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The effect of feedstock cost on biofuel cost as exemplified by biomethane production from grass silage

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Abstract: The potential variance in feedstock costs can have significant implications for the cost of a biofuel and the financial viability of a biofuel facility. This paper employs the Grange Feed Costing Model to assess the cost of on-farm biomethane production using grass silages produced under a range of management scenarios. These costs were compared with the cost of wheat grain and sugarbeet roots for ethanol production at an industrial scale.

Of the three feedstocks examined, grass silage represents the cheapest feedstock per GJ of biofuel produced. At a production cost of €27/tonne (t) feedstock (or €150/t volatile solids (VS)), the feedstock production cost of grass silage per gigajoule (GJ) of biofuel (€12.27) is lower than that of sugarbeet (€16.82) and wheat grain (€18.61). Grass biomethane is also the cheapest biofuel when grass silage is costed at the bottom quartile purchase price of silage of €19/t (€93/t VS). However, when considering the production costs (full-costing) of the three feedstocks, the total cost of grass biomethane (€32.37/GJ of biofuel; intensive 2-cut system) from a small on-farm facility ranks between that of sugarbeet (€29.62) and wheat grain ethanol (€34.31) produced in large industrial facilities.

The feedstock costs for the above three biofuels represent 0.38, 0.57, and 0.54 of the total biofuel cost. The importance of feedstock cost on biofuel cost is further highlighted by the 0.43 increase in the cost of biomethane when grass silage is priced at the top quartile (€46/t or €232/t VS) compared to the bottom quartile purchase price.

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Introduction

Energy vectors and feedstocks in a post-peak-oil world are still unclear, especially in the transport sector. Various alternative fuel systems have been suggested including 'the hydrogen economy', biofuels and electric vehicles, with all having distinct advantages and disadvantages. Hydrogen has a high energy value per unit mass (*ca.* 142 megajoule (MJ)/kg), but per unit volume it is low (*ca.* 12 MJ/m³ normal temperature and pressure (m_n³)). It is in essence an energy carrier which is typically made from electricity or natural gas. Methane (present in natural gas or biomethane), in contrast, has an energy value of 37.78 MJ/m_n³. A question may be raised as to why energy should be spent converting methane to hydrogen (increasing the volume of the gas by a factor of three) and then using more energy to compress hydrogen to place in a vehicle. Thus, it may be argued that methane and biomethane have more engineering merit as a transport fuel than hydrogen generated from methane.¹

Biogas can be produced from a wide range of feedstocks (e.g. agricultural crops, animal manure, organic fraction of municipal solid waste, organic wastes from food industries) through anaerobic digestion (AD) and can be upgraded to biomethane for use as a transport fuel. In recent years, dedicated energy crops (e.g. maize, grass, sugarbeet) have also been grown specifically for biogas production. In temperate regions, grassland in particular represents a significant biomass resource for biogas production.

Recent research suggests that grass biomethane produces more fuel per hectare, has a superior energy balance, and is more sustainable (i.e. more greenhouse gas savings) than indigenous European first-generation liquid biofuels such as wheat ethanol and rapeseed biodiesel.^{2,3} In addition, grass biomethane has been shown to be cost efficient as a transport fuel if the appropriate government policy is in place.⁴

The cost of biofuels is a very significant issue for the transport industry. Feedstock costs can represent an important proportion of the final biofuel cost and variance in feedstock costs can have a sizeable impact on the cost of a biofuel. Thus, there is a need to quantify the relationships between the cost of grass silage produced under scenarios of different yields or choice of crop production inputs, and the total cost of the subsequently produced

biomethane. In addition, the cost of producing gaseous biofuels needs to be assessed alongside liquid biofuels to generate some idea of the forward momentum of the transport fuel industry.

The aim of this paper is to assess the cost of on-farm biomethane production using grass silages produced under seven contrasting management scenarios and to relate these outcomes with the cost of industrially produced first-generation ethanol from wheat grain and sugarbeet.

Grass silage production

The Grange Feed Costing Model (GFCM), developed by Teagasc (Irish Agriculture and Food Development Authority) to identify the relative costs of feeds produced for ruminants, is used in this analysis.⁵ The GFCM is a static, spreadsheet-based, agro-economic simulation model for evaluation of the physical and financial performance of alternative feed crop production and utilization options in Ireland. The GFCM employs a full-costing approach to calculate total feed cost and includes all production (e.g. sowing and crop management) and utilization (e.g. storage, labor, and feed-out) costs associated with the feed.

