

Refining Estimates of Land for Biomass

Route map to 1.4M ha of bioenergy crops

Reference number:	BI2012_WP7_D11
Version:	v2.1
Date:	May 2016
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Executive Summary

ETI have identified that if ~1.4 M ha of land were used for bioenergy crop production (including Miscanthus, short rotation coppice and forestry) it would make a significant contribution towards the achievement of the UK's 2050 carbon target in a cost effective way. There are currently approximately 122,000 ha of bioenergy crops grown in the UK, including 10,500 ha of second generation (2G) bioenergy crops such as Miscanthus and Short Rotation Coppice (SRC). This leaves a significant area of land still to be identified for future bioenergy crop production. Types of land for consideration for bioenergy production include uncropped arable land, white land such as Ministry of Defence (MOD) or public land as well as making better use of the existing arable and grassland in the UK.

This report has identified that between **1.0-1.8 Mha** of land is potentially available for conversion to bioenergy, of which the two largest contributors are by utilising the surplus area of arable crops by sending surplus production for first generation (1G) bioenergy processing as demand dictates (314,000-494,000 ha) and improved utilisation of grassland (350,000-700,000 ha). The range in values represents the uncertainty around figures, with the lower value representing the most likely land area to be converted, whilst the higher area represents the potential area available for conversion if the market drivers are sufficient to convert all identified spared land to bioenergy production. The potentially available area can be categorised into land that can be converted relatively easily in the short term with few/no barriers to conversion as opposed to mid and longer term availability. The estimated area that could be made available under each timescale (short, mid and long) is shown below:

- *Short-term* – potential to be available within 1-5 years, with minimal constraints or challenges to access - Approximately **541,000-829,000 ha** available.
- *Mid-term* – potential to be fully available in 5-10 years, with some constraints to overcome that will take time to act upon - Approximately **218,600 to 417,000 ha** available.
- *Long-term* – Land could be made fully available in the future (10+ years) but constraints are more challenging to overcome and will require more significant changes in practice and or engagement with large parts of society to enable access - Approximately **249,500 to 513,500 ha** available.

For all the land types identified, the main driver behind making land available for bioenergy crop production is to develop a suitable market for bioenergy crops. For 1G bioenergy crops this is relatively straightforward as the feedstock for any refinery is already being widely produced across the UK requiring a switch in marketing policy to enable sale of excess food crops, which are currently sold on the export market, to industrial uses or to animal feed manufacturers, to go to the bioethanol/biodiesel market instead. This is dependent on food prices vs bioethanol prices, distance to processing plant and farmer trust in the bioethanol/biodiesel market. For 2G bioenergy crops, market development is likely to take longer as the feedstock for this market has to be purpose grown, and, at current market prices, the planting of 2G bioenergy crops and the subsequent gross margin does not compare well with conventional arable land, although is more competitive with marginal land or renting grassland areas. The non-eligibility for bioenergy crops under agri-environmental schemes and competition for land from housing and renewable energy sources also restricts uptake. If measures were taken to reduce these barriers e.g. through lobbying regional government to include bioenergy crops in future environmental schemes and by further developing the bioenergy market so that bioenergy crop economics compared more favourably to those of conventional arable crops this could aid access to land and make the target of growing 1.3-1.4 Mha of bioenergy crops more feasible.

Figure 1 outlines the route map to availability of land for bioenergy production, showing the drivers and barriers for uptake in the short, medium and long term.

