification reactions can be carried out without a catalyst, or can be catalysed using alkali-catalysis, acid-catalysis or enzyme-catalysis. Alkali-catalysed trans-esterification is faster and is most commonly used than acid-catalysis commercially due to its high conversion yield of 98% [23]. Alkali-catalysed trans-esterification is also the most economical process as it utilises low temperatures and pressures to achieve a high yield [24].

1.8 Pre-treatment

For oils and fats with high FFA content, a pre-treatment step is recommended. Pre-treatment involving neutralisation or an acid catalysed pre-esterification integrated with water separation, can be used to reduce FFA content prior to alkali trans-esterification [24]. The most commonly utilised method for lowering the FFA content of oils is neutralisation (also known as caustic deacidification). Neutralisation lowers the FFA, along with substantial quantities of mucilaginous substances, phospholipids and colour pigments [26]. An alkali is added to the oil and precipitates the FFA as soap stock which is then removed by mechanical separation from the neutral oil. However, for oils with more than 5% of FFA, neutralization causes high losses of neutral oil due to saponification and emulsification [26].

1.9 Acid-catalysed processes for high FFA feedstocks

Acid catalysed transesterification is suitable for biodiesel production from waste oils and fats due to its tolerance to high FFA and water contents [22]. The reaction can produce high yields (over 90%), however, a drawback is the long reaction time of 1 to 8 hours, compared to 30 minutes for alkali-catalysed reactions [27]. In addition, the corrosive nature of the catalyst (commonly H_2SO_4), can lead to corrosion in the reactor and pipelines [16]. Due to the negative aspects of the acid-catalysed reaction, alkali-catalysed reactions are favoured and as such, the combination of pre-treatment and alkali-catalysed trans-esterification is common.

1.10 Alternative trans-esterification methods for high FFA feedstocks

Enzymatic catalysis is an alternative method to acid or alkali-catalysed reactions which can be utilised for trans-esterification of high FFA feedstocks, as it is insensitive to both high FFA and water contents. The trans-esterification process is catalysed by different lipases such as Candida, Pseudomonas sp., Pseudomonas cepacia, Candida rugasa, Rhizomucor miehei and immobilized lipase [22]. Enzymes can catalyse both esterification of FFA and transesterification of triglycerides, as such the FFA contained in waste oils and fats can be completely converted to biodiesel [28]. Enzymatic catalysis allows easy recovery of biodiesel and glycerol, easy separation and re-use of enzymes, and no soap formation in the system [28]. The reaction can be carried out at low temperature and pressure which reduces energy consumption and as such improves environmental performance [29]. A limiting factor on the implementation of enzymatic catalysis is their sensitivity to alcohol, typically methanol, that can cause enzyme deactivation [16,30]. Another drawback is the high cost of enzyme production [31].

The supercritical methanol method represents a possibility for biodiesel production from waste oils and fats as it is not sensitive to high FFA or water contents. It is a non-catalytic reaction, using alcohol (typically methanol) under supercritical conditions at high temperatures and pressures [22]. Free fatty acids in the oil or fat are trans-esterified simultaneously in the supercritical methanol method [32]. The reaction time is low at 12.5 to 50 minutes required [33]. The elimination of the pre-treatment step and soap and catalyst removal can reduce costs, however the expected high operation costs due to the requirement for high temperature and pressure may represent a disadvantage.

Figure 1 shows the effects of different production technologies on the yield of methyl esters from various triglycerides containing varying FFAs contents.

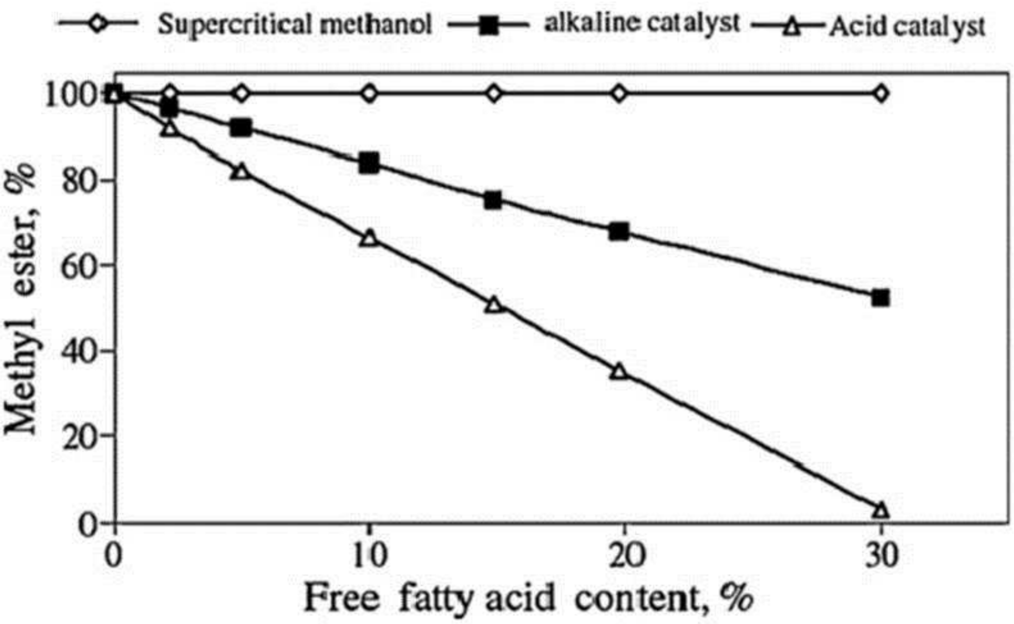

Figure 1 - Yields of methyl esters as a function of FFAs content in the transesterification of triglycerides [22]**.**

Table 2 outlines a number of studies dealing with high FFA content tallow and UCO [34]. The table shows that most of these processes produce over 90% biodiesel yield and as such are suitable for biodiesel production. However, the yield from utilising alkaline catalysis in a one-step process is low at 34.5% so does not represent a viable technology.

Table 2 – Processing conditions and biodiesel yield from Tallow and UCO [34]

	Alkaline catalysis (one-step) [35]	**Acid, alkaline catalysis (two-step)** [36]	**Acid catalysis (one-step)** [37]	**Supercritical methanol** [37]	**Lipase catalysis** [38]
Feedstocks	Tallow	Tallow	UCO	UCO	UCO
% FFA in feedstock	20	9	5.6	5.6	8.5
Process temperature (°C)	55	60	65	350	50
Process pressure (MPa)	0.1	0.1	0.1	43	0.1
Catalyst used	KOH	H_2SO_4	$H_2SO_4.NaOCH_3$	No	Immobilized lipase PS-30
Residence time	1 h	48 h	1 h, 1 h, 8 h[a]	4 min	18 h
Biodiesel yield (%)	34.5	97.8	90.2	96.9	94

[a] Two stages of pretreatment by acid-catalyzed esterification with residence time of 1 h each and 8 h for alkaline-catalyzed trans-esterification.

1.11 Biodiesel properties

Fuels are required to meet certain fuel specifications to ensure adequate performance in spark and compression combustion engines. When these specifications are met, biodiesel can be used in the most modern engines without any modification while maintaining the engines durability and reliability [39]. European standards include EN 590:2009 and EN 14214:2008. These standards specify property limits which marketable fuels must conform to. The standards also outline test procedures which are to be followed to accurately determine these properties for fuels.

The EN 14214:2008 standard specifies all necessary characteristics, requirements and test methods for marketable FAME to be used as automotive diesel fuels. Many of the test methods included in the standard were tested using FAME produced from vegetable oils available in the market at that time, i.e. rapeseed, palm, soy and sunflower oil. This standard is applicable to FAME to be used either as automotive fuel for diesel engines at 100% concentration, or as an extender for automotive fuel for diesel engines in accordance with the requirements of EN 590. At 100% concentration it is applicable to fuel for use in diesel engine vehicles designed or subsequently adapted to run on 100% FAME. Some important fuel properties include;

- Viscosity is defined in the International Standard EN 3104:1996 as "the resistance to flow of a fluid under gravity". Viscosity is a measure of a liquids resistance to internal displacement and flow. Since liquid fuels expand with temperature rise, intermolecular distances increase, and the viscosity falls. In a diesel combustion engine, the fuel is injected into the combustion chamber and is atomised into small droplets [39]. Viscosity is a key fuel property as it influences the atomisation of the droplets, affecting quality, size and penetration [40,41].
- Density is defined by the International Standard EN 3993:1996 as: "mass of the liquid divided by its volume at 15 °C or 20 °C, reported in units of mass and volume, together with the standard reference temperature; for example, kilograms per cubic metre at 15 °C for practical purposes, the apparent mass in air corrected for air buoyancy may be taken to represent the mass". Knowledge of density gives a broad indication of fuel type. For fuels of a known type, it serves as a general inspection check for the presence of contaminants [42]. It also influences the performance of pumps in fuel systems [43]. Biodiesel has a higher density than conventional diesel, thus as fuel injection equipment operates on a volume metering system, a slightly greater mass of fuel is delivered [44].
- The cold filter plugging point is defined in the International Standard EN 116:2009 as "the highest temperature at which a given volume of fuel fails to pass through a standardised filtration device in a specified time, when cooled under standardised conditions". The cold-filter plugging point is a key cold flow property for diesel [45]. Improvements in the low temperature properties of biodiesel can be achieved through the use of additives, esters other than methyl, or through modification of the fatty acid profile [44]. The cloud point is the temperature at which crystallisation in the fuel begins [46], while the pour point is the lowest temperature at which the fuel will pour [24,47].

- The cetane number is defined in the International Standard EN 5165:1998 as a "measure of the ignition performance of a diesel fuel oil obtained by comparing it to reference fuels in a standardized engine test". The cetane number is a dimensionless descriptor of the tendency of the fuel to self-ignite when the fuel is injected into the combustion chamber, the higher the cetane number, the more efficient the ignition [44]. The cetane number mainly depends on the composition of the fuel and can impact the engine's startibility, noise level, and exhaust emissions [48]. Biodiesel produced from feedstock containing long fatty acid carbon chains (high SFA), has a higher cetane number than from low SFA feedstocks [15].
- The iodine value is defined in the International Standard EN 14111:2003 as "the mass of halogen, expressed as iodine, absorbed by the test portion when determined in accordance with the procedure specified in this European Standard, divided by the mass of the test portion". The iodine value is a measure of total unsaturation within a mixture of fatty acids. The iodine value is expressed in grams of iodine which reacts with double bonds in a 100 g oil sample. The iodine value indicates the tendency of the biodiesel to oxidation. Biodiesel with high concentrations of unsaturated fatty acid chains, and therefore with high iodine numbers, is more susceptible to oxidative degradation [49].. The higher the iodine value the higher the level of unsaturation and the "softer" the oil and higher energy value.
- The acid value is defined in the International Standard EN 14104:2003 as "the number of milligrams of potassium hydroxide required to neutralise the free fatty acids present in 1 g of FAME". Acid value is a measure of the number of acidic functional groups in the biodiesel. High acid value in biodiesel may be caused by either high FFA content in the feedstock oil or by the quantity of acid added during transesterification [33,50,51]. Biodiesel with a higher acid value has a negative impact on the diesel engine [33]. In the case of oils with a high acid value, a pre-treatment step can be used to reduce the acid value. The pre-

treatment step consists of an acid catalyzed reaction with an alcohol in order to transform the free fatty acids into their corresponding esters [27].

