Final report to Defra

AC0401: Direct energy use in agriculture: opportunities for reducing fossil fuel inputs

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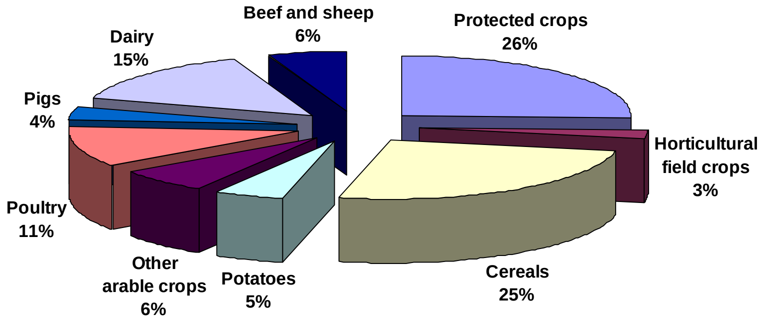
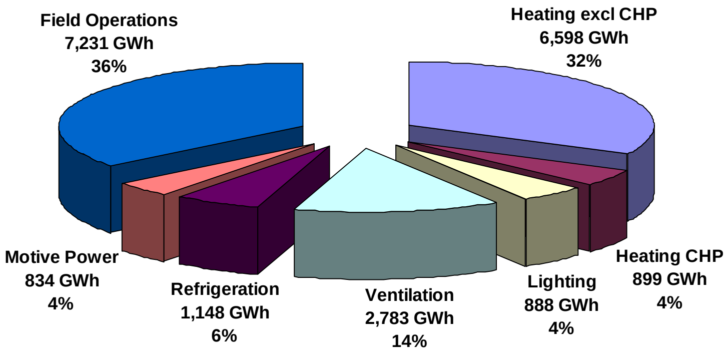
Executive Summary

A bottom-up approach has been taken to estimate direct energy use in agriculture, with 2005 as the baseline year. Data comes from CCL returns, professional surveys and best available professional knowledge. The total, direct, primary energy use sums to 20,387 GWh (73,393 TJ), but with an associated CHP electricity generation credit of 748 GWh (2,693 TJ). This is around 12% more than the total given by DTI for 2005 in its Digest of UK Energy Statistics (DUKES), which is based on returns made by energy suppliers. However, the Dukes data include forestry and fisheries so our estimate for agriculture alone is significantly greater. There are also marked differences in fuel usage by type between our estimates and DUKES data. Our analysis further indicates that agriculture emits around 1.19 million tonnes of carbon as a result of direct energy use, which is equivalent to 0.8% of total UK emissions. This is relatively small when put in the context of emissions for the whole food chain.

We estimate that petroleum products make up 56% of direct energy use in agriculture, with oils for mobile operations accounting for 63% of this. Electricity (when expressed in primary terms) accounts for 33%, gas 11%, and coal 0.4%. Renewables probably account for no more than 0.1% of direct energy use. The split in energy use between sectors (ignoring the CHP credit), and the uses of energy in agriculture are shown below. Electricity is used throughout agriculture but features most strongly in the dairy, poultry and cereals sectors. Gas oil / diesel is a large element of the fuel use in the field crop sectors and in dairy, beef and sheep. The protected crops sector differs from all others in that the bulk of the fuel use is for heating, principally by gas, oils and LPG.

Direct energy use in agriculture in 2005 (20,387 GWh expressed in primary terms), broken down by agricultural sector and use.





Around 37% of direct energy use in agriculture is for heating, and 61% of this is expended in the protected crops sector for greenhouse heating and humidity control. Potential energy saving measures include the adoption of temperature integration regimes that take account of outside weather conditions, a greater use of thermal screens (particularly for edible crops), making greater use of correctly sized, insulated thermal stores, and an increased uptake of CHP technology. A further 24% of heating energy in agriculture is used to provide temperatures suitable for the rearing of chicks and piglets, 9% is to provide hot water in dairying for hygiene purposes, and 9% is for drying, conditioning and storage of grain and other agricultural products. A key energy-saving measure in all of these sectors is improved buildings insulation. With sufficient investment, it would not be unrealistic to reduce the overall energy used for heating in agriculture by around 20% (by 2015). This would save 1,500 GWh (5,400 TJ).

Waste heat from industry or waste incineration appear to be excellent alternative sources of heating energy for protected crops businesses that are able to relocate. However, biomass has the greatest overall potential as a heating energy source since this could provide heat for most sectors of agriculture. Geothermal, solar thermal and ground source heat pumps are currently too expensive to be exploited on any major scale.

Around 36% of direct energy use in agriculture is gas oil / diesel for field operations. The largest users are the arable crop sectors (66%), principally cereals (42%). The dairy, beef and sheep sectors use an additional 31% and the horticultural field crops sector uses 3%. Savings can be made by the producers themselves by correct tractor ballasting, tyre selection and implement matching, but it is thought unlikely that these measures have the potential to save more than 10% of the total fuel used (720 GWh, 2,592 TJ). Biodiesel or straight vegetable oil (SVO) could be used as a substitute for conventional diesel with little or no capital cost implications. However, biodiesel and SVO is currently considerably more expensive than red diesel.

A further 28% of direct energy used in agriculture is electricity used to power ventilation, refrigeration, lighting and motive power applications. This comprises around 85% of the total electricity used in agriculture, with the remainder being used for heating. Ventilation and refrigeration jointly account for 19% of energy use (3,931 GWh, 14,151 TJ), and lighting and motive power each use around 4% of energy use (888 and 834 GWh or 3,197 and 3,002 TJ respectively). Ventilation energy is especially important in the cereals sector since grain drying and storage accounts for 44% of the total ventilation energy in agriculture. Potential electrical savings relating to grain and potato storage amount to around 400 GWh (1,440 TJ). There are large electricity savings to be made in the poultry and pigs sectors by the use of improved fans, ventilation control, ducting design and cleaning, and by the adoption of high efficiency lighting and lighting layouts (330 GWh, 1,188 TJ). Refrigeration accounts for around 35% of the electrical energy used in the dairy sector but potential savings appear rather modest (60 GWh, 216 TJ). Improved motive power applications will save around 10-30 GWh (36-108 TJ) energy in most of the agricultural sectors.

Whilst large-scale wind farms may be cost effective as a source of renewable electricity, intermittency of supply and economies of scale make the technology more suited to supplying the grid. Small-scale wind turbines and solar photovoltaic panels are currently only cost effective for remote applications where a grid connection is not available. The take-up of micro-hydro power will be limited by the availability of suitable sites.

Combined heat and power (CHP) has the potential to supply both heat and electricity where both are required, or where the electricity can be exported to the grid. Due to the improved efficiency of energy use, conventional CHP, using natural gas, could save up to 60,000 tonnes of carbon per annum. The technology is mature but is hindered by the energy markets (spark spread). Further savings could be made by clustering protected crops growers with different energy demands. Biomass CHP and anaerobic digestion (AD) have the potential to reduce carbon emissions further by generating electricity using a renewable fuel. These technologies are in their infancy in the UK, but have great potential. AD also helps dispose of waste and reduces methane emissions.

It is believed that the overall, potential energy efficiency saving that is feasible by 2015 in UK agriculture is around 3,000 GWh (10,800 TJ) (15%), and this would reduce carbon emissions by around 175,000 tonnes per annum. However, this saving could be much higher with the adoption of alternative, low-carbon energy sources. It is concluded that, if all of the barriers to the uptake of alternative fuels were removed, agriculture could ultimately become almost carbon neutral with regards to direct energy use. However, without Government support, the high associated costs are likely to be a considerable barrier to the uptake of such energy sources.

This report concludes with “Action Points” and “Recommendations to Defra”. A list of organisations to whom the report was circulated whilst in draft form is provided in Appendix 3.

Section 1: Quantification of direct energy use in agriculture, with a breakdown by agricultural sector and fuel type

1.1 Introduction

DTI, in its Digest of UK Energy Statistics (DUKES), publishes "Final Energy Consumption" data for a range of industries based on returns made by energy suppliers[1]. From this it appears that direct energy use in agriculture accounts for just 0.6% of the UK's annual energy use. According to a recent report by the Congressional Research Service (CRS) to Congress[2], this compares with 1.1% in the USA.

As well as using energy directly, agriculture also uses a substantial amount of energy indirectly. The CRS report estimates, for example, that of the energy used in agriculture in the USA in 2002, only 65% was consumed as direct energy; the remaining 35% was accounted for by indirect use via the manufacture of fertilisers (29%) and pesticides (6.3%). Estimates by ADAS for Defra's Sustainable Farming and Food Strategy (SFFS)[3] suggest that indirect energy accounted for 60% of the total energy used in UK agriculture in 2004. This comprised 31% for fertiliser manufacture, 8% for pesticide production, 9% for tractor manufacture and 12% for animal feeds.

The combined total of direct and indirect energy use in agricultural production is still small when compared with the associated energy used in food processing, the retail chain, food transport, and domestic storage and cooking. According to DUKES, direct energy use in agriculture amounts to around just one quarter of that expended directly in the food and beverages industry[1]. In this study, we examine direct energy use in agriculture, and estimate the separate usages of the component agricultural sectors, in total and by fuel type.

1.2 Published estimates of direct energy use in agriculture

1.2.1 DTI estimates

Table 1 shows 2005 data for "agriculture", extracted from DUKES and tabulated by fuel source[1]. Energy supply is expressed in thousand tonnes of oil equivalent (1,000 toe) as in DUKES, and also in gigawatt hours (GWh) and tera joules (TJ) (see Appendix 1 for conversions). DUKES energy data are compiled on an "energy delivered" basis and relate only to the combustible energy content of the fuels as supplied to final users. They take no account of energy used or lost in the conversion of primary fuels to secondary fuels and in their distribution to the end user. Adding in these additional energy factors to DUKES data gives the delivered energy attributable to agriculture expressed in primary terms, and this is also tabulated by fuel source in Table 1. For brevity, this is referred to in the Tables and text that follow as "primary energy". The difference between delivered energy and primary energy is large for electricity, reflecting the burning of fossil fuels in power stations to generate electricity, and transmission line losses, and a multiplication factor of 2.6 has been used to convert from delivered electrical energy to primary electrical energy. In contrast, the additional energy used to refine and to distribute other fuels is relatively small, and there are no agreed conversion factors available. Consequently, and to be consistent with accounting procedures associated with the UK Climate Change Levy (CCL), delivered energy and primary energy are taken to be the same for all fuels except electricity. This approach is the same as that used by the Energy Information Administration in the USA and DTI in the UK for the reporting of energy information and statistics.

Table 1. DTI (DUKES) energy use statistics for UK agriculture in 2005

	Delivered Energy[a]			Primary energy[a]	
Energy source	**1,000 toe**	**GWh**	**TJ**	**GWh**	**%**
Electricity	357.0	4,151.7	14,947.0	10,794.5	59.5
Natural gas	189.0	2,201.2	7,924.8	2,201.2	12.1
Petroleum products	364.0	4,227.5	15,210.1	4,227.5	23.3
Gas oil/diesel	(209.2)	(2,432.6)	(8,759.0)	(2,432.6)	(13.4)
Propane (LPG)	(135.6)	(1,577.3)	(5,679.2)	(1,577.3)	(8.7)
Burning oil	(13.2)	(154.0)	(554.4)	(154.0)	(0.8)
Fuel oils	(5.2)	(60.4)	(217.5)	(60.4)	(0.3)
Coal	6.0	70.0	252.0	70.0	0.4
Renewables & Waste	74.0	859.5	3,094.2	859.5	4.7
TOTAL agriculture	990.0	11,509.5	41,436.1	18,152.3	100.0
TOTAL UK energy	172,111	2,001,639	7,206,246	--	--

[a] *See text and Appendix 1 for details of energy units and conversions*

Expressed in primary energy terms, electricity and petroleum products, particularly diesel and propane/LPG (liquid petroleum gas), appear to account for the bulk of agriculture's fuel use (60% and 23% respectively). These are followed by natural gas (12%), renewables and waste (5%), and coal (0.4%). Renewables relate principally to straw used in straw-fired boilers for heating, but the data are rather old and may now be an over-estimate given that surplus straw in East Anglia is generally used in the power-station generation of electricity for the national grid (Steve Dagnall, AEA Technology, personal communication).

Agriculture in DUKES (Table 1) is defined by SIC (2003), an official listing that classifies businesses by economic activity (Appendix 2). On this basis, the energy use data in DUKES for agriculture actually relate to many more activities than simply the growing of crops and the farming of animals; additionally they include landscape gardening, hunting, forestry and logging, fishing and fish farming. Unfortunately, disaggregated data concerning agriculture are not kept and there is no way of allocating energy use more precisely to growing and farming (Mark Buckmaster, DTI, personal communication).

1.2.2 ADAS and Netcen estimates

ADAS has derived estimates of direct energy use in agriculture as an indicator for Defra's Sustainable Farming and Food Strategy (SFFS)[3]. However, these data are largely based on DUKES and cannot be considered as wholly independent. Minor differences between the ADAS and DUKES data in Fig. 1 for natural gas, renewables and electricity (shown expressed in primary energy terms) can be accounted for simply as differences due to accounting year (ADAS data from DUKES 2004, versus DUKES 2005). Estimated coal usage is, however, around 60% higher than in DUKES 2005, and the use of petroleum products is around 30% lower.

A third set of energy-use estimates for agriculture and forestry (combined) is provided by the National Environmental Technology Centre (Netcen), now part of AEA Energy and Environment[4]. This is as an element in the annual UK Greenhouse Gas Inventory. Netcen provides no estimate of the use of electricity in agriculture, but the 2004 estimates (Fig. 1) for coal, natural gas and renewables (exclusively straw) are very similar to those in DUKES 2005. There is a major difference, however, in the estimated usage of petroleum products, with the Netcen estimate being around four times greater than that in DUKES. The major reason for this is that Netcen includes independently-derived estimates of petroleum products used for agricultural off-road machinery and vehicles in the arable, pasture and forestry sectors. Of the Netcen total of 16,540 GWh for petroleum products, 16,259 GWh (>98%) relates to gas oil/diesel. This usage seems especially high, being 6.6% of the total figure for gas oil associated with road transport in DUKES. It is also worth noting that subtracting gas oil/diesel from the Netcen total for petroleum products leaves only 281 GWh for LPG and burning oils, a much smaller estimate for these petroleum products than is given in DUKES (see Table 1).

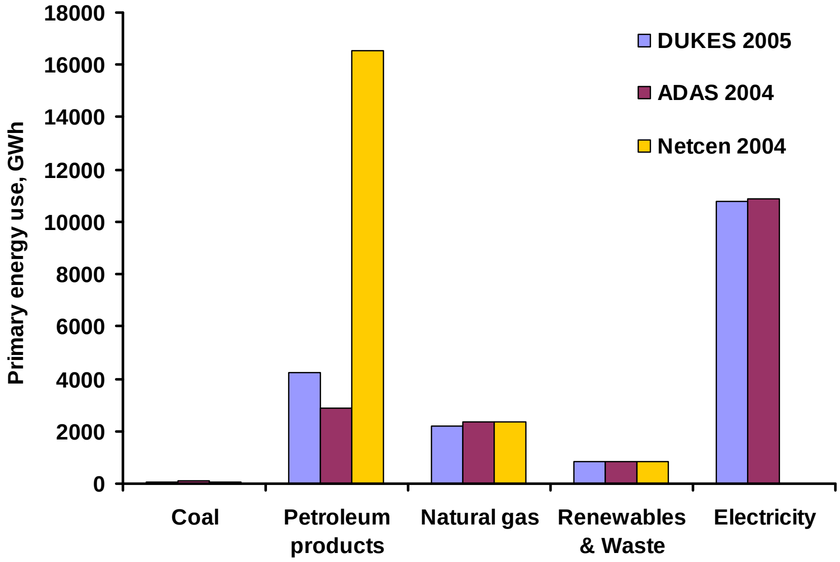


Fig. 1. Comparative estimates of energy use in agriculture, expressed in primary terms, from DUKES (2005), ADAS (2004) and Netcen (2004) (see text for details)

1.3 Bottom-up estimates of direct energy use in agriculture

Since the energy-use data in DUKES, ADAS and Netcen cannot be allocated specifically to individual sectors of agriculture, we have adopted an alternative, bottom-up approach. Energy inputs have been allocated to each of the varied sectors of agriculture, using 2005 as the base year whenever possible, and these have then been aggregated to give a final total. Estimates of energy inputs have been made, wherever possible, using data derived from CCL returns and other professional surveys carried out by FEC Services. Where precise data have not been available, estimates have been based on best available, professional knowledge of the sectors. Primary energy inputs into each sector have been split between "Electricity", "Other static" and "Mobile machinery". "Electricity" is used mainly to power fixed installations used for heating and lighting, but also equipment such as milking machines, irrigation pumps, spray rigs etc. "Other static" covers gas, petroleum products and coal used in fixed equipment, particularly for heating, and gas used to operate combined heat and power units (CHP). "Mobile machinery" covers petroleum fuels used to power tractors and other machines for field or bed cultivation, and off-road use for transportation, animal feeding etc. Estimates of oils/diesel used in field operations in the arable and livestock sectors have been derived principally from a Life Cycle Assessment report by Williams *et al*, 2005[5] with guidance in interpretation given by Dr Adrian Williams of the Natural Resources Management Institute, Cranfield University. Additional information comes from a scientific publication by Dalgaard et al., 2001[6], and J. Nix's Farm Management Pocketbook for 2007 published by Imperial College, Wye[7]. All calculations have been made on a primary energy basis (see comments in the text relating to Table 1). The word "trace" is used in the tables that follow where fuel usage is believed to be insignificant (and has not been added into sector-derived totals) but is, probably, not zero.

1.3.1 Horticultural crops

A major use of energy in the horticultural sector is to enable the growing of crops under protection, in greenhouses and other temperature-controlled structures such as mushroom houses. These inputs (GWh/ha) are shown in Table 2, categorized by crop. Production areas of edible crops (excluding lettuce and mushroom) and of cut flowers are taken directly from Defra census data for 2005[8]. The area of protected lettuce is complicated by the growing of multiple crops per year and we have used an industry estimate of 97 ha rather than the 262 ha given in the Defra statistics (Graham Ward, personal communication). The area of mushrooms (11 ha) is based on a total yield of 74,000 tonnes (Defra statistics for 2005) and assumptions that the average tray yield is 30 kg/m^2, that trays are stacked three high, and that there are 7.5 crops per year. Areas of ornamentals other than cut flowers are attributed in proportion to millions of containers produced per annum (Defra statistics for 2005) and taking into account the total area given by Defra for protected ornamentals of 1,043 ha. Energy inputs by crop are based principally on CCL returns.

Electricity use tends to be low for all commodities except mushrooms, cut flowers and pot plants, and is mainly associated with pumps for hot water circulation, irrigation and fertigation, for ventilation and for air re-circulation. In mushroom production, electricity is mainly used for cooling and to run heat pumps. Electricity use tends to be high for cut flowers and pot plants because lighting is used on around 25% of the area in each case to improve plant growth in the winter and/or to regulate flowering. Heating is mainly by gas and petroleum products, rarely by electricity. Tomatoes, cucumbers and peppers tend to be grown at higher temperatures than other edible crops and larger heating energy inputs reflect this. Cut flowers and pot plants also tend to be grown at high temperatures but the common use of energy-saving screens at night reduces average heating inputs. The lowest heating inputs are associated with container-grown nursery stock and the forcing of bulb flowers. Additional inputs of oils/diesel have been attributed to protected crops in Table 2 on an area basis to cover the powering of tractors and machinery for bed cultivation. This has been done by estimating the total number of 20 kW tractors likely to be in use in protected cropping (number of holdings[9] divided by six), and assuming an average annual use per tractor of 60 hours.

Table 2. Primary energy inputs into horticultural protected crops

Crop	Area (ha)	Primary energy inputs (GWh/ha)			Energy use (GWh)
		Electricity	Other static	Mobile machinery	
Edible crops					
Tomatoes	187	0.26	6.0	0.0017	1,171
Cucumbers	120	0.26	5.5	0.0017	691
Sweet peppers	59	0.26	5.5	0.0017	340
Lettuce	97	0.26	2.3	0.0017	249
Celery	26	0.26	2.3	0.0017	67
Mushrooms	11	6.8	2.0	0.0017	97
Fruit	194	0.26	2.3	0.0017	497
Other edibles	55	0.26	3.5	0.0017	207
TOTAL	749	-	-	-	3,318
Ornamental crops					
Cut flowers	104	0.58	4.0	0.0017	477
Pot plants	123	0.58	4.0	0.0017	564
Bedding plants	224	0.26	1.6	0.0017	417
Nursery stock	368	0.26	0.6	0.0017	317
Bulb flowers	224	0.26	0.25	0.0017	115
TOTAL	1,043	-	-	-	1,889
GRAND TOTAL	1,792	-	-	-	5,207

Energy used in the production of horticultural field crops are shown in Table 3. Most can be accounted for by oils/diesel for field operations and estimates are based on typical cultivation practices given in Williams *et al*., 2005[5] and Dalgaard *et al*., 2001[6]. Field usage (GWh/ha) for dry flower bulb production has been taken to be half of that for field vegetables since daffodil crops are typically grown "two-years down". Mobile machinery fuel use for outdoor hardy nursery stock (HONS) has been calculated on the basis of 20 W tractors (holdings[9] divided by eight), and assuming an average annual use per tractor of 180 hours. Table 3 also includes estimates of electricity used for the cooling/packing of harvested leafy salad crops from an FEC study with leading leafy salads producers, electrical and other fuels used for the drying and storage of onions and flower bulbs, and non-electrical heating energy used in hop drying.

Table 3. Primary energy inputs into horticultural field crops

Crop	Area (ha)	Primary energy inputs (GWh/ha)			Energy use (GWh)
		Electricity	Other static	Mobile machinery	
Field leafy salads	5,593	0.03	trace	0.0011	174
Onions	8,561	0.01	0.003	0.0016	125
Other vegetables	107,537	trace	trace	0.0016	172
Fruit	25,837	trace	trace	0.0003	8
Hops	1,400	trace	0.005	0.0003	7
Flower bulbs	5,726	0.0006	0.005	0.0008	37
HONS	9,519	trace	trace	0.0003	3
TOTAL	164,173	-	-	-	526

Of the 5,732 GWh estimated as the energy input for horticulture, around 58% is attributable to protected edibles (20% for tomatoes), 33% to protected ornamentals, and just 9% to field crops (Fig. 2).

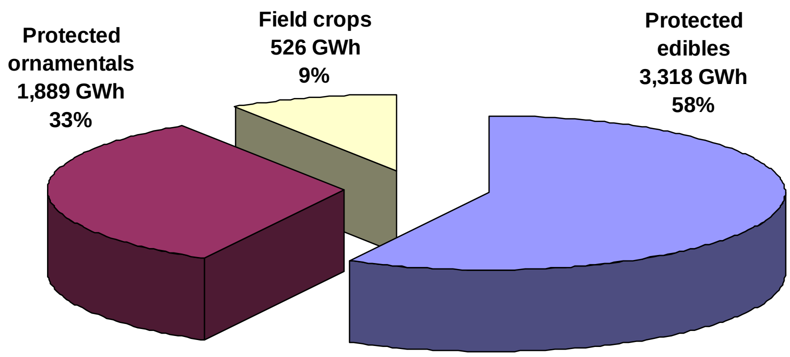


Fig. 2. Primary energy inputs into horticulture

Table 4 shows primary energy inputs into horticulture by fuel type. CCL returns for 2003/4 have been used (together with an informed knowledge of businesses not in the scheme) to calculate that gas use in horticulture is around 2,235 GWh, a similar figure to the 2,201 GWh given in DUKES (Table 1). Of this, around 899 GWh (40%) can be attributed to use in CHP. This calculation is based on CO_2 emissions attributable to horticultural CHP units that are registered (compulsorily) in the European Union Emissions Trading Scheme (EUETS), and assumes a standard CO_2 conversion factor (Appendix 1) of 0.19 kg CO_2 per 1 kWh gas consumed[10]. This CHP gas usage not only produces essential heat and CO_2 for aerial enrichment, but can be assumed to have also generated around 748 GWh primary electricity (electricity generation factor by CHP from natural gas of 32%, and multiplied by 2.6 to convert to primary units). This is about 86% of the total electricity use within horticulture, but there is no way of knowing how much of the CHP-derived electricity is actually used within the sector to reduce the requirement for grid electricity, and how much is simply exported to the grid. Consequently Table 4 simply shows CHP-derived electricity as an output from the sector. Coal used for heating in agriculture can be split between the horticulture, pigs and poultry sectors and our best estimate is that annual use in horticulture amounts to around 53 GWh. The remaining heating energy used in this sector (from Tables 2 and 3) is assumed to be from oils and LPG in the ratio of 8.5:1 for protected crops (based on 2003/4 CCL returns) and 6:4 for field crops. The use of biomass and waste products to generate energy for heating in the horticultural sector (as boiler fuels) was believed to be negligible in 2005.