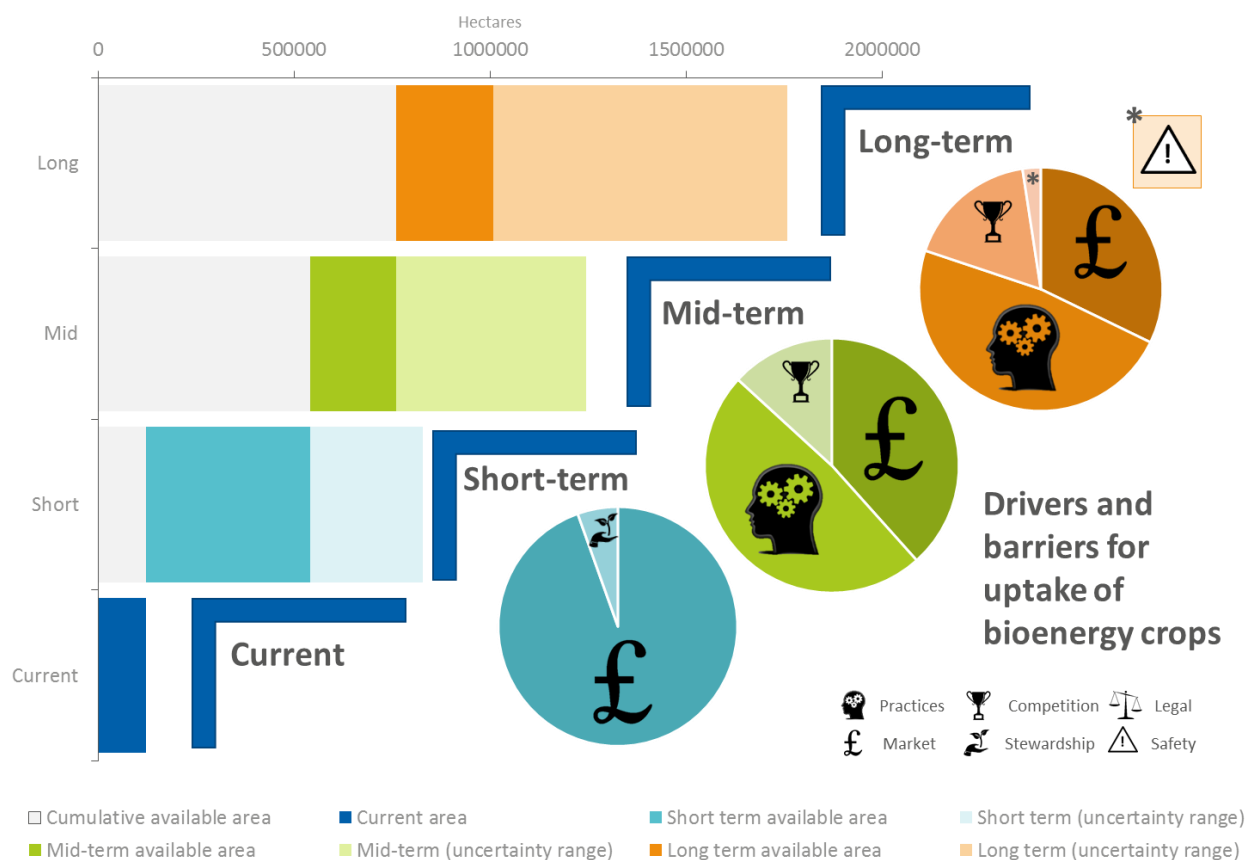


Figure 1. Route map to bioenergy crop production (uncertainty ranges are cumulative – with the long term uncertainty range picking up areas from short and mid term) – safety refers to the safety of production on road verges and embankments.

The detail behind the route map and the assumptions on land availability under each category are shown in Table 1.

Table 1. Summary of land types available over the short, medium and long term (hectares)

Land-Type	Total area in UK (ha)	Area (ha) available in:					
		Short term+		Medium term+		Long term+	
		Min	Max	Min	Max	Min	Max
Existing land under bioenergy crops	122,000	122,000		-	-	-	-
Cereal over production*	2,900,000	314,000	494,000*	-	-	-	-
Oilseed rape over production	600,000	69,000	166,000	-	-	-	-
<i>Economically marginal arable land**</i>	<i>144,000</i>	<i>87,000</i>	<i>98,000</i>	-	-	-	-
Uncropped arable land	214,000	36,000	47,000	-	-	-	-
Reduction in on-farm waste	62,000	-	-	13,600	62,000	-	-
Reduction in consumer waste	196,000	-	-	-	-	49,000	98,000
Improved utilisation of grassland	11,100,000	-	-	150,000	300,000	200,000	400,000
<i>Ecological Focus Areas (EFAs)***</i>	<i>403,000</i>	-	-	-	-	-	-
Brownfield sites	451,000	-		45,000		-	
Verges and Embankments	145,000	-	-	-	-	0	15,000
White land****	15,000	-	-	10,000		500	
Total		541,000	829,000	218,600	417,000	249,500	513,500
Total all scenarios						1,009,100	1,759,500

+Total area based on statistics, but area available for bioenergy is based on a series of assumptions which are set out later in the report.

*The max figure given for cereal surplus is the average surplus of wheat and barley over 5 years, rather than the actual maximum as the maximum figure is not considered realistic of actual practices.