Table 3: Properties of TME, UCOME and RME

	Biodiesel			
Fuel properties	**Tallow Methyl Ester**	**UCO Methyl Ester**	**Rape Methyl Ester**	**EU biodiesel standards**
Density (kg/L)	0.832[a]	0.897[d]	0.882[h]	0.86 - 0.90
Viscosity (mm^2/s)	4.89[a]	5.3[d]	4.46[h]	3.5-5.0
Cetane number	58.0[b]	54.5[e]	52.9[i]	>51.0
Cold filter plugging point (°C)	15[a]	2[f]	-11[h]	-
Pour point (°C)	9[c]	-4[f]	-15[j]	-
Cloud point (°C)	11[c]	2[f]	-7[h]	-
Acid value (mg KOH/g)	0.62[a]	0.55[g]	0.0.8[h]	<0.5
Iodine value	35[a]	97.46[g]	114[h]	<120

[a][52], [b][53], [c][54], [d][32], [e][55], [f][56], [g][57], [h][58], [i][59], [j][60]

1.12 Summary of commercial biodiesel operations

The European Union, with production of 10,710 million litres in 2011, is the main producer of biodiesel in the world. Biodiesel is also the most important biofuel in the EU, on a volume basis representing about 70 percent of the total biofuels market in the transport sector [61].

Table 4 illustrates biodiesel production in Europe from 2006 to 2013. The table shows a slow-down in biodiesel production capacity in recent years. From 2006 to 2009, production capacity increased by 360%, followed by very small increases in 2010 and 2011 of just 2% and 3% respectively. For 2012 and 2013, capacity is forecast to contract by 0.5 and 0.3 percent, respectively.

The reduced interest in biodiesel capacity can be attributed to difficult market conditions. From 2008 onwards, comparatively low crude oil prices, high vegetable oil prices, increasing imports, and the financial crisis resulted in a difficult market for biodiesel. As a result, use of production capacity dropped from 68% in 2007 to 44% percent in 2011. A number of plants all over the EU temporarily stopped production or closed. Under the current market conditions with high imports, high feedstock prices and only limited projected increase in consumption it is questionable that the EU biodiesel market can support all existing production capacity and many projects that were planned under different conditions were delayed or stopped altogether. Even with the projected increase in EU biodiesel consumption through mandates, one can expect to see a number of plants closing their operation or even having to file for bankruptcy in the coming years [61]. In addition to these pressures, the proposed indirect land use change directive will further burden the biodiesel industry in Europe which is heavily dependent on oilseed rape, a food crop.

Table 4: European Biodiesel production 2006 – 2013 (million litres) [61]

Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Production	5,410	6,670	9,550	9,860	10,710	10,710	10,850	11,475
Imports	70	1,060	2,020	2,190	2,400	3,160	3,070	2,425
Exports	0	0	70	75	115	100	115	125
Consumption	5,480	7,730	10,400	12,270	13,270	13,750	13,800	13,775
Ending stocks	0	0	1,100	805	530	550	550	550
Production capacity (conventional)								
No. of biorefineries	119	187	240	248	260	256	257	252
Capacity	6,600	12,745	18,375	23,230	23,700	24,465	24,345	24,265
Capacity Use (%)	55	69	61	47	46	44	44	47
Production capacity (advanced)								
No. of biorefineries	-	-	-	-	-	-	-	-
Capacity	-	-	-	-	-	-	-	-
Capacity use (%)	-	-	-	-	-	-	-	-
Feedstock use (MT)								
Rapeseed oil	3,710	4,230	6,040	6,050	6,220	6,310	6,410	6,250
Soybean oil	570	830	960	1,050	1,100	1,080	1,060	1,280
Palm oil	280	390	600	660	910	710	740	1,100
Rec veg oils	100	200	320	380	650	670	780	800
Animal fats	60	140	350	360	390	420	335	340
Sunflower oil	30	70	130	170	150	180	185	190
Other	10	10	10	10	10	60	140	140
Total	4,760	5,870	8,410	8,680	9,430	9,430	9,650	10,100

Table 5: Biofuel demand EU 2020 in Mtoe [62]

	Biofuel type	Demand outlook (scenarios)
Conventional	Bio-ethanol from fermentation	16830
	FAME (and FAEE)	22085
Advanced	Bio-ethanol from lignocellulose	1188
	Hydrogenated natural oils (HVO)	3930
	Biomass to Liquids (BtL)	411.25

2 Feedstocks

2.1 Tallow

Tallow is a by-product of the animal processing industry. Most specifically, tallow generally relates to the rendered fats resulting from beef and veal processing industries. When a bovine is slaughtered the most valuable lean meat components are carved from the carcass and directed into the higher value consumer meat supply chain. The remaining offal, bones and surplus fat are then disaggregated into their individual components. The fat components are further separated based on the quality of the fats and also in relation to their specific risk in relation to human and animal health. Due to the presence of certain disease-causing pathogens, in particular Bovine spongiform encephalopathy or BSE, specific risk material associated with the brain and spinal cord are considered unsuitable for sale or supply into the food and feed markets. For this reason, in the EU tallow is grouped according to its specific health risk with three main categories. Category 1 tallow is not permitted into the food, feed or chemical/cosmetic chains and must be destroyed. Category 2 tallow (from parts of animals unfit for human consumption) can be processed into fat derivatives for use in organic fertilizers or for other industrial use if processed under minimum process conditions (hydrolysis, saponification) in a category 2 oleochemical plant. Category 3 tallow (from animals fit for human consumption) can be used for all technical applications (including cosmetic and pharmaceutical applications) and animal feed provided it is free from insoluble impurities (< 0.15%). Oleochemical plants can either process category 2 or category 3 tallow and must be approved and registered. Therefore, in the EU currently the majority of EU member states favour biodiesel (through double counting) produced from Category 1 tallow rather than Category 3 or Category 3 and the greatest growth in tallow methyl ester (TME) production is in the cat. Tallow is generally produced at licensed rendering facilities and is quite highly regulated by EU health and safety and sanitary authorities in each member state.

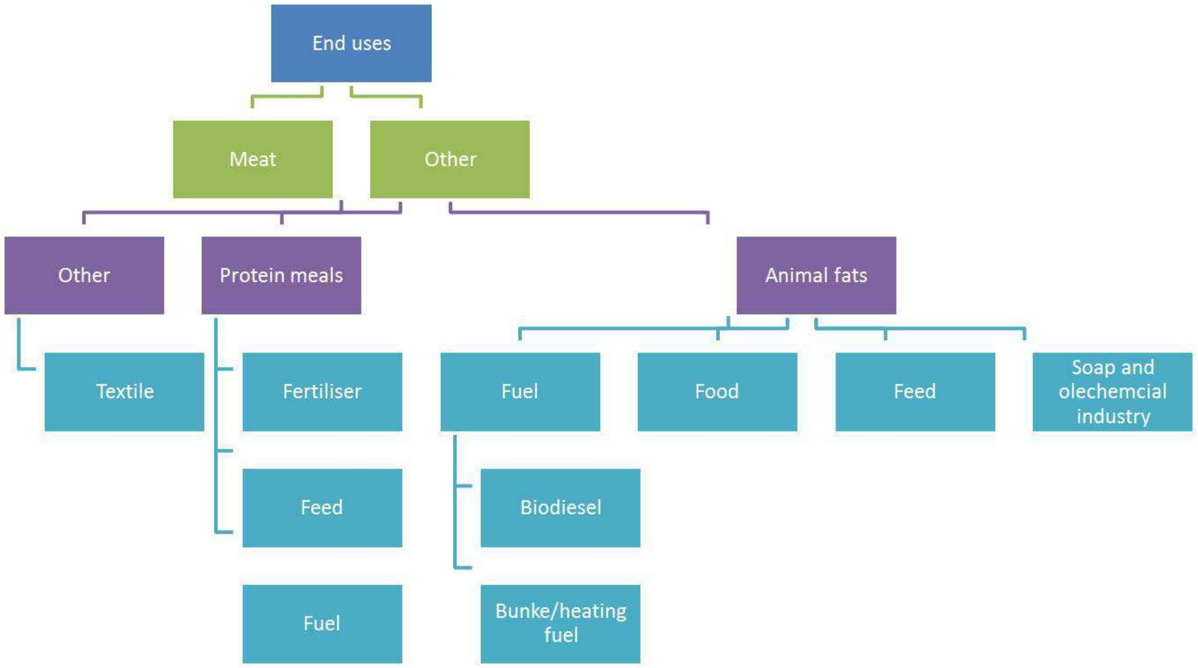

Figure 2 – End uses of animal carcass components

Tallow is a saleable product and biodiesel producers must compete with a number of other industries. Depending on the category produced these can include; animal feed, oleo-chemicals, and soap manufacture. A significant portion of the tallow produced is used in the rendering plants as to produce heat for the rendering process.

Figures for tallow production in the individual rendering plants are unavailable due to commercial sensitivity concerns.

2.1.1 Indigenous supply

The total number of number of livestock (i.e. cattle, pigs, and sheep) slaughtered in Ireland is estimated to be approximately 7 million annually [63]. Over 60% of the total carcass weight of livestock slaughtered in Ireland can be attributed to cattle (see

Table 6). Approximately 93% of beef produced in Ireland is exported [64], of which more than 85% are slaughtered in Ireland with the remainder exported live [33].

There are nine licensed rendering plants in Ireland;five category 1, four category 3, and no no category 2. Approximately 35% of the live weight of all animals is treated in rendering plants as by-products [65]. Of the by-products produced in cattle slaughtering, approximately 16% can be converted to tallow, 27% to meat and bone meal (MBM), and 57% is lost in the process [66]. There is a high rate of loss in rendering as carcasses contain a considerable quantity of water, up to 68% [65].

Tallow production can be estimated from statistics on animal slaughtering numbers.

- Slaughtering tonnages [63]
- Average live-weights (EU data)
- % available as by-products [65]
- % of by-products available as tallow [34]

Table 6: Tallow calculations

Slaughterings	*Unit*	*2009*	*2010*	*2011*
Cattle	kt	514.4	558.9	546.9
Sheep	kt	55.1	47.7	48.1
Pigs	kt	195.6	214.4	233.7
Total	kt	765.1	821	828.7
Carcass weight as percentage of live weight	%	54	77	49
Live weight	kt	1416.9	1066.2	1691.2
35% of live weight as by-products	kt	495.9	373.2	591.9
16% of by-products as tallow	kt	79.3	59.7	94.7
On-site energy use	kt	13.8	14.3	7.6
Tallow available (all categories)	kt	65.5	45.4	87.1

2.1.2 Future indigenous supply

The future use of tallow in biodiesel plants depends on the growth of the biodiesel industry in Ireland and also on tallow prices remaining competitive. The rendering industry works in a fast-changing regulatory environment, meaning forward planning is difficult. Estimations of the quantity of tallow used for biodiesel in 2020 are therefore problematic and subject to considerable change. Singh et al. [67] takes into consideration the different existing markets for tallow, and the future reduction in the national herd, and predicts half of the tallow available for sale in 2020 (19,000 t) will be converted to biodiesel. This results in a practical energy of 0.715 PJ or 21 million litres per annum.