This analysis indicates that approaching half (45%) of all the primary energy expended in horticulture is derived from petroleum products, and that most of this is used in static heating installations (92%). The remaining 8% is used to power mobile machinery. The other major fuel is gas, accounting for a further 39% including that used with CHP. Whilst CHP use is primarily for electricity production, the heat generated does substitute for boiler-derived heat and reduces other fuel inputs. Electricity generation associated with CHP is equivalent to around 13% of total horticultural energy usage.

Table 4. Primary energy use in horticulture by fuel type

Energy Source	Primary energy use		
	GWh	TJ	%
Electricity	867	3,121	15
Natural gas	1,336	4,810	23
Natural gas for CHP	899	3,236	16
Petroleum products	2,577	9,278	45
Oils - static	(2,099)	(7,558)	(37)
Oils – mobile machinery	(211)	(758)	(4)
LPG	(267)	(962)	(5)
Coal	53	191	1
Renewables & Waste	trace	trace	0
TOTAL	5,732	20,636	100
CHP electricity generation	748.0	2,693	13

1.3.2 Arable crops

Defra statistics for 2005[9] show the UK arable crop area to be 4.3 million hectares, with cereals accounting for 68% of this, oilseed rape, sugar beet, peas, beans, linseed etc 28%, and potatoes 3%. FEC estimates of electricity use in cereals in Table 5 assume 50 kWh/tonne for low-temperature grain drying (50% of the tonnage), 5 kWh/tonne for high-temperature drying and the maintenance of storage temperatures, and 2 kWh/tonne for the operation of ancillary equipment such as conveyers and stirrers. Estimates of non-electrical inputs to run static equipment assume 100 kWh/tonne for high-temperature grain drying (25% of the UK tonnage). Cereal yields are also based on Defra statistics for 2005[9]. Estimates of static energy inputs in potato (Williams *et al*., 2005)[5] are for the storage of 90% of the maincrop harvest, approximating to 40% of the total potato yield. Yields in 2005 are estimates from the British Potato Council[11]. Primary electrical use in Table 5 is derived using estimates of 247 kWh/tonne to run refrigeration plant and to operate fans. Additionally, 5 kWh/tonne is typically input for heating using other fuels. There are no significant static energy inputs into the cultivation of other arable crops. However, all arable crops use significant amounts of oils for mobile, field operations, and estimates by crop in Table 5 are based on usages in Williams *et al*., 2005[5]. These range from 3,750 kWh/ha for non-organic potatoes to 736 kWh/ha for organic spring barley.

Table 5. Primary energy inputs into the arable crops sector

Crop	Area (1,000 ha)	Primary energy inputs (kWh/ha)			Energy use (GWh)
		Electricity	Other static	Mobile machinery	
Wheat	1,868	621	203	1,078	3,553
Barley	942	449	146	942	1,448
Oats	91	451	150	1,078	153
Other cereals	22	307	100	1,078	33
Potatoes	137	4,208	85	3,230	1,031
Other arable	1,211	trace	trace	1,074	1,301
TOTAL	4,271	-	-	-	7,518

Of the 7,518 GWh of energy usage estimated for the arable sector, 69% is associated with cereals production, 14% with potatoes and 17% with other crops (Fig. 3).

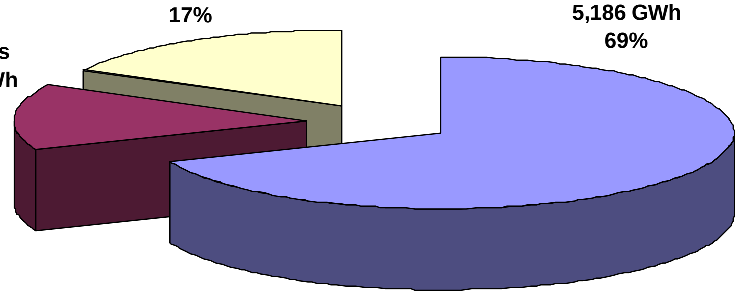


Fig. 3. Primary energy inputs into arable crops

Energy use by fuel type for the arable sector is shown in Table 6. Heating fuels, excluding electricity, have been split 6:4, oils to LPG. Overall, petroleum products dominate energy use in the sector (71%) but, in contrast to horticulture, the great bulk of this (89%) can be attributed to mobile machinery. The only other significant fuel used in this sector is electricity (29%).

Table 6. Primary energy use in the arable crops sector by fuel type

Energy Source	Primary energy use		
	GWh	**TJ**	**%**
Electricity	2,207	7,946	29
Natural gas	0	0	0
Natural gas for CHP	0	0	0
Petroleum products	5,310	19,117	71
Oils - static	(327)	(1,176)	(4)
Oils – mobile machinery	(4,766)	(17,158)	(63)
LPG	(218)	(784)	(3)
Coal	trace	trace	0
TOTAL	7,518	27,063	100

1.3.3 Livestock

Poultry – meat and eggs

The poultry sector is taken to include chickens (meat and eggs), turkeys, ducks and geese. However, there is minimal direct energy expended in the fattening of geese since nearly all are imported as goslings and raised free-range[12]. Estimates of energy use in the rearing of other species (Table 7) assume an annual production of 863 million chickens, 21 million turkeys and 19 million ducks[12], and an average live weight per bird at marketing of 2.2 kg for chickens, 14 kg for turkeys and 3.5 kg for ducks (industry standards). CCL returns (2001/2) have been used to estimate primary energy inputs as 0.3 kWh/kg live weight for electricity used mainly for ventilation and lighting, and 0.5 kWh/kg live weight for non-electrical heating. This gives primary energy input multipliers (per bird) as shown in Table 7. These figures make allowance for energy expended in the maintenance of parental flocks and in hatcheries. The use of petroleum products other than for heating has been taken as negligible. Summation shows that the overall, annual energy use for poultry meat production is 1,807 GWh.

Energy used in egg production (Table 7) has been based on an annual yield of 737 million dozen eggs[13] and multipliers derived from CCL returns (2001/2) of 0.54 kWh/dozen eggs for primary electricity and 0.09 kWh/dozen eggs for non-electrical heating. As for meat production, the use of petroleum products other than for heating is taken as negligible. This gives an annual energy usage for egg production of 464 GWh and a total primary energy use for the whole sector (meat and eggs) of 2,272 GWh. Energy use by fuel type is included in Table 11 which covers all of the livestock related sectors of agriculture.

Table 7. Primary energy inputs into the poultry meat and egg sector

	Annual production (millions)	Primary energy inputs (kWh/bird or dozen eggs)			Energy use (GWh)
		Electricity	Other static	Mobile machinery	
Chickens	863	0.66	1.10	trace	1,519
Turkeys	21	4.20	7.00	trace	235
Ducks	19	1.05	1.75	trace	53
Geese	0.12	trace	trace	trace	0
Dozen eggs	737	0.54	0.09	trace	464
TOTAL	-	-	-	-	2,272

Pigs

Estimates of primary energy use in the UK pig sector in Table 8 are based on the number of sows and gilts in pig and sows for breeding taken from Defra's June census returns for 2005[9]. This number has been multiplied by energy inputs derived by FEC from CCL industry returns for 2001/2, and these include energy use associated with maiden gilts, piglets and boars. Energy imputs are 1,402 kWh/sow for electricity, which is principally used for radiant heating, lighting, ventilation and waste handling, and 155 kWh/sow for non-electrical heating. The use of oils/diesel other than for heating is taken to be negligible. This gives a total primary energy use for the sector of 732 GWh. Energy use by fuel type is included in Table 11 which covers all of the livestock related sectors of agriculture.

Table 8. Primary energy inputs into the pig sector

	Annual production (1,000s)	Primary energy inputs (kWh/sow)			Energy use (GWh)
		Electricity	Other static	Mobile machinery	
Pigs (sows)	470	1,402	155	trace	732

Dairy farming

The total UK dairy cow herd in 2005 has been taken as 2,065,000[9] and it is assumed that the only significant energy inputs into the sector (Table 9) are electricity for such operations as cooling milk, heating water (hygiene), operating milking machines, lighting and ventilation, and oils/diesel for field operations. The multiplier used to estimate primary electricity use in the sector is 910 kWh/cow, a well established industry standard which takes into account the management requirements relating not only to cows, but also the associated heifers, calves and bulls. Diesel use is based on data of Williams *et al*., 2005[5], augmented by personal communications with the principal author of this report, and takes account of diesel used for herd management and feeding, and diesel for forage management, including silage production. The former total has been based on an estimate of 574 kWh diesel used per 10,000 litres of milk produced and Defra statistics for milk production in 2005[9]. The latter total takes account of average dry matter consumption estimates for cows, heifers, bulls etc given by Nix, 2006[7], numbers of days per year that each of these categories of animal can be expected to be housed and fed on hay and silage, numbers of days spent outside, and relationships linking diesel use with silage production and lowland pasture maintenance. These two totals have then been added and divided by herd size to give an energy input for diesel of 548.7 kWh/cow. This is only around 40% of the 1,412 kWh/cow calculated as diesel use on Irish farms by Casey and Holden (2005)[14]. Our estimates of diesel usage may be under-estimated since Refsgaard *et al* (1998) noted in relation to a crop and dairy study in Norway, for example, that actual farm diesel use was, on average, 47% higher than that expected on the basis of summing individual operations and applying standard energy inputs for these[15]. Summation of electricity and diesel use gives a total primary energy input into the sector of 3,012 GWh. Energy use by fuel type is included in Table 11 which covers all of the livestock related sectors of agriculture.

Table 9. Primary energy inputs into the dairy sector

	Annual production (1,000s)	Primary energy inputs (kWh/cow)			Energy use (GWh)
		Electricity	Other static	Mobile machinery	
Dairy cows	2,065	910	trace	548.7	3,012

Beef and Sheep

The only significant energy inputs into the beef and sheep sectors are oils/diesel for field operations, and estimates of these have been derived using data from Williams *et al*., 2005[5] and Nix 2006[7] in an exactly analogous manner as for the dairy sector. Estimates for herd management and feeding assume 839 and 500 kWh diesel per 1,000 kg edible carcass weight respectively (beef and sheep) and Defra production statistics for 2005[9].

Estimates linking diesel use with pasture maintenance assume lowland production for beef cows, and half lowland and half upland for ewe production. Dividing total diesel use by herd size in Defra's 2005 June census[9] gives primary diesel inputs of 453.1 kWh/beef cow and 18.9 kWh/ewe, and total energy uses of 801 GWh for the beef sector and 320 GWh for the sheep sector. Energy use by fuel type is included in Table 11 which covers all of the livestock related sectors of agriculture.

Table 10. Primary energy inputs into the beef and sheep sectors

	Annual production (1,000s)	Primary energy inputs (kWh/unit)			Energy use (GWh)
		Electricity	Other static	Mobile machinery	
Beef cows	1,768	trace	trace	453.1	801
Ewes/shearlings	16,990	trace	trace	18.9	320
TOTAL	-	-	-	-	1,122

Combined livestock sector

Fig. 4 summarizes primary energy use in the combined livestock sector (7,137 GWh). The sector with the largest energy use (3,012 GWh) is the dairy sector (42%), largely due to electrical inputs relating to milk handling. This is followed by the poultry sector (32%) with 1,807 GWh consumed in meat production and 464 GWh in egg production. The beef and pigs sectors have a similar total energy use (801 GWh and 732 GWh) but whilst this is wholly accounted for by diesel in the former case, electricity use dominates in the latter. The sheep sector has the lowest energy input (320 GWh, 5%).

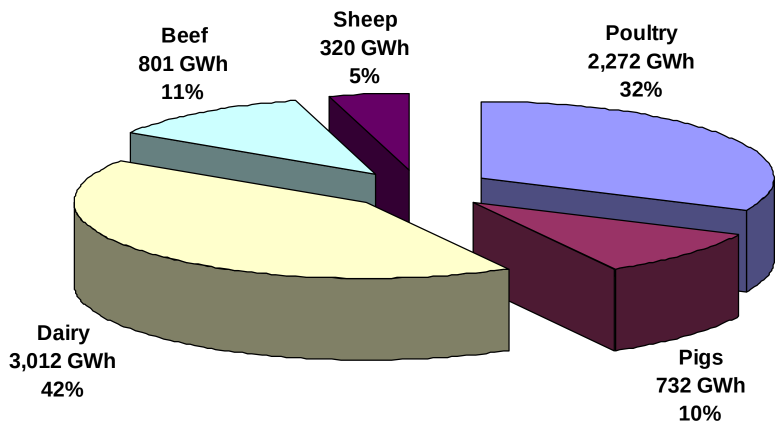


Fig. 4. Primary energy inputs into the combined livestock sector

Table 11 shows primary energy use in the combined livestock sectors by fuel type. Non-electrical heating energy relating to poultry meat production, egg production and pig rearing has been allocated to oils/diesel, LPG and coal on a proportional basis appropriate to each, reflecting 2001/2 CCL returns. Energy use is split almost equally between electricity and petroleum products, with an additional very minor usage of coal. Of the petroleum products usage, 36% is associated with heating (1,250 GWh) and 64% with field operations (2,255 GWh).

Table 11. Primary energy inputs into the combined livestock sector by fuel type

Energy Source	Primary energy use		
	GWh	TJ	%
Electricity	3,614	13,010	51
Natural gas	0	0.0	0
Natural gas for CHP	0	0.0	0
Petroleum products	3,505	12,617	49
Oils - static	(337)	(1,214)	(5)
Oils – mobile machinery	(2,255)	(8,117)	(32)
LPG	(913)	(3,285)	(13)
Coal	19	67	0.3
TOTAL	7,137	25,694	100

1.3.4 Other agricultural commodities

Agriculture in the sense of growing crops and farming animals includes some sectors that have not specifically been referred to in the bottom-up analysis above. This is because their energy usages are too small to be classified as other than "trace". Examples include the farming of deer, llamas, goats, rabbits etc, bee-keeping, honey and beeswax production and grape production for wine.

1.3.5 Agriculture in total

The bottom-up analysis indicates that the total direct, primary energy use in agriculture is around 20,387 GWh, but with a CHP electricity generation credit of 748 GWh (Table 12). Petroleum products make up just over half of the fuel used (56%) with oils/diesel for field use accounting for over half of this (63%). Electricity accounts for 33%, gas 11%, and coal, 0.4%. We do not believe that renewables account for more than 0.1% of direct energy use in agriculture, equating at most to 20 GWh, and this potential fuel is not shown in Table 12. However, renewables are increasingly being used and waste products such as straw are, of course, used indirectly as fuels in the production of grid electricity. It was estimated that around 4,105 GWh of electricity was generated from biomass and agricultural waste in 2004[3], but this has not been ascribed here as an output from agriculture as has CHP electricity, since electricity generation from waste is not an agricultural activity whilst electricity generation from CHP is essentially a by-product of the generation of heat and CO_2 required to grow crops.

Table 12. Primary energy use in agriculture as a whole by fuel type

Energy Source	Primary energy use		
	GWh	TJ	%
Electricity	6,688	24,078	33
Natural gas	1,336	4,810	7
Natural gas for CHP	899	3,236	4
Petroleum products	11,392	41,012	56
Oils - static	(2,763)	(9,948)	(14)
Oils – mobile machinery	(7,231)	(26,032)	(35)
LPG	(1,398)	(5,032)	(7)
Coal	72	258	0.4
TOTAL	20,387	73,393	100
CHP electricity generation	748	2,693	4

The split between sectors (ignoring the CHP electricity credit) is arable, 37%, livestock, 35%, and horticulture, 28%. (Fig. 5).

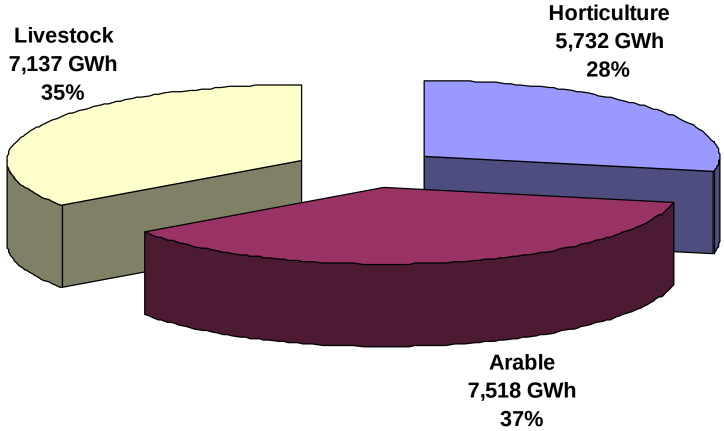


Fig. 5. Primary energy inputs into agriculture as a whole

Whilst the three main sectors in Fig. 5 are reasonably similar in terms of total fuel use, commodities differ greatly with regard to fuel type used, as shown in Fig. 6. Electricity is used throughout agriculture but features most strongly in the dairy, poultry and cereals sectors. Gas oil/diesel is a large element of the fuel use in the field crop sectors and in dairy, beef and sheep. The protected crops sector differs from all others in that the bulk of the fuel used is for heating, principally gas, oils and LPG. When electricity and gas oil/diesel for mobile machinery is excluded from account, the protected crops sector accounts for around 71% of agriculture's total energy use and

99% of horticulture's use. These figures approach the 85% and 95% respectively referred to by Chris Plackett at a recent Horticulture in Focus conference[16].

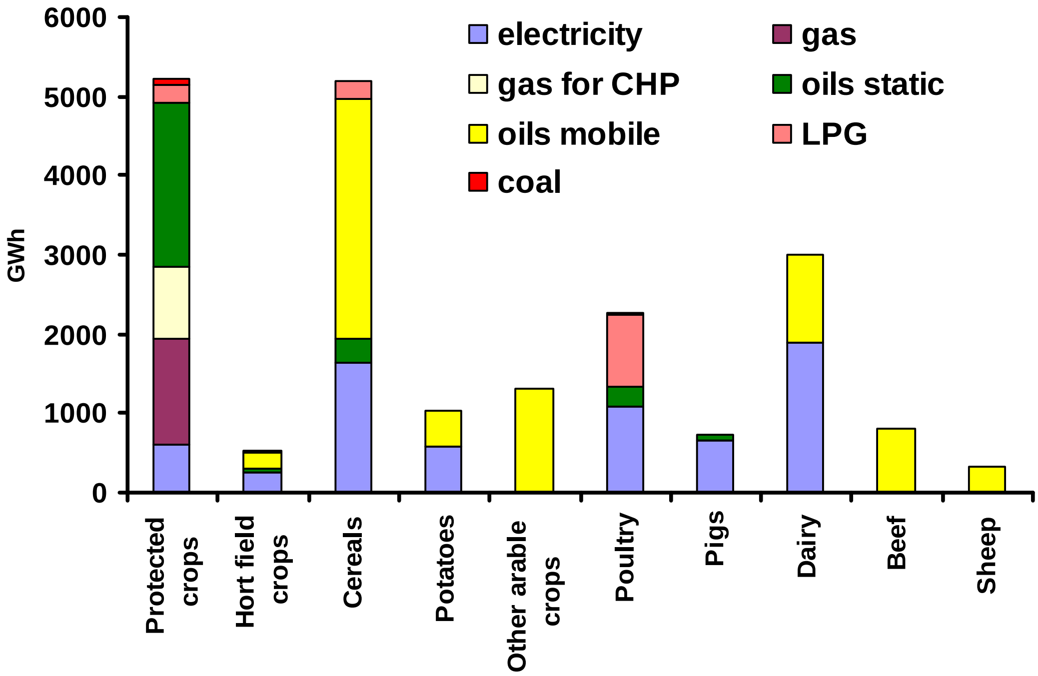


Fig. 6. Bottom-up estimates of direct, primary energy use in agriculture in 2005 by fuel type

The 20,387 GWh estimated in this report as the total primary energy use in agriculture is around 12% more than the 18,152 GWh given for 2005 in DUKES[1] (Table 1). However, the Dukes data include forestry and fisheries so our estimate for agriculture alone is significantly greater than the DUKES figure would have been had it excluded all elements not associated with the growing of crops and the farming of animals. There are also marked differences in fuel usage by type between our estimates and DUKES data. These differences can be seen in Fig. 7, which also includes Netcen (2004) data. It appears that our bottom-up approach gives a lower estimate than DUKES for electricity (62%), a similar estimate for gas (102%), and a much higher estimate for the use of petroleum products (270%). This higher estimated usage of petroleum products is still only around 69% of that given by Netcen. Furthermore, oils/diesel for off-road (field) use make up over 98% of the Netcen estimate, but comprise only 63% of the bottom-up estimate. Thus, oils/diesel for field use in the bottom-up analysis is less than half (45%) of the Netcen estimate for this fuel (7,231 GWh as against 16,259 GWh). All three surveys give similar totals for coal, but this fuel is of only minor importance so far as agriculture is concerned.

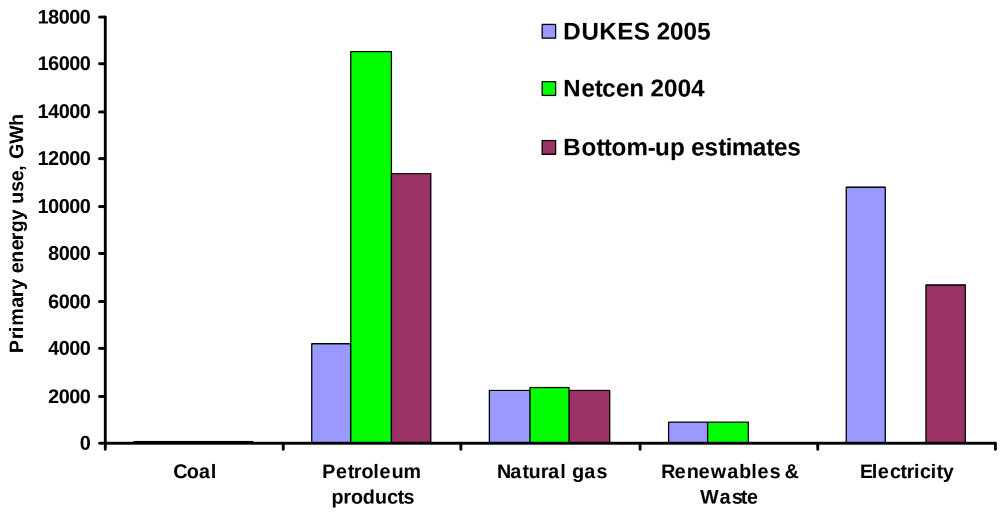


Fig. 7. Comparative estimates of primary energy use in agriculture derived from DUKES (2005), Netcen (2004) and the bottom-up analysis reported here

1.4 Carbon emissions from direct energy use in agriculture

Table 13 gives estimates of carbon (C) emissions resulting from direct (primary) energy use in agriculture based on DUKES, Netcen and the bottom-up fuel use data reported here. The 748 GWh of electricity generated by CHP will effectively displace 33,700 tonnes of C that would have otherwise been generated by power stations supplying the grid, and is shown as a CHP credit.