**A total of 144,000 ha of economically marginal land is present in the UK but only 87,000-98,000 ha is considered suitable for bioenergy crop production. These figures are not included in the total row of Table 1 to avoid double counting as it is assumed that these figures are already included in the estimates of land available under cereal and oilseed rape overproduction.

*** No figures were given for EFA's inclusion of 2G bioenergy crops in EFA requirements has the potential to stimulate uptake of bioenergy crops, but these would be on land already identified (e.g. economically marginal land).

****White land area is calculated over 5 years as it is unclear exactly how much land will be made available annually.

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Introduction

The UK has a requirement to reduce its greenhouse gas (GHG) emissions by 80% from 1990 levels by 2050 using low carbon approaches, which include bioenergy crops (UK Government, 2009) from both agricultural and forestry sources. Bioenergy can be produced from a number of different sources, these are broadly classified into first, second and third generation crops. First generation (1G) bioenergy crops are crops that can be used for food or fuel e.g. wheat, sugar beet and oilseed rape in the UK, with no requirement for direct land use change. Second generation (2G) bioenergy crops are those that are non-food crops such as Miscanthus, Short Rotation Coppice (SRC) and Short Rotation Forestry (SRF) in the UK. These crops require a direct change in land use (from food production to fuel production) to enable an increase in their area. Third generation bioenergy comes from more technical innovations such as the use of algae. This study focusses on identifying the land that is suitable for 1G and 2G bioenergy crops. ETI have identified that converting between 1.3-1.4 Mha of bioenergy crops will significantly contribute to the UK meeting its future energy demands, whilst reducing the reliance on fossil fuels and reducing greenhouse gas (GHG) emissions from energy production, cost effectively by 2050. It is the 2G bioenergy crops that have the greatest potential to mitigate GHG emissions through low input systems and the potential for carbon storage within undisturbed soil and vegetation, therefore it is preferable that bioenergy comes from these sources rather than 1G, although the barriers to conversion and the timescales to conversion are more challenging than for 1G. There are currently approximately 122,000 ha of bioenergy crops grown in the UK, including both 1G and 2G crops, leaving a significant area of land still to be identified for future bioenergy crop production (Defra, 2015a). Types of land for consideration for bioenergy production include changing the existing use of arable land, improving utilisation of grassland, white land such as Ministry of Defence (MOD) or public land and idle land such as brownfield sites and roadside verges.

This study provides a route map that enables ETI to identify which areas of land are potentially available for bioenergy crop production and what drivers are required or barriers need to be overcome in order to support the conversion of that land to bioenergy crop production. In order to develop the route map the following processes were followed.

1. Identify, describe and quantify potential land available for bioenergy production.
2. Assess the relative ease of land conversion to bioenergy crops and identify key constraints that affect ease of conversion such as location, land quality, economics, physical availability and legal constraints.
3. Identify timescale for land conversion, prioritising easy wins vs mid and longer term goals and describe what steps are needed to convert this land to bioenergy cropping.

Identification of land types potentially available for bioenergy crop production

Approach

A range of different studies have been done to assess the availability of land for bioenergy crops. The majority of these assessments, such as that used in the earlier part of the RELB project, focused on what land types could be made available for bioenergy crops, working on a top down approach, i.e. these studies consider broad categories of land, e.g. arable, to be available and then apply additional constraints, e.g. Agricultural Land Classification criteria, onto that area to reduce it down to an area that is considered to be 'available'. This brief desk study takes a bottom up approach to the assessment of land availability for bioenergy crops. It looks at the type of land that bioenergy crops

could be grown on and considers what actions are needed in order for that land to become available for bioenergy crop production, and the timescales over which those changes might occur.

Scope - The scope for this assessment was UK land that could potentially be made available to bioenergy crop production up to 2050.

The first stage of the process was to identify types of land that could become available to bioenergy crop production and the mechanism by which that land could become available. These categories of land were identified in discussion with the ETI during the project inception as set out in Table 2.