2.1.3 International supply

According to statistics by Oil World, North America, including the USA and Canada are the largest producers of tallow and grease accounting for nearly 50% of the world’s supply (Figure 3). This can be attributed to its large cattle slaughtering’s and developed processing and handling infrastructure. The next largest suppliers of tallow in a global context would be the regions of South and Central America, China and Australasia. The EU-27 would account for around 13% of global tallow supply.

The development of the supply of tallow is one not defined by strong growth or contraction (Figure 3) with global production stable at around 8 mmt per year.

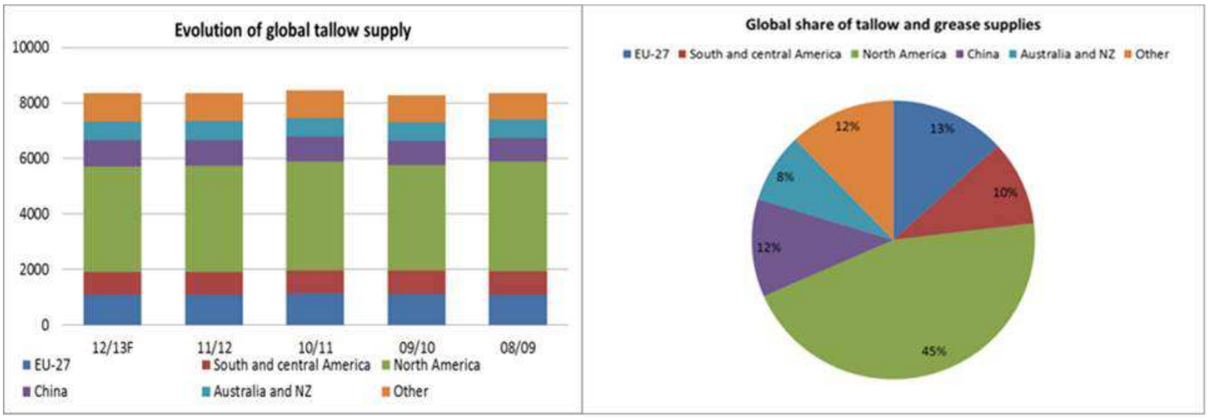

Figure 3 – Global tallow supply (kilotonnes)

On a regional basis, within the EU France, Germany and the UK dominate tallow supply. Holland also has a reasonably large share of tallow supply at 11%. These countries have progressed most rapidly the preferential support for TME through double counting.

2.1.4 Existing demand

There are a broad range of potential uses for rendered products including tallow and greases. Fats and greases tend to have 4 primary usage categories including, fuel/energy, food, feed and soap/oleochemical uses. These would be the main demand sources competing with biofuels. Global demand mirrors closely supply while there are trade imbalances between regions. For example, the EU and China are deficit countries and the US generally has an exportable surplus. In Europe, energy (on site heat and power and rendering facilities), feed and oleochemcial industries dominate demand even with the growth in the use of tallow for TME production. Another source of growth in demand is the pet-food industry whereby some tallow deemed not suitable for the food chain may be available for sale into the pet-food industry. In recent years, overall demand has stabilised around the 2,700 kt level.

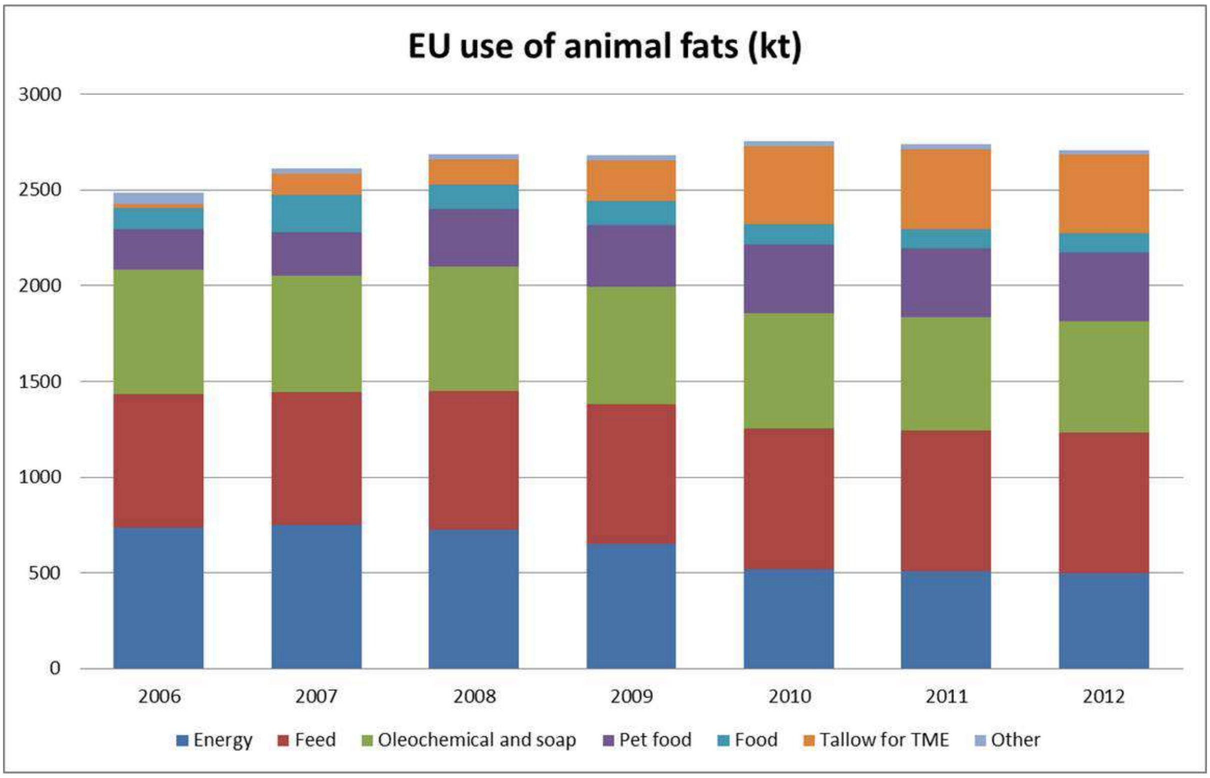

Figure 4 - EU use of animal fats

2.1.5 Trade flows

In world trade, the main source of tallow to the world market is North America with the US a dominant exporter. Australia is also a large exporter of tallow. Both countries have large cattle herds and meat processing capacity. The US has a diverse range of trade partners including Mexico, South America, Europe and Asia. On the import side, Mexico and China dominate imports in order to facilitate their feed and chemical demands. The European Union imports approximately 7% of world exports with the US being the dominant source.

Figure 5 – World trade flows in tallow

2.2 UCO

Used cooking oil (UCO) (also commonly referred to as recovered vegetable oil (RVO)) is the product of the collection of vegetable oils that have previously had a non-destructive use such as for deep frying take-away goods.

UCO had traditionally been used in animal feed, however its use as a raw material in animal feed has been banned in the EU since 2004 [35]. UCO can be used as a raw material for many applications including biodiesel and a variety of oleochemical products such as surfactants, plasticizers, cosmetics and lubricants [57]. The quality and properties of used cooking oils differ from those of refined and crude oils. The presence of heat and water accelerates the hydrolysis of triglycerides and increases the content of FFA in the oil [68]. In addition, the viscosity of the oil increases due to the formation of dimeric and polymeric acids and glycerides in used cooking oils [69]. UCO also contains impurities polymers, chlorides and phospholipids [70]. A pre-treatment step is utilised to reduce the FFA and water content of the UCO. In this step free fatty acid is reduced via an esterification reaction with methanol in the presence of sulfuric acid [71]. Supercritical methanol transesterification offers a promising method for UCO biodiesel production which achieves high yields [32]. The advantages of this method include; no sensitivity to FFA and water content, no catalyst required, and FFAs in the oil are esterified simultaneously [71].

2.2.1 Indigenous supply

UCO is collected by waste collection permit (WCP) holders, reporting to the Environmental Protection Agency (EPA). WCP holders reported collecting 22,031 tonnes of UCO in 2011. It is estimated that 14,676 tonnes of UCO was managed in 2011, i.e. the waste was reported as disposed or recovered in Ireland or abroad. This tonnage does not include any waste in storage, which would in part account for the difference between tonnage collected and managed. Of the 14,676 tonnes managed, 4,447 tonnes of this was reported as sent abroad for treatment, with the remainder 10,229 tonnes treated within the State. See .

Table 7 for a breakdown of uses for UCO.

Table 7 – UCO statistics[72]

Edible oils and fats 2011			
Collected	22031	t	
Managed	14676	t	
Sent abroad	4447	t	
Processed in Ireland	10229	t	
Incineration without energy recovery	9.45	t	abroad
Use as fuel	0.81	t	abroad
Composting, anaerobic digestion, rendering plants	1943	t	Ireland
Used in oil refining	8286	t	Ireland
	4436	t	abroad

2.2.2 Future indigenous supply

Singh et al. [67] predicts that, with better collection networks and waste management strategies, two thirds of available RVO will be collected in 2020 and that 75% of this will be converted to biodiesel. This equates to 0.45 PJ or 13 million litres per annum.

2.2.3 International supply

The UCO market is not highly regulated and is therefore ill-defined. However, this may change in coming years as legislation at the member state and EU level is being considered to regulate the UCO market. As such, assumptions can be made regarding the potential availability of UCO. UCO is generally sourced through a network of small collection companies who re-sell to larger aggregators. Originally, UCO would have been destined for the feed industry but, as discussed above, recent restrictions on feeding UCO limits this demand. As such, the biodiesel market has become a rising source of demand for UCO. There are a few approaches that can be taken to estimate potential supply. In the UK and Ireland approximately 100 kt and 10 kt respectively are collected annually [73]. On a per capita basis this equates to about 1.6 and 2 kg UCO collected per head of population respectively. With this information, and assuming an EU population of 500 million then an approximate collectible supply of around 1 Mt of UCO might be inferred. This production ratio is backed up by US statistics whereby the US census bureau record the production of yellow grease in the US at 636 kt in 2010 which equates to a per capita production rate of 2 kg [74] .

2.2.4 Existing demand

There is a lack of clear statistics regarding the end uses of UCO. Anecdotally, UCO is used in the animal feed sector, energy sector, oleochemical and FAME market. The most reliable sources of data for end-uses emanates from the biodiesel market where there are statistics for the amount of UCO consumed in the FAME market. Based on Oilworld data, in 2012 approximately 900 kt of UCO methyl ester (UCOME) was produced in the EU while the US produced just over 400 kt.