Table 13. Carbon (C) emissions resulting from direct energy use in UK agriculture derived from primary energy use in DUKES (2005), Netcen (2004) and the bottom-up analysis reported here

Energy source	C emissions (1,000 tonnes)[a]		
	DUKES	**Netcen**	**Bottom-up**
Electricity	485.7	N/A	301.0
Natural gas	114.5	122.5	116.2
Petroleum products	279.0	1,125.1	764.9
Oils - static	(15.2)	(15.3)	(185.1)
Oils – mobile machinery	(165.4)	(1,109.8)	(491.7)
LPG	(99.4)	-	(88.1)
Coal	5.7	5.7	5.9
Renewables and Waste	0.0	0.0	0.0
TOTAL	884.9	1,253.3	1,188.0
CHP electricity generation			33.7

[a] *See Appendix 1 for relationships between energy fuel source and emissions and to inter-convert units of C and* CO_2

The Table shows that the total emissions based on DUKES primary energy data amount to 0.88 million tonnes of carbon, which is just 0.58% of the total of UK emissions for 2004 tabulated by Defra[17]. Electricity accounts for around half (55%) of DUKES emissions, with petroleum products and natural gas making up most of the remainder (32% and 13% respectively). Netcen does not allocate electricity use to agriculture so a full comparison with DUKES is not possible. Nevertheless, calculations based on Netcen show emissions from petroleum products in agriculture are four times greater than those estimated from DUKES, but that emissions from gas and coal are similar to those based on DUKES. Our bottom-up analysis indicates that total carbon emissions (1.19 million tonnes) are around 34% greater than those based on DUKES and equivalent to 0.78% of total UK emissions[17]. Emissions from petroleum products are 2.7 times greater than those based on DUKES and account for 64% of emissions overall. However, they are still only 68% of those based on the Netcen analysis. Emissions from electricity in our analysis are lower than those based on DUKES (62%), but those from gas and coal are very similar. These contrasts are shown graphically in Fig. 8.

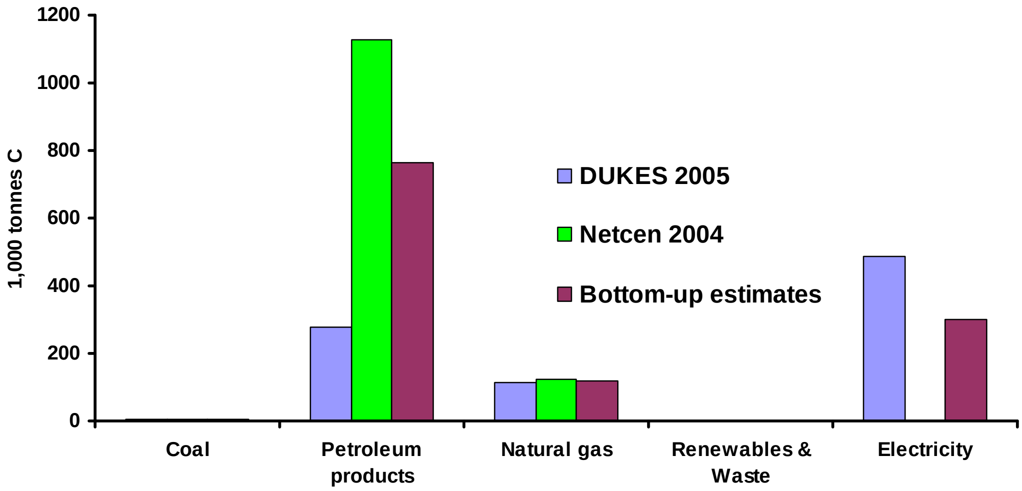


Fig. 8. Carbon emissions resulting from primary energy use in UK agriculture derived from DUKES (2005), Netcen (2004) and the bottom-up analysis reported here

While CO_2 emissions resulting from direct energy use within agriculture have been calculated to approach 1.2 million tonnes of carbon, around 0.8% of the UK total, this is not the full story. There are considerable CO_2 emissions from cropped soils and Netcen and the Institute of Grassland and Environmental Research (IGER) estimated that these raised total CO_2 emissions from agriculture in 2004 from 1.3 million tonnes of carbon, based on direct use, to 2.2 million tonnes, equating to 1.4% of total UK emissions[17]. Agriculture was also estimated in

2004 to account for 46% of methane emissions and 67% of N_2O emissions, making this sector the second largest source of greenhouse gasses, and accounting for 7% of UK total emissions[18]. Globally the contribution of agriculture to greenhouse gas emissions is even greater than this. A recent report published by the United Nations Food and Agriculture Organization (FAO)[19] estimates that the livestock sector generates 18% of the world's greenhouse gas emissions, which exceeds even the transport sector. The livestock sector produces 9% of human-induced CO_2 emissions, 64% of ammonia and 37% of methane (which is 23 times worse than CO_2 as a greenhouse gas).

The emissions in our analysis resulting from direct energy use in agriculture are small when put into the context of the whole food chain. Several studies have shown that food contributes 20-30% of total emissions across the EU25[20]. Meat and meat products are singled out as having the most impact, followed by dairy products.

1.5 Summary

- A bottom-up approach has been taken to estimate delivered energy, expressed in primary terms, in agriculture and in its component sectors, with 2005 as the baseline year. Data are based on CCL returns, professional surveys and best available professional knowledge.

- The total, direct, primary energy use in agriculture is estimated as 20,387 GWh, but with an associated CHP electricity generation credit of 748 GWh. Petroleum products make up 56% of fuel used, with oils for mobile operations accounting for 63% of this. Electricity accounts for 33%, gas 11%, and coal, 0.4%. Renewables probably account for no more than 0.1% of direct energy use.

- The split between sectors (ignoring the CHP credit) is estimated as: arable, 37%; livestock, 35%; horticulture, 28%. Electricity is used throughout agriculture but features most strongly in the dairy, poultry and cereals sectors. Gas oil/diesel is a large element of the fuel use in the field crop sectors and in dairy, beef and sheep. The protected crops sector differs from all others in that the bulk of the fuel used is for heating, principally gas, oils and LPG.

- The energy usage estimated for agriculture in this report is around 12% more than that given by DTI for 2005 in its Digest of UK Energy Statistics (DUKES), based on returns made by energy suppliers. However, DUKES includes forestry and fishing, which are excluded from our study. Furthermore, our sector-based approach gives a lower estimate than DUKES for electricity (62%), a similar estimate for gas (102%), and a much higher estimate for the use of petroleum products (270%). This higher estimated usage of petroleum products is, however, still only around 69% of that given in a separate report by Netcen.

- Our bottom-up analysis indicates that agriculture emits around 1.19 million tonnes of carbon as a result of direct energy use, which is 34% greater than estimates based on DUKES and equivalent to 0.8% of total UK emissions as reported by Defra.

Section 2: Energy use technologies and the potential for improvement in energy efficiency

2.1 Introduction
This section considers the uses to which energy in agriculture is put, and the potential for improvement in energy efficiency, excluding the potential impact of fuel substitution and the adoption of new heating technologies (Section 3). Calculations are based on the energy use total for 2005, estimated in Section 1 (20,387 GWh). The first part (Section 2.2) is concerned with the diverse energy requirements of the various agricultural sectors, and potential energy-saving measures that could be adopted, whilst the second part (Section 2.3) attempts to quantify the impact of these measures, assuming barriers to their implementation can be overcome.

2.2 Energy uses and energy saving measures
Fig. 9 shows how the energy in agriculture in 2005 was expended, on the basis of use. Energy expenditure has been categorized into seven uses by FEC on the basis of professional knowledge and experience. These are: heating excluding that by CHP; heating by CHP; ventilation; refrigeration and cooling; lighting; motive power (e.g. conveying, pumping etc); and field operations including bed cultivation.

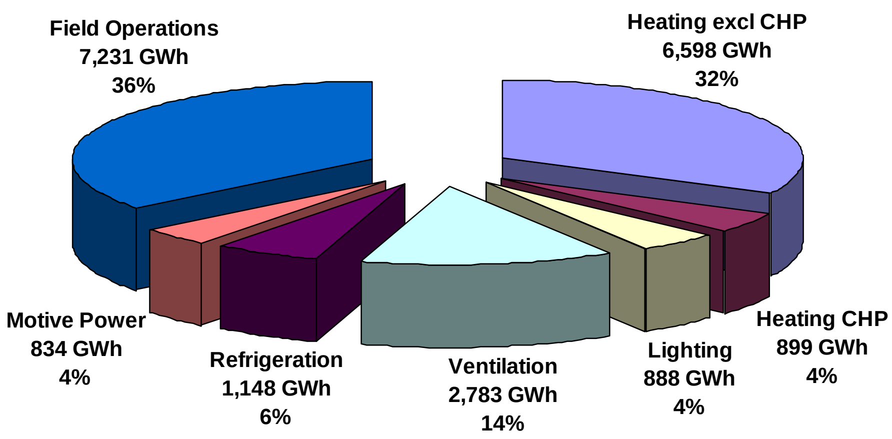


Fig. 9. Energy expended in agriculture by use (expressed in primary terms)

It can be seen that the two largest uses of energy are for heating and field operations, accounting for 37% (7,497 GWh including CHP) and 36% (7,231 GWh) respectively, and reducing these is likely to give the greatest energy savings overall. Ventilation and refrigeration jointly account for 20% of energy use (3,931 GWh), and lighting and motive power each use around 4% of energy (888 and 834 GWh respectively).

The split by use in Fig. 9 is for agriculture as a whole. However, the various component sectors vary greatly in their profile of energy use, and this is seen in Fig. 10. Thus, heating, for example, dominates energy use in protected cropping whilst field operations are predominant in the energy use of the cereals sector. Not only does energy use vary across agricultural sectors, it also varies between producers of the same crop. Not all producers give the same attention to this issue, and experience has shown that the implementation of energy management practices, regular equipment maintenance and making essential repairs as soon as they are needed, can often save up to 10% of energy[21]. It is important to know where the energy is being used, and to understand the factors leading to increases and decreases in energy consumption. To enable this, energy use data have to be collected regularly, and compared with energy use in previous seasons, taking account of differences in climate, fuel costs, production statistics etc. In some cases this can be problematic as it is often difficult to identify the energy use that relates to a specific production process. With this in mind, energy sub-metering may have to be installed. Benchmarking against the energy costs of comparable producers can be very helpful and instructive.

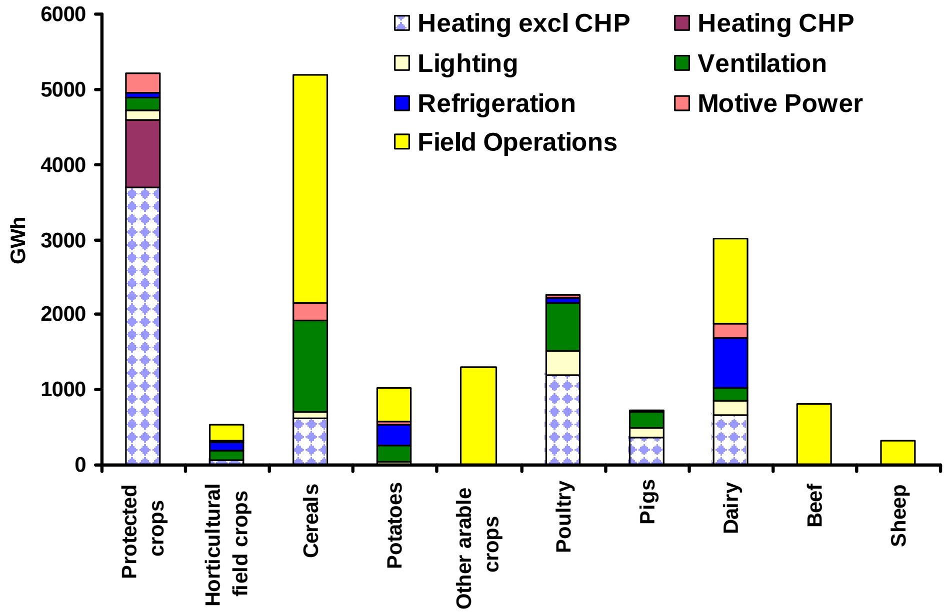


Fig. 10. Energy expended in the various sectors of agriculture, by use

2.2.1 Heating excluding CHP

Fig. 11 shows that over half of the non-CHP heating energy used in agriculture (56%) is used in protected cropping. This requirement is mainly to raise air temperatures inside greenhouses for the efficient production of long-season edible and ornamental crops, but also to regulate atmospheric humidity so as to restrict the spread of fungal disease. A further 24% of heating energy in agriculture is used to provide temperatures suitable for the rearing of chicks and piglets, 10% to provide hot water in dairying for hygiene purposes, and 10% for drying, conditioning and storage of grain and other agricultural products such as potatoes, onions, ornamental bulbs and hops.

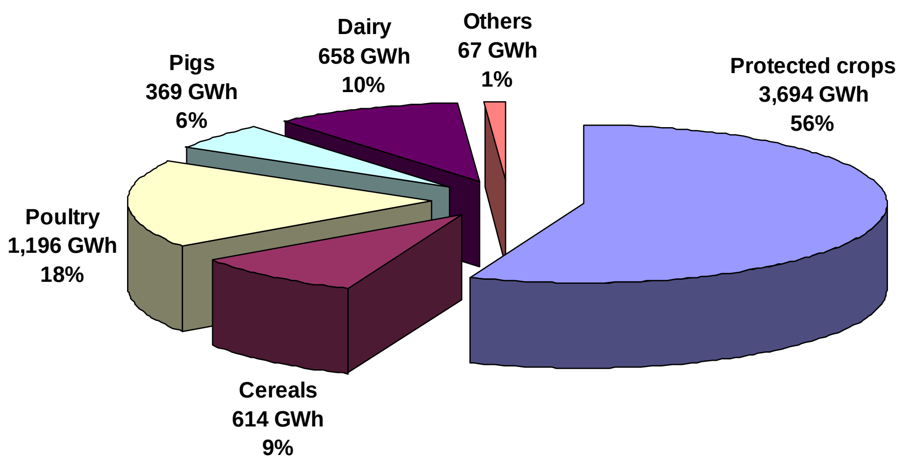


Fig. 11. Energy used for heating in agriculture, by sector

2.2.1.1 Heating used in greenhouse production

Although direct-fired heaters burning gas, LPG, kerosene or gas oil, are still to be found in older and / or less sophisticated greenhouses, heating in the protected crops sector is mainly by large, centralised, fossil-fuel fired boilers. Older, steam-based systems have now largely been replaced by low temperature, hot water systems (maximum 90^{o}C). Pipework is used to transfer the hot water to heat areas distant from the boiler itself, and temperature control is generally given by computer and microprocessor-based climate control systems. Boilers have a high capital cost and installation is complex. For these reasons, boilers tend not to be used outside of protected cropping, though there are examples of boilers used in mushroom production and in pig rearing. Enrichment of the CO_2 content of the air is an essential element in the production of many protected crops, and CO_2 is most often provided as the exhaust product of on-site combustion of carbon-based fuels. The fuel used and the equipment in which it is burnt must be chosen so that minimal levels of undesirable or harmful products of combustion (ethylene, SO_x, NO_x, CO etc) also enter the greenhouse aerial environment. Equipment used for CO_2 production include boilers, low-emission space heaters and CHP units, and the key fuels are gas, LPG and kerosene. Flue gases recovered from modern boilers and from micro-CHP units are normally considered to be sufficiently clean for direct use in the greenhouse, so long as the fuel is gas or kerosene. However, the flue gases from large CHP units have to be treated using catalytic conversion equipment before injection into the greenhouse.

Energy saving by optimised heat storage
There are often occasions when the demand for CO_2 is greater than the demand for heat, and this is most commonly dealt with by the provision of heat stores. These store excess heat as hot water in a large tank, and this resource is used for greenhouse heating at other times when heat demand is high, such as at night. However, it is important that heat stores are correctly sized and adequately insulated in order to minimise energy loss. HDC-funded work by B. J. Bailey has provided guidelines for storage tank sizing[22]. However growers have been slow to implement this work, and further knowledge transfer activities could reap rewards.

Energy saving using decentralised boiler plant
The fashion for large centralised boiler plant has led to long and, sometimes, inefficient, hot-water distribution systems, and it is possible that overall efficiencies could be improved in some situations by the installation of a number of smaller, localised heating systems. This could be useful in the summer, for example, when the main boiler plant often has to service only a small requirement for remote summer heating. Careful planning is required, however, to ensure that specific production areas can be isolated and heating systems turned off during the periods of low or no heat demand. Another advantage of decentralised heating systems is that the length of the distribution pipework can be dramatically reduced, and this reduces energy losses from the pipework itself.

Energy saving by improved boiler design
Boiler refinements can provide quick paybacks in energy efficiency in protected cropping. Measures include the fine-tuning of combustion efficiency through the adjustment of parameters such as the fuel/air mix, and boiler control. This can include the use of variable speed drives on the boiler fan motor to ensure the correct fuel air mix is maintained in all operating conditions.

Newer designs of boilers have higher intrinsic efficiencies than older designs, and the careful matching of boiler capacity to demand, and the use of multiple boilers, can lead to significant energy savings. The use of flue gas condensers can also improve the overall efficiency of gas-fuelled boilers. These generate low-grade energy in the form of hot water, typically at 40–45^{o}C and careful planning is required to ensure that this is not wasted.

Energy saving by the use of thermal screens
Heat transmission losses in greenhouses are high. They could be reduced by the installation of low emissivity glass, or double-skinned cladding materials such as twin wall acrylics. However, there is less condensation on the walls of double-skinned structures and savings given by a reduced need for heating are somewhat offset by the need to supply additional energy for dehumidification. Additionally, any energy savings are at the expense of reduced light transmission and consequential losses in crop yield and quality. For this reason, such approaches have not achieved wide commercial uptake in the UK.

More successful as an energy-saving measure has been the use of thermal screens, since it has long been known that these can reduce the instantaneous heat loss from a greenhouse by up to 40%[23]. Thermal screens can take two forms, fixed screens or retractable screens. Fixed screens normally comprise polythene sheets that line the roof and/or sidewalls of the greenhouse, and these tend to be used during the winter months when heat loss is at its highest and when light levels are low. In this way heat loss is minimised, and the light loss caused by the screen installation has less of a negative effect on production than it would during the spring, summer and autumn. This method of screening has been used extensively in the past, particularly by vegetable crop growers. Retractable screens are typically drawn across at night and at other times when energy losses would be high, but are otherwise drawn back, allowing maximum light to reach the crop. However, gapping of the screens is often necessary at night to reduce the atmospheric humidity associated with screen use and this reduces their energy-saving potential. Screens of this type have been popular with growers of ornamental crops for many years and Kittas et al. (2003)[24] showed that a retractable, aluminized screen that was nine years old reduced the energy inputs to a rose crop in Greece by about 15%. With recent improvements in thermal screen technology, and increases in energy prices, vegetable growers are also starting to show interest. The latest materials minimise heat losses, maximise light transmission (up to 88% diffuse light, 80% direct light), and fold away discretely to give minimal crop shading[25]. Promotion of the results of recent research should result in a reduction of the considerable greenhouse area that is currently without modern screens, and would contribute significantly to energy savings.

Energy saving by pipe insulation
Pipe insulation materials are in widespread use throughout agriculture and, whether it is for the frost protection of water supply pipes, or to minimise energy losses from hot water-based, greenhouse heating systems, the technology is very similar. Historically, mineral fibre based products have been used for pipe insulation, in some cases clad with aluminium foil to provide weather and impact protection. The commercial experience of FEC is that materials of this type work well if installed correctly, but that poor installation, degradation of materials, damage and water-logging can all reduce potential savings. An uninsulated external pipe loses eight times the energy of an equivalent pipe that is lagged with 50 mm of good quality, dry insulation material, so the replacement of damaged or missing insulation with new materials conforming to BS5422 (2001) would give good energy savings. Rigid, phenolic foam-based materials have recently been introduced that give improved insulation for a given thickness. These are also less prone to damage and are simpler to install than mineral wool insulation. However, uptake has, so far, been very limited in agriculture. Energy savings would also follow from the insulation of flanges, valves etc in pipe heat distribution systems. These have tended not to be insulated in the past because of difficulty and cost. However, phenolic foam-based products can now be pre-formed to make installation simpler.

Energy saving by reduced air leakage
A serious cause of energy wastage in older greenhouse structures is air leakage through glass/glass and glass/framework joints, and through poorly fitted ventilators and doors. This increases the rate of air exchange to as much as one air change/hour. This contrasts with only 0.25 air changes/hour in a recently constructed greenhouse built to the highest standards. Such a reduced air change rate has been calculated by FEC to reduce the heat demand of a greenhouse by 12% per annum. Some air exchange is desirable to keep humidity levels at an acceptable level, to promote good air movement around the crop and to remove atmospheric pollutants from the greenhouse (e.g. products of combustion from air heaters etc). This can be done by using the greenhouse climate control computer to set a “minimum ventilation rate”. However, venting is very wasteful of energy, and it would be beneficial if alternative strategies could be developed to keep air exchange rates to a minimum.

Energy saving by “temperature integration” and improved climate control
The use of computer and microprocessor-based climate control systems is commonplace on larger greenhouse sites, and these can be used to optimize energy use. However, there is considerable scope for improvement on smaller holdings where the environment is less well controlled. Work carried out by Bailey in the mid 1990s indicated that energy consumption could be reduced significantly by adopting “temperature integration”, a control strategy that allowed heating set-points to vary more widely than was usual, but still maintained the same average temperature[26]. More recent studies using both edible and ornamental greenhouse crops has shown that this approach can typically give 12% energy savings with little or no adverse effect on crop performance[27]. Current research on temperature manipulation is likely to increase potential savings on an individual nursery still further[28], but take-up by the industry will need to be improved.

Energy saving by improved humidity control
Heating to lower the atmospheric humidity of the air is used in greenhouse growing to reduce fungal disease spread and to ensure adequate plant transpiration and crop development. This approach works because, as the temperature of a volume of air rises, its moisture holding capacity increases. In practice, a vent then heat strategy is followed with ventilation, to replace the warm, moisture-laden air of the greenhouse with colder, drier air from outside, followed by heating to restore greenhouse air temperature. However, this “air mixing” approach requires careful control to ensure that the humidity does not exceed some pre-set maximum, and to prevent excessive fluctuations in air temperature. Venting heated air and replacing with cooler outside air clearly costs energy, and studies are in progress to devise more energy-efficient, humidity control protocols[28].

Refrigerant dehumidification has great potential for use in greenhouse production. This works by drawing moisture laden air over an evaporator coil (cold coil) where its temperature is reduced to below its dew point. In so doing, water condenses out of the air, thereby reducing its moisture content. The dried air is then reheated by passing it over the condenser coil (warm coil). To date, however, the high capital cost of equipment, and difficulties with its integration into current greenhouse heating and ventilation systems, have prevented its uptake.

Energy saving by the utilisation of heat pumps
Heat pumps are very attractive from an energy efficiency standpoint in that they can produce 3-5 units of heat for each unit of delivered electricity. Ground-source heat pumps and the association of heat pumps with “closed greenhouses” are dealt with in sections 3.2.2.5 and 3.2.2.6, respectively. There are a number of examples of reversible, air-source heat pumps in use in the mushroom industry. However, these tend to be less efficient from an energy point of view.

2.2.1.2 Heating in the livestock sector

Around 18% of heating energy is used in the poultry industry, principally for the raising of chicks during their first three weeks after hatching (see Fig. 11). In general, birds are reared in large, wide-span buildings and heating is supplied by LPG direct-fired, flue-less heaters or by electrically powered, infra-red, radiant heaters. Radiant heating provides useful energy savings, since these allow rearing house temperatures to be reduced. However, there are high, associated capital and labour costs since large numbers of heaters are needed to achieve a good radiant spread, and the heaters have to be moved, cleaned and maintained after each batch of birds. As the cost of energy increases, and the running cost/investment cost balance changes, the use of radiant heating will become more attractive. With this in mind the advantages of these systems must be clearly demonstrated.