Table 2 Type of land and mechanism by which land could be made available to bioenergy production

Type of land	Mechanism
Existing land in bioenergy crops	Included in current
Arable land- Uncropped arable land	Market changes to encourage conversion to bioenergy
Arable land- Economically marginal land	As above
Arable land- Releasing surplus production	As above
Arable land- On farm food waste	Reduction in on farm food waste – sparing land for bioenergy crop production
Arable land- Ecological focus areas (EFAs)	Policy change to encourage uptake of bioenergy
Arable land- Temporary grassland	Improved utilisation of grass or livestock producers reducing area due to poor economics
Permanent grassland	Improved utilisation of grass or livestock producers reducing area due to poor economics
White land	Sell off of publically owned land (e.g. MoD land)
Other Underutilised / under managed land	Market changes and management changes to encourage uptake of bioenergy crops on this land

For each land type identified, the first task was to identify what the total area of land was in the UK, e.g. total area of uncropped arable land. Where relevant, Defra statistics were used in the identification of the land areas, e.g. the Defra June agricultural survey. The second task was to consider what proportion of this land could be made available to bioenergy crop production. This stage involved considering the mechanisms identified in Table 2 and how they could spare or convert land currently being used for one purpose to bioenergy crop production. This analysis then produced a more refined area of land potentially available to bioenergy crop production. The third task was to consider what constraints there were on this potentially available land in order to determine over what timescale the land could become available and to identify what actions would need to be taken in order for that land to become available. The availability constraints considered included; location, scale, land quality, economics, physical availability and legal constraints. A scoring system was used to quantify each of the different constraints on land availability, this scoring system ranged from 0 = major constraint with significant barriers to overcome before land could be made accessible to 2 = minor constraints that are considered to be relatively straight forward to overcome, land should be straight forward to access. The scores for all the constraints were combined (with an equal weighting)

to provide an overall accessibility score. Those land types that had higher accessibility scores were deemed to be more likely to be available in the short term, whilst those with the lowest scores were considered to have a longer timescale to availability. There was no absolute cut off used to classify into short, medium and long term, these scores were used as a guide, with expert interpretation and consideration of more specific barriers and challenges over laid on top (e.g. competition with housing) prior to making the final categorisation. The definition of the specific scoring for each constraint is provided in Table 3.

Table 3 Factors that affect land availability (0, 1, 2) showing the different constraints on land availability for bioenergy crop production

	Availability Score		
	2	1	0
Practicalities of conversion	Limited changes required, fits in with existing farm system and farmer/consumer behaviours	Some changes to consumer/farmer behaviour and practices required	Major change, would require significant change to consumer/farmer behaviours and practices
Location	Suitable for bioenergy crop production – site easy to access for cultivation and harvest	Suitable for bioenergy crop production – site more challenging to access for cultivation and harvest	Land more marginal for bioenergy crop production with challenges to cultivation and harvest such as steep slopes
Scale	Potentially large pieces of land available in e.g. whole fields	Both larger areas and smaller areas of land available	Smaller, widely distributed pockets of land, e.g. parts of fields
Land quality	Good quality land, land has potential to yield well	Moderate quality land, average yields.	Poor quality land e.g. with shallow soils, likely to have poor yields
Economic availability	Market immediately accessible	Requires some market incentive for land to be accessible	Requires significant market change to enable access
Physical availability	Currently cultivated and used for intensive agriculture / or already planted to bioenergy	Not currently cultivated, but no barrier to cultivation.	Not been cultivated in last 5 years and barriers to cultivation e.g. habitat loss if cultivated / regulatory barrier
Legal constraints	No legal constraints	Some legal constraints that could be overcome	Major legal constraints e.g. SSSI, BAP habitat etc.

Land type definition, availability and assumptions

For this study, it is assumed that conversion to 1G bioenergy crops is straightforward for most arable land types as it would just involve selling conventional food crops to the bioethanol/biodiesel market. Selling conventional arable crops to the biofuel market would depend on grain prices vs bioethanol prices, distance to processing plant (Figure 2) and farmer trust in the bioethanol/biodiesel market. Historically the biofuel market has been volatile with numerous plants closing when market economics



do not favour biofuel production or diversifying into other businesses. This has largely been driven by the impact of cheap biofuel imports from outside the EU, overcapacity of biodiesel production in general in Europe and high feedstock prices, particularly in years such as 2012 when quality of cereal feedstocks was low (ECOFYS, 2013).

Figure 2 Operational and planned larger scale commercial biofuel production plants (ECOFYS, 2013).

Land conversion to 1G bioenergy crops would not be as straightforward on white land, idle land and grassland where this would require a change in land use, and may not deliver the GHG emission savings anticipated from the bioenergy chain if LUC emissions are considered.

Converting land use to 2G bioenergy crops would require land use change on all land types except on land which is currently being used to grow these crops (10,500 ha). This means that there are additional challenges to conversion that need to be overcome compared to 1G bioenergy. The main barriers and opportunities for 2G bioenergy were discussed in the main RELB final report but examples include; farmers having access to the right knowledge and equipment to grow the crops, cost of establishment and a behaviour change to recognise the value of including a perennial crop on their farm.