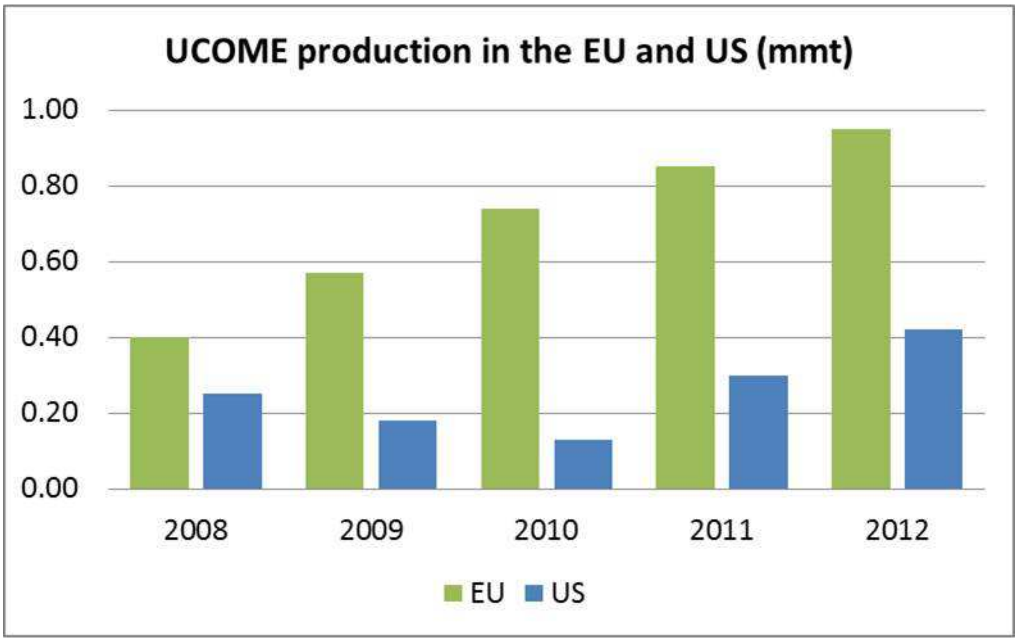

Figure 6: UCOME production in the EU and US

2.2.5 Trade flows

UCO can, and is, traded locally, regionally and globally. While it can potentially be transported in bulk the most common method of international shipment is in flexi-tanks contained within bulk containers. There can be a requirement to heat the UCO prior to discharge due to its high melting point. Europe is a significant buyer of UCO importing from the US and Asia. Due to the traceability requirements in order to use UCO in the biodiesel industry waste transfer notes are required. For this reason the main source of UCO into Europe is the US which has a high level of traceability. While Asia is potentially a large source of UCO certification and traceability tends to be a limiting factor.

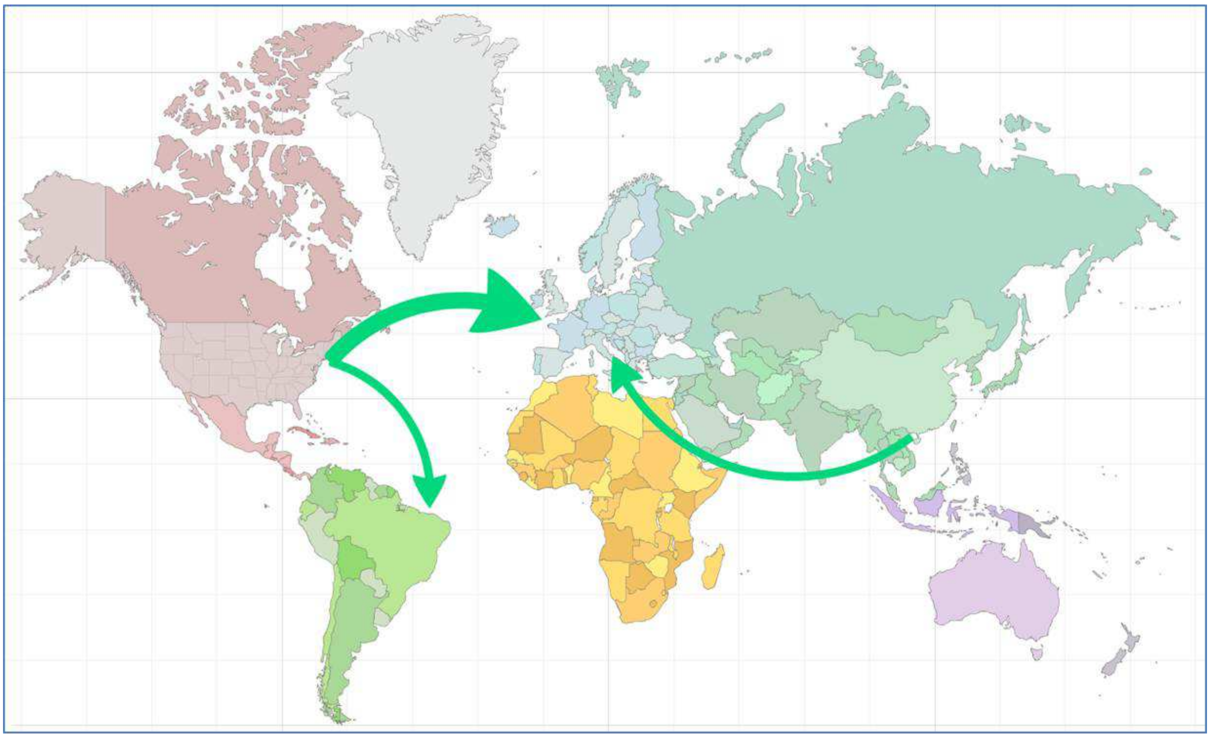

Figure 7: Diagram of global UCO trade flow

2.3 Rapeseed

Oilseed rape, a crop grown for its high oil yield, is one of the primary feedstocks for biodiesel production in Ireland. It is grown in rotation, 1 year in every 4 or 5, with conventional agricultural crops such as wheat [75]. The seed of the rape plant is cold pressed to release the oil, it is then filtered and can either be used pure in modified diesel engines, or can be processed into biodiesel The by-product of the system, residue, is compacted into rape cake, which is used as a high-protein animal feed [13]. The utilisation of the by-product improves the sustainability of the system.

Oilseed rape is becoming progressively more attractive at farm level, with prices increasing, resulting in the crop becoming a key profit generator [76]. As such, the area of oilseed rape planted has almost doubled from 6,300 ha in 2009 to 12,400 in 2011, resulting in the production of 56,000 tonnes in 2011 [73].

The viability of rapeseed as a biodiesel feedstock is under threat from the proposed indirect land – use change directive. Under the directive rape methyl ester will only be single counted towards the biofuel targets, while TME and UCOME will be double counted. In addition to this, as an oil crop, the contribution of RME to the 10% biofuel will be limited to 5%. Furthermore, the ability of RME to meet the sustainability requirements in RED will be further hampered by the inclusion of additional greenhouse gas emissions from indirect land use change (55 g CO2eq/MJ).

Table 8: Oilseed rape production [73]

	2008	2009	2010	2011
Area under Crops (000 Hectares)	5.6	6.3	8	12.4
Crop Yield per Hectare (Tonnes)	3.6	3.7	3.5	4.5
Crop Production (000 Tonnes)	20.3	23.7	28.1	55.9

2.3.1 Future indigenous supply

With the appropriate supports, indigenous production of biodiesel from oilseed rape has the potential to thrive. Hamelinck [77] has estimated that the realistic potential production of oilseed rape in the medium term is 10-15 kha, equating to 17.3 million litres or 0.6 PJ per annum at the higher end.

2.4 Projections

2.4.1 Tallow

A reasonable assumption based on literature reviews, research and analysis is such that an assumption of reasonably stable tallow supply to 2020 could be considered for the following reasons:

- Meat consumption trends favour growth in pork and poultry production and consumption
- Rising feed costs favour the production of more efficient meat sources such as poultry and tallow
- Rendering infrastructure and regulation is already well developed in the key regions of Europe and the America's
- Any increases in meat demand on the back of rising global population is offset by greater emphasis on pork and poultry meat as staple protein sources

This fundamental reasoning is evident in the Food and Agriculture Organization (FAO) projections for beef and veal production. Globally, beef and veal production is expected to rise slightly by 2020 (+1.4%). Regionally, beef and veal production is expected to rise slightly in the US (+0.5%) and decline slightly in the EU-27 (-0.4%). In essence however, by 2020 one might not expected a large change in overall tallow supply over the projected period. Assuming a similar relative change in tallow supply in accordance with changes in beef processing one might expect an overall slight increase in tallow supplies from the US and slight decline in the EU to 2020.

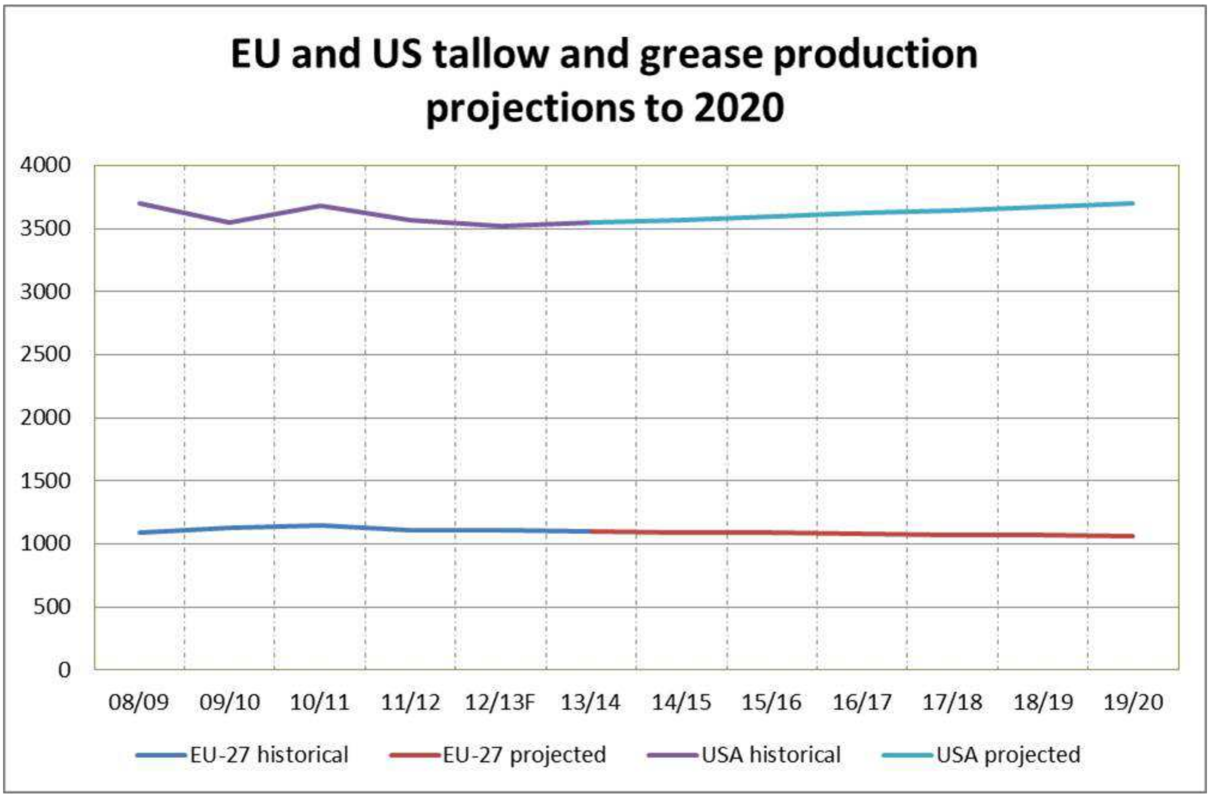

Figure 8: EU and US tallow and grease production projections to 2020

2.4.2 UCO

In terms of production and supply projections, it is difficult to assess even total current production of UCO. Also, it is further complicated by the potential for fraudulent UCO entering the UCOME supply chain. It may be fair to assume however, that there should be growth in legitimate UCO over time as infrastructure to collect UCO is developed and the economic incentive to collect it also increases. Whatever the quantity of UCO produced, it will be at least smaller than the demand for vegetable oils for food use. Using US statistics, around 71% of the fats and oils destined for food use is used for salad or cooking oil. Of this the vast majority would not be recoverable.