Humidity control is important for the welfare of the birds and to optimise broiler production and this is generally carried out in much the same way as in greenhouse production (section 2.2.1.1).

A further 6% of heating energy is used in the pig industry, with around one quarter of this for the weaning of piglets during their first three weeks of life in heated “creeps”. Creeps are boxes installed adjacent to the nursing sow, and these are typically heated by direct-acting, electric radiant lamps. These are relatively cheap and give good results. However, a wide range of other heating systems are also to be found, including dull-emitter radiant systems, under-floor heating, convection systems and small gas-fired systems. After weaning, pigs need to be kept in heated accommodation for a further 2-4 weeks and heating is most usually supplied by electrically powered duct heaters or radiant heaters. Large, centralised, fossil-fuel fired boilers are occasionally found on pig holdings and comments on localised heating systems, new boiler designs and pipe insulation in section 2.2.1.1 (greenhouse production) apply.

Around 10% of heating energy is expended in dairying. This is wholly electrical using conventional emersion heater technology, and is primarily to provide hot water for hygiene purposes.

Energy saving by improved building insulation

Buildings in the intensive livestock sector (poultry and pigs) are mainly of timber framed construction and their average age is estimated as at least 15 to 20 years. At the time of their construction, fibre wool insulation materials were widely used because of their low cost, but damage caused by vermin and moisture is very common, greatly reducing its efficiency. There is considerable potential for energy saving by the replacement of older buildings and the use of either blown fibre or slab insulation products. Creeps used in piglet raising are also often badly constructed with air gaps in lids and sides, and these are seldom insulated. Energy would be saved, therefore, by improved construction methods, the use of insulation (including the installation of strip plastic curtains across access holes). A British Standard (BS5502) gives details of the requirements for best practice insulation of agricultural structures.

Energy saving by improved temperature control

Many electrical heating installations in the livestock sector are manually controlled. This is particularly wasteful, and the adoption of simple thermostatic control with “dimmers” could give considerable energy savings. Electronic systems are now also widely available, and the use of these could yield further energy savings. Investment costs and cultural resistance to the use of such equipment (which is often viewed as complex and difficult to operate) are inhibiting uptake, and further demonstration and communication are required to ensure greater uptake.

2.2.1.3 Heating used in crop drying and storage

There is a high usage of flue-less, direct-fired heaters for grain drying, onion curing etc. Grain drying also employs electrical resistance heaters. Humidity control is an essential element in crop storage, with de-humidification frequently required to ensure that grain drying can be carried out when ambient outside air is moist. In practice, this tends to be achieved by the installation of simple heaters (either electric, gas or oil powered) in the inlets of grain drying fans to reduce the humidity of air entering the store. However, humidities are also lowered by the application of refrigerant and desiccant dehumidification. Refrigerant dehumidification has proved particularly useful in bulk grain drying, and the underlying principles of its operation are given above in Section 2.2.1.1. Desiccant dehumidification relies on moist air being passed over a material that can absorb moisture. This often involves using a “wheel”, whereby moisture is removed whilst passing over one sector of the wheel, whilst the remainder of the wheel is being treated to reinstate its moisture removal capabilities, often by being heated. Constant rotation of the wheel means that moisture removal occurs continuously.

Energy saving by improved building insulation

Energy would be saved if all controlled temperature stores (both ambient and refrigerated) and controlled atmosphere stores e.g. potato, onion, cabbage, brassica, apple etc. were to be adequately insulated. Slabs of extruded polystyrene can be used, either fixed internally within the building or used as an internal layer between the internal wall and the external cladding. “Spray-on foam” (polyurethane) can also be used and this has the advantage that it not only improves the insulation value of the building, but also acts to fill any gaps in the structure, thereby reducing heat losses due to air leakage. As noted under Section 2.2.1.2, there is a British Standard (BS5502) that provides a code of practice for the insulation of agricultural buildings.

Energy saving by improved humidity control
Energy can be saved during grain drying by the careful monitoring of ambient outside humidities to ensure that no more heat is supplied to inlet air than is strictly necessary. This can be achieved in bulk grain dryers, for example, by the use of modulating heaters. Excellent control of de-humidification is also given by the use of refrigeration technology (see Section 2.2.5).

2.2.2 Heating by CHP
Heating by CHP accounts for around 4% of energy used in agriculture and this is all associated with the protected crops sector. CHP units burn gas to generate heat and CO_2 which are both used on the nursery, and electricity which is mainly sold on the national grid. The sale of electricity is generally necessary since the on-site, horticultural demand for electricity is usually far less than that generated by CHP. This is covered in greater detail in section 3.4.1.

Energy saving by greater investment in micro-turbine CHP units
Micro-turbine CHP units are now available with an electrical output of 30-100 kW_e, and their use in horticulture has been reviewed by FEC[29]. Several ornamentals nurseries with high electricity requirements for lighting have installed these to make use of the electricity on site. These micro-turbine CHP units have the further advantage over traditional boilers in that their exhaust gas can be used for CO_2 enrichment without the need for “scrubbing” to remove pollutants.

Hamer and Langton (2005)[30] have estimated that reductions in emissions of CO_2 would typically be in the range 25-35% if electricity for pot plant production, for example, were to be generated by micro-turbine CHP units rather than purchased from the national grid. However, there are questions about the economic viability of such units given current energy prices, their high capital expense, and the fact that CHP units can only be run when electricity is being used, so that most growers would still need a conventional boiler to provide heat at other times.

CHP units are not yet to be found in agriculture outside of the horticultural sector, but they could be of interest to pig farmers, for example, since these have a sustained, year-round requirement for heat and electricity. Unfortunately, the lack of a mains gas supply is a frequent barrier to CHP adoption in the countryside.

2.2.3 Field operations and bed cultivation
Field operations and bed cultivation account for around 36% of the energy used in agriculture. As Fig. 12 shows, 66% of this gas oil / diesel is expended in the arable sector, with an approximate split of 7 : 1 : 3 between cereals, potatoes and other crops. A further 31% is accounted for by field operations in the dairy, beef and sheep sectors, and 3% is used in horticulture.

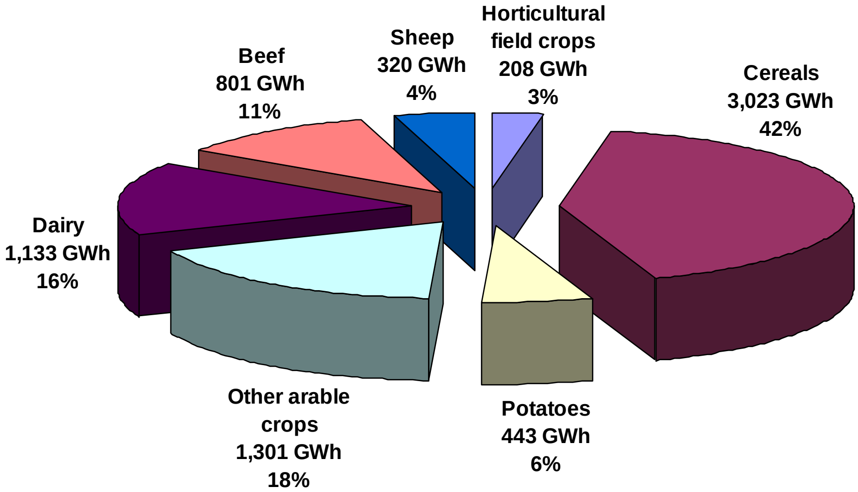


Fig. 12 Energy used for field operations and bed cultivation in agriculture, by sector

Energy saving by improved field cultivation practices
The efficiency of energy use in field operations is dependent upon such factors as the choice of prime mover (typically a tractor) to carry out the task, the implement that is used, the way in which the prime mover and the implement are combined and operated, and ground conditions and soil type. There is little that the operator can

do to influence the efficiency of the prime mover, since this is largely inherent in its basic design. Only at the time of purchase of a new machine can a decision be made on the relative efficiencies of the various alternatives under consideration. Generally, modern tractors of a similar size have similar fuel efficiencies. However, machines of more recent manufacture tend to be more efficient than similar machines that are older. In the longer term therefore, a large potential contribution to the improved efficiency of field operations lies in the hands of engine / equipment manufactures as they will be required to produce better designs that consume less fuel.

In contrast, operational efficiencies relating to tractor implement matching, tractor operation etc, can be significantly influenced by the user. A significant amount of research work has been undertaken in the past, particularly by Silsoe Research Institute, to investigate areas where fuel savings can be made. Areas of consideration included such factors as tractor and ground drive system selection and ballasting, implement control, cultivation methods, cultivations organisation and reduced tillage methods. Work also extended to an investigation of alternative prime mover systems, including gantries that could minimise soil compaction and optimise field conditions for crop growth. A more recent development that could have a significant impact on the fuel efficiency of field operations is the advent of GPS systems, and their integration into "precision farming" methods. GPS and field mapping allow the farmer to access precise information about the land being worked and / or crop performance, and the requirements for cultivation and other inputs. With this in mind such developments have much to offer.

Work on correct tractor ballasting, tyre selection and implement matching has been particularly valuable, as illustrated in the results of a recent field-based test that were published in Farmers Weekly[31]. The data show that fuel consumption savings of up to 11.5% can be achieved by setting up the tractor and implement combination correctly and by adopting the correct driving technique. Therefore, whilst much of the research relating to this work dates back some 25 years, its relevance is not diminished and the results are worth exploiting so that they are widely applied in practice.

2.2.4 Ventilation and air movement

Ventilation accounts for around 14% of energy used in agriculture, the third largest use after heating and field operations. The sectors using the most energy for ventilation are cereals (44%) and poultry (23%) (Fig. 13). Most ventilation processes use forced air ventilation, although natural air movement in and out of greenhouses through roof ventilators is the process by which air temperature and humidity are controlled in protected cropping. Key uses for forced ventilation are to assist crop drying and storage (cereals, potatoes, and horticultural field crops), to reduce heat stress and to remove atmospheric pollutants in intensive livestock housing (poultry, pigs and dairy sectors), and to provide air re-circulation and uniform temperature profiles in greenhouses (in addition to or instead of natural ventilation). The most common type of fan used in agriculture is the propeller fan. This design is well suited to promoting air movement in buildings as it can move significant volumes of air at relative low pressures. The energy efficiency of this fan design is relatively good. Axial flow and centrifugal fan designs are predominantly used in crop storage applications where the airflow has to be maintained against the significant back-pressure imposed by the crop being dried or cooled.

The energy-saving possibilities relating to ventilation are essentially generic and are not especially sector based. However, potential savings will be proportional to the importance of ventilation in each of the sectors.

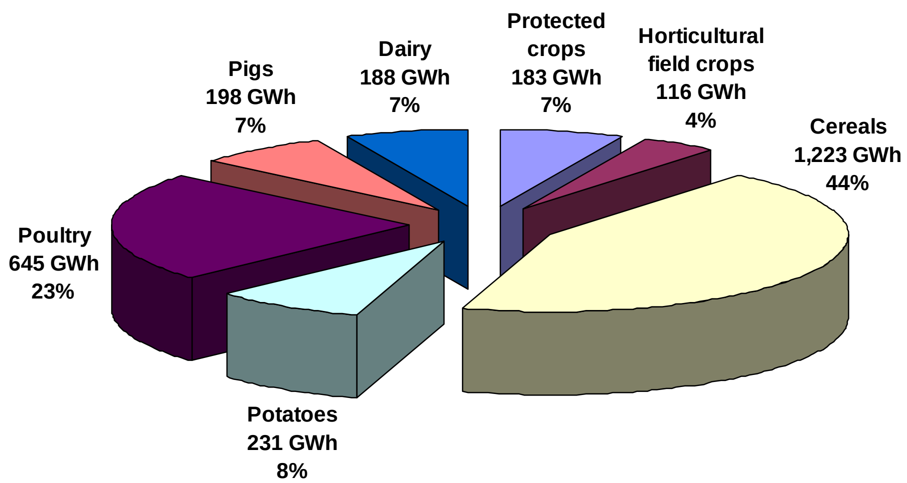


Fig. 13. Energy used for ventilation in agriculture, by sector

Energy saving by the application of improved ventilation technology
Independent testing in the past has shown that propeller fans from different manufacturers can differ by more than 30% in their specific energy consumption characteristics[32]. However, in contrast to the situation in the USA[33], good comparative information on the performance of fans at a range of speeds and operating pressures is not currently available in the UK. In the absence of such information, rational fan selection is difficult, and energy is undoubtedly wasted as a consequence.

Ventilation in agricultural buildings is frequently controlled by adjustment of fan speed. However, in the case of single-phase fans, the wiring of start and run windings within the motor can have an effect on energy efficiency, with three-wire control being the least efficient. The energy performance of speed-controlled fans is poorly documented, and further evaluation work would be helpful since significant energy savings could probably be made through the implementation of best practice methods. Similarly, scientific and commercial evaluation is required for three-phase fans with inverter speed control, since these are now starting to be installed and appear to show improved energy performance and speed stability. However, a wholesale move to three-phase fans is unlikely in the existing buildings stock because of problems relating to wiring and control systems.

Inlet and outlet ducting impose a back-pressure on fans, reducing air throughput. Many commercial installations have badly designed ducting systems that increase the energy consumption of ventilation systems. Generally, air-handling systems have not been designed using guidelines from good ventilation engineering practice. Research on the performance of ducting systems is patchy, but Pedersen and Strøm (1995)[34] showed, for example, that good ducting design could improve the energy performance of complete ventilation units by a factor of two. The problem of mismatched ducting and ventilation systems is widespread in agriculture, but is particularly bad in the intensive pig and poultry sectors.

There is heavy deposition of dust on ventilation components in many agricultural applications and, particularly, in those relating to livestock. The effect of this is to reduce the efficiency of ventilation, but the extent of this reduction is somewhat uncertain. Simple cleaning activities are sure to have a beneficial effect on performance, and these can be regarded as low cost measures that can be easily implemented on many sites with good energy efficiency gains.

2.2.5 Refrigeration and cooling

Refrigeration and cooling account for around 6% of energy use in agriculture, with the greatest requirements being associated with dairying (57%), potatoes (23%) and horticultural field crops (10%) (see Fig. 14). The main use of refrigeration and cooling in dairying is the rapid removal of “body heat” from milk, whilst in the case of field vegetables it is the rapid removal of “field heat” after harvest. Refrigeration and cooling are also used during the storage of crops such as potatoes where quality would otherwise soon be lost due to high “in-store” temperatures.

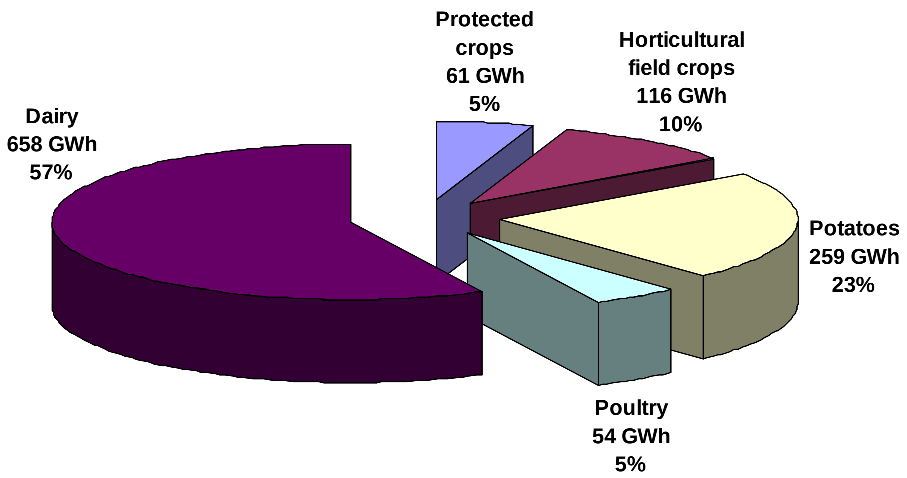


Fig. 14. Energy used for refrigeration and cooling in agriculture, by sector

2.2.5.1 Refrigeration and cooling in the dairy sector

The temperature of milk needs to be quickly reduced from body heat (37°C) after milking to a storage temperature of 4°C to ensure adequate longevity. This is either achieved using a direct expansion (DX) cooler, or with iced water using an ice bank cooler. The DX cooler works in a similar manner to a domestic refrigerator, with the evaporator coil in direct contact with the milk and located within the milk storage tank. Iced water for cooling is produced by placing the evaporator in a water bath in direct contact with the milk, and allowing ice to form on its surface. The chilled water that results, typically at a temperature of 1–2°C, is then passed, with the milk, through a counter flow heat exchanger, commonly called a plate cooler, or is used to surround the milk storage compartment of a bulk tank. Ice bank coolers are less efficient than DX systems. They are, however, popular with dairy farmers because they allow a store of ice to be created when electricity prices are low (i.e. during off-peak hours on a day/night electricity tariff), and this can then be used when electricity prices are higher. Peak loads on electricity supplies can be reduced by this time-shifting of consumption periods, and this can be particularly useful on sites with a limited electricity supply.

Pre-cooling of the milk can be used to reduce the demand on refrigerated cooling and, thereby, save energy. This involves the use of a counter flow heat exchanger, either of a plate or tube design, in which water from the mains or a bore hole, and typically at 10^{o}C, flows in one direction and the milk flows in the other. Since the feed water tends to be around 25^{o}C cooler than the milk, it serves to partially cool the milk. During pre-cooling, the temperature of the milk is typically lowered to around 18^{o}C and the water temperature is raised to 15^{o}C. For pre-cooling to be technically and economically feasible, a suitable water supply is required and the water has to be re-used. A popular option is to use it as drinking water for the stock, as cows prefer warmed water in winter!

Energy saving in dairying by the use of more efficient refrigeration systems
Pre-cooling essentially provides “free” energy, and greater uptake of this technique will save energy by reducing the required refrigeration capacity, and shortening the duration of use. Better insulated milk tanks will also save energy. Recovering heat from the condenser will save energy if this is then used to meet some of the water heating requirements of dairying. Looking further forward, new developments in refrigeration technology will offer energy-saving opportunities in new installations. These include the use of new refrigerants, and electronic refrigeration cycle control.

2.2.5.2 Refrigeration and cooling in crop storage
Ambient cooling is a low cost technique, similar to pre-cooling in the dairy industry, used for the storage of ”durable” agricultural commodities, such as potatoes and onions, where reliable storage/temperature control is only required through the winter and early spring months (i.e. from harvest until late March / April). Cool, outside air is passed over or through the stored crop, picking up crop heat and effecting cooling. However, to be effective, the ambient air temperature has to be significantly lower than the temperature of the stored product.

Refrigerated cooling ensures that store temperatures can be maintained irrespective of outside conditions. It enables crop temperature to be rapidly “pulled down” after harvest, and allows the duration of storage to be extended. There are several refrigeration systems currently in use but, perhaps, the commonest is DX, or conventional refrigeration. Stores refrigerated in this way are, essentially, scaled up versions of the domestic refrigerator, but care has to be taken to ensure the correct sizing of the key components, particularly the compressor and evaporator. Under-sizing the compressor, for example, will result in the equipment not being able to cope with high load conditions, whilst under-sizing the evaporator will give low humidity conditions in store, and these can result in severe crop dehydration and loss of quality. The technique is, therefore, best suited to durable crops that require long term storage, but where high humidity conditions are not a pre-requisite. Spray humidifiers can be incorporated if high humidity conditions are required, and these introduce a “fog” of tiny water droplets into the air stream. However, this can cause operational problems such as the freezing of water vapour on the evaporator coil, leading to the need for regular de-frosting and poor system performance. Better control of atmospheric humidity is given by ultra-sonic humidifiers that use ultra-sound to break the water into small droplets, and best control of all is given by pad humidifiers, which work by blowing the air stream over material kept saturated with water. These humidifiers can be used continuously without the fear that stored crops will become wet.

Conventional refrigeration can be combined with ambient cooling. This allows a flexible approach to be taken with ambient air being used whenever temperatures are suitable. Systems of this type have the potential to be energy efficient as they offer the best of both worlds.

Moist air cooling is an adaptation of conventional refrigeration, where a water-based system is used for heat transfer. The evaporator coil is immersed directly in water and this, after being chilling, is passed down a cooling tower with air moving in the opposite direction. This causes the air to be chilled to near-freezing, but its humidity remains close to saturation. The advantage of this approach is that crop storage can be achieved without the risk of product dehydration. Consequently, it can be used to effect long-term storage without product weight loss, or short-term, rapid cooling of vegetable crops, such as brassicas, to remove field heat.

Vacuum cooling is a further, rapid method of removing field heat, and involves placing harvested crops such as lettuce in a sealed container from which the air is evacuated. This lowers the air pressure and reduces the boiling point of water to below ambient temperature. At this point, the water captures heat from the crop and effects cooling. The surface moisture on the crop boils off and is condensed using evaporator coils. The method works well, but care has to be taken not to over-do the treatment and cause crop dehydration.

Hydro-cooling is a refrigeration procedure in which the crop is immersed in a water bath that is kept cold by having the evaporator coil immersed directly in it, as in moist air cooling. It is a procedure that is particularly well suited to produce that needs to be washed prior to marketing, since washing and cooling can be combined into one operation. A typical crop that can be successfully hydro-cooled is carrots.

Absorption cooling is a technology that allows cooling by the utilisation of heat rather than electricity. It is unlikely to replace conventional, mechanical compression refrigeration for most applications, since the latter is well proven and there is a good support network of suppliers and maintenance companies. However, there are a number of applications where absorption cooling is the superior alternative, judged in economic and environmental terms. In general, absorption cooling is worth considering when the cooling requirement is large and one of the following factors applies: waste heat is available; a CHP unit is available which can produce more heat than is needed for simple heating operations; the electrical capacity of a site has been reached and it would be expensive to upgrade; or a cheap (or free) heating fuel is available, such as biomass or biogas. In these cases, savings can be made on energy costs, and these will offset the higher capital cost of absorption cooling equipment. Unfortunately, applications in agriculture are limited because the criteria outlined above are not commonly found. However, an exception may be in protected cropping where greenhouses need to be cooled to optimise summer production, and heat can be readily sourced on site from CHP units or under-utilised boiler equipment.

Energy saving in crop storage by the use of more efficient refrigeration systems
Energy can be saved by good design and control. Components need to be sized carefully in accordance with their intended use and function. The condenser, which rejects the removed heat, needs to be correctly positioned and well maintained. If not, it will not function correctly and energy consumption will be increased. The coils must be positioned so that airflow is good, and they must be kept free of debris and dirt. Opportunities exist to recover the heat from the condenser, and this can then be used for other purposes. Similar considerations extend to the evaporator coils. Refrigerant levels must be as prescribed, and routine, annual checks need to be made by a qualified refrigeration engineer to ensure that refrigerant loss has not occurred as a result of damaged seals etc. Improved airflow through the store will ensure that the refrigerated air reaches the entire crop, and this will result in energy savings. As in the case of dairying, new developments in refrigeration technology will also, ultimately, offer energy-saving opportunities.

Energy will be saved by combining conventional refrigeration with ambient cooling. This will allow cool, ambient air to be used whenever possible, and will enable the size of refrigeration components to be reduced and operational hours to be minimised.

It probably has to be concluded, however, that the largest, potential energy savings relating to refrigerated storage probably relate to the stores themselves, rather than the refrigeration equipment. Energy could be saved by better insulation and reducing air leakage, and these topics are discussed in Section 2.2.1.3.

2.2.6 Lighting

Lighting accounts for around 4% of the energy expended in agriculture (888 GWh) (See Fig. 15). It is used in most areas of agriculture for the general illumination of yards, walkways, packhouses, buildings etc and to aid security. However, it is also used more specifically in the livestock sector to provide suitable environments for broiler production and egg laying (36%) and for the raising of piglets (15%). It is also used in protected cropping (14%) to raise productivity during low-light periods of the year and for the daylength control of flowering in ornamental crops.