Background and model assumptions

Grassland in Ireland

Of the 4.2 million hectares of land used for agriculture in Ireland, approximately 0.90 is devoted to grassland, and this provides most of the feed requirements of the ruminant population.^{6,7} High quality swards on fertile soils are generally dominated by perennial ryegrass (PRG), meadow grass, and white clover.^{7,8} In commercial agricultural practice, PRG is the most widely sown grass accounting for approximately 0.95 of forage grass seed sold.⁹ For the purposes of this study, assumptions are based on a PRG-dominant permanent grassland sward.

Grass silage – ensiling

If grass is to be used as a feedstock for AD, it must be harvested and stored as silage to ensure year round availability and a predictable quality. Silage is currently made on 0.86 of Irish farms (*ca.* 1.24 million ha), and precision-chop silage (0.6 of national silage area) is usually chopped to a mean

particle length of 2 to 10 cm.¹⁰ Further chopping (<6 mm) would be required prior to AD to reduce the problems associated with floating herbage particles.¹¹

Potential losses during ensilage which could impact the methane production potential include field losses, effluent production, fermentation losses in the silo and aerobic deterioration during storage and at feedout.¹² Thus, losses of 0.03 and 0.175 are assumed for harvesting (i.e. field losses) and ensilage (including effluent), respectively.¹³ Some of these losses are inevitable but the extent can be minimized by good farm management practices. For example, silage effluent represents an excellent feedstock for AD, and thus losses associated with effluent production (0.11) should be minimized by directing the effluent stream to the digester, thus supplementing the total feedstock yield. Both the effects of excluding and including silage effluent to supplement total feedstock yield are costed in this study.

Climate and soil

Local climate and soil factors can be responsible for a large variability in grass yield and quality. The east midlands of Ireland (Teagasc Grange; 53° 31' N, 06° 40' W; grass growth up to 8 months per annum) is assumed as the location for silage production.

Land

Land is costed in the GFCM by means of an annual land charge, or portion thereof, with charges based on the proportion of time during the year when the land is contracted for silage production (i.e. the length of time between closing (final defoliation prior to harvest) and harvest date). Based on the rental market price for productive agricultural land, an annual land charge of €300/ha is assumed.⁵

Labor and machinery

Labor, time, and machinery costs involved in producing grass silage are addressed in the GFCM by assuming contractor costs and published work rates for all applications (e.g. sowing, fertilizer application, harvesting).¹⁴ While this approach may over-estimate the true cost of these operations (i.e. it includes profit retained by the contractor), it removes

the requirement for complex machinery depreciation and operation costings.⁵

Fixed assets

Long-term investment for constructing and maintaining fixed facilities (including fencing, roadways, and the concrete silo and effluent storage tank) are valued in the GFCM at their replacement cost based on the costing of the Irish Department of Agriculture and Food.¹⁵ Fixed facilities are assumed to depreciate over a period of 20 years using the declining balance method.⁵ The entire cost of providing the silo and effluent tank is allocated to the grass silage cost, while the cost of providing fencing and roadways is proportioned relative to the time during the year the land is in use for silage production. Interest on borrowing for fixed assets is charged at 8%, while annual maintenance and repairs are charged at 1% of the construction cost per year.¹⁶

Grassland management factors

Reseeding

Reseeding of permanent grassland is recommended to improve grassland productivity and yield,¹⁷ and to provide a herbage more suitable for achieving a successful preservation during ensiling.¹⁸ A reseeding rate of once every 10 years is assumed in this analysis with the crop assumed to be 5 years old (i.e. mid-point of the 10-year reseeding interval).

Direct sowing is the most common method of pasture establishment. The existing sward is sprayed off with glyphosate, then ploughed and allowed to senesce for 2 to 3 weeks before sowing. The land is then harrowed, rolled, and fertilized before sowing, and rolled again after sowing. A seeding rate of 33 kg/ha is assumed in this study.¹⁷

Fertilizer application

Current Teagasc recommendations for N, P, and K fertilization rates of permanent grassland managed for silage production (Table 1) form the basis of this analysis. Fertilizer is applied in the least-cost combination of compound and single-nutrient inorganic fertilizer based on crop nutrient requirements and constrained by statutory limits.²²

Table 1. Fertilizer application rates for each scenario.