FAO/OECD projections for per capita vegetable oil consumption suggests overall per capita vegetable oil consumption will be stable to higher in 2020 compared to the 2008-10 average. The EU-27 per capita consumption is estimated at around 25kg per person. When compared to the UCO collection rate in studied EU member states and the US, UCO collection rates work out approximately 8% of the vegetable oils destined for the food industry. This may change with cooking habits. Overall, total vegetable oil consumption is expected to increase with rising population levels. Assuming an 8% collection rate for developed countries rising to 9% by 2020, EU rate of UCO collection and supply should reach around 2.7 Mt by 2020. Total UCO supply across the developed countries might be expected to be around 4 Mt. Looking at developing countries, the UCO supply potential is limited. Even if a relatively optimistic rate of collection of half the developed country rate (4%) then current supply might amount to around just over 1 Mt for large countries such as China rising to 1.8 Mt in 2020 (assuming collection rates rise to 5%).

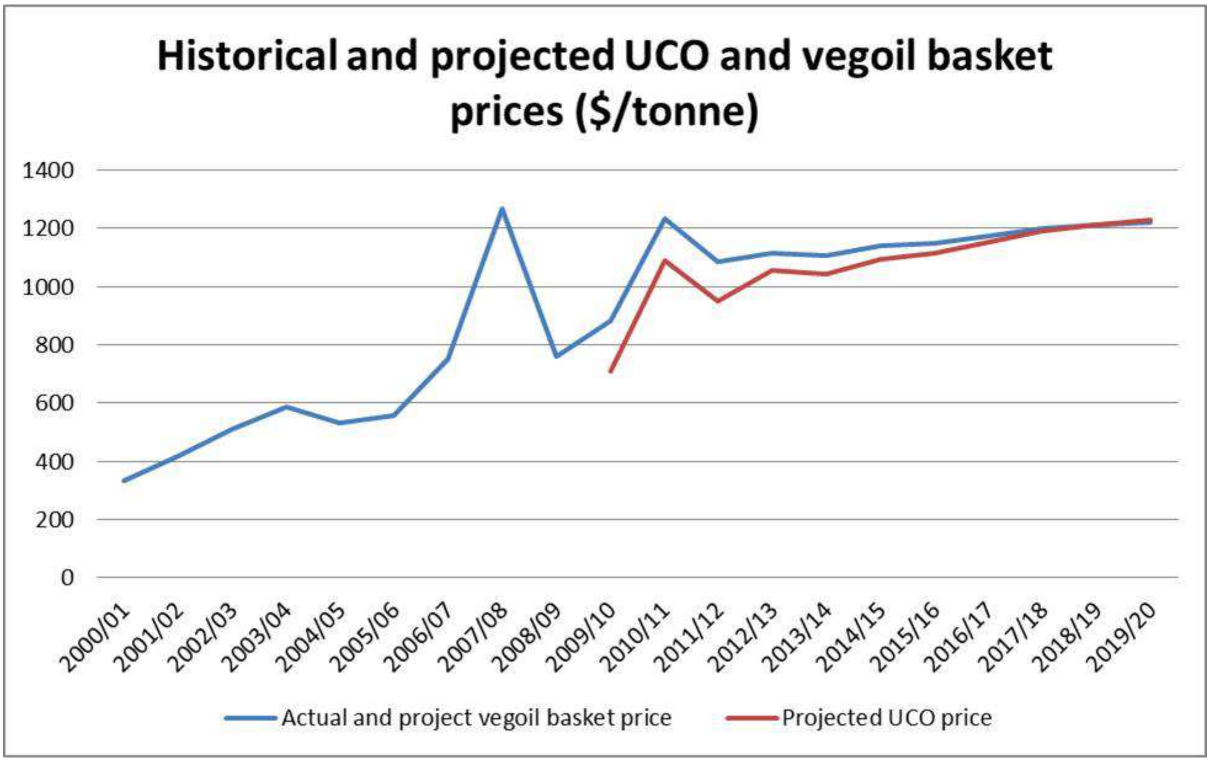

Figure 9: Historical and projected UCO and vegetable oil basket prices

3 Financial analysis of feedstocks

There has been a general increase in prices of feedstocks for biodiesel production since 2000. As discussed previously, the EU introduced the biofuels directive in 2003 which required each member state to replace 5.75% of all transport fossil fuels with biofuels by 2010. The directive also set an intermediate target of 2% by December 2008. In 2009, the Renewable Energy directive introduced a 10% target is set for all member states to be achieved in the transport sector from renewable sources by 2020.

The EU and national biofuel requirements generated increasing demand for biofuel feedstocks. Figure 10 shows the price evolution of tallow, UCO and crude palm oil feedstocks from 2000 to 2012.

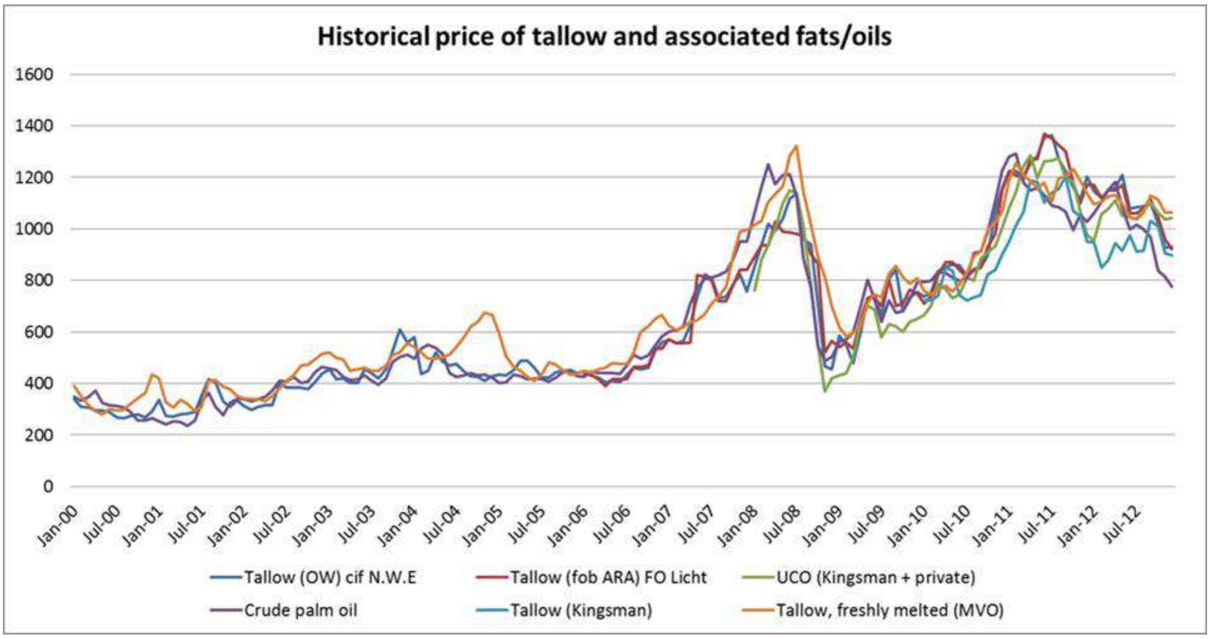

Figure 10 : Historical price analysis of tallow and associated fats/oils

3.1 Tallow

3.1.1 Seasonality

Tallow prices were analysed for any price seasonality that may exist within the market. There is an apparent seasonality of price appreciation during Q1 into Q2 with values on average appreciating 10-15% from January into May/June. This price appreciation generally turns to price weakness during Q3 and Q4 which probably related to declining demand in the colder periods of the year.

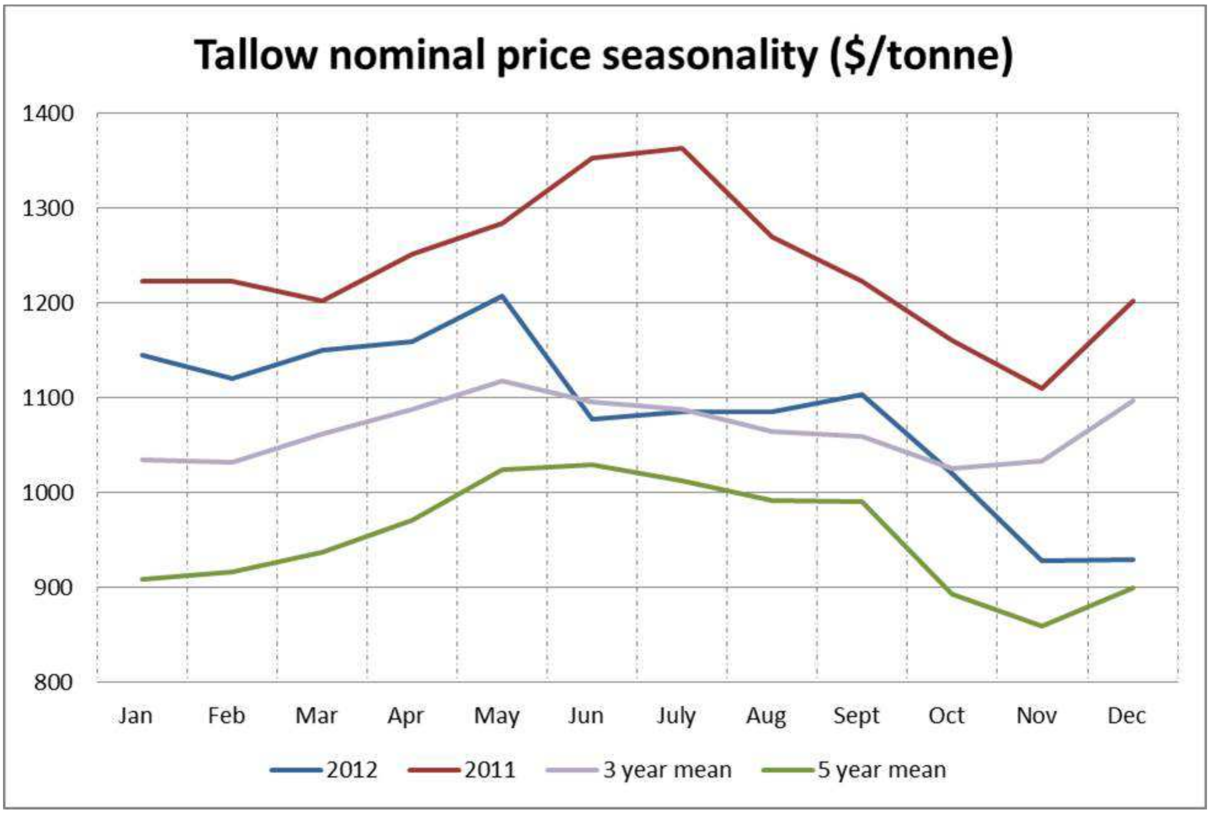

Figure 11: Tallow nominal price seasonality

Some of this seasonality may be explained by the relative availability of tallow feedstock coming from the beef slaughtering rate in the EU and US markets. The peak in tallow price tends to be in Q2 and Q3 which compares with the trough in EU slaughtering. The US however peaks its slaughtering around this period too. The relationship may be such that EU prices peak due to an additional requirement to import tallow and with the freight costs involved price rises are required during this period of low regional slaughtering of cattle. There is also a demand peak from the biofuel industry during the summer when TME blends can be optimised. TME tends to have a higher CFPP value than other FAME sources leading to limitations on the blending rates depending on latitude and time of year.