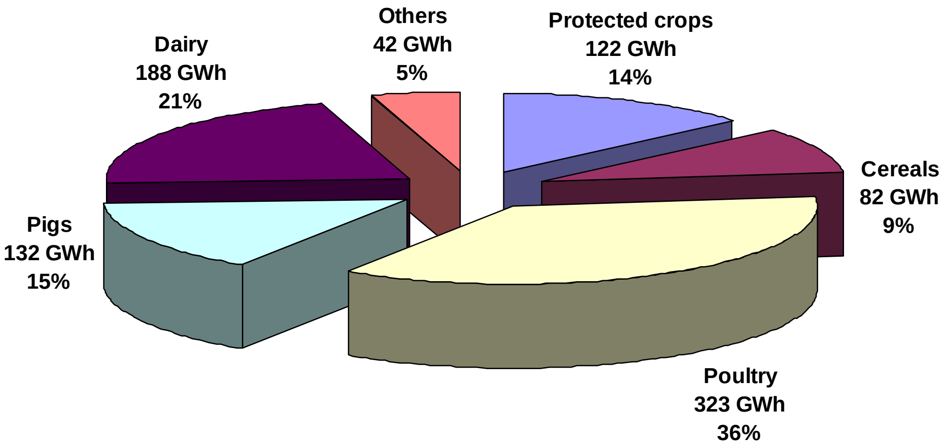


Fig. 15. Energy used for lighting in agriculture, by sector

Energy saving in general by the use of more efficient lamps and lighting controls
General lighting in agriculture is mainly tungsten-based, principally because capital and lamp replacement costs are low. However, such installations tend to be energy inefficient, and savings could be made by conversion to some form of discharge lighting, including fluorescent. Lit areas are frequently left unattended for long periods, and energy could also be saved in many cases by the use of timers, light sensors and proximity sensors to turn off lighting when it is not needed. Dairying and crop storage account for a high percentage of general lighting, and would particularly benefit from improved lighting installations

Energy saving in the livestock sector by the use of more efficient lamps
A low level of lighting (*ca*. 5 lux) is required for efficient broiler production, and this is also generally provided by tungsten lamps, controlled by dimmer systems. However, there is now a move towards the use of more energy-efficient, compact fluorescent lamps, and the industry would benefit from a continued move in this direction. Low level lighting is also a key element in poultry egg production. The traditional light source has been tungsten at a level between 5 and 20 lux and, as with broiler production, energy savings could be made by a switch to the use of fluorescent lamps. Some producers have made this change without apparent problem, but many others feel unable to make the change because of worries over the effects of changed light quality etc on egg laying. Further research and development is clearly needed into the effects of light quality, light intensity and lighting duration on egg laying to guide best practice.

Pig buildings are often lit during the working day for stock inspection etc, but it is generally accepted that the pigs, themselves, only require very low light levels. However, recent research has shown that lighting periods of 16 hours per day may be physiologically beneficial, and some farms have adopted this practice for sow housing. The general replacement of tungsten by fluorescent lighting, using either strip lamps or compact fluorescents, would greatly reduce lighting energy use in this sector. Lighting controls using proximity sensors or room entry switches would also reduce energy input significantly on many units. The use of natural light by the installation of vents or roof-lights could also be advantageous, particularly in new building designs.

Energy saving in protected cropping by the use of more efficient lamps
Daylength control is used to manipulate the flowering of ornamental plants such as chrysanthemums and poinsettias. Generally, light is supplied as night-break lighting using tungsten bulbs strung along catenary wiring. Timers are used to ensure that the night breaks are appropriately positioned during the night and are of an appropriate length. Lighting during the night break is often cycled, with successive periods of light on and light off. Fluorescent lighting can be used to provide more energy-efficient daylength control, but great care has to be taken to ensure that the irradiance levels of alternative light sources are high enough to achieve satisfactory results, given their different spectral light outputs. Fluorescent lighting is also less suited to cycling and capital costs are higher, and for all of these varied reasons, take-up of fluorescent lighting for daylength control has been low.

Light levels required for efficient daylength control (50-150 lux, 0.2-0.6 W/m^2 PAR) tend to be rather low (although much higher than is needed in the livestock sector), so there is great interest in the development by several manufacturers of alternative light sources based on light emitting diodes (LEDs). A potential advantage of LEDs is that they can be selected to deliver specific spectral outputs. Prototype systems have been described but, in the absence of clear guidelines relating to the effectiveness of LEDs, there has not yet been any commercial take-up.

Artificial light is increasingly being used in the UK to supplement solar radiation during low-light periods of the year. Levels of lighting are much higher than in other agricultural situations (3,000-5,000 lux, 7.2-12 W/m^2 PAR) and the lamp of first choice has, for long, been the high-pressure sodium lamp. This is generally regarded as being the most energy efficient of all of the various high light output lamps, although fine-tuning is still increasing its value in horticulture. Recent developments include the use of electronic ballasts and lamps with rated outputs of up to 1000 W and these, together, offer efficiency savings against conventional equipment of around 5 to 8%. Manufacturers are also developing lamps specifically for plant lighting with high outputs of photosynthetically active radiation (PAR, 400-700 nm), rather than high outputs of radiation to which the human eye is particularly sensitive (500-600 nm). Manufacturers are also working to develop lamps that show a less rapid fall-off in light output with age. FEC has shown, for example, that conventional lamps typically show a 9% reduction in efficiency after 12,000 hours of use[35]. Energy will be saved by the uptake of improved horticultural lamps though capital costs of such lighting installations are very high.

Energy saving in protected cropping by the use of improved reflector design
It is important to ensure that the light that is generated from lighting systems is effectively directed to where it is needed. This is particularly important for high output lighting in greenhouse production, where light that misses the crop is wasted light, and where uneven crop lighting gives variable crop yield and quality. Well designed and carefully spaced reflectors will help avoid such problems and will avoid wasted energy. Well designed and maintained reflectors will have a high light output ratio (LOR) or downwards light output ratio (DLOR), and a reflector that is made from materials with good reflection properties and that is kept in a clean condition can be up to 25% more efficient than one of a poor design which is dirty.

2.2.7 Motive power

Motive power applications account for 4% of energy used in agriculture and are associated especially with cereals (29%), protected crops (29%), dairying (23%) and the pigs (4%) and poultry (7%) sectors (See Fig. 16). Main uses in cereals are conveying, elevating and pumping. In dairying, motive power applications are mainly pumping**.** Motive power applications in protected cropping are mainly concerned with water circulation for irrigation, plant feeding and heating. In intensive poultry production, motive power is mainly used in feeding, egg collection, and waste handling. Finishing pigs are often fed “wet food” through pipeline systems and these use feed circulation pumps that have to deliver a variable amount of feed to each trough, and have to deal with various delivery pressure problems. Large pumps are also used in slurry disposal systems.

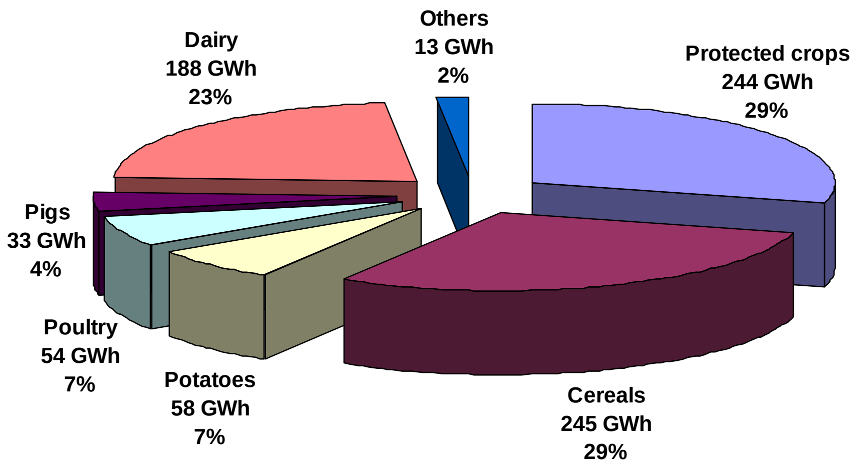


Fig. 16. Energy used for motive power in agriculture, by sector

Energy saving by use of improved motive power applications
Energy could be saved in all agricultural sectors by the utilisation of high-efficiency motors in new motive applications, and where motors have to be rewound. The use of such motors appears to be especially well suited for feed and manure conveyance, egg collection and water pumping in the poultry industry. In general, energy efficiencies of 5-8% can be expected in these operations.

The application of variable speed drives (inverter drives) linked to feed system pressure is likely to reduce the energy use in pig feeding systems, for example, by at least 25%. Circulation pumps used for irrigation and for heating in greenhouses could also benefit from the use of pressure linked variable speed drive technology. As well as reducing electricity use, there would be a knock-on saving due to increased operational efficiency of boiler systems. Variable speed drives are starting to be adopted for large poultry ventilation systems where three-phase equipment can be employed. However the consequential energy savings of these systems are not yet well promulgated.

2.3 Quantification of energy savings

Table 13 summarizes the energy-saving measures described in Section 2.2 by agricultural sector, and indicates the potential energy savings that could be made if adopted by the whole of the sector. Potential barriers to the adoption of these measures are listed, but the calculations of potential savings do not take these into account; savings assume that these barriers are, in some way, overcome. The calculations have been made by FEC with 2005 as the base year. The assessments are based on FEC's professional knowledge of the agricultural industry. Percentage savings against a particular measure are given in terms of the total energy used in the sector. Carbon savings take account of the fuel that is currently used to power the application concerned. In practice, measures leading to energy savings will only be realized if the payback period to the grower is reasonably short. Pay-back periods are indicated in the tables as 0-2 years, 2-5 years, 5-10 years and >10 years.

It is believed that 8-10% energy savings could be made, almost across the whole of agriculture by benchmarking and technology transfer. Energy use varies greatly between producers of the same item, and the pooling of energy use data improves energy awareness, and can be a powerful stimulus to action. The key for a producer is to know where energy is being expended or lost, and sub-metering will assist this greatly. Technology transfer will ensure that producers have the necessary background information to carry through energy savings without compromising economic viability.

Reducing the heating energy of agriculture is important since this accounts for around 37% of total energy use. The consumption of heating energy varies greatly across the agricultural sectors, but the greatest user, by far, is protected cropping (61% including energy to run CHP units). Heating accounts for over 88% of energy use in this sector, and it is, perhaps, not surprising that most of the energy saving measures relating to protected cropping (Table 13) are concerned with increases in the efficiency of heating. There is the potential for significant savings to be made by the adoption (or further adoption) of temperature integration regimes that take account of outside weather conditions (800 GWh), by a greater use of thermal screens (particularly for edible crops) (240 GWh), and making greater use of correctly sized, insulated thermal stores (240 GWh). Further expansion of CHP technology within protected cropping could also save around 1,050 GWh.

Energy can also be saved in other agricultural sectors by reducing the energy expended on heating. The insulation of agricultural buildings features particularly strongly, for example, in the poultry (240 GWh) and pigs (70 GWh) sectors. The insulation of crop stores will also save considerable energy, particularly in the potatoes sector (90 GWh).

It cannot be assumed that the potential heating energy savings will be the sum of all of the listed savings in Table 13. This will almost certainly result in an over-estimate because the energy saving measures that are listed for a given sector are frequently alternatives or are interactive. However, it would not be unreasonable to set an overall, aspirational target for reducing energy use for heating across agriculture (by 2015) of, say, 20% (1,500 GWh).

Field operations utilising gas oil / diesel account for around 36% of the energy use in agriculture (7,231 GWh), with the largest users being the arable crop sectors (66%), principally cereals (42%). The dairy, beef and sheep sectors use an additional 31% and the horticultural field crops sector uses 3%. Savings can be made by the producers themselves (Section 2.2.3 and Table 13) but these are judged to be relatively small. Overall improved utilisation of gas oil / diesel probably has the potential to save around 10% of fuel used (720 GWh).

Electricity expressed in primary terms accounts for 33% of the energy used in agriculture (excluding that generated by CHP), and 85% of this (5,653 GWh) is used for ventilation, refrigeration, lighting and motive power. Ventilation energy is especially important in the cereals sector since 44% of the total ventilation energy used in agriculture is expended in grain storage. As Table 13 shows, potential electrical savings relating to grain storage amount to 200 GWh. There are also similar savings to be made relating to potato storage (190 GWh).

There are also large electricity savings to be made in the livestock sectors. In poultry, significant savings are possible by the use of improved fans, ventilation control, ducting design and cleaning (100 GWh), and also by the adoption of high efficiency lighting and lighting layouts (135 GWh). Respective savings relating to the measures in the pig sector are 30 GWh and 65 GWh. Refrigeration accounts for much of the electrical energy used in the dairy sector (35%, 658 GWh), but potential savings are rather modest (60 GWh). Improved motive power applications will save around 10-30 GWh energy in most of the agricultural sectors.

Summation indicates that the potential for making electrical energy savings in agriculture amounts to around 10% (670 GWh).

Overall, it should be possible to save around 3,000 GWh (15%) of direct energy use in agriculture by 2015, excluding savings given by fuel substitution.

Table 13. Prospects for energy and carbon saving in agriculture

a) Protected crops sector (total energy use of 5,207 GWh)

Energy-saving measure	Potential energy savings	C savings (1,000 tonnes)	Payback period (years)	Barriers to take-up
Monitoring and benchmarking	520 GWh 10%	30	0-2	Sub-metering needed. Communal action needed.
Improved greenhouse cladding and reduced air leakage	230 GWh 4%	13	2-5	Investment in new glasshouses
Decentralised boiler plant	230 GWh 4%	13	2-5	High capital cost. Cultural resistance.
Improved boiler design (including flue gas condensers)	230 GWh 4%	13	2-5	High capital cost. Only practical with gas, and where low grade heat can be utilised.
Thermal screens	240 GWh 5%	14	2-5	High capital cost. Cultural resistance in edibles sector.
Correct insulation and sizing of thermal stores	240 GWh 5%	14	2-5	
Temperature integration and climate control	800 GWh 15%	45	2-5	Technology transfer needed. Worry about losing control! Research gaps.
CHP installation	1,050 GWh 20%	60	5-10	High capital cost. Electricity requirements have to be high or there is export potential (local infrastructure needed).
High efficiency lighting	15 GWh 0.2%	0.7	2-5	High capital cost. Research gaps.
Improved motive power application	30 GWh 0.6%	1.4	0-2	Research gaps. Technology transfer needed.

b) Horticultural field crops sector (total energy use of 526 GWh)

Energy-saving measure	Potential energy savings	C savings (1,000 tonnes)	Payback period (years)	Barriers to take-up
Store insulation, optimised storage	9 GWh 2%	0.5	2-5	Technology transfer needed
Improved field heat removal	15 GWh 3%	0.7	2-5	
Optimisation of field operations	15 GWh 3%	1	0-2	Technology transfer needed

c) Cereals sector (total energy use of 5,186 GWh)

Energy-saving measure	Potential energy savings	C savings (1,000 tonnes)	Payback period (years)	Barriers to take-up
Monitoring and benchmarking	390 GWh 8%	23	0-2	Technology transfer and communal action needed.
Optimisation of field operations	360 GWh 7%	24	0-2	Technology transfer needed.
Optimised grain drying,	200 GWh	13	2-5	Technology transfer needed.

storage and ventilation	4%			
High efficiency lighting	26 GWh 0.5%	1.2	0-2	Technology transfer needed.
Improved motive power applications	21 GWh 0.4%	1	0-2	Research gaps. Technology transfer needed.

d) Potatoes and Arable crops sectors, excluding cereals (total energy use of 1,031 GWh for potatoes and 1,301 for other arable crops)

Energy-saving measure	Potential energy savings	C savings (1,000 tonnes)	Payback period (years)	Barriers to take-up
Monitoring and benchmarking	230 GWh 10%	14	0-2	Technology transfer and communal action needed.
Optimisation of field operations	100 GWh 5%	7	0-2	Technology transfer needed.
Optimised ventilation and cooling in store	190 GWh 9%	11	2-5	Technical evaluation and technology transfer needed. Information gaps. Fan recommendations needed.
Improved store insulation	90 GWh 4%	5	2-5	Economics information needed
High efficiency lighting	5 GWh 0.3%	0.2	0-2	Technology transfer needed.
Improved motive power applications	30 GWh 1.5%	1	2-5	Research gaps. Technology transfer needed.

e) Poultry sector (total energy use of 2,272 GWh)

Energy-saving measure	Potential energy savings	C savings (1,000 tonnes)	Payback period (years)	Barriers to take-up
Monitoring and benchmarking	230 GWh 10%	13	0-2	Technology transfer and communal action needed.
Building insulation and heat containment	240 GWh 11%	13	2-5	Technology transfer needed. Concerns over cost-effectiveness.
Radiant heaters for bird rearing	60 GWh 3%	3	5-10	Cultural resistance.
Improved fans, control of ventilation, improved ducting design and cleaning	100 GWh 4%	4.5	2-5	Technical evaluation and technology transfer needed. Information gaps. Fan recommendations needed.
High efficiency lighting and lighting layouts	135 GWh 6%	6	0-2	Research gaps. Technology transfer needed.
Improved motive power applications	11 GWh 0.5%	0.5	2-5	Research gaps. Technology transfer needed.

f) Pigs sector (total energy use of 732 GWh)

Energy-saving measure	Potential energy savings	C savings (1,000 tonnes)	Payback period (years)	Barriers to take-up
Monitoring and benchmarking	70 GWh 10%	3	0-2	Technology transfer and communal action needed.
Building insulation	70 GWh 10%	3	2-5	Technology transfer needed. Cost-effectiveness.
Improved creep construction, heated floor pads and thermostatic heating control	50 GWh 6%	2	2-5	Research gaps, cultural resistance, technology transfer needed.
Improved fans, control of ventilation, improved ducting design and	30 GWh 4%	1	2-5	Technical evaluation and technology transfer needed. Information gaps. Fan

cleaning				recommendations needed.
High efficiency lighting and lighting controls	65 GWh 9%	3	0-2	Technology transfer needed.
Improved motive power applications	10 GWh 1.5%	0.5	2-5	Research gaps. Technology transfer needed.

g) Dairy sector (total energy use of 3,012 GWh)

Energy-saving measure	Potential energy savings	C savings (1,000 tonnes)	Payback period (years)	Barriers to take-up
Monitoring and benchmarking	300 GWh 10%	15	0-2	Technology transfer and communal action needed.
Optimisation of field operations	150 GWh 5%	10	2-5	Technology transfer needed.
Efficient refrigeration	60 GWh 2%	3	2-5	Technology transfer needed. Research gaps.
Optimisation of water heating, heat recovery	60 GWh 2%	3	>10	Technology transfer needed. High cost of heat recovery equipment.
Improved motive power applications	50 GWh 2%	2	5-10	Technical evaluation and technology transfer needed.
High efficiency lighting	35 GWh 1%	1.5	2-5	Technology transfer needed.

h) Beef and Sheep sectors (combined total energy use of 1,122 GWh)

Energy-saving measure	Potential energy savings	C savings (1,000 tonnes)	Payback period (years)	Barriers to take-up
Monitoring and benchmarking	80 GWh 7%	5	0-2	Technology transfer and communal action needed.
Optimisation of field operations	55 GWh 5%	4	0-2	Technology transfer needed.

2.4 Summary

- Estimates have been made of energy expenditure in agriculture by use. Around 37% is for heating (7,497 GWh including by CHP), 36% for field operations (7,231 GWh), and 28% for ventilation, refrigeration, lighting and motive power (5,653 GWh).

- Around 61% of heating energy in agriculture is expended in the protected crops sector for greenhouse heating and humidity control. Potential energy saving measures include the adoption of temperature integration regimes that take account of outside weather conditions, a greater use of thermal screens (particularly for edible crops), making greater use of correctly sized, insulated thermal stores, and an increased uptake of CHP technology.

- A further 24% of heating energy in agriculture is used to provide temperatures suitable for the rearing of chicks and piglets, 9% is to provide hot water in dairying for hygiene purposes, and 9% is for drying, conditioning and storage of grain and other agricultural products. A key energy-saving measure in all of these sectors will be better buildings insulation.

- An overall, aspirational target for heating energy saving across agriculture by 2015 would be around 20% (1,500 GWh).

- Field operations and bed cultivation using gas oil / diesel account for around 36% of the energy used in agriculture. The largest agricultural users are the arable crop sectors (66%, 4,766 GWh), principally cereals (42%). The dairy, beef and sheep sectors use an additional 31% (2,255 GWh) and the horticultural field crops sector uses 3% (208 GWh). Savings can be made by the producers themselves by correct tractor ballasting, tyre selection and implement matching, but it is thought unlikely that these have the potential to save more than around 10% of the total fuel used (720 GWh).

- The electrical energy used to power ventilation, refrigeration, lighting and motive power comprises around 85% of total electricity use in agriculture, with the remainder being used for heating. Ventilation energy is especially important in the cereals sector since this uses 44% of the total ventilation energy in agriculture. Potential electrical savings relating to grain and potato storage amount to around 400 GWh.

- There are large electricity savings to be made in the poultry and pigs sectors by the use of improved fans, ventilation control, ducting design and cleaning, and by the adoption of high efficiency lighting and lighting layouts (330 GWh). Refrigeration accounts for around 35% of the electrical energy used in the dairy sector but potential savings are rather modest (60 GWh). Improved motive power applications will save around 10-30 GWh energy in most of the agricultural sectors.

- The overall, potential energy saving that could be made by 2015 in agriculture, excluding fuel substitution, is believed to be around 3,000 GWh (15%). This would result in an annual reduction in carbon emissions of around 1,750 tonnes.

Section 3: Energy supply options and the potential for the integration of renewable energy

3.1 Introduction

Energy sources in agriculture currently (2005) comprise (in descending order of importance and expressed in primary terms): petroleum products (11,392 GWh split approximately 5 : 2 : 1, gas oil/diesel : heating oils : LPG), electricity (6,688 GWh), natural gas including that used to power CHP units (2,235 GWh), and coal (72 GWh). (Table 12, Section 1). As already noted, renewables and waste products probably account for no more than 20 GWh of agriculture's fuel use. This current Section is concerned with the prospects and potential for substitution of conventional fuels with alternatives that would make agriculture more sustainable, with lower carbon emissions.

3.2 Energy for heating

Heating, including that given by CHP units, accounts for 37% of the energy used in agriculture and, of this, 86% is currently provided by the on-site combustion of conventional fossil fuels (petroleum products (64%), gas (35%) and coal (1%)) and 14% is provided by grid electricity. However, there are other potentially useful and more environmentally friendly sources of heating energy, and these include waste heat, combustible waste, biomass, geothermal energy and solar energy. Electricity as a heating fuel has a high point of use efficiency but a low, overall energy efficiency when account is taken of production and transmission losses. Consideration of electricity as a fuel source in agriculture is deferred to Section 3.3.

3.2.1 Conventional fossil fuels

The brief sections on fossil fuels that follow (and that on electricity in Section 3.3.1) use abstracted information from several sources including DTI's Digest of UK Energy Statistics (DUKES)[1], the Government's Energy White Paper 2003, "Our Energy Future - Creating a Low Carbon Economy"[36], and subsequent Annual Progress Reports, DTI's "Energy Consumption in the UK"[37] and the Government's Energy Review Report, 2006, "The Energy Challenge"[38].

3.2.1.1 Oil

Oil accounted for 34% of the UK's primary energy demand in 2005, with 74% being used for transport. UK oil reserves have produced 36 billion barrels of oil equivalent, and there are around 21-27 billion barrels remaining. By around 2010, the UK is set to become a net importer of oil. Globally, conventional reserves are sufficient to meet demand for around 30 years, but non-conventional reserves (e.g. oil shales, oil sands, extra heavy crude etc, notably from Canada and Venezuela) have the potential to add another 30 years. Around half of the world's oil reserves are in the Middle East with Saudi Arabia holding about a quarter. The cost of petroleum products to commercial users remained relatively static at 0.6–1.0 pence/kWh between 1990 and 1999 (declined in real terms) but increased steadily after that, reaching 1.7–2.6 pence/kWh in 2005[39]. This was 20–85% higher than the cost of gas, depending on the actual petroleum fuel used and purchasing power, but was still substantially below the cost of electricity (>4.0 pence/kWh). Unless trends change greatly or other options become available, it can be expected that UK growers and producers will continue into the future to use petroleum products for heating. However, with an expected, sustained demand for petroleum products in the emerging economies of Asia, oil price is likely to remain high into the forseeable future.