The following sections set out the types of land that could be used for bioenergy crop production and calculates the proportion of the total area that could be made available to bioenergy crop production if certain drivers were put in place and barriers overcome.

Definitions of land types

Below are the high level definitions of the land uses assessed in this report and a broad summary of their distribution. These are then followed by individual sections with the statistics on the total land area for each land type and detailed assumptions on what proportion of that land area could become available for bioenergy crop production.

Existing land under bioenergy crops

This is land identified by Defra as currently being used to produce 1G or 2G bioenergy crops. It includes wheat and oilseed rape, maize, Miscanthus and SRC.

Cereal & oilseed over production

Cereals and oilseed comprise the majority of the UK arable crop area. Based on AHDB statistics (AHDB, 2016) on cereal production, in most years more wheat and barley is produced than is required for the UK domestic market, with excess grain either exported or held in stock. It is assumed for this study that given the right drivers some of the land used to grow cereals (and by inference oilseed rape) could be converted to bioenergy crop production either 1G or 2G. Cereal and oilseed rape production is focussed in the southern and eastern parts of the UK, although there are arable crops grown in all regions.

Economically marginal arable land

Economically marginal arable land refers to arable land of ‘typically low agricultural productivity, which is likely to change use based on economic and social drivers’ (Defra, 2009). This land comprises part of the total cereal and oilseed rape area and represents the land most likely to be converted to bioenergy crop production, especially 2G bioenergy. Economically marginal land is assumed to follow a similar distribution to that of cereals and oilseeds.

Uncropped arable land

Uncropped arable land (fallow) is land that has in the past been cultivated for arable crop production, but in the current season is not being used for crop production. This land is split into rotational fallow, where land is left uncropped for a single season as part of a planned rotation and more permanent fallow that is left uncropped for multiple years. Uncropped arable land has a similar distribution to cereals and oilseeds, with larger areas in regions with a higher proportion of arable land.

Reduction in on-farm waste

Recent studies have identified that up to 30% of fresh fruit and vegetable production is wasted before it leaves the farm (Feedback Global, 2009), in part due to failure to meet supermarket specifications. In this report we assess what proportion of the associated crop area might become ‘available’ for bioenergy production. Fruit and vegetable production is focused on more localised regions within the UK compared to arable crops targeting specific soil types, e.g. light easily cultivated land for potatoes and carrots – potatoes which comprise the largest proportion of the area tend to be grown in Norfolk, parts of the Fens, the Midlands and Yorkshire, with pockets of production in Pembrokeshire, parts of North East Scotland and other English counties.

Reduction in consumer waste

In addition to food waste on farm there is a large amount of food that is wasted at the consumer level. This report uses WRAP data and Defra Statistics to convert food waste into relevant UK crop area (excluding area associated with feed production for livestock) and considers what proportion of this area could be spared for bioenergy production given suitable drivers. Distribution is similar to on-

farm waste for fruit and vegetable consumer waste, whilst reductions in bakery waste would spare land in the cereal areas identified above and reductions in meat waste a most likely to spare land in the north and west where the main livestock producing areas are focused.

Improved utilisation of grassland

The majority of UK permanent and temporary grassland is currently used for grazing livestock, however the grazing systems used are highly inefficient resulting in large amounts of grass being wasted. This report assesses ways of improving the efficiency of livestock grazing allowing the same number of stock to be grazed on a smaller area of grassland and considers how the spared land could be accessed for bioenergy crop production. The main grazed livestock production areas in the UK are in the north and west, therefore the majority of the land spared would be in those regions.

Ecological Focus Areas (EFAs)

Since 2015, every farmer in the European Union who claims a direct payment and has more than 15 ha of arable land is obliged to have 5% of their arable land covered by Ecological Focus Areas (EFA's). At present bioenergy crops, especially 2G bioenergy crops are not well supported (if at all) by the EFA requirements. However, it is considered that if EFA requirements were adjusted there is the potential that this could support and provide additional motivation for planting 2G bioenergy crops. This land overlaps with most of the land types that are identified above and therefore no separate figures are presented.