3.1.2 Quality

In pricing terms, Category 1 tallow tends to be the cheapest fat source compared to other fats and oils in $/tonne terms. In the oil and fats industry there are several quality parameters that can be used to compare the relative feeding, energy and food value such as melting point, colour, taste, fatty acid content, MIU (moisture, impurities and unsaponifiables). One particular test has a good correlation to the relative value of one fat/oil to another is the iodine value, discussed in section 1.12. As a general rule, the higher the iodine number, the higher the potential nominal value of the particular fat or oil. When tallow prices are compared to its iodine value, in 2012 Category 1 tallow has tended to price below it iodine value, while Category 3 prices above it. This likely reflects the broader range of uses and demand for Category 3 tallow compared to Category 1and 2 material. One might assume that over time the relative value of Category 1 and 2 material will rise with additional demand for TME and additional processing capacity.

Downstream, looking at TME, the cold flow properties are a key quality parameter as for the resulting FAME. In this regard, TME has a relatively high CFPP of 15-20°C which makes it least suitable for Northern climates.

3.2 Used cooking oil

UCO tends to track quite closely the value of other vegetable oils with the closest “cousin” of UCO being palm oil due to the similar physical characteristics. However, in recent times UCO has gone from a discount to palm oil to a premium.

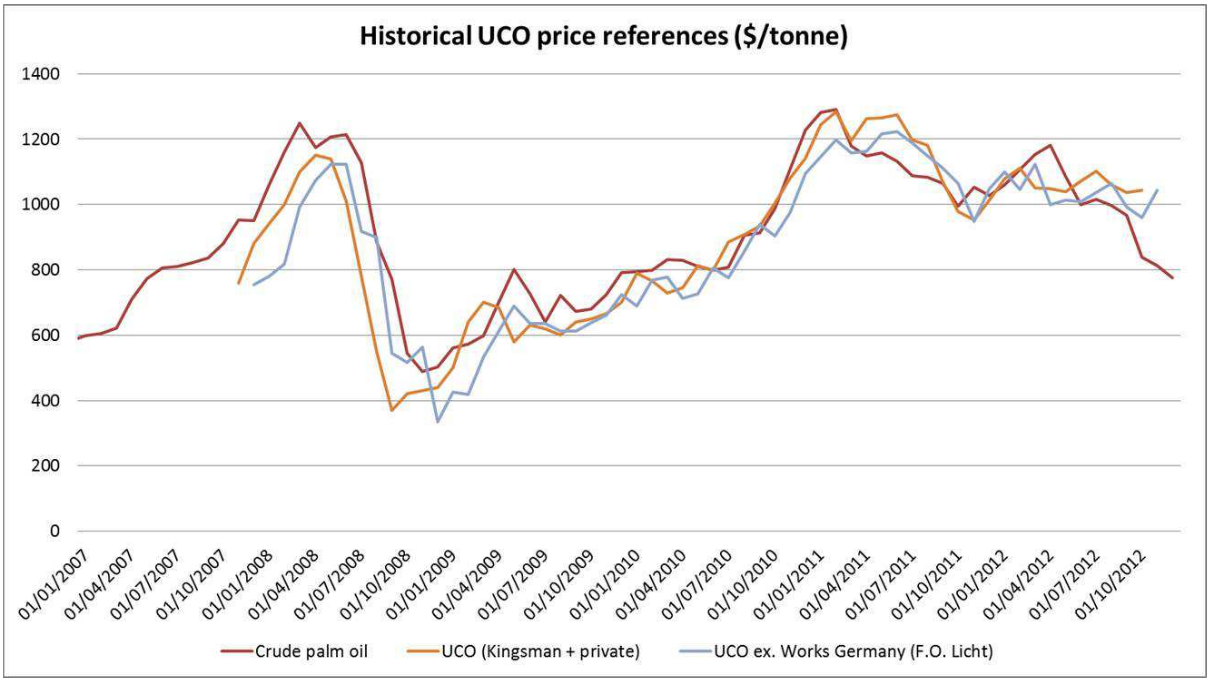

Figure 12: Historical UCO reference prices

Using the iodine value as a quality and value barometer can be difficult as UCO tends to have a wider range of iodines value than other fats and oils because it can be made up of several different types of fats. This can influence considerably the level of saturation and the fatty acid content of the resulting UCO. That said, it can be assumed that an iodine value of around 100 would be average. At this level it places UCO somewhere between the lowest value fats and oils and the more valuable fats and oils. At current market levels, UCO is priced relatively in line with its iodine value. This has not always been the case and historically it traded at a sizeable discount to other vegetable oils in real and relative terms. Taking a basket of vegetable oils priced in North West Europe; the premium for the basket of vegetable oils (lard, bleachable fancy tallow, palm oil, rapeseed oil, sunflower oil, soybean oil, linseed oil) averaged $245/tonne in 2008/09 with most recent pricing being much lower at $60/tonne. Figure 13 shows the historical price data in € / ton for oil seed rape starting from the year 2000 to January 2013. The trend is very similar to that of the UCO reference prices and effectively shows similar sharp price increase around 2008 and 2011 when new legislation in the form of the mineral oil tax relief (2010) and biofuels obligation scheme (2011) were driving prices higher.

Figure 13 : Historical price analysis of rapeseed.

In most recent times, UCO has been able to demand very close to its full value according to its level of saturation/iodine value. This stands to reason, as demand for UCO has increased due to the increased production capacity of UCOME in Europe. In fact, when one looks at the increase in UCOME processing capacity over time there is also a good relationship with that and the increase in the relative value of UCO.

In terms of projecting future price developments, the evidence suggests UCO will continue to appreciate in value. Already UCO is priced at a premium to palm oil and may develop a premium over other vegetable oils, despite its lower value physical characteristics. This phenomenon of a post-use premium can potentially open the door for very large scale fraud in relation to true UCO production. Quite simply, one in theory can buy virgin vegetable oil and fraudulently sell it as used cooking oil at a higher level without even using the oil. There are moves on-going among the EU UCOME producers to set in place audit control to prevent this but as the premium for UCO appreciates over virgin vegetable oils there is a real threat and economic incentive to manipulate the source of used cooking oils.

4 Biodiesel prices

Figure 14 shows the price evolution of TME, UCOME and RME from 2010 to 2012. The biodiesel prices climbed from €1,300 - €1,500 per tonne at the start of 2010 to highs in the range of €2,100 - €2,400 in summer 2011. After reaching this peak, prices fell to below €1,700 at the end of 2012 and have now stabilised in the range of €1,300 - €1,700 per tonne [78].

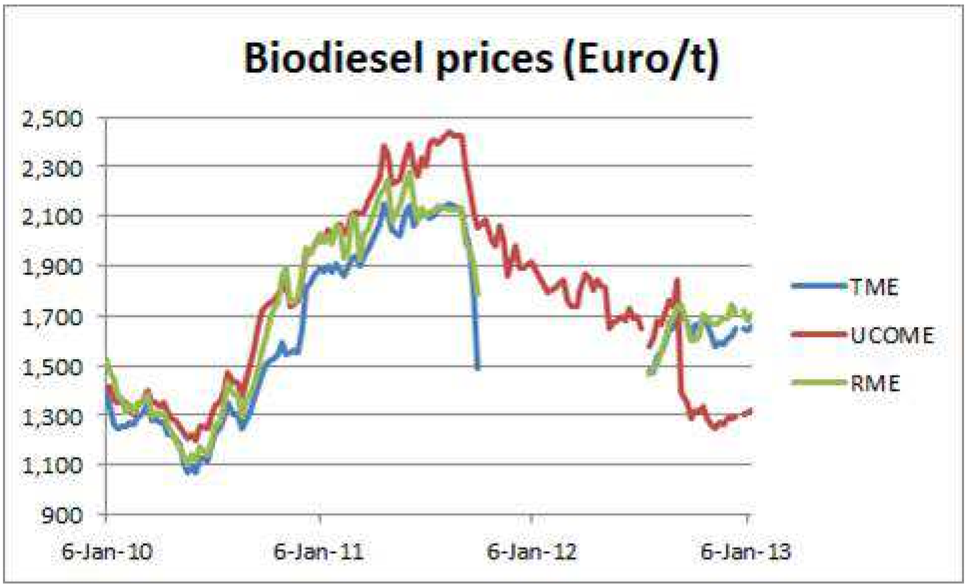

Figure 14 – Biodiesel prices 2010 – 2013

Based on the Energy Technology Perspectives BLUE Map Scenario, the IEA has developed detailed cost estimates for a range of fuels today and in the future, based on a bottom-up analysis of supply-chain components. Fuel-cost estimates presented below reflect retail price-equivalents and take into account all the key steps in biofuel production, including feedstock production and transport, conversion to final fuel, and fuel transport and storage, to the point of refuelling. In addition, the analysis considers the cost of biofuel production represented by oil use (such as for shipping) and the effect of changes in oil price on other fuel and commodity prices (such as crops).

Figure 15 presents two different cost analyses in order to take into account uncertainties such as the dynamic between rising oil prices and biofuel production costs. The low-cost scenario anticipates minimal impact of rising oil prices on biofuel production costs. Biofuel production costs fall as scale and efficiency increase. The costs (retail price equivalent, untaxed) of advanced biofuels such as cellulosic-ethanol and Biomass-to-Liquid-diesel reach parity with petroleum gasoline and diesel fuel by about 2030. Sugarcane ethanol remains the lowest-cost biofuel throughout.

In the high-cost scenario, oil prices have a greater impact on feedstock and production costs and most biofuels remain slightly more expensive than gasoline/diesel, with oil at USD 120/bbl in 2050. Nonetheless, the total cost difference per litre compared with fossil gasoline and diesel is less than USD 0.10 in 2050 (with exemption of conventional biodiesel), and bio-synthetic gas as well as sugarcane ethanol can be produced at lower costs, leading to actual savings in fuel expenditure. Most conventional biofuels are close to cost parity or, in the case of sugarcane ethanol, lie well below reference gasoline and diesel prices (Figure 15).