Scenario	Fertilizer	N (kg/ha)			P (kg/ha)			K (kg/ha)		
		1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
(1) Intensive, two-cut, no digestate ^a	Organic	0	0	-	0	0	-	0	0	-
	Inorganic	125	100	-	20	10	-	170	35	-
	Total		225			30			205	
2(a), 2(b), (3) Intensive, two-cut plus digestate ^b	Organic	87	0	-	3	0	-	128	0	-
	Inorganic	38	100	-	17	10	-	42	35	-
	Total		225			30			205	
(4) Intensive, three-cut plus digestate ^c	Organic	113	0	0	5	0	0	166	0	0
	Inorganic	12	100	100	15	10	10	4	35	35
	Total		325			40			240	
(5) Extensive, two-cut plus digestate ^d	Organic	59	0	-	2	0	-	87	0	-
	Inorganic	0	42	-	0	5	-	0	0	-
	Total		101			7			87	

^a Assumes a soil P and K index of 3 and a target dry matter yield of 12 t/ha for a two-cut harvesting regime.¹⁹

^b Assumes all digestate (41 460 kg/ha) applied before 1st cut; N, P and K values of 2.1, 0.087 and 3.08 kg/t assumed for digestate.²⁰

^c Assumes all digestate (53 745 kg/ha) applied before 1st cut; N, P and K values of 2.1, 0.087 and 3.08 kg/t assumed for digestate.²⁰

^d Target N: P: K fertilizer application rate of 101: 7: 24 kg/ha/annum which represents mean fertilizer usage on Irish farms.²¹ Assumes all digestate (28 270 kg/ha) applied before 1st cut; N, P and K values of 2.1, 0.087 and 3.08 kg/t assumed for digestate.²⁰

In traditional Irish grass-based ruminant production systems the progressive increase in the cost of fertilizer N contributes to the erosion of profitability.²³ Therefore, the valuable nutrient content of digestate from AD should be exploited, with application to grassland reducing the requirement for inorganic fertilizer. At present, however, there is limited information in the literature regarding digestate nutrient composition. An available N, P, and K digestate nutrient content of 2.1, 0.087, and 3.08 kg/t digestate is used in this study, with the assumption that 0.873 t digestate (~90 g DM/kg) is produced per 1 t total feedstock (silage plus effluent) digested (Tables 1 and 2).²⁰ This is based on a 70% destruction of volatile solids in the digester (e.g. scenario 1 – Table 2: 47,491 kg total feedstock/ha = 8,575 kg volatile solids (VS)/ha; 1 kg feedstock = 0.181 kg VS; @ 70% destruction of VS = 0.127 kg converted to biogas).²

Herbicides

Effective weed control in permanent grassland can be achieved through good management practices including

effective drainage, grazing, cutting, and fertilizer application. Herbicide is assumed to be applied once at crop establishment and this is included within the reseeding costs. Spot spraying costs are assumed to be included in the land charge.

Lime

The recommended optimum soil pH for grassland is 6.3 and grassland should be limed at least once every five years.¹⁹ An application rate of 2 t/ha is assumed in this study at a cost of €20 per tonne of ground lime (including spreading).

Harvesting regime

Harvesting for silage is assumed to take place twice per year (i.e. a two-cut silage harvesting regime) with the first cut at the end of May and the second cut in mid-July following a seven-week regrowth period. For comparison purposes, a three-cut harvesting regime is also evaluated with the third cut taking place in late August. In both regimes the grassland would be grazed by livestock for the remainder of the growing season after the final harvest for

Table 2. Scenario outputs.

Scenario	Cut	Harvest date	Grass yield		Silage yield ^a		Silage DMD	Effluent yield ^b		Total feedstock yield ^c	
			kg/ha	kg DM/ha	kg/ha	kg DM/ha		L/ha	kg DM/ha	kg/ha	kg VS/ha
(1), 2(a) Intensive, two-cut, no effluent	1	29 May	30 639	6649	24 519	5321	739	-	-	24 519	4895
	2	17 July	21 724	4714	17 385	3772	715	-	-	17 385	3470
<i>Total</i>			52 363	11 363	41 904	9093	-	-	-	41 904	8365
2(b), (3) Intensive, two-cut	1	29 May	30 639	6649	24 519	5321	739	3269	163.5	27 788	5018
	2	17 July	21 724	4714	17 385	3772	715	2318	115.9	19 703	3557
<i>Total</i>			52 363	11 363	41 904	9093	5587	5587	279	47 491	8575
(4) Intensive, three-cut	1	29 May	30 639	6649	24 519	5321	739	3269	163.5	27 788	5018
	2	17 July	21 724	4714	17 385	3772	715	2318	115.9	19 703	3557
	3	28 Aug ^d	15 516	3367	12 417	2694	680	1656	82.8	14 073	2541
<i>Total</i>			67 879	14 730	54 321	11 787	7243	7243	362	61 564	11 116
(5) Extensive, two-cut ^e	1	29 May	21 424	4649	17 145	3720	739	2286	114.3	19 431	3508
	2	17 July	14 281	3099	11 428	2480	715	1524	76.2	12 952	2339
<i>Total</i>			35 705	7748	28 573	6200	3810	3810	191	32 383	5847

DM = dry matter; DMD = dry matter digestibility; VS = volatile solids.