3.2.1.2 Natural gas

Natural gas accounted for 40% of the UK's primary energy demand in 2005. The UK is now a net importer of gas and it is estimated that, to meet demands, net gas imports will be required to rise from the current 7% to around 40% by 2010, and to 80-90% by 2020. Norway will be a major source of our gas over the next decade but supplies will need to be sourced from elsewhere, e.g. Russia, the Middle East, North Africa and Latin America. Russia has the largest reserves, around a third of the world's total. Liquefied natural gas (LNG) can be produced by cooling natural gas to minus 160°C at atmospheric pressure. This can then be transported by ship and re-gasified for injection into a gas pipeline system. The UK is expanding its LNG import facilities, adding more than 100 million m^3/day capacity over the next 5 years. Demand for gas in the UK is highly seasonal, yet compared with France, Germany and Italy, the UK has relatively little strategic gas storage. As UK gas output falls, so also will its ability to meet short-term periods of demand. For this reason, flexible storage and import contracts are likely to become more important. It is concluded that there is unlikely to be a global shortage of gas in the near future, since proven gas reserves appear sufficient to last for over 45 years. However, many agricultural producers in the countryside do not have ready access to mains gas, and there is the risk of price increases and instability due to geopolitical disruption to supplies, or damage to infrastructure. Whilst the gas price for the average commercial user remained steady at around 0.5-0.8 pence/kWh between 1990 and 2000 (declined in real terms), it reached 1.4 pence/kWh in 2005[39]. Gas prices in the future are expected to remain high by historical standards and a central gas price of 1.26 pence/kWh [1 therm = 29.3 kWh] was assumed in the 2006 Energy Review[38]. Continued high gas prices will increase the pressure on agricultural producers to remain competitive, and should stimulate interest in energy saving measures and in alternative energy sources.

3.2.1.3 Coal

Coal accounted for 17% of the UK's primary energy demand in the UK in 2005, and 85% of this was used in power stations for electricity production. Coal production in the UK has declined to an annual production of around 20 million tonnes, and is expected to decrease further in the future due to difficult geological and mining conditions, and because most existing, deep mines will have exhausted their economic reserves within 10 years. Imports of coal totalled around 44 million tonnes in 2005, and came mainly from Russia and South Africa. Coal averaged 0.6 pence/kWh in 2005[39]. Coal makes up only a very small fraction of agriculture's direct fuel needs, and it seems most unlikely that the availability of coal supplies will have any major impact on agriculture in the future.

3.2.2 Alternative heating fuels

3.2.2.1 Waste heat

Many industrial concerns generate heat which, if recovered and used, could reduce the energy requirements of the company producing the heat, or that of a second company located near by. DETR's Good Practice Guide 141[40] indicates that the chemical industry alone could save >13,300 GWh per annum through the recovery of waste heat, which is greater that the total heating energy used in agriculture (Section 2). The Guide further estimates that there is the potential to save a further 2,300 GWh per annum from the food and drink industry, and 1,250 GWh per annum from the paper and board industry.

Agricultural concerns can well take the role of the associated company, and there are several examples where such industrial symbiosis has already occurred. For example, John Baarda Ltd built a 9 ha tomato nursery in close proximity to Terra Nitrogen's Billingham site in the Tees Valley in 2005. A further 6 ha are planned for construction in 2007/8. Waste heat (steam) and CO_2, generated during the manufacture of ammonia fertiliser, are used in the glasshouse, together with electricity imported from Terra for lighting to enable year-round tomato production. Similarly, Cornerways Nursery has recently increased the size of its glasshouse unit at British Sugar's Wissington plant near Downham Market in Norfolk to 10.7 ha. The glasshouses utilise low-grade waste heat and CO_2 from the sugar factory's CHP to grow tomatoes. Linking tomato production to the operation of the sugar factory allows the overall cost effectiveness of the Wissington operation to be improved, whilst reducing its environmental impact.

There are potential financial and environmental benefits in collaborating with industries that have a supply of waste heat and CO_2, but close proximity is essential. This usually means a new-build project, and it is sometimes impossible to accommodate an agricultural business next to an industrial site due to the large land area that is required. For this reason, it is probably the protected crops sector that is best suited to collaboration since this has a relatively intensive energy use and can readily make use of warm water for heating. Capital investment and the need to relocate are issues that are likely to limit the use of waste heat. Nevertheless this is an option to be explored when new glass is planned.

Whilst it may not always be practical to use waste heat from other industries, there are often opportunities to recover waste heat from agriculture itself. Waste heat energy can be trapped and then used for space and water heating for example. The cost benefits of a heat recovery system depend largely on the type and scale of the installation, but heat recovery can give substantial long-term energy savings. Potential sources of waste heat within agriculture/horticulture are boilers, CHP units, diesel generators and refrigeration plant. Boilers can employ air pre-heaters, recovering exhaust heat to pre-heat the combustion air, and condensers can also be incorporated which generate a supply of warm water (Section 2.2.1.1). Reciprocating engines can also be useful sources of heat ranging from moderate temperature exhaust gases, to lower grade heat in the water cooling system. In the case of refrigeration plant, heat captured from the condenser can be used in applications where low-grade heat is required. Captured heat can be used in the process from which the heat was derived, for example to pre-heat a boiler. It might be possible to utilise waste heat in hot water heating systems (e.g. in glasshouses) or to generate hot water (e.g. for use in dairying). Another option is to use the waste heat for cooling through the use of adsorption coolers.

3.2.2.2 Combustible waste

Whilst not classified as renewable, energy from waste is a secure energy supply. The waste can be burnt to generate heating energy or utilised as a source of gas from landfill and anaerobic digestion. However these latter options are dealt with separately in Section 3.4.3. Other waste products such a waste wood are dealt with in the biomass section below (Section 3.2.2.3).

Waste generation is growing, and landfill resources are limited. Accordingly, EU Landfill Directive 1999/31/EC obliges member states to reduce organic waste going into landfill to 35% of 1995 levels by 2010, and this has increased pressure to use waste productively. The use of waste as a fuel is one option. However, the UK's waste policy prioritises prevention, re-use and re-cycling of waste over the burning of waste to recover heat. Recovery of energy could reduce CO_2 emissions where re-use or re-cycling is not possible; however, strong opposition from some sectors of the public has hindered the development of this technology. The UK currently has less incineration capacity than many other EU member states. In 2004, the UK was incinerating 3.3 million tonnes of waste and generating 210 MW from 15 "Energy from Waste" (EfW) plants[41]. In 2006, the UK had 19 such plants, although only four produced both heat and electricity; the remainder produced only electricity and so were less efficient[42]. The net electrical energy recovered from these facilities represents around 17-21% of the energy in the waste, compared with 35% recovery for a coal-fired power station, or 50% for a gas-fired, combined cycle power station[43].

Certain wastes, when sorted, can have a high calorific value; mixed plastics, for example, have a calorific value similar to coal. On the other hand, minimally treated waste, where just the glass, metal and wet organic materials are removed, has an energy potential of around half that of coal. It is estimated that just 10% of pre-sorted municipal waste could provide 5% of the EU's energy needs[44].

Conventional EfW plants feed waste into a furnace operating at 850-1350°C. Such temperatures destroy up to 80% of contaminants, including dioxins and PCBS. Hot gasses are cooled down in a heat exchanger to 150-200°C, and the heat is used to produce steam from water, to drive electricity-generating turbines. Combustion reduces the volume of waste by around 90%, and the ash residue can be used for road building or landfill construction. Alternatively, co-incineration can be used; waste (sometime hazardous) is added to conventional fuels and used at higher temperatures in existing processes.

Refuse-derived fuel can be used as an alternative to fossil fuels, enabling waste to be burnt without specialist incineration plant. In this case, sorted combustible waste is shredded and compressed into pellets which can be mixed with solid fuels in a conventional power station or manufacturing plant. However, this approach is unlikely to be widely adopted in future as waste incineration directives apply[43].

There are fears over the impact of incineration on human health, although there have been significant improvements in the emissions from EfW plants, and they now compare well against gas-powered stations with regards to overall emissions.

It is likely that, in the future, there will be an expansion in the EfW sector, probably with mechanical treatment to pre-sort waste. In the UK, few EfW plants currently produce heat and electricity, unlike other EU countries where the heat is often used in district heating schemes. Given that the UK has few district heating schemes, there might be greater potential for industry to utilise this low grade heat. The issues for agriculture are similar to those involved in the utilisation of waste heat as discussed in section 3.2.2.1; agricultural holdings would need to be co-located with EfW plants and this would limit their ability to exploit the energy. A further barrier for protected edible crops could be the lack of associated CO_2, since the flue gases from waste incineration would not be suitable.

3.2.2.3 Biomass

Biomass fuel is any biological mass derived from plant or animal matter. It can be categorised into three types: dry biomass for burning, including forestry products, crop waste products (straw, waste wood and grain) and energy crops (short-rotation coppice (SRC), and *Miscanthus*); wet biomass for anaerobic digestion to produce biogas, including animal manures (chicken litter, cow and pig slurry) and municipal solid waste (MSW) (Section 3.4.3); and potential biofuel crops such as oilseed rape (Section 3.5.1). Dry biomass is used for heating, either directly to supply an end user's heat requirements, or indirectly to power a CHP unit for electricity generation, and appears to show the greatest potential as a renewable fuel. It is referred to as a renewable fuel because the carbon that is released in burning is equalled by carbon sequestered in growth, and because consumption as fuel is generally taken to be matched by replacement. Currently, biomass contributes 1.5% of the UK's electricity requirements and approximately 1% of heat requirements[45]. However, it has been estimated that with an availability of dry feedstock of 1.5 million tonnes of high quality wood waste, 2–3 million tonnes of contaminated wood waste, and 8 million tonnes of energy crops, biomass could provide up to 7% of heat requirements by 2015. All of these feedstocks have the ability to provide high grade heat and are capable of being transported easily from supply to point of use.

Biomass has been used for many years in agriculture to provide heat via commercially available technologies, such as the Farm 2000 straw boiler[46]. Recently, with increases in energy costs, there has been renewed interest in the use of biomass as a fuel, and the number and variety of biomass heating systems have increased greatly. In general, biomass heating systems comprise a fuel storage and feeding system, a boiler (incorporating grate, fire box and heat exchanger), a flue for gas release and a de-ashing system. The complexity of the system is dependant on the requirements of the end user and the range of fuels that the system is expected to burn. As a guide, the cost of a 1 MW biomass boiler currently ranges from £100,000 for a simple, single fuel system to £400,000 for a completely automatic system that can burn a wide range of fuels. Many biomass heating systems have been installed in commercial and public buildings, and these range from domestic size applications feeding a few offices, to large estate systems (typically 10 – 500 kW).

Fuel quality is of paramount importance in the performance of biomass heating systems and, for this reason, many biomass suppliers enter into heat-based contracts in order that the security of the supply is not a barrier to the uptake of the technology. Fuels are characterised by their calorific value (energy content in MJ/kg) and their moisture content (% water by weight). The general rule is that the available, useful energy in a fuel decreases as the moisture content increases. This is because a proportion of the energy content of the fuel is required to drive off the moisture that it contains. A high quality fuel such as wood pellets has a moisture content of 10% and a calorific value of 16.9 MJ/kg, and costs around 2.5 pence/kWh. In contrast, a less refined wood fuel such as wood chips has a calorific value of 12.6 MJ/kg because of its increased moisture content of 30%. However, this fuel can cost up to 50% less than wood pellets at around 1.0–1.5 pence/kWh. In general, the cost of biomass is highly dependant on the degree of processing needed and the transportation requirements from source to point of use. The cheapest fuels are those that require relatively little processing and are used close to where they are produced.

Waste materials provide a cheap source of energy in cases where disposal would otherwise have to be paid for, in landfill for example, and it is possible to obtain payment (a gate fee) for the burning of such fuels in biomass systems. However, some wastes such as waste wood from the construction industry are covered by the waste incineration directives (WID), and this may prevent the use of such waste products as fuel. Waste is an under-utilised resource and The Biomass Task Force has made recommendations to government that the stringency of WID regulations be relaxed and simplified to increase the use of waste as an energy source[45].

Energy crops such as SRC and *Miscanthus* require significant amounts of land for their growth, and their cost as an energy source will be lowest when they are used close to where they are grown. Their use as heating fuels in agriculture appears, therefore, to be sensible. Furthermore, it has been judged that the cost of energy crops in 2020 is likely to be similar to those of conventional fuels, i.e. around 2.5-4.0 pence/kWh, against 2.0-2.3 pence/kWh for gas and 3 – 3.5 pence/kWh for coal[47]. Concerns over the carbon balance of energy crops because of the field operations necessary to plant and to harvest and the requirement for fertiliser, have been shown to be unfounded[48].

In general, waste resources such as forestry products and waste woods are more economically viable than energy crops, especially where a gate fee can be used to offset some of the operational costs. However these biomass sources can be of unreliable quality, and the security of supply is not always guaranteed. Where there is a guaranteed need for good quality reliable heat, then wood pellets and contracted energy crops may be the best alternatives, although at greater financial cost.

Overall, it is judged that biomass could provide an economically and environmentally friendly replacement for conventional heating fuels in agriculture, particularly where sources of biomass waste or land for the growing of energy crops are located close to where the heating is required, and where transport and processing can be minimised. However, an important constraint to the switch from fossil based fuels to biomass fuels for an already existing agricultural business is the high capital cost that most would have to meet for boiler replacement. Additionally, greenhouse growers of protected edible crops would no longer have a source of CO_2 to enrich the greenhouse environment. Currently, CO_2 is taken directly from the flue gasses of cleaner burning fossil fuels such as gas and kerosene, or commercially available technologies are utilised to release the CO_2 from less clean fuels. However, biomass fuels are unpredictable in their composition and it is, therefore, difficult and expensive to release the CO_2 from the flue gases. There are commercial systems that can do this, but these demand that the fuel is always within specified limits, and this compromises the requirement for economic viability that biomass systems are able to cope with varying specifications and even fuel types.

3.2.2.4 Geothermal energy

Worldwide, geothermal resources are widely used to provide heating energy for agriculture. According to Lund *et al*., (2005)[49], there are around 30 countries with greenhouses heated in this way, and 15 countries use geothermal energy for the drying of grain, vegetable and fruit crops. However, geothermal energy is not used in UK agriculture. In general, the UK possesses only relatively low-temperature geothermal resources and exploitation is minimal. The City of Southampton Energy Scheme remains the UK's only major exploitation of geothermal energy[50]. This pumps brine at a temperature of around 74^{o}C from an aquifer in the Wessex Basin around 1.8 km below the earth surface, and uses a heat exchanger / absorption pump system to heat water which is fed into a piped heating scheme.

There are considerable commercial and technical constraints on the development of geothermal energy in the UK. As noted above, only low grade heat is available, the resources are often not where the energy is needed, and there are considerable financial risks associated with drilling wells that subsequently prove unusable. Garnish

(1978)[51] noted that it might well cost £2 million to drill a 5 km well, and that was around 30 years ago! It seems unlikely that geothermal energy will prove useful as a heating source in agriculture, even in areas of the country where such energy is theoretically available.

3.2.2.5 Solar heating systems

Active solar heating systems convert solar radiation into heat, and these are becoming more common in the UK, primarily to provide a contribution to domestic water heating and to heat swimming pools etc. Solar water heating panels contain water which, when hot, usually travels to a coil in a hot water cylinder and transfers the heat to the water there. This is known as an "indirect" system. Alternatively, in "direct" systems, hot water from the panels goes straight into the cylinder. However, these systems are unsuitable for use in areas with very hard water. There are two main types of commercial, solar water heating panel available, flat plate and evacuated tube. The latter are the more efficient, but they cost considerably more[52].

Solar water heating is currently the largest micro-generation technology in the UK for domestic use; in 2006, there were 78,470 installations[53]. However, the technology is not yet cost-effective. A report by the Energy Saving Trust[54] suggests that the technology is unlikely to break-even before 2050. The authors conclude that significant grant funding (around 50% of the capital costs) would be needed to maintain the market.

It appears, therefore, that whilst the technology has the potential for use in agriculture, particularly to produce hot water in the dairy sector, the technology is unlikely to be widely adopted as the benefits do not justify the capital expenditure.

3.2.2.6 Solar heating – the closed greenhouse

An alternative approach to the exploitation of solar energy is to capture this in "closed greenhouses". Bakker (2006)[55] has discussed this possibility, pointing out that greenhouses are large solar collectors, capturing up to 80% of the solar radiation that is incident on them. On an annual basis, this equates to around 972 kWh/m^2 greenhouse floor area in North West Europe. Conventionally, all of the solar heat that is in excess of that immediately required for crop growing is expelled from the greenhouse by venting, and fossil fuels are used for heating at other times when the solar energy is insufficient to maintain required temperatures. Annually, fossil fuel used in this way amounts to around 400-600 kWh of natural gas per m^2 of greenhouse. Since the incoming solar radiation represents around twice the energy used in the greenhouse itself, there is the possibility of using the greenhouse as a combined crop and heat producing system. The technical challenge is to find cost-effective methods of storing incoming heat energy. Growers of edible crops commonly use buffer tanks at present for short-term storage of heat as hot water. However, the quantities of heat that can be stored in this way are small compared with what would have to be stored in summer, for use in winter.

There are currently several projects in The Netherlands where aquifers are used to store greenhouse heat. A minimum of two boreholes (wells) are used, one hot and one cold, and these are typically 30–80 m deep, reflecting usual aquifer depth. Water from the cold well (5-7°C) is used in summer to cool and to de-humidify the greenhouse, and the heat that is collected is stored in the warm well (16–18°C). This is used in the winter to heat the greenhouse, using a heat pump to boost the water temperature to around 40°C. The resulting cold water (at around 5°C) is stored in the cold well. Over the course of a year the heat stored and that removed has to balance. Greenhouse heating and cooling are carried out using air treatment units, which blow warm or cold air (extracted from the warm and cold water) into the greenhouse via inflatable ducts. The electricity used to run the air treatment units, heat pumps etc is typically from CHP, and many nurseries are using the excess heat from the CHP and closed greenhouses to heat other, conventional greenhouses. The capital costs of such systems are high; currently around €70-90 per m^2 greenhouse area on top of the cost of a conventional glasshouse and boiler (€60-70 per m^2). Drilling costs are typically €100,000 per well.

Projects in The Netherlands currently claim a 35% reduction in the use of fossil fuels for combinations of closed and conventional greenhouses. This being so, the energy savings appear insufficient to justify the capital expenditure. However, the projects make more economic sense, at least for edible crops, when account is taken of 15-20% yield increases resulting from the maintenance of higher concentrations of CO_2. There are also a number of commercially viable, closed greenhouse systems operating on orchid nurseries in The Netherlands. In these cases it is the added value of being able to cool the greenhouses in summer and increase the percentage of plants with two flower spikes that tips the balance. Whilst many of the demonstration projects have operated as closed greenhouses in order to maximise the energy that can be collected, it is likely that commercial follow-on systems will be semi-closed. These will not store as much heat in the summer, and will lose some of the advantage of conserving CO_2. However, capital costs will be lower and the schemes will be more cost-effective.

Such systems work in The Netherlands because most areas have suitable aquifers. This is not necessarily the case in the UK, although growers in the Hampshire and London basins might be able to utilise aquifers as a means of storing heat[56], although the technology is not proven in the UK. In other areas, an alternative technology would be to use ground source heat pumps (see Section 3.2.2.7). However, GSHP systems with a 10-14°C source for heating and cooling can be expected to be less efficient than heat pumps associated with aquifer thermal energy storage where there are wells at 6°C and 17°C. Furthermore, the installation costs of ground heat pumps will probably be higher since they rely on conduction for heat transfer, and so more boreholes are required.

It is concluded that, at present, the closed greenhouse technology is not viable in the UK when judged purely on the basis of energy saving. Nevertheless, it will be worth following developments in The Netherlands and possibly conducting some further studies as to the areas of the UK where suitable aquifers might be available. Almost certainly, the technology will be best suited to the growing of protected edible crops (tomatoes, peppers, cucumbers etc) and orchids.

3.2.2.7. Ground source heat pumps (GSHP)

Ground source heat pumps (GSHP) use the ground as a sink or source of heat, exploiting the fact that at a depth of 2 m or more, ground temperatures remain fairly constant. At present there is estimated to be 5 MW of GSHP capacity in the UK, comprising 600 - 700 units[53]. GSHP systems have been developed to heat domestic premises and offices, but they appear ideal for use in relation to greenhouse units, farms and rural premises where there is sufficient land for the necessary horizontal trenches, or for larger installations boreholes.

A major advantage of GSHP systems is that they have the potential to cool in summer and heat in winter. GSHP systems also have the potential to reduce CO_2 emissions. Based on the information in Appendix 1, a GSHP with a seasonal efficiency of 350% would produce 0.033 kg C from electricity for every 1 kWh of heat, whereas a gas boiler operating at 65% efficiency would produce 0.078 kg C for every 1 kWh of heat. However, electricity is more expensive than gas, and the installation costs are often £1,000 to £1,700 per kW for commercial systems[57].

3.3 Electricity

As noted earlier, electricity expressed in primary terms accounts for 33% of the energy used in agriculture. Of this, around 15% (1,036 GWh) is used for heating and 85% (5,653 GWh) for ventilation, refrigeration, lighting and motive power. This excludes the 748 GWh of electricity generated by CHP units (Table 12) since this is largely exported to the national grid (see also Section 3.4). Almost all of the electricity used in agriculture is taken from the national grid and there is, currently, very little electricity generated locally, other than via CHP. However, there is increasing interest in electricity generation using alternative technologies such as photovoltaics, wind energy and micro-hydro energy.

3.3.1 Grid electricity

In 2005, 37% of the UK's grid electricity generation was from gas, 34% was from coal, 20% was from nuclear, 3% was from renewables, and the remaining 4% was either from oil or was imported. The actual make-up of fuels used in generation changes with time, and coal made up around 50% of generation through the winter of 2005/6. However, coal generation is set to decline with the phased implementation of European measures to reduce carbon emissions, and the closure of older coal-fired plant. Electricity generation by nuclear power will also decrease unless new stations are commissioned, or life-extensions for existing power stations are agreed. Currently, only one nuclear plant is scheduled to be operating in 2025, but this may change since nuclear is currently an important source of carbon-free electricity. The economics of nuclear power stations have appeared unfavourable in the past, and nuclear waste is an obvious concern. However, projected increases in the price of fossil fuels and the value that has been placed on CO_2 emissions appear to be making the nuclear power generation of electricity a more attractive option.

The significant investment in generation capacity during the 1990s was largely in gas-fired plant and, without changes to the current market framework, the number of gas-fired power stations is set to increase further as coal and nuclear stations are decommissioned. However, this would make the UK increasingly dependent on gas imports, and would reduce the diversity of the UK's electricity generation mix.

The UK produces less electricity from renewables than its European partners, although the proportion of electricity generated from these sources is increasing. The Government's aim is that renewables supply 10% of electricity by 2010, and 20% by 2020. If the UK is to achieve a 60% reduction in carbon emissions by 2050, then renewables will probably need to contribute 30-40% of electricity generation by that time.

The grid will still distribute electricity generated from large power stations, and some of these will be off-shore (wave, tidal and wind farm). However, there is also likely to be more local generation, and this will feed distributed networks and will sell excess capacity to the grid; micro-generation (e.g. via CHP, fuel cells and photovoltaics) is also set to rise.