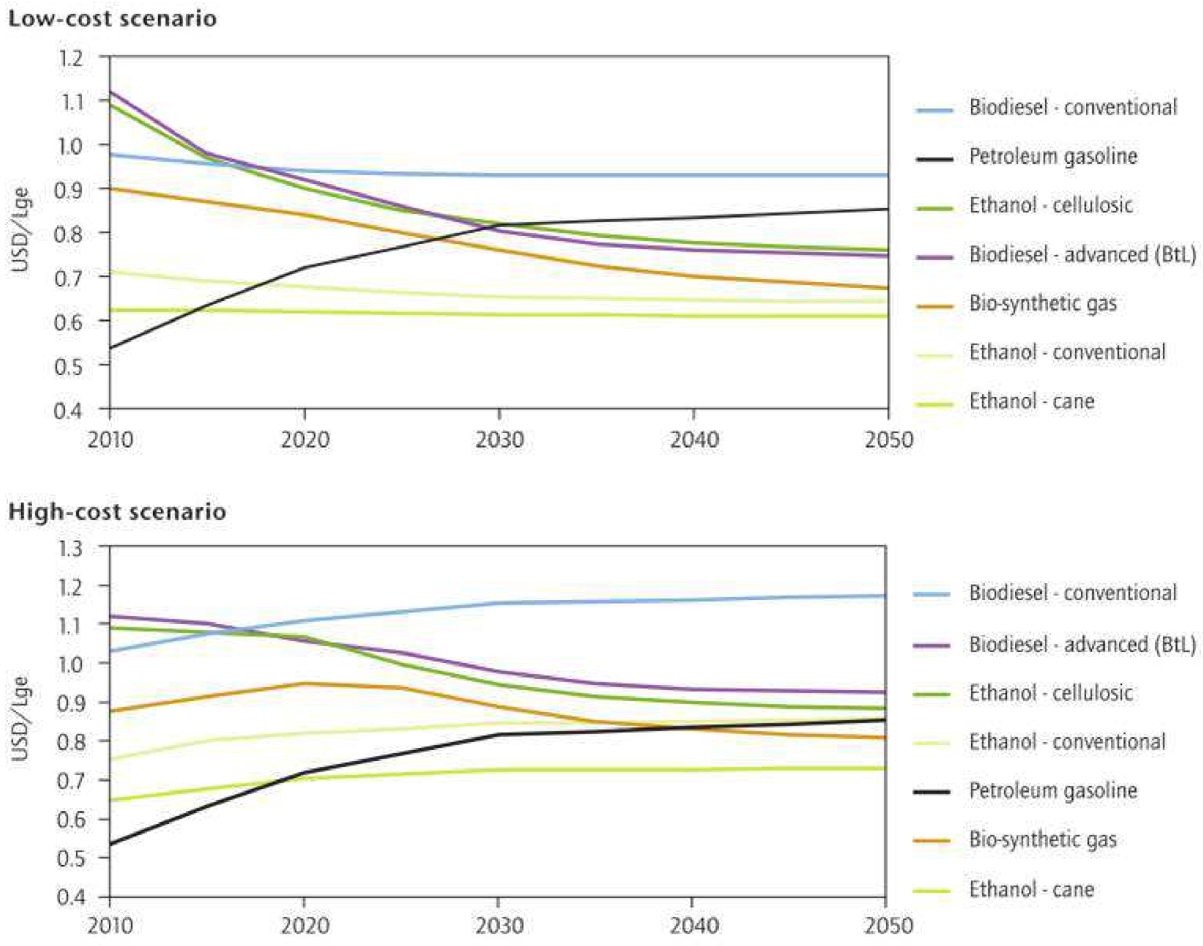

Figure 15 - Costs of different biofuels compared to gasoline (BLUE Map Scenario) [79]

Note: costs reflect global average retail price without taxation. Regional differences can occur depending on feedstock prices and other cost factors.

5 EU sustainability criteria

The increased use of biomass for biofuel production has led to concerns regarding the sustainability of this practice. Concerns surround the methods of cultivating and producing biofuels, particularly in regard to actual greenhouse gas emissions reductions in comparison with fossil fuels, and in concerns with land use change due to increased demand for arable land for biomass production. In order to ensure the sustainability of biofuel used to achieve the targets in the EU, the European

Commission proposed a set of sustainability criteria in the Directive 2009/28/EC on the promotion of the use of energy from renewable sources. The sustainability criteria consist of the following main points:

- The directive lays out certain greenhouse gas emissions reductions to be achieved from the use of biofuels. In the case of biofuels and produced by installations that were in operation on 23 January 2008, GHG emissions savings must be at least 35% from 2013. This figure rises to 50% in 2017, and further to 60% for biofuels produced in installations in which production started on or after January 2017.
- The raw materials sourced for biofuel production, from within the EU or from third countries, should not be obtained from land with high biodiversity value, land with a high carbon stock, or land that was peatland in 2008 [2].

These criteria, while undoubtedly good for the sustainable production of biofuels, may restrict growth of the biofuel production industry in Ireland as biofuels must meet certain minimum criteria.

5.1 Breakdown of LCA results

From 2013 to 2017, biofuels must achieve a minimum 35% reduction in greenhouse gas emissions versus fossil fuels. According to table 9 which summarises the GHG emissions from the production of indigenous biofuels in Ireland, only biodiesel produced from residues meets this minimum reduction. In 2017 the targeted reduction increases to 50%, which both biodiesels from residues can meet. However, beyond 2017 the target reaches 60%, which only biodiesel from recovered vegetable oil can meet. As it is, biodiesel from oil seed rape fails to meet even the minimum sustainability criteria. This shows the improvements necessary in current biomass production and processing methods required to increase the sustainability of these biofuels.

Table 9: GHG emissions associated with indigenous biofuel production in Ireland[80]

	Total GHG emissions (kg CO_2 -eq/GJ)	**% reduction in GHG emissions versus fossil fuels**
Biodiesel		
Rapeseed[a]	62.16	29
Tallow[b]	40	54
Recovered vegetable oil[b]	27.11	69

[a] [81]

[b] [82]

6 Conclusions

Tallow is a relatively mature market with a sophisticated and regulated rendering industry that has the capacity to provide relatively large shipments of traceable feedstock. Supply, while in the millions of tonnes globally is limited in its growth potential due to changing demand profiles in the meat sector. There is some capacity for international trade and supply of tallow into Europe, however the most likely sources (North and South America – Brazil) are also expanding their use of tallow in their respective FAME markets. This will likely limit the availability of tallow and TME from these sources. Also, within the tallow market itself, there may be additional demand for tallow from the chemical and feed industries as existing restrictions on tallow as an animal feed additive evolves to allow greater quantities be used in that sector. With concerns over the sustainability and social and environmental impacts of palm oil the oleochemcial industry may also wish to optimise its use of tallow.

UCO is an established feedstock with established markets dominated by the feed and the biofuel industries. Supply is limited and the resulting FAME has a rising pool of demand as additional member states move towards double counting UCO based biofuels . This is likely to maintain UCOME premiums at current relative values compared to other VVO sources. Feedstock supply should be expected to slowly increase but demand will likely always outstrip creating an environment of supply deficits for end users.

While Europe produces around 400kt of TME per year, the processing capacity is around 1.5mmt. With a large degree of overlap in processing capacity between TME and UCOME production and UCOME production at around 950kt, there is limited growth potential for additional processing capacity from now to 2020. In pricing terms, with TME finding levels around 1.5 times the nearest spec'd single count source (PME) and nearly double premium of benchmark FAME 0 there is likely now to be stabilisation in price premiums between TME and other conventional FAME sources. With countervailing duties being implemented by the EU on US and Argentine FAME and other biofuel sources the environment of protectionism should limit external sources of TME. In the broadest sense, expectations should be stability in supply and price (relative to other FAME sources).

Although the RME industry is well established in Europe its continued viability is uncertain due to the proposed indirect land use change directive. Existing RME production plants may continue to contribute to the 10% target although only up to the 5% level. Any expansion of RME production capacity will have to meet the required greenhouse gas emission reductions mandated by the renewable energy directive. As such, there is little growth potential in RME.

6.1 Implications for Ireland

Ireland's biofuel production is still very much in its infancy. Given 5.5 billion litres of fuel is imported every year, the vast majority is pre-blended with biodiesel and bioethanol already and thus poses an obstacle for any planned indigenous producers. While the legislation is there under the Biofuels Obligation Scheme to incorporate the biofuels, there is no legislation to say that it must be produced in Ireland. Having said that, of the 13 oil companies operating in Ireland, a lot now want to do more business with Irish based companies as it is seen as a method to drive economic growth and indeed improve the sustainability aspect to their business also. This will be very important in developing the role of the certificates for biofuel producers and being competitive with price perlitre. At present, the value of certificates are unknown but it's this value that must be retracted from the sale price of the biofuel to be market competitive. If not then it could imply selling the fuel cheaper than the cost of production which is obviously not viable from any perspective if an indigenous biofuel industry is to develop and survive.

Acknowledgement

This study was funded under the Charles Parsons Energy Research Program (Grant Number 6C/CP/E001) of Science Foundation Ireland (SFI) in co-operation with Irish Biofuels Production Ltd.

7 References

[1] European Commission. Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport. Off J Eur Union 2003.

[2] Commission E. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC 2009.

[3] Department of Communications M and NR. Government White Paper - Delivering a Sustainable Energy Future for Ireland. 2007.

[4] Department of Communications, Energy and Natural Resources. Regulatory Impact Assessment - Biofuels Obligation Scheme. 2009.

[5] United Nations. Kyoto Protocol to the United Nations Framework Convention on Climate Change. 1998.

[6] European Commission. Renewable Energy Roadmap - Renewable energies in the 21st century: building a more sustainable future. 2007.

[7] European Commission. Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Brussels: 2012.

[8] Department of Environment H and LG. National Climate Change Strategy 2007 - 2012. 2007.

[9] Sustainable Energy Association Ireland. Energy Security in Ireland: A Statistical Overview - 2011 Report. 2011.

[10] National Oil Reserves Agency. Statistics. 2012.

[11] Department of Communications E and NR. National Renewable Energy Action Plan Ireland - Submitted under Article 4 of Directive 2009/28/EC. 2010.

[12] Howley M, Ó Gallachóir B. Energy in Transport 2009. Sustainable Energy Ireland - Energy Policy Statistical Support Unit; 2009.

[13] Hearne J. Turning the tapon biofuels. Irish Exam 2012.

[14] Howley M, Dennehy E, Ó Gallachóir B. Energy in Ireland 1990 - 2009. Sustainable Energy Ireland - Energy Policy Statistical Support Unit; 2010.

[15] Ramos MJ, Fernández CM, Casas A, Rodríguez L, Pérez Á. Influence of fatty acid composition of raw materials on biodiesel properties. Bioresour Technol 2009;100:261–8.

[16] Lam MK, Lee KT, Mohamed AR. Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: a review. Biotechnol Adv 2010;28:500–18.

[17] Knothe G. Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. Fuel Process Technol 2005;86:1059–70.

[18] Serrano M, Oliveros R, Sánchez M, Moraschini A, Martínez M, Aracil J. Influence of blending vegetable oil methyl esters on biodiesel fuel properties: Oxidative stability and cold flow properties. Energy 2014;65:109–15.