^a Losses of 0.03 and 0.175 are assumed for harvesting (i.e. field losses) and ensilage (including effluent), respectively. Silage dry matter (DM) = 217 g/kg.

^b Effluent yield is based on 110 L (0.11) of effluent (5 g DM/kg) being produced per t fresh grass after applying 0.03 field losses.²⁴

^c Total feedstock = silage yield + effluent yield; based on 0.92 volatile solids (VS) content in grass silage and 0.75 VS content in silage effluent.²⁵

^d Based on average yield data (two years) for an old permanent grassland sward with an annual N fertilizer input of 330 kg/ha.²⁶

^e Yield calculated as a function of annual nitrogen application.²⁷ 0.80 of annual production is assumed to be harvested in cuts 1 and 2.

silage. Grass is assumed to be subjected to a minimal level of field-wilting, to be harvested with a precision-chop harvester with no additive applied, and then ensiled beneath two layers of black polyethylene sheeting in a walled concrete bunker silo.

Stage of maturity at harvest

The stage of maturity of the plant at harvest will influence its potential energy yield. As a plant matures the increase in yield is accompanied by an increase in the content of indigestible fiber and this has negative implications for the methane production potential of the ensiled crop.²⁸⁻³⁰ Dry matter digestibility (DMD) values for the grass silages are taken from Teagasc field trials (Table 2).^{31,32} Default DMD losses during ensilage are assumed to be 0.02.¹³

Grass yield

Smit *et al.* reported that the highest grassland productivity in Europe is achieved in north-western Europe, while Dillon reported Ireland has the potential to produce up to 0.20 more than much of the rest of western Europe.^{33,34} The yield data described in Table 2 are derived from Teagasc field trials.^{31,32}

Other factors

Land improvement costs, for example drainage, are assumed to be included in the land charge. Further chopping of the silage (6 mm) and the feedout of both silage and effluent to the digester are apportioned to the operation of the AD plant and are not included in the total feedstock cost.

Management scenarios investigated

The cost of grass silage will vary from farm to farm and from region to region so that no single universally applicable value can be provided. Thus, seven contrasting scenarios were investigated to provide a range of values for the cost of grass silage:

1. Intensive farming enterprise with high inorganic fertilizer input (Table 1), two-cut harvesting regime, high DM yield and assets 50% depreciated.
2. Intensive farming enterprise as in (1) but utilizing digestate to reduce inorganic fertilizer requirement. 2(a) Silage effluent not utilized. 2(b) Silage effluent collected

and used to supplement grass silage as the total feedstock.

3. Intensive farming enterprise as in 2(b) but with total feed cost inclusive of a return to labor, capital, and enterprise cost. This added value is derived from the net profit (€57/ha; excluding premia) of a beef farmer in 2009 (top one-third beef suckling farms).³⁵
4. Intensive farming enterprise as in 2(b) but with a three-cut harvesting regime.
5. Extensive farming enterprise with surplus grass, utilizing digestate and with a low inorganic fertilizer input (Table 1), and assets fully depreciated.
6. The GFCM employs a full-costing 'bottom-up' approach for calculating total feed cost, but as with any commodity, market factors will dictate the price for any feed that is traded. The commercial price of grass silage varies widely across the country, and is heavily dependent on availability and demand. In order to find a representative commercial price for grass silage, a survey was carried out with the help of Teagasc advisors (n = 26) from across Ireland, who were asked to provide a value for which grass silage traded over the 2008/2009 and 2009/2010 winter seasons. Where silage is purchased from a farmer the recovery of effluent is unlikely and as such is not included in the analysis of this scenario. Purchased silage: mean of bottom quartile of prices = €86/t silage DM (= €19/t silage @ 217 g DM/kg or €93/t VS @ 0.92 VS).
7. Purchased silage as in (6); mean of top quartile of prices = €213/t silage DM (= €46/t silage @ 217 g DM/kg or €232/t VS @ 0.92 VS).

Scenario outputs

Grass silage

Table 2 outlines grass silage feedstock yield and digestibility data for both intensive and extensive scenarios as outlined. As expected, the extensive system with limited fertilizer input resulted in the lowest grass silage yield (6200 kg DM ha). The third cut of the intensive three-cut system provided a modest increased yield of 2694 kg DM ha compared with the two-cut system. Table 2 also outlines the importance of directing the silage effluent to the

digester, thus reducing the potential losses associated with ensiling.