Grid electricity appears an “easy” fuel for agricultural producers to use for heating, lighting etc, but it is a highly inefficient fuel in terms of carbon emissions, and is a very expensive fuel. Grid electricity increased in average cost by around 36% between 2004 and 2005 (33% in real terms) to >4.0 pence/kWh, around three times the cost of gas and twice the cost of petroleum fuels. There are obvious incentives for agricultural producers to switch to more cost-effective energy sources for heating, and to cheaper and more sustainable sources of electricity than that available from the grid for lighting etc.

3.3.2 Alternative sources of electricity

3.3.2.1 Solar photovoltaic energy

The sun’s energy can be converted directly into electricity using photovoltaic (PV) cells. A PV cell consists of thin layers of a semi-conducting material which, when exposed to light, generate electrical charges that can be conducted away by metal contacts as direct current. This is then converted to AC via an inverter. The most commonly used semi-conductor material is silicon, but gallium arsenide, cadmium telluride and copper indium diselenide are also used. The electrical energy that is produced depends on the amount of light that falls on the PV material, but the electrical output from a single PV cell is small. However, multiple cells can be connected together and encapsulated to form panels which can, themselves, be linked. These will give a proportionally greater electrical output. Accordingly, PV technology can be used for both small, stand alone applications, or for large-scale electricity generation for export to the grid. There are several PV cell types, but the monocrystalline has the highest light-to-electricity conversion efficiency of around 15-18%.

PV generation can be very cost-effective in areas where grid connection or other forms of electricity generation are too expensive or not feasible, and there has been a rapid increase in installed PV systems in the UK in recent years. However, despite this, the potential capacity of PV systems in the UK in 2005 was only around 11 MW[58], well behind Germany, for example, which had a PV capacity of 768 MW in 2004[59]. Little or none of the UK capacity is associated with agriculture.

The length of deployment that is required for a photovoltaic system to generate an amount of energy equal to the total energy that went into its production (the energy payback time or EPBT) is relatively short (1-2.7 years)[60], but a much greater period is required to cover the capital expenditure. According to the 2005 National Survey Report of PV Power Applications in the UK[58], the average cost of a PV panel in 2005 was around £3.7-5.0 per watt, and overall prices for grid-connected systems ranged from £3.4-15.2 per watt. The average turnkey price for a 1-3 kW system in 2005 was £6.1 per watt. It appears, therefore, that even if the capital cost is spread over 20 years (the expected life span of some systems), the cost of electricity would still equate to 41 pence/kWh, without capital grants and assuming no running costs. The Energy Saving Trust have also reported[54] that solar PV is not cost effective at present, and that significant incentives are needed to maintain the market for small grid-connected systems. Cost effectiveness is not predicted until 2030, although a technology breakthrough could reduce this to 2020. Lack of planning issues means that the market for this technology could be large and the technology could supply almost 4% of UK electricity demands. Looking ahead to 2020, the Energy Review, 2002, estimated that the cost of electricity generated by solar photovoltaics would be 10-16 pence/kWh, against 2.0-2.3 pence/kWh for that generated from gas[47].

From an agricultural perspective, solar PV technology is most likely to be attractive to producers in remote, rural locations where connection to the grid is difficult or likely to be very expensive. However, such systems have the drawback that electricity can only be produced during the day, and electricity outputs will be far lower in the winter than in the summer. This need not be a problem for minor applications where battery charging is all that is required. However, PV technology is much less well suited to larger applications where a year-round, regular supply of electricity is needed. Additionally, the economics of electricity production using PV technology are not very attractive, although the provision of grants could change this.

3.3.2.2 Wind energy

Perhaps, a more attractive option for electricity generation, at least within agriculture, is wind power, since the UK is reputed to have some of the best wind resources in Europe. Modern wind turbines are designed to operate unattended whenever sufficient wind is available, are reliable, require little maintenance, and have a design lifetime of 20 years[61]. They are relatively easy to install, and range in size from a few kW to 5 MW. The average size of an on-shore wind turbine installed in 2005 was approximately 2 MW, and the UK currently has 129 on-shore wind farms (1,640 MW) and 5 off-shore wind farms (304 MW)[62]. There are a further 24 farms under construction, 89 consented projects and 201 projects in planning.

According to the Sustainable Development Commission’s report on “Wind Power in the UK”[63], the average utilisation factor for wind power is around 30-35%, depending on location, turbine type, wind conditions etc. Thus, 1 MW of installed wind capacity will be expected to produce around 300-350 kW of energy. Furthermore, wind turbines can be expected to produce “useful power” for 70-85% of the year. Generation is generally possible at wind speeds as low as 3-4 m/s (8 mph), and generate maximum “rated” power at around 15 m/s (30 mph)[62]. The power available from the wind is a function of the cube of the wind speed. Therefore, if the wind blows at twice the speed, its energy content will increase eight-fold. Turbines at a site where the wind speed averages 8 m/s produce around 75-100% more electricity than those where the average wind speed is 6 m/s[62].

The generation costs of onshore wind power are currently around 3.2 pence/kWh, compared with electricity generation costs of around 3.0 pence/kWh[63]. However, the estimated net additional cost of providing 20% of total output from wind energy in 2020 is 0.17 pence/kWh based on current gas prices due to the need to have some additional standby generation capacity[63]. This would be compensated for by the social benefits of switching to renewable power. An alternative authority has estimated that the cost of on-shore, wind-derived electricity in 2020 is likely to be 1.5-2.5 pence/kWh, against 2.0-2.3 pence/kWh for that generated from gas[47]. Without doubt, wind energy is one of the cheapest of the renewable energy technologies; it is competitive with new clean coal-fired power stations and cheaper than new nuclear power[62]. It has been calculated that the average wind farm in the UK will pay back the energy used in its manufacture within a year[62,63].

It is clear that large on-shore and off-shore wind farms will, increasingly, provide electricity for the national grid in the years ahead. However, stand-alone wind turbines will also have an increasingly important role to play in providing electricity where grid electricity is unavailable, or where connection is too expensive. As with photovoltaics, small wind turbines could be used to charge batteries for small agricultural applications such as water heating or pumping, electric livestock fencing, lighting or any kind of small electronic system used to control or monitor remote equipment. An Energy Saving Trust Report[54] suggests that, whilst small wind systems are generally not cost-effective at the moment, mass commercialisation could occur around 2015. However, intermittency of supply will militate against wind power as an energy source where electricity is required “on demand”. The technology is, perhaps, better suited to supplying the grid.

3.3.2.3 Micro-hydro energy

Micro-hydro refers to hydro-power systems with a power rating of 100 kW or less, and much of the information in this section is from The British Hydropower Association[64]. New technology, less stringent regulation of grid-connected micro-generation, and standardised turbine designs are now encouraging uptake in the UK. Micro-hydro schemes tend to give a more constant generation compared to wind or solar PV. Micro-hydro systems also have low maintenance and a life expectance of 25 years or more. The payback for grid connected systems can be 10 years or less, although sites need to be carefully chosen.

Hydro-turbines convert water pressure into mechanical shaft power, which then drives an electricity generator. The electrical output of micro-hydro schemes depends on the flow of water and the “head”, or distance over which the water falls, and well established relationships can be used to calculate the potential of any given water source. There is, however, a balance to be struck between choosing a larger, more expensive turbine that can utilise high flows, but is often not working to full capacity, (lower capacity), and a smaller turbine that produces less energy but works at full capacity more often (higher capacity). The capacity factor that gives the best return on investment for most micro-hydro schemes is 50-70%.

Costs for a low head system (<10 m) are around £4,000 per kW for projects under 10 kW (not including civil works). This contrasts with £2,500 per kW plus a fixed cost of £10,000 for projects under 10 kW for a medium head scheme (10–50 m head). A typical 5 kW domestic scheme costs around £20,000 to £25,000, but unit costs drop for larger schemes[65].

Micro-hydro schemes can have a negative impact on fish migration, since fish can be damaged in turbines, on flood risk, impact on flora and fauna and on water quality issues. Care is needed, therefore, to take such issues into account. A water abstraction licence is also generally required from the Environment Agency in order to take water from a river and pass it through a turbine.

The number of sites suited to micro-hydro will, inevitably, be limited. Nevertheless, it has been estimated that this technology has the potential to supply 100 MW energy in the UK[54]. Agriculture will be better placed to exploit this energy source than many other industries, but uptake will still be limited by site suitability, high capital cost, the need to obtain an abstraction licence, and the need for planning permission.

3.4 Combined heat and electricity generation

3.4.1 Combined heat and power (CHP)

CHP is the simultaneous generation of usable heat and power (usually electricity) from a reciprocating engine, gas turbine, stem turbine or combined cycle system. Such units provide efficiency gains compared with the separate generation of heat and electricity. CHP units are often sized to particular heat demands and are connected to lower voltage distribution systems. This reduces transmission and distribution losses compared to power stations which distribute at very high voltages to the grid. It is estimated that in 2005, CHP reduced carbon emissions by 0.61 million tonnes C per 1,000 MW_e installed capacity[1].

Government has set a target for good quality CHP of 10,000 MW_e by 2010. To encourage this, good quality CHP is exempt from CCL charges. At the end of 2005, the installed capacity was 5,792 MW_e and CHP provided 7.5% of the UK's electricity[1]. It has been estimated that the cost of electricity produced from gas-fired units in 2020 will be <2.0 pence/kWh, as against 2.0-2.3 pence/kWh for that generated from gas[47].

The economics of CHP are largely determined by the cost of the fuel (generally gas) and the value of the electricity sold, and the difference between these two is known as the "spark spread". In recent years, the spark spread has generally been too small and the capital and fixed costs too high to justify new CHP installations. Furthermore, 69 MW_e of good quality CHP were mothballed at the end of 2005[1]. As a consequence, Alan Whitehead MP has put forward a proposal for a new spark spread hedge mechanism that would guarantee a minimum spark spread. The concept is that when the spark spread falls below the minimum, Government will fund the difference, and when the spark spread is above the guaranteed spread, CHP producers will refund the difference. In a report to Defra, Ilex Consulting examined the feasibility of such a scheme and concluded that this would be workable, and that significant reductions in carbon emissions could be achieved. However, due to the tight timescale, Government spend would have to be high to achieve the 2010 CHP capacity target[66].

There is already over 100 MW_e of CHP generation within agriculture, and virtually all of this is associated with the protected crops sector. Most of the CHP units are reciprocation engines (1-3 MW_e) powered by natural gas. In 2005, the average performance of reciprocation engines (from all fuels) was 26% electrical efficiency and 43% heat efficiency, giving an average overall efficiency of 69% and a heat to power ratio of 1.7[1]. The electrical efficiency of natural gas-fired engines can range from 28 - 40% and waste heat recovery can increase the overall efficiency to 70-80%. Reciprocating engines produce two grades of waste heat, high grade heat from the engine exhaust, and low grade heat from the engine cooling.

Gas turbines are typically 0.5 MW to 250 MW, although smaller units are now available. The capacities of mini-turbines range from 100 kW to 1,000 kW, and micro-turbines range from 25 kW to 100 kW. These turbines exhaust high quality heat that can be used to reach overall system efficiencies of 70-80%. This new generation of smaller CHP units should enable the technology to be used for a much wider range of applications, including many within agriculture. Currently, a number of 500 kW units are in use in the protected crops sector, with the electricity powering crop lighting, and the exhaust gases being used to elevate CO_2 levels without the need for scrubbing to remove pollutants. The technology would appear also to be appropriate for use in livestock rearing, and particularly in the pig and dairy sectors. There is, however, a question over the economics when installation charges are taken into account, since such units can only be run to produce heating energy when there is a need for electricity[30].

3.4.2 CHP and cluster projects

"Glasshouse clusters" have been generated in The Netherlands by the relocation and co-location of horticultural businesses in order to free up space for housing. Such clusters are associated with centralised boilers and CHP units, and these greatly improve the efficiency of energy use. One such example is the Bergenden Horticulture Cluster which will eventually comprise 215 ha of glass (40 nurseries) on a 350 ha site. The glasshouses and centralised plant are all controlled using the same computer software system, and this enables the energy demand of all the greenhouses to be taken into account, together with the weather forecast, when controlling the boilers and CHP units. Having a combination of different crops in the cluster helps to balance energy demands since if one unit has a peak in its energy demand, this can be offset by another with a lower requirement. CHP units can be used to provide electricity to nurseries with a high electricity demand, whilst the heat can be utilised elsewhere by crops with a greater heat demand. The reductions in CO_2 emissions are recognised by Government by the award of subsidies. The economies of scale also mean that the gas can be bought more cheaply, resulting in a cost saving of around 10%.

Similar benefits could be achieved in the UK, but considerable incentives would have to be provided to offset the large, associated capital investment and infrastructure costs.

3.4.3 Biogas/anaerobic digestion and CHP

Biogas is produced as a result of anaerobic digestion (AD), a process in which organic matter is broken down by microbial activity in the absence of oxygen. Biogas comprises carbon dioxide (typically 35%) and methane (typically 65%) and, whilst this mixture can be compressed for use as a vehicle fuel, it is most commonly used to power CHP units for electricity production. About a third of the heat produced from such CHP units is typically used for the AD process itself. AD bioreactors can be used wherever there is a suitable source of organic material, such as slurry, sewage, green waste and waste food. There is also increasing interest in the capture of methane from municipal landfill sites. In 2002, methane capture from landfill sites was the second largest source of renewable energy in the UK (400 MW).

The biogas that can be used in the CHP-generation of electricity is produced using a continual AD process, where some digestate is removed each day, and raw biomass is pumped in. The most common form of AD is mesophilic. This is particularly used to process waste material with around 40% of volatile suspended solids. The process occurs in large digestion tanks over a period of 15-40 days, at a temperature of 30-40°C. The alternative, thermophilic digestion, is a less common and a less mature technology. In this case, the digester is heated to 55°C and digestion takes 12-14 days. Thermophilic digestion systems give higher levels of biogas production, faster throughput and an improved pathogen and virus "kill". However, the technology is more expensive, more energy is needed, and it is necessary to have more sophisticated control and instrumentation.

It has been estimated that around 150 million wet tonnes of cattle and pig slurry, and 3.4 million wet tonnes of poultry litter and excreta, are produced in the UK each year, and that this could, via the biogas CHP route, provide 9.4 TWh of electrical power. It is also estimated that there are around one million tonnes of food processing waste that would also be suitable for AD[67]. In contrast, the Biomass Task Force[45] estimated that there are around 3 million tonnes of wet animal slurries and manures in the UK, and that if half of this were used for AD, up to 1.1 TWh of electricity would be produced per annum. This would save over 0.13 million tonnes of C per annum.

AD can be carried out in on-farm units. This is particularly popular in Germany which has around 3,000 biogas plants. There are few such systems in the UK, although one example is at Walford College Farm, near Shrewsbury. The 260 ha mixed livestock farm produces 3,000 tonnes of organic manure each year and an AD system, complete with CHP and composter units, was installed in 1994 at a cost of around £134,000. The slurry is fed into a reception pit and then on into a 335 m^3 digester sited above ground. Digestion takes 16 to 20 days and the system produces 450 m^3 of biogas per day. The biogas is used to power a CHP unit and much of the recovered heat from the CHP is used to heat the digester which is maintained at around 35-37°C. A stand-by boiler is used to heat the digester in the event of CHP failure or during very cold weather. After digestion, the fibre (3 tonnes/day) is removed and used for composting, while the odourless liquor (15 m^3/day) is fed to a storage tank and spread over grass fields. The CHP unit is rated at 35 kW_e and 58 kW_{th}, although it actually averages 18.22 kW_e for 19.5 hours/day. The reported savings from electricity generation were around £17,000 per year, while savings from hot water, fertiliser and reduced slurry spreading costs were around £2,600, £2,000 and £2,500 per year, respectively. The system requires no more attention than one hour per day from the farm workers, and the running costs, repairs and call-out charges are estimated at around £2,000 per year. On the basis of these costs and savings, the payback time of such a system is around six years[68].

More recently, a family run farming business in Milton Ernest near Bedford has set up an AD unit (Bedfordia Biogas) which became operational in March 2006[69]. The unit takes in 200 m^3 of pig slurry and 100 tonnes of food waste each week and is expected to produce between 0.75 and 1.0 MW.

Central anaerobic digestion (CAD) plants are operational in a number of countries, notably Denmark and Sweden. CAD plants can make use of a wider range of organic material, and are therefore often more efficient than on-farm digesters. The organic fraction of municipal solid waste, for example, can produce around 6.5 times as much methane per tonne as can cattle slurry. However, the drawback of CAD plants is the costly process of transporting livestock manure which is required to achieve the correct consistency. Consequently, plants have to be sited in areas where there is good local supply of organic matter. There is a CAD plant at Holsworthy in the UK which was built by the German company, Farmatic Biotech Energy ag. The plant collects around 146,000 tonnes per annum of food processing waste and cattle, pig and poultry manure from 30 farms within an 8 km radius. The waste and manure are mixed and prepared and then pasteurised at >70°C for one hour to kill pathogens, seeds etc. Having been pasteurised, the mixture is pumped to two 4,000 m^3 digesters where anaerobic digestion takes place for 20 days at 37°C. The digested waste mixture is eventually returned to the farmers as a valuable bio-fertiliser with 90% less odour and more balanced nutrients compared to the original slurry. The scheme is budgeted to produce 3.9 million m^3 of methane per year (which equates to 39 GWh) which is burnt in two CHP units with a combined capacity of 2.1 MW. The electricity sold at 5.93 pence/kWh in 2003, according to the Non-Fossil Fuel Obligation (NFFO) contract. Plans are underway to sell the excess heat through a new domestic heating system to the market town of Holsworthy.

The capital cost of the Holsworthy scheme was £7.7 million, and there have been a further £0.5 million of subsequent improvements; capital grants were obtained for 50% of the plant cost. The running costs are estimated at £450,000 per annum. The project receives around £800,000 from electricity sales and £200,000-300,000 from gate fees for the food waste. Based on these figures, a group at the University of Strathclyde concluded that the scheme is not profitable, even taking into account the 50% capital grant[70]. This was, in part, due to the high transport costs of the manure, because no revenue was generated from sales of heat, and no revenue was generated from digestate sales, as the plant was being run as a co-operative by the farmers. However, it was concluded that the scheme could just be profitable if a value were to be attached to the digestate, and the heat was sold.

Of the 17 CAD plants in Denmark in 1998, only nine could be considered as profitable[71]. It was concluded that, for the CAD plants to be profitable, they needed to incorporate a source of waste with the livestock manure. However, this analysis did not include the economic advantages to the farmer; this was estimated to be DKK 5-10 per m^3 of manure.

As well as providing a source of energy, AD has a number of additional environmental benefits. These include the production of digested waste with a very much reduced odour compared to farm slurry, a reduced risk of spreading harmful bacteria, viruses and weeds, and a reduced risk of pollution to water courses. According to Greenfinch[72], seven farm biogas plants have recently been built in South-west Scotland as part of a Scottish Executive research programme into diffuse pollution of bathing waters. Furthermore, AD can decrease methane emissions (methane is converted into carbon dioxide, a less potent greenhouse gas), and substitute for conventional fossil fuel use.

According to a report published by the United Nations Food and Agriculture Organization (FAO)[73], the global livestock sector generates 18% of global greenhouse gas emissions (CO_2 equivalent), which is even more than the transport sector. The livestock sector produces 9% of human-induced CO_2 emissions, 64% of ammonia and 37% of methane (which is 23 times worse than CO_2 as a greenhouse gas). The report specifically highlights the potential importance of AD, since this technology can halve emissions in cool climates, and reduce these by up to 75% in warm climates where methane emissions from slurry are much greater.

It is concluded that the economics of biogas production are questionable. For them to be viable, AD and CAD plants will need to be carefully sited, and consideration will have to be given to the availability of other organic materials which can improve overall methane production, and generate gate fees. However, AD can potentially contribute to the solving of other environmental issues, and so should be considered in a more holistic way, rather than just as a source of energy. As such, this technology is very much under-utilised within agriculture and should be encouraged.

3.4.4 Biomass CHP

By far the greatest proportion of electricity from biomass is generated in co-fired power stations, such as Drax in the north of England which uses SRC to support the burning of coal. Other examples of large scale biomass electricity generation include a straw-fired power station at Ely in Cambridgeshire, and a poultry litter-fuelled power station at Eye in Suffolk.

There are relatively few commercially available biomass CHP systems available on the market other than those based on anaerobic digestion (Section 3.4.3). Perhaps the best known example is the 100 kW_e 200 kW_{th} Talbotts system where combustion fires a micro-gas turbine indirectly via a high temperature heat exchanger[74]. The value of the electricity from such a system is the sum of the sale price of electricity to the national grid and the value of the renewable obligations certificates (ROCs). While the technology is still in its infancy, the approach is well suited to use in agriculture as an alternative to biomass heating providing that electricity can be used on site or exported.

3.5 Field operations

The future availability of gas oil / diesel, used conventionally to power field operations in agriculture, is covered in Section 3.2.1.1. However, biofuels are likely to feature more in the future, if for no other reason than the announcement by Government in November 2005, that it intends to introduce a Renewable Transport Fuel Obligation (RTFO). The RTFO will be introduced in 2008/9 with the obligation level rising to 5% by 2010/11. If certain criteria concerning cost, the environment and suitability for new cars are met, the obligation may be raised further to 10% by 2015.

According to the UK report to the European Commission on Biofuels[75], the total sales of biofuels in the UK in 2005 amounted to 118 million litres, around 0.24% of total road fuel sales. Of this biofuels total, 28% (33 million litres) was biodiesel and 72% (85 million litres) was bioethanol. In the long term, the large-scale use of biofuels could reduce CO_2 emissions from transport to very low levels. However, a very high penetration of the fuel market would have to be achieved in order to reach such levels. Assuming a maximum growing area in the UK of 4 million ha, indigenous resources could supply a maximum of around 500 PJ of energy, and this is only around 29% of the total energy consumption by road transport in 2002. By 2050, the complete substitution of petrol and diesel could require that approximately two thirds of total biofuel demand is met by imports.

The lowest projected biofuel costs, excluding co-products, are for processes using ligno-cellulosic crops. It is likely therefore, that these technologies will dominate in the future. However, the availability of biomass for biofuel production is likely to be limited by competing resource demands from heat and power generation. In general, biofuels currently present a relatively expensive method of carbon abatement given their high production costs.

However, these costs may fall in the future, particularly if new technologies come on-stream or if there are economies of scale resulting from increased production.

3.5.1 Biodiesel and straight vegetable oil (SVO)

It is possible to use straight vegetable oil (SVO) in diesel engines with suitable modifications. Many vegetable oils have similar properties to diesel, except for higher viscosity and lower oxidative stability. This can result in poor atomization, incomplete combustion and carbonization. One solution is to pre-heat the SVO to reduce its viscosity. This can be done by starting the engine using diesel (or biodiesel) and then switching over to SVO when it has warmed up. SVO can be produced by farmers by cold-pressing and filtering oilseed crops.

Biodiesel fuel can be made from new or used vegetable oils and animal fats, which are non-toxic, biodegradable and renewable resources[76]. Typical vegetable oils include oilseed rape, sunflower and soybean. The oils are reacted with methanol to produce methyl esters with glycerol as a by-product. Biodiesel is the name given to these esters when they're intended for use as fuel. Rape methyl ester, or RME, is the most common in the UK. Biodiesel is typically sold as a blend of 5% biodiesel and 95% ultra low sulphur diesel (ULSD) that conforms to the current diesel specification, EN 590. No modifications are needed to vehicles running on such a blend, and fuel efficiency is actually improved[77].Biodiesel is considered a renewable fuel because the crops that are used in its production fix CO_2 when they grow. Life cycle emissions of greenhouse gases from biodiesel are 55% lower than from fossil diesel. In use, biodiesel gives a 3% reduction in CO_2 emissions when used in a 5% blend with ULSD. Emissions of carbon monoxide are also around 40% lower. Particulate emissions of biodiesel are 20-39% lower, and emissions of oxides of sulphur are at least 80% lower. Nitrogen oxide emissions from biodiesel are comparable with those from ULSD and the emission of volatile organic compounds are 55% lower. Biodiesel has significantly lower toxicity, better biodegradability and higher flash points than fossil fuels.