[19] Falk O, Meyer-Pittroff R. The effect of fatty acid composition on biodiesel oxidative stability. Eur J LIPID Sci Technol 2004;106:837–43.

[20] Gerpen J Van. Biodiesel processing and production. Fuel Process Technol 2005;86:1097–107.

[21] Saraf S, Thomas B. Influence of Feedstock and Process Chemistry on Biodiesel Quality. Process Saf Environ Prot 2007;85:360–4.

[22] Atadashi IM, Aroua MK, Abdul Aziz AR, Sulaiman NMN. Production of biodiesel using high free fatty acid feedstocks. Renew Sustain Energy Rev 2012;16:3275–85.

[23] Helwani Z, Othman MR, Aziz N, Fernando WJN, Kim J. Technologies for production of biodiesel focusing on green catalytic techniques: A review. Fuel Process Technol 2009;90:1502–14.

[24] Kombe GG, Temu AK, Rajabi HM, Mrema GD. High Free Fatty Acid (FFA) Feed stock Pre-Treatment Method for Biodiesel Production, Hyderabad, Andhra Pradesh, India: 2013.

[25] Zhang Y. Biodiesel production from waste cooking oil: 1. Process design and technological assessment. Bioresour Technol 2003;89:1–16.

[26] Bhosle BM, Subramanian R. New approaches in deacidification of edible oils - a review. J Food Eng 2005;69:481–94.

[27] Felizardo P, Correia MJN, Raposo I, Mendes JF, Berkemeier R, Bordado JM. Production of biodiesel from waste frying oils. Waste Manag 2006;26:487–94.

[28] Christopher LP, Zambare VP. Enzymatic biodiesel: Challenges and opportunities. Appl Energy 2014;119:497–520.

[29] Hama S, Kondo A. Enzymatic biodiesel production: an overview of potential feedstocks and process development. Bioresour Technol 2013;135:386–95.

[30] Gharat N, Rathod VK. Ultrasound assisted enzyme catalyzed transesterification of waste cooking oil with dimethyl carbonate. Ultrason Sonochem 2013;20:900–5.

[31] Banerjee A, Chakraborty R. Parametric sensitivity in transesterification of waste cooking oil for biodiesel production—A review. Resour Conserv Recycl 2009;53:490–7.

[32] Demirbas A. Biodiesel from waste cooking oil via base-catalytic and supercritical methanol transesterification. Energy Convers Manag 2009;50:923–7.

[33] Thamsiriroj T, Murphy JD. How much of the target for biofuels can be met by biodiesel generated from residues in Ireland? Fuel 2010;89:3579–89.

[34] Thamsiriroj T, Murphy JD. How much of the target for biofuels can be met by biodiesel generated from residues in Ireland? Fuel 2010;89:3579–89.

[35] Rice B, Fröhlich A. The Potential of Recovered Vegetable Oil and Tallow as Vehicle Fuels. Crops Research Centre, Oak Park, Carlow: Teagasc; 2005.

[36] Canakci M, Van Gerpen J. A pilot plant to produce biodiesel from high free fatty acid feedstocks. Trans ASAE 2013;46:945–54.

[37] Kusdiana D, Saka S. Effects of water on biodiesel fuel production by supercritical methanol treatment. Bioresour Technol 2004;91:289–95.

[38] Hsu A-F, Jones K, Marmer WN, Foglia TA. Production of Alkyl Esters from Tallow and Grease Using Lipase Immobilized in a Phyllosilicate Sol-Gel. J Am Oil Chem Soc 2001;78:585–8.

[39] Alptekin E, Canakci M. Determination of the density and the viscosities of biodiesel–diesel fuel blends. Renew Energy 2008;33:2623–30.

[40] MEHER L, VIDYASAGAR D, NAIK S. Technical aspects of biodiesel production by transesterification—a review. Renew Sustain Energy Rev 2006;10:248–68.

[41] Meng X, Chen G, Wang Y. Biodiesel production from waste cooking oil via alkali catalyst and its engine test. Fuel Process Technol 2008;89:851–7.

[42] Murphy F, McDonnell K, Butler E, Devlin G. The evaluation of viscosity and density of blends of Cyn-diesel pyrolysis fuel with conventional diesel fuel in relation to compliance with fuel specifications EN 590:2009. Fuel 2012:112–8.

[43] Goodger EM. Hydrocarbon fuels: production, properties and performance of liquids and gases. Wiley; 1975.

[44] Rashid U, Anwar F, Knothe G. Evaluation of biodiesel obtained from cottonseed oil. Fuel Process Technol 2009;90:1157–63.

[45] Murphy F, Devlin G, McDonnell K. The Evaluation of Flash Point and Cold Filter Plugging Point with Blends of Diesel and Cyn-Diesel Pyrolysis Fuel for Automotive Engines. Open Fuels Energy Sci J 2013;6:1–8.

[46] IMAHARA H, MINAMI E, SAKA S. Thermodynamic study on cloud point of biodiesel with its fatty acid composition☆. Fuel 2006;85:1666–70.

[47] Sharma BK, Suarez PAZ, Perez JM, Erhan SZ. Oxidation and low temperature properties of biofuels obtained from pyrolysis and alcoholysis of soybean oil and their blends with petroleum diesel. Fuel Process Technol 2009;90:1265–71.

[48] Piloto-Rodríguez R, Sánchez-Borroto Y, Lapuerta M, Goyos-Pérez L, Verhelst S. Prediction of the cetane number of biodiesel using artificial neural networks and multiple linear regression. Energy Convers Manag 2013;65:255–61.

[49] Tubino M, Aricetti JA. A green potentiometric method for the determination of the iodine number of biodiesel. Fuel 2013;103:1158–63.

[50] Felizardo P, Machado J, Vergueiro D, Correia MJN, Gomes JP, Bordado JM. Study on the glycerolysis reaction of high free fatty acid oils for use as biodiesel feedstock. Fuel Process Technol 2011;92:1225–9.

[51] Azócar L, Ciudad G, Heipieper HJ, Muñoz R, Navia R. Lipase-catalyzed process in an anhydrous medium with enzyme reutilization to produce biodiesel with low acid value. J Biosci Bioeng 2011;112:583–9.

[52] Teixeira LSG, Couto MB, Souza GS, Filho MA, Assis JCR, Guimarães PRB, et al. Characterization of beef tallow biodiesel and their mixtures with soybean biodiesel and mineral diesel fuel. Biomass and Bioenergy 2010;34:438–41.

[53] Ali Y, Hanna M, Cuppett S. Fuel properties of tallow and soybean oil esters. J Am Oil Chem Soc 1995;72:1557–64.

[54] Wyatt V, Hess M, Dunn R, Foglia T, Haas M, Marmer W. Fuel properties and nitrogen oxide emission levels of biodiesel produced from animal fats. J Am Oil Chem Soc 2005;82:585–91.

[55] Issariyakul T, Kulkarni MG, Dalai AK, Bakhshi NN. Production of biodiesel from waste fryer grease using mixed methanol/ethanol system. Fuel Process Technol 2007;88:429–36.

[56] Cao L, Wang J, Liu K, Han S. Ethyl acetoacetate: A potential bio-based diluent for improving the cold flow properties of biodiesel from waste cooking oil. Appl Energy 2014;114:18–21.

[57] Yaakob Z, Mohammad M, Alherbawi M, Alam Z, Sopian K. Overview of the production of biodiesel from Waste cooking oil. Renew Sustain Energy Rev 2013;18:184–93.

[58] Sharafutdinov I, Stratiev D, Shishkova I, Dinkov R, Batchvarov A, Petkov P, et al. Cold flow properties and oxidation stability of blends of near zero sulfur diesel from Ural crude oil and FAME from different origin. Fuel 2012;96:556–67.

[59] Panoutsou C, Namatov I, Lychnaras V, Nikolaou A. Biodiesel options in Greece. Biomass and Bioenergy 2008;32:473–81.

[60] Lang X, Dalai AK, Bakhshi NN, Reaney MJ, Hertz PB. Preparation and characterization of bio-diesels from various bio-oils. Bioresour Technol 2001;80:53–62.

[61] Flach B, Lieberz S, Bendz K. EU-27 Annual Biofuels Report. USDA Foreign Agricultural Service - GAIN Report; 2012.

[62] Lonza L, Hass H, Maas H, Reid A, Rose KD. EU Renewable Energy Targets in 2020 - Analysis of Scenarios for Transport - JEC Biofuels Programme. EU Joint Research Centre - Institute for Energy and Transport; 2011.

[63] CSO. Livestock Slaughterings December 2012 - CSO - Central Statistics Office 2012.

[64] Central Statistics Office. Meat Supply Balance 2011. 2012.

[65] European Commission. Integrated Pollution Prevention and Control - Reference Document on Best Available Techniques in the Slaughterhouses and Animal By-products Industries. 2005.

[66] Mooney P. Big losses for Ronans and Tiernans. Irish Farmers J 2007.

[67] Singh A, Smyth BM, Murphy JD. A biofuel strategy for Ireland with an emphasis on production of biomethane and minimization of land-take. Renew Sustain Energy Rev 2010;14:277–88.

[68] Tomasevic AV, Siler-Marinkovic SS. Methanolysis of used frying oil. Fuel Process Technol 2003;81:1–6.

[69] Enweremadu CC, Mbarawa MM. Technical aspects of production and analysis of biodiesel from used cooking oil—A review. Renew Sustain Energy Rev 2009;13:2205–24.

[70] Winfried R, Roland M-P, Alexander D, Jürgen L-K. Usability of food industry waste oils as fuel for diesel engines. J Environ Manage 2008;86:427–34.

[71] Van Kasteren JMN, Nisworo AP. A process model to estimate the cost of industrial scale biodiesel production from waste cooking oil by supercritical transesterification. Resour Conserv Recycl 2007;50:442–58.

[72] Environmental Protection Agency. National Waste Report for 2011. 2011.

[73] Office CS. Area, Yield and Production of Crops 2011. 2012.

[74] USCensusBureau. M311K - Fats and Oils: Production, Consumption, and Stocks 2013.

[75] Teagasc. Winter Oilseed rape. 2009.

[76] Doyle A. Oilseed rape still key crop profit generator for 2012. Irish Farmers J 2011.

[77] Hamelinck C, van den Broek R, Rice B, Gilbert A, Ragwitz M, Toro F. Liquid Biofuels Strategy for Ireland. Sustainable Energy Ireland; 2004.

[78] KingsmanEnergyFromNature. Biofuels price and analysis data 2013.

[79] International Energy Agency. IEA Technology Roadmap - Biofuels for Transport. 2011.

[80] Gusciute E, Devlin G, Murphy F, McDonnell K. Transport sector in Ireland: can 2020 national policy targets drive indigenous biofuel production to success? Wiley Interdiscip Rev Energy Environ 2013;3:n/a–n/a.

[81] Thamsiriroj T, Murphy JD. Is it better to import palm oil from Thailand to produce biodiesel in Ireland than to produce biodiesel from indigenous Irish rape seed? Appl Energy 2009;86:595–604.

[82] Thamsiriroj T, Murphy JD. The impact of the life cycle analysis methodology on whether biodiesel produced from residues can meet the EU sustainability criteria for biofuel facilities constructed after 2017. Renew Energy 2011;36:50–63.