For scenarios 2 to 4, the costs associated with harvesting represent the largest single contribution to the total feedstock production cost, followed by the fertilizer cost and land charge (Fig. 1). When the digestate is not used as a biofertilizer (Scenario 1), fertilizer costs (0.38) make up a greater proportion of the total production cost than harvesting (0.35). The purchase price of grass silage ranged between €19 (Scenario 6) and €46/t (Scenario 7) over the 2008/2009 and 2009/2010 winter seasons reflecting changes in availability and demand. All scenarios investigated using the GFCM estimated the cost of feedstock production to be well within this range (€27 to €31/t; Fig. 2), showing that in some instances farmers sell their crop considerably below the apparent cost of production or have much lower production costs than assumed in the GFCM (e.g. machinery). The intensive two-cut system that did not utilize silage effluent as a feedstock or digestate as a fertilizer (Scenario 1) had the highest grass silage production cost at €34/t total feedstock. Using the digestate as a

fertilizer reduced the cost of production to €31/t (Scenario 2(a)), while the inclusion of silage effluent to supplement the grass silage yield further reduced the cost to €27/t (Scenario 2(b)). Fertilizer from digestate contributed 0.39, 0.35 and 0.58 of the total N fertilizer requirements of the intensive two-cut, intensive three-cut and extensive scenarios examined (Table 1), respectively.

Despite the higher total feedstock yield with the three-cut system (Scenario 4), the relatively small yield from the third cut, coupled with higher harvesting costs and an increased land charge, combined to make this production system more expensive than the two-cut system (Scenario 2(b)). The relatively low yields of the extensive two-cut system (Scenario 5) also resulted in a slightly more expensive feedstock compared with the intensive two-cut system, despite the substantial savings in fertilizer costs.

Wheat and sugarbeet

Wheat grain and sugarbeet roots represent important feedstocks for ethanol production. Table 3 outlines the total feedstock cost of wheat and sugarbeet as determined using the GFCM.

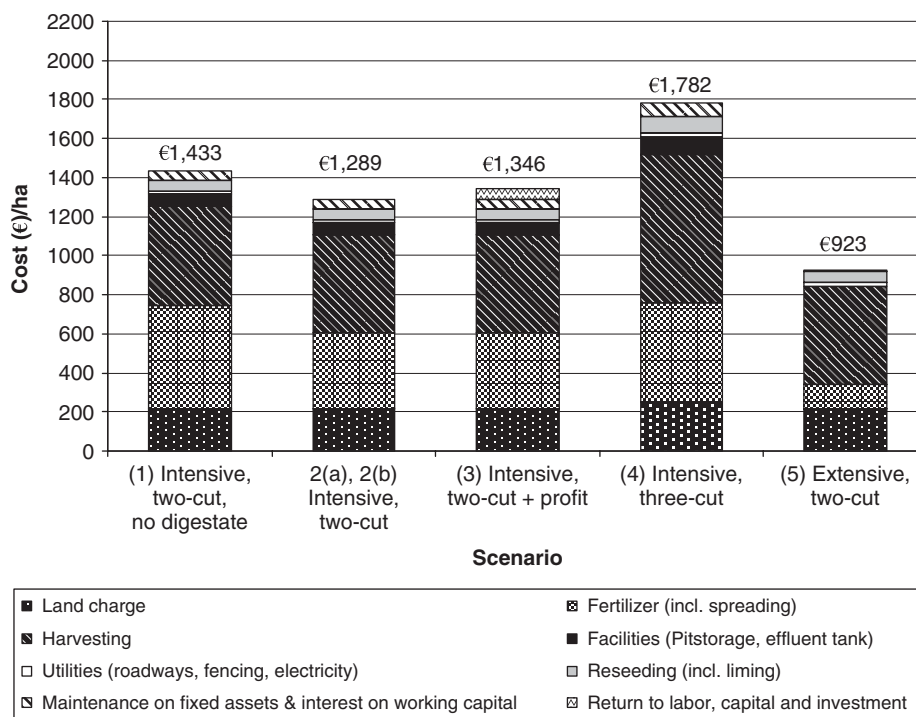


Figure 1. Grass silage feedstock costs per hectare, with digestate being employed to reduce inorganic fertilizer inputs (unless otherwise stated).