The cost and carbon-saving potential of biodiesel depend on the feedstocks, processes and methodologies used in its production. The production of biodiesel from waste vegetable oil (WVO) has benefited from low feedstock prices, making it economic to manufacture in the UK with the current duty incentive. However, WVO prices have increased recently and limited supplies of WVO and fuel quality issues limit the contribution that this can make. Otherwise, good quality biodiesel (fuel standard EN 14214) tends to cost two to three times as much to make as fossil diesel (although prices vary considerably as the market is immature). For this reason, and to promote the use of biofuels generally, the UK Government reduced the tax on biodiesel in July 2002. This has stimulated some limited production of biodiesel from imported palm and soya bean oils, which are generally cheaper than home-grown, rape-seed oil. Some biodiesel produced from rape is currently imported from Europe, though the extra costs that are involved (UK prices fluctuate between £350-600 per tonne for virgin rape-seed oil) require the final blended product to be sold at a premium over conventional diesel, and this clearly limits demand.

Greenergy has built a biodiesel plant at Immingham on the east coast of England[78]. This has been designed to process 114 million litres of biodiesel per year. There are also plans for a second phase which will double the production capacity, and a sister plant is also being planned in the Liverpool area (with Cargill). Biodiesel Corporation plc have completed their biodiesel processing plant at Seal Sands, Middlesbrough which has a 284 million litre output. Other biodiesel producers in the UK include D1 oils.

Farmers could make their own biofuels, but due to warrantee issues they would be most likely to use a 5 or 10% biodiesel blend for new vehicles, although they might consider 100% biodiesel of SVO in older vehicles if there was a financial advantage. However, given the high cost of production and fuel duty rates, liquid biofuels are currently only considered as relevant to agriculture for road transport purposes. Whilst the duty rate for biodiesel for road use (27.1 pence/l) is 20 pence/l less than that of USLD (47.1 pence/l) in order to make the pump prices similar, duty on biodiesel for off-road use (3.13 pence/l) is only 3.31 pence/l less than that of red diesel (6.44 pence/l). This means that biodiesel is an expensive option for off-road use. If, as proposed, the HMRC simplify regulations so that those producers of biodiesel or SVO generating less than 2,500 litre per annum are exempted from paying duty, the economics will be transformed and farmers will be encouraged to trial fuel substitution. However, the 2,500 litre threshold will restrict use in agriculture and the NFU has suggested that a higher limit would be advantageous.

3.6 Prospects and potential for the integration of renewable energy in agriculture

Table 14 summarizes the apparent pros and cons of utilizing alternative energy sources in agriculture. Section a) deals with alternative sources of heat, section b) with alternative sources of electricity, section c) with alternative sources of heat and power, and section d) with alternatives to gas oil / diesel for field operations. The reductions in carbon emissions are calculated assuming zero emissions for renewables, unless stated otherwise. These reductions cannot all be summed as clearly some of the techniques are alternative solutions. The payback periods are indicated in the tables as 0-2 years, 2-5 years, 5-10 years and >10 years.

Whilst the use of alternative direct energy sources could greatly reduce the carbon emissions of agriculture, the payback periods are generally long. This is in contrast with the efficiency measures discussed in Section 2. Conventional fossil fuels are still convenient and cost effective and are likely to continue to be so in the near future. Therefore, to encourage a greater uptake of low-carbon technologies, additional government support and financial incentives will be needed in the short to medium term.

The one exception with regards to long payback is the use of waste heat (including heat from incineration) for glasshouse production. For this, the payback period can be short for new build projects when build costs are excluded. However, the cost of such a scheme will be very business specific and will depend on the source of the heat, the availability of suitable land and its distance from the source of waste heat. A barrier to uptake is the availability of information concerning possible sources of waste heat. Whilst the Carbon Trust has networks which aim to share information, additional mechanisms are needed to ensure that information on waste heat is made more widely available. Waste incineration directives (WID) may prevent the use of some potentially viable waste streams such as waste wood.

Of the other alternative sources of heat energy, biomass stands out as the one with the greatest potential. Biomass boilers are available in a range of sizes and so biomass could be used in most sectors of agriculture. However, there are barriers to uptake: capital expenditure is required to replace existing boilers, boiler management is likely to be more time consuming (depending on the fuel source) and the flue gasses may be unsuitable for CO_2 enrichment in glasshouses. Biomass is certainly more promising than geothermal, solar heating, and GSHP systems on the basis of cost and payback. However, the economics of biomass will be dependent on whether a suitable fuel is available locally. In that regard, agriculture should be well placed to exploit biomass, in comparison with other industries. Biomass is a promising heat source that needs continued support to allow the technology to develop in the UK.

Of the alternatives to grid electricity, solar PV is currently not economical except in remote locations where grid electricity is not available. Some micro-hydro schemes could pay back within 10 years, but the potential is relatively small. The technology with the greatest potential is wind. Larger wind turbines can be cost effective as a source of electricity, and farmers could make use of land in suitable locations for wind farms. Wind has the potential to produce more than enough electricity of offset that used in agriculture However, intermittency of supply will mean that grid connections will be needed to ensure consistent supply. Wind farms are perhaps better suited to supplying the grid rather than simply a source of electricity for agriculture.

CHP is a proven technology in the UK and has the potential to reduce carbon emissions. The protected crops sector is well placed to use the heat and CO_2 from CHP units and the development of micro-turbines will enable other sectors of agriculture to exploit the technology. However, the biggest barrier to uptake is currently the spark spread. Additional government support, for example through the ”Whitehead proposal”, would enable greater exploitation of this technology.

Biomass CHP and anaerobic digestion (when integrated with a CHP) also have considerable potential within agriculture. However, these technologies are not well developed in the UK and there is a need for further development and technology transfer. If a range of biomass CHP units were to become available, carbon emissions would be reduced to a greater extent than by conventional CHP units since the fuel is a renewable resource. As with conventional CHP, suitable grid connections would be needed, and this factor determines that biomass CHP could not be used on as many sites as a conventional biomass boiler.

The economic viability of anaerobic digestion has to be considered borderline. To be viable, suitable material will have to be available locally to minimise transport costs, and consideration will need to be given to gate fees. The significant advantage of the technology is that it can not only provide heat and electricity, but it also offers a solution to waste disposal and reduces methane emissions. Both large CAD plants and smaller on farm systems could be viable longer term. Considerations should be given to mechanisms that would financially support the development of this technology in the UK.

Biodiesel has the potential to reduce carbon emissions from field operations without any capital cost. The carbon reduction would be proportional to the degree of diesel substitution. If a 10% blend were used across the whole of agriculture, the carbon reduction would be around 30,000 tonnes. However, biodiesel is currently not economical for off-road use. For road use there is a 20 pence/l reduction in the duty to make pump prices comparable to fossil diesel, while for off-road use the duty rate is only 3.31 pence/l cheaper. Even if there were no duty on biodiesel for off-road use, it would still be more expensive than red diesel. Therefore, cost is going to be a barrier to uptake.

Table 14. Alternative energy sources in agriculture

a) Heat sources – alternatives to conventional fossil fuels

Alternative	**Potential for fossil fuel displacement (1,000 tonnes C / annum)**	**Minimum payback (years)**	**Most compatible sectors of agriculture**	**Barriers to uptake**
Waste heat	60	0-2 (excluding build cost)	Protected crops – high energy use.	Lack of information concerning waste heat availability. Need for location close to source. New build
Energy from waste	100	0-2 (excluding build cost)	Protected crops – high energy use.	WID directives will limit RDF. No associated CO_2 supply for protected edibles
Biomass	300	2-5	All sectors	Boiler replacement and maintenance, biomass availability, no CO_2 supply for protected edibles
Geothermal	5	>10	Protected crops	Very high cost. Few suitable locations
Solar – hot water	5	>10	Dairy for hot water	High capital cost
Solar – closed greenhouse	20	>10	Protected crops	High capital cost and limited availability of suitable aquifers
Ground Source heat pumps	100	>10	All sectors	High capital cost and ground conditions

b) Electricity sources – alternatives to conventional generation

Alternative	**Potential for fossil fuel displacement (1,000 tonnes C / annum)**	**Minimum payback (years)**	**Most compatible sectors of agriculture**	**Barriers to uptake**
Solar PV	50	>10	Livestock sectors - solar panels roof mounted	High capital cost. Not all roofs suitable
Wind -large	300	5-10	All sectors	High cost. Suitable sites needed
Wind - small	100	>10	All sectors	High cost. Suitable sites needed
Micro-hydro	10	5-10	Livestock sectors, particularly in hilly areas	High cost. Suitable sites needed and abstraction licence

c) Combined heat and power – alternatives to conventional generation

Alternative	**Potential for fossil fuel displacement (1,000 tonnes C / annum)**	**Minimum payback (years)**	**Most compatible sectors of agriculture**	**Barriers to uptake**
CHP	60	5-10	Protected crops and, to a lesser degree, livestock	High cost. Spark spread prevents investment. Needs suitable grid connections
Cluster projects	10	5-10 (excluding build cost)	Protected crops	New build only, lack of suitable land and infrastructure
Anaerobic digestion with CHP	100 plus reduced methane emissions	5-10	Livestock and protected crops - generate organic material and able to use heat.	Need for suitable local sources of organic material. Technology not well established in the UK
Biomass CHP	150	5-10	Protected crops and livestock.	Technology in its infancy. Maintenance more time consuming than conventional CHP. CO_2 supply an issue for protected edibles

d) Field operations – alternatives to conventional fossil fuels

Alternative	Potential for fossil fuel displacement (1,000 tonnes C / annum)	Minimum payback (years)	Most compatible sectors of agriculture	Barriers to uptake
Biodiesel or SVO	30 (assuming a 10% biodiesel blend)	>10	Arable crops, field operations	High cost; biodiesel is not cost-effective for off-road use

3.7 Summary

- The use of alternative low-carbon energy sources has the potential to make agriculture carbon neutral with regards to direct energy use. However, high costs are likely to limit uptake without government support in the short to medium term.

- Biomass as an alternative heat source has the greatest potential for reducing carbon emissions. It could provide heat for most sectors of agriculture, and the industry ought to be well placed for exploitation. The use of waste heat from industry or waste incineration can be a good option for protected crops businesses that are looking to build new glass and are able to re-locate. Geothermal, solar thermal and ground source heat pumps are currently too expensive to be exploited on any major scale.

- Large scale wind farms are cost effective as a source of renewable electricity. However, intermittency of supply and the need for large turbines makes the technology more suited to supplying the grid. Wind farms could off-set the electricity use in agriculture. Small scale wind turbines and solar photovoltaic panels are currently only cost effective for remote applications where a grid connection is not available. Micro-hydro will be limited by the availability of suitable site.

- Combined heat and power (CHP) has the potential to supply both heat and electricity where both are required, or where the electricity can be exported to the grid. Due to the improved efficiency of energy use, conventional CHP, using natural gas, could save up to 60,000 tonnes of carbon per annum. The technology is mature but is hindered by the energy markets (spark spread). Further savings could be made by clustering protected crops growers with different energy demands. Biomass CHP and anaerobic digestion (AD) have the potential to reduce carbon emissions further by using a renewable fuel. These technologies are in their infancy in the UK but have great potential. AD also helps dispose of waste and reduces methane emissions.

- Biodiesel or SVO could be used as a substitute for conventional diesel with little or no capital cost implications. However, biodiesel is considerably more expensive than fossil diesel. A 10% blend of biodiesel could save 30,000 tonnes of carbon per annum.

Section 4: Action points and recommendations to Defra

4.1 Prioritized list of energy-saving measures and technologies to reduce carbon emissions from agriculture

The following list of energy saving measures and technologies has been compiled on the basis of their potential to reduce carbon emissions from agriculture, with those that could make the greatest impact first. There is also brief comment on current barriers to take-up, and Section 4.2 (that follows) recommends Government-based actions that might be expected to assist this process.

1. **Biomass heating.** This has the greatest potential to reduce carbon emissions from agriculture. Biomass could provide most of the heating demand of agriculture, saving up to 300,000 tonnes of carbon per annum. However, the high capital and running costs of biomass boilers, and the suitability of biomass flue gasses for CO_2 enrichment in protected cropping, are currently limiting uptake. Biomass CHP would also be very well suited for use on sites which require electricity as well as heat, or which have suitable grid connections. This technology is, however, still in its infancy in the UK.

2. **Wind farms.** These could provide more than enough electricity to meet the demands of agriculture, saving 300,000 tonnes of carbon per annum. However, electricity generated in this way will rarely match the patterns of use within agriculture and it can be expected that on-farm wind generation will primarily be to supply the grid.

3. **Use of waste heat.** The co-location of glasshouses with industries producing waste heat (and CO_2) is attractive from an environmental standpoint and can be highly cost effective. Furthermore, burning waste could provide a valuable source of heat. However, the waste incineration directive (WID) effectively prevents the use of some potentially useful wastes as fuels. The heat from most energy from waste (EfW) incineration plants in the UK is unused and could be used to heat glasshouses, although the need to relocate and the fact that flue gasses would be unsuitable for CO_2 enrichment are key barriers. Savings of up to 100,000 tonnes of carbon could be made per annum through the use of waste heat.

4. **Anaerobic digestion.** The combination of this and CHP could integrate well into some livestock and protected crops businesses. Around 100,000 tonnes of carbon could be saved per annum and the technology would also have other environmental benefits. Uptake is currently limited by high capital cost and the fact that the technology is not well established in the UK. The success of schemes will be highly dependent on the availability of local sources of suitable organic material.

5. **Monitoring and benchmarking.** Adopting energy efficiency measures as a result of monitoring and benchmarking could save up to 105,000 tonnes of carbon per annum across the whole of agriculture. However, with increases in energy costs and the desire to meet CCL targets, farmers and growers are likely to have already achieved some of the easy "wins" since the base year of 2005. In general, the uptake of energy-saving measures would be promoted by increased technology transfer activities and the plugging of some specific research gaps.

6. **Reducing glasshouse heating.** The protected crops sector differs from other sectors of agriculture in that most of the fuel used is gas, fuel oil and LPG for heating. As a result, this sector has the greatest potential within agriculture to cut carbon emissions. Key approaches to improve energy efficiency include the use of temperature integration (saving up to 40,000 tonnes of carbon), the installation or replacement of thermal screens (saving up to 14,000 tonnes of carbon), the installation of well insulated thermal stores (saving up to 14,000 tonnes of carbon), the use of decentralised boiler plant (saving up to 13,000 tonnes of carbon), more efficient boiler design (saving up to 13,000 tonnes of carbon), and improved cladding of glasshouses and reducing air leakage (saving up to 13,000 tonnes of carbon).

7. **CHP.** The increased uptake of CHP could save an additional 60,000 tonnes of carbon per year from the protected crops sector if only the economics of CHP electricity generation (spark spread) were more favourable.

8. **Reducing diesel use.** Diesel use for field operations accounts for around 36% of the energy use in agriculture and up to 45,400 tonnes of carbon per annum could be saved by more efficient tractor ballasting, tyre selection and implementation matching. MAFF funded R&D in this area, however, there is a need for this information to be updated and for more technology transfer. A further 30,000 tonnes of carbon could be saved if the industry used a 10% blend of biodiesel. However, this is currently not cost effective.

9. **Improved drying and store facilities.** Optimisation of grain drying, improved storage and ventilation technology could save up to 24,500 tonnes of carbon per annum.

10. **Building insulation.** A key energy-saving measure in the livestock and arable crops sectors is buildings insulation. Across the whole of agriculture, improved insulation would save an additional 21,000 tonnes of carbon per annum.

11. **High-efficiency lighting.** A move to high-efficiency lighting could save up to 13,300 tonnes of carbon per annum.

4.2 Recommendations to Defra

1. The use of alternative low-carbon energy sources has the potential to make agriculture carbon neutral with regards to direct energy use. However, high costs are likely to limit uptake without government support in the short to medium term. Defra should investigate mechanisms, such as capital grants, to encourage greater uptake of renewables until these markets are more mature.

2. Protected crops businesses are well suited to utilise low grade waste heat from industry or EfW plants, although would usually need to relocate. However, potential sources of waste heat are not well publicised and appropriate networks need to be developed to promulgate information and to promote uptake.

3. Defra should consider funding a technical evaluation of the use of flue gasses from biomass boilers for CO_2 enrichment in protected crops. This would be done primarily to provide recommendations for safe use.

4. Although the glasshouse crops sector uses only around one quarter of the energy expended by agriculture as a whole, it has the greatest potential for energy saving. This is because of its uniquely high, non-electrical heating demand. It is recommended that agricultural research and technology transfer aimed to reduce carbon emissions are focused on this sector.

5. Consideration should be given to streamlining procedures and advice for evaluating, sizing and obtaining grid connections for CHP units in the range 50 kW - 2 MW.

6. Conventional CHP is a proven and well established technology that could contribute to a reduction in carbon emissions, especially those relating to protected crops. However, the economics of electricity production via CHP (spark spread) are not sufficiently favourable to encourage further investment. Mechanisms such as the Whitehead proposal should be considered in order to promote the use of CHP.

7. Data on tractor fuel consumption is not widely available which makes it difficult for farmers to optimise diesel use. Setting up schemes for monitoring and benchmarking, when combined with technology transfer activities, would help to encourage best practice.

8. Waste is a potentially valuable asset, however, the UK’s waste policy prioritises prevention, re-use and recycling. The waste incineration directive (WID) effectively hinders the use of certain waste products; additional exclusions might be appropriate.

Appendix 1: Conversions relating to energy use and carbon emissions

DTI's Digest of UK Energy Statistics (DUKES) uses the tonne of oil equivalent (toe) as the measure of energy consumption common to all fuels. However, units based on the watt hour (kWh, GWh etc) are probably the most commonly encountered energy units, and units based on the joule are preferred in scientific circles. Therms and British Thermal Units (BTU) are also commonly used. Table 1.1 allows these units to be inter-converted.

Table 1.1. Energy unit conversion chart

Multiply by		To convert from				
		GWh	**TJ**	**toe**	**therms**	**BTU**
To Convert to	**GWh**	1	0.27778	0.01163	29.3×10^{-6}	0.293×10^{-9}
	TJ	3.60	1	0.04187	0.27778	1.06×10^{-9}
	toe	85.98	23.88	1	0.00252	0.0252×10^{-6}
	therms	34,121.24	9,478.12	396.83	1	10.0×10^{-6}
	BTU	3.412×10^{9}	0.947×10^{9}	39.6×10^{6}	100,000	1

Note:
k = 1,000 units (10^3 units) (kilo)
M = 1,000,000 units (10^6 units) (mega)
G = 1,000,000,000 units (10^9 units) (giga)
T = 1,000,000,000,000 units (10^{12} units) (tera)

Whilst fuel consumption is increasingly measured in energy terms (kWh), fuel purchase frequently uses other units. Table 1.2 shows relationships between the net energy content of a fuel and purchase units based on DUKES[1].

Table 1.2. Relationships between the net energy content of a fuel and purchase units

Fuel	kWh/m^3	kWh/litre	kWh/tonne
Natural gas	9.89	--	--
<u>Petroleum products</u>			
Gas oil / diesel	--	10.10	12,054.99
LPG	--	7.07	13,082.72
Burning oil	--	9.76	12,193.87
Fuel oil	--	11.17	11,471.68
Coal (for agriculture)	--	--	7,388.54
Renewables - straw	--	--	3,555.39
Renewables – SRC*	--	--	2,499.88

* SRC is short rotation coppice (see Section 3.2.2.3)

"Energy delivered" and "Primary energy"
DUKES energy data are compiled on an "energy delivered" basis, whilst our report concerns energy use expressed in primary terms and referred to as "primary energy". This takes into account energy used or lost in the conversion of primary fuels to secondary fuels and in their distribution to the end user. However, for the sake of consistency with others (see Section 1), "energy delivered" and "primary energy" are taken to be the same for all fuels except electricity (i.e. conversion factor = 1.0). For electricity, "energy delivered" has been multiplied by 2.6 to convert it to "primary energy".

Primary energy and carbon emissions
Relationships between primary energy and carbon dioxide (CO_2) / carbon (C) emissions are given in Table 1.3 below using the kWh as, probably, the most widely used energy unit across all reference websites. The two primary reference sources used in the construction of this Table are:
http://www.defra.gov.uk/environment/ccl/pdf/pp3-02ei.pdf
http://www.bre.co.uk/filelibrary/CO2EmissionFigures2001.pdf.

A multiplication factor of 0.2729 can be used to convert units of CO_2 to equivalent units of C, and a factor of 3.6642 to convert units of C to equivalent units of CO_2. These conversions reflect the atomic weights of carbon and oxygen, 12.0107 and 15.9994 respectively (International Union of Pure and Applied Chemistry).

Table 1.3. Relationships between fuel type and carbon emissions (C and CO_2)

Fuel	kg C/kWh[1]	kg CO_2/kWh[1]
Grid electricity (delivered)	0.117	0.43
Grid electricity (primary)	0.045	0.165
Natural gas	0.052	0.188
Petroleum products		
Gas oil/diesel	0.068	0.248
Propane (LPG)	0.063	0.214
Burning oil	0.067	0.245
Fuel oil	0.070	0.258
Non-domestic coal	0.082	0.298
Renewables	0.00	0.00
Waste	0.00	0.00

[1] Note that the conversion factor is the same for kg/kWh and 1,000 tonnes/GWh

Appendix 2: Standard Industrial Classification, SIC (2003), and "Agriculture"

"Agriculture" in DTI's "Digest of UK Energy Statistics" (DUKES) is defined by SIC (2003), an official classification first introduced into the United Kingdom in 1948 for use in classifying business establishments and other statistical units by the type of economic activity in which they are engaged. "Agriculture" in SIC (2003) comprises:

01 Agriculture, Hunting and Related Service Activities

- 01.1 Growing of crops; market gardening; horticulture
- 01.2 Farming of animals
- 01.3 Growing of crops combined with farming of animals (mixed farming)
- 01.4 Agricultural and animal husbandry service activities, except veterinary activities; landscape gardening
- 01.5 Hunting, trapping and game propagation including related service activities

02 Forestry, Logging and Related Service Activities

- 02.0 Forestry, logging and related service activities

05 Fishing, Fish Farming and Related Service Activities

- 05.0 Fishing, fish farming and related service activities

Appendix 3: Consultation

The following is a list of organisations to whom this report was circulated whilst in draft form:

British Beet Research Organisation (BBRO)
The Research Station, Great North Road, Thornhaugh, Peterborough, PE8 6HJ
www.bbro.co.uk

British Leafy Salads Association
www.britishleafysalads.co.uk

British Potato Council (BPC)
BPC, 4300 Nash Court, John Smith Drive,Oxford Business Park, Oxford. OX4 2RT
www.potato.org.uk

British Protected Ornamentals Association
The British Protected Ornamentals Association, PO Box 475, Huntingdon, PE28 3YP
www.thebbpa.org.uk

Cucumber Growers' Association
www.cucumbergrowers.co.uk

Home-Grown Cereals Authority (HGCA)
HGCA, Caledonia House, 223 Pentonville Road, London N1 9HY
www.hgca.com

Horticultural Development Council (HDC)
HDC, Bradbourne House, East Malling, Kent, ME19 6DZ
www.hdc.org.uk

Meat and Livestock Commission (MLC)
MLC, PO Box 44, Winterhill House, Snowdon Drive, Milton Keynes, MK6 1AX
www.mlc.org.uk

Milk Development Council (MDC)
MDC, Stroud Road, Cirencester, Gloucestershire, GL7 6JN
www.mdc.org.uk

National Farmers' Union (NFU)
Agriculture House, Stoneleigh Park, Stoneleigh, Warwickshire, CV8 2TZ
www.nfuonline.com

Tomato Growers' Association
Pollards House, Pollards Nursery, Lake Lane, Barnham, West Sussex, PO22 0AD
www.britishtomatoes.co.uk

Processors and Growers Research Organisation (PGRO)
The Research Station, Great North Road, Thornhaugh, Peterborough, PE8 6HJ
www.pgro.org

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