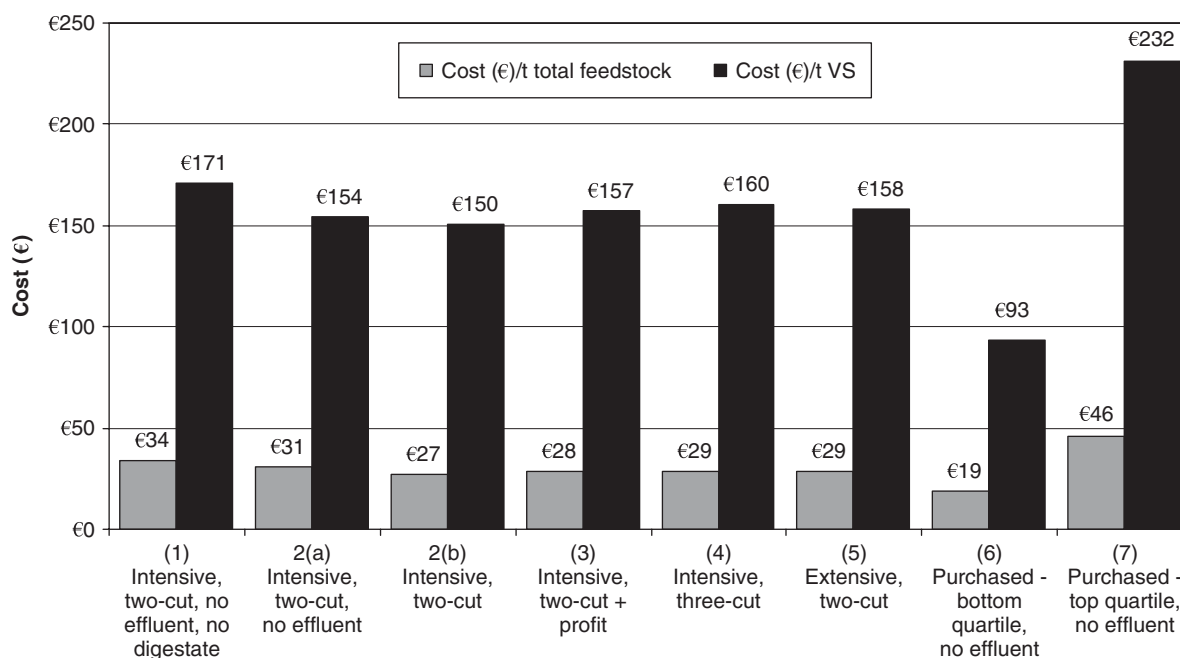


Figure 2. Grass silage feedstock costs per tonne total feedstock (silage + effluent (Table 2); unless otherwise stated) and per tonne volatile solids (VS), with digestate being employed to reduce inorganic fertilizer inputs (unless otherwise stated).

Production costs of indigenous Irish biofuels

Grass biomethane

Smyth *et al.* carried out a rigorous analysis of an on-farm (137.5 ha) grass-to-biomethane facility.⁴ Briefly, the process involved the anaerobic digestion of grass silage to produce biogas (0.55 methane), upgrading of the biogas to biomethane (>0.97 methane) and injection into the natural gas grid. This allows for widespread distribution using existing infrastructure and for biomethane to be used as a renewable transport fuel in compressed natural gas (CNG) vehicles. The cost analysis performed by Smyth *et al.* had significant detail on the technology of producing grass biomethane, but little analysis of the effects of feedstock cost. In that study, the cost of silage was assessed from a survey of the farming press, with a figure of €17/t silage (€77/t DM or €930/ha) reported, which is in the bottom-quartile of feedstock costs as assessed in this paper. This paper differs in that the emphasis is on the cost of feedstock and its effect on the total cost of the biofuel. Smyth *et al.* reported a cost of production of 10.2 c/kilowatt hour (kWh) for grass biomethane based on a feedstock cost of €17/t silage. One tonne of

grass silage is estimated to yield 60 m³ of biomethane (600 kWh or 2.2 GJ), so this equates to a feedstock purchase price of €0.0283/kWh or €7.73/GJ of biomethane produced. Removing the cost of the feedstock (i.e. €0.0283/kWh), the cost of the grass biomethane production technology can be estimated to be €0.0737/kWh or €20.10/GJ (Table 4).

Wheat ethanol

One tonne of wheat grain as harvested (200 g DM/kg) is estimated to yield 374 L of ethanol.³⁶ Using the GFCM, the cost of producing wheat grain was estimated at €147/t feedstock (800 g DM/kg; Table 3), which is €0.39/l of ethanol. Given that 1 L of ethanol has an energy value of 21.1 MJ, the feedstock cost equates to €18.61/GJ of ethanol (Table 4). Power *et al.* also assessed the cost of producing ethanol and reported a figure of €0.60/l ethanol for a 150 million l/annum facility when wheat grain prices were €100/t. Removing the cost of the feedstock (i.e. €0.27/l), the cost of this ethanol production technology can be estimated to be €0.33/l or €15.70/GJ of biofuel. Thus, the cost of producing ethanol based on a feedstock production cost of €18.61/GJ and a technology cost of €15.70/GJ is €34.31/GJ. However, wheat grain prices increased to over €250/t in 2011, which would represent a

significant rise in the production cost of ethanol, equivalent to €0.88/l ethanol or €47.35/GJ.

Sugarbeet ethanol

One tonne of sugarbeet roots as harvested (240 g DM/kg) is estimated to yield 104 L of ethanol.³⁶ In the current study, the cost of producing sugarbeet was estimated at €37/t feedstock (232 g DM/kg; Table 3) which is equivalent to €0.36/l or €16.82/GJ of ethanol. Power *et al.* also assessed the cost of producing ethanol from sugarbeet and reported a figure of €0.80/l ethanol for a 75 million l/annum facility when the cost of sugarbeet was €55.00/t. Removing the cost of the feedstock (i.e. €0.53/l), the cost of this ethanol production technology can be estimated to be €0.27/l or €12.80/GJ of biofuel (Table 4). Thus the cost of producing ethanol based on a feedstock production cost of €16.82/GJ and a technology cost of €12.80/GJ is €29.62/GJ.

Comparison of technology costs

As already outlined, the wheat ethanol production technology cost is based on a 150 million l/annum facility, which is considered optimal internationally for cost-effective ethanol production.³⁶ Likewise, the sugarbeet facility is based on 75 million l/annum facility which is considered practical for ethanol production in Ireland as sugarbeet would be grown in a one-in-three-year rotation.³⁶ In contrast to these two facilities, the grass biomethane facility does not optimize economies of scale and is based on an on-farm system producing 450 000 m_n³ biomethane/annum (i.e. 60 m_n³/h of biomethane). This is at the lowest economically viable scale for a biogas upgrading and injection facility.⁴ Typically, facilities

would be economically efficient at 200 m³ biomethane/h. The grass biomethane facility described here generates 16.6 terajoule (TJ)/a, so 95 such systems would be required to equal the fuel output of the sugarbeet ethanol facility. Unlike industrial ethanol production facilities, the biogas/biomethane industry is not centralized. Germany, for example, has *ca.* 6000 biogas plants throughout the country which are generally associated with relatively small catchment areas, rural employment and sustainable communities.³⁷ As a result, the technology cost is greater for the biomethane industry (€20.10/GJ) compared with ethanol from wheat grain (€15.70/GJ) and sugarbeet (€12.80/GJ). This cost may be reduced somewhat by larger-scale systems, but this would require the transport of feedstock over much larger distances.

Comparison of feedstock costs

Grass silage represents the cheapest feedstock for biofuel production (Table 4). At €19/t (Scenario 6 – bottom-quartile purchase price) the feedstock cost of grass silage (€/GJ of biofuel) is half that of sugarbeet and wheat grain charged at the cost of production. When the cost of production is considered for all feedstocks, grass silage is also significantly cheaper reflecting reduced establishment and input costs. Even when the top-quartile purchase price for grass silage is considered and compared with the 2010 purchase price for wheat grain and sugarbeet, grass silage represents a cheaper feedstock.

Total biofuel cost

- Of the three biofuels examined, grass biomethane is the cheapest biofuel when grass silage is priced at the bottom-quartile purchase price (Scenario 6).

Table 3. Total feedstock costs for ethanol production.

Crop	Sowing date	Harvest date	Fresh yield (kg/ha)	DM (g/kg)	DM yield (kg/ha)	Total feedstock cost ^a		
						€/ha	€/t feedstock	€/t DM
Winter wheat grain ^b	20 Oct	20 Aug	10 478	800	8 382	1537	147	183
Sugarbeet roots ^c	1 Apr	1 Nov	54 736	232	12 699	2041	37	161

^a Assumes no further losses between harvesting and processing for ethanol production.

^b Assumes a harvesting efficiency of 0.985; N: P: K inputs of 160: 25: 100 kg/ha.

^c Assumes a harvesting efficiency 0.96; N: P: K inputs of 145: 40: 160 kg/ha; Boron = 3 kg/ha; Sulfur = 20 kg/ha; no utilization of sugarbeet tops and leaves; includes beet washing costs.

Table 4. Effect of feedstock cost on biofuel cost.

	Technology cost (€/GJ biofuel) ^a	Feedstock cost (€/t)	Yield of biofuel/t feedstock	Feedstock cost (€/GJ biofuel)	Total biofuel cost (€/GJ biofuel) ^b
Grass biomethane					
Scenario (1) - Intensive, two-cut, no digestate, no effluent	20.10	34	60 m ³ biomethane or 2.2 GJ ^c	15.46	35.56
Scenario (2a) - Intensive, two-cut, no effluent	20.10	31		14.09	34.19
Scenario (2b) - Intensive, two-cut	20.10	27		12.27	32.37
Scenario (3) - Intensive, two-cut + profit	20.10	28		12.73	32.83
Scenario (4) - Intensive, three-cut	20.10	29		13.18	33.28
Scenario (5) - Extensive, two-cut	20.10	29		13.18	33.28
Scenario (6) - Purchase price bottom quartile	20.10	19		8.64	28.74
Scenario (7) - Purchase price top quartile	20.10	46	20.91	41.01	
Wheat ethanol					
Cost of production	15.70	147	374 L ethanol or 7.9 GJ ^d	18.61	34.31
Purchase price (2010)	15.70	250		31.65	47.35
Sugar beet ethanol					
Cost of production	12.80	37	104 L ethanol or 2.2 GJ ^e	16.82	29.62
Purchase price (2010)	12.80	55		25.00	37.80

^a Biofuel production cost excluding feedstock cost.
^b Total biofuel cost = technology cost + feedstock cost.
^c Yield of biomethane/t grass silage.⁴
^d Yield of ethanol/t wheat grain.³⁶
^e Yield of ethanol/t sugar beet roots.³⁶

- When considering the cost of production (full costing – GFCM), grass biomethane (€32.37/GJ biofuel; Scenario 2(b) – intensive two-cut system) is more expensive than sugarbeet ethanol (€29.62) but less expensive than wheat ethanol (€34.31).
- At the upper price range for the three feedstocks (i.e. €46/t grass silage, €250/t wheat and €55/t sugarbeet), grass biomethane is again more expensive than sugarbeet ethanol but less expensive than wheat ethanol.

Limitations of this analysis

One of the significant benefits of biomethane is that injection into the natural gas grid allows for the gas to be readily

distributed and sold to agents on the gas grid. For example, a compressed gas service station takes gas from the grid and pays the producer of biomethane. As such, the distribution system is in place and vehicles are not required to travel to the biomethane facility. In addition, the gas is transported for no extra energy cost as it is typically compressed to ca. 7 bar during upgrading. However, the gas must be further compressed before injection to a vehicle. In contrast, ethanol produced in a centralized facility must be transported significant distances to its consumers, with additional energy and financial costs. As with biomethane, the ethanol must also be dispensed at the service station. For both the gaseous and liquid biofuels described in this study, this costing has not been included.

Conclusions

Of the grass silage production scenarios investigated in this study, the intensive two-cut system which utilized silage effluent to supplement silage feedstock yield, and returned digestate to the land so as to reduce inorganic fertilizer costs, had the lowest grass silage production cost. Directing the silage effluent stream to the digester (€4/t decrease in feedstock cost) and employing the digestate as a biofertilizer (€3/t decrease in feedstock cost) had a significant impact on feedstock cost. Despite the higher total feedstock yield with the three-cut system, the higher fertilizer and harvesting costs made this feedstock production system more expensive than the two-cut system, suggesting that of the scenarios examined the two-cut intensive system represents the most economic option of producing silage for AD. The wide range of price values presented for the purchase of grass silage highlights the large variability in feedstock costs for biofuel production, while also indicating that in some instances it may be more economically viable to purchase feedstock from farmers at a low price. However, this strategy may compromise the security of feedstock supply.

Anaerobic digestion of farm-produced feedstocks is a technology that tends to be decentralized and based on relatively small catchment areas, promoting rural employment and sustainable communities. It contrasts with the present system of oil refineries and even large renewable biorefineries. There is considerable potential for a number of farmers, an existing co-operative of farmers, or a community to develop an anaerobic digester. The expected investment cost would be less than €2 million compared to the sugarbeet ethanol facility which would cost in the region of €70 million for a 75 million l/a facility.^{4,36} To match the output of the sugarbeet ethanol facility, 95 of these small-scale grass biomethane facilities would be required. As a result, the cost of this technology per unit of biomethane is expensive compared with the output of larger, industrial-scale wheat and sugarbeet ethanol facilities.

In this study, grass silage generated the cheapest biofuel when grass silage was priced at the bottom-quartile purchase price. When comparing grass silage, wheat grain and sugarbeet roots on a feedstock production cost basis using the Teagasc GFCM, sugarbeet ethanol was the cheapest biofuel (€29.62/GJ) followed by grass biomethane (€32.37/

GJ) and wheat ethanol (€34.31/GJ). The feedstock costs for the above three biofuels represent 0.57, 0.38, and 0.54 of the total biofuel cost, further highlighting the significantly lower feedstock costs and higher technology costs of the small-scale on-farm grass biomethane production facility described.

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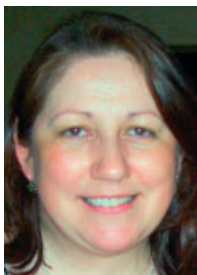
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