Brownfield sites

Brownfield' (previously developed) land is defined in Annex 2 of the National Planning Policy Framework as:

Land which is or was occupied by a permanent structure, including the curtilage of the developed land (although it should not be assumed that the whole of the curtilage should be developed) and any associated fixed surface infrastructure. This excludes:

- land that is or has been occupied by agricultural or forestry buildings;
- land that has been developed for minerals extraction or waste disposal by landfill purposes where provision for restoration has been made through development control procedures;
- land in built-up areas such as private residential gardens, parks, recreation grounds and allotments; and
- land that was previously-developed, but where the remains of the permanent structure have blended into the landscape in the process of time.

Brownfield sites typically require preparatory regenerative work before any new development goes ahead, and can also be partly occupied. The UK government has an ambition to encourage building on brownfield sites and has set a goal for local authorities to use local development orders being used to get permissions in place on over 90% of suitable brownfield land by 2020 (Department for Communities and Local Government, 2015a). In 2010, the Government identified that there are approximately 70,000 ha of brownfield land that are unused or may be available for redevelopment. Much of this land is located in existing urban areas and approximately 35,000 ha of this land is considered suitable for housing. Brownfield land which is considered suitable for housing is not distributed evenly all over the country; for example, the North West contains around 7,000ha or 20% of England's brownfield land and the South East West Midlands together contain around 5,000 ha or 15% of England's brownfield land (CPRE, 2014).

Verges and Embankments

There is a significant area of land that comprises road verges, railway embankments and areas adjoining canals that could potentially be used for the production of bioenergy crops. Much of this

land is planted to grass to ensure that there is good visibility for drivers, but some is also planted to trees and scrub and could be converted to 2G bioenergy crops. This land is available in narrow strips right across the country, with more land present in areas with denser road or rail networks.

White land

White land is a general expression used to mean land (and buildings) without any specific proposal for allocation in a development plan, where it is intended that, for the most part, existing uses shall remain undisturbed and unaltered (Department for Communities and Local Government, 2016). Each year small areas of white land are sold off. The two main sources considered in this report are Forestry commission and MoD land as these are considered to have the greatest potential for conversion to bioenergy crop production. The forestry commission land is predominantly in parts of Scotland, with smaller areas dotted around the rest of the UK. MoD land is a relatively small area, with ex RAF airfields considered to have some of the greatest potential for conversion. These airfields are in the flatter parts of the UK, such as parts of the Eastern region.

Summary of land types available

In total it is estimated that between **1.0 Mha-1.8 Mha** is available for bioenergy crop production (Table 4). Land is considered to be available over the following timescales.

- *Short-term* – potential to be available within 1-5 years, with minimal constraints or challenges to access. Approximately **541,000-829,000 ha** potentially available consisting of utilising surplus arable production for 1G bioenergy, converting marginal land, uncropped arable land and some brown field sites to bioenergy crop production, either 1G or 2G.
- *Mid-term* – potential to be available in 5-10 years, with some constraints to overcome that will take time to act upon. Approximately **218,600 to 417,000 ha** potentially available including grassland spared as a result of improved utilisation, reductions in on farm food waste and a switch to growing bioenergy on verges and embankments.
- *Long-term* – Land could be made available in the future (10+ years) but constraints are more challenging to overcome and will require more significant changes in behaviour or practice to enable access. Approximately **249,500 to 513,500 ha** potentially available including further grassland spared by improved utilisation, conversion of white land to bioenergy and sparing of both arable land and grassland through reductions in consumer food waste.

Table 4. Summary of land types available over the short, medium and long term (hectares)

Land-Type	Total area in UK (ha)	Area (ha) available in:					
		Short term+		Medium term+		Long term+	
		Min	Max	Min	Max	Min	Max
Existing land under bioenergy crops	122,000	122,000		-	-	-	-
Cereal over production	2,900,000	314,000	494,000*	-	-	-	-
Oilseed rape over production	600,000	69,000	166,000	-	-	-	-
<i>Economically marginal arable land**</i>	<i>144,000</i>	<i>87,000</i>	<i>98,000</i>	-	-	-	-
Uncropped arable land	214,000	36,000	47,000	-	-	-	-
Reduction in on-farm waste	62,000	-	-	13,600	62,000	-	-
Reduction in consumer waste	196,000	-	-	-	-	49,000	98,000
Improved utilisation of grassland	11,100,000	-	-	150,000	300,000	200,000	400,000
<i>Ecological Focus Areas (EFAs)***</i>	<i>403,000</i>	-	-	-	-	-	-
Brownfield sites	451,000	-		45,000		-	
Verges and Embankments	145,000	-	-	-	-	0	15,000
White land****	15,000	-	-	10,000		500	
Total		541,000	829,000	218,600	417,000	249,500	513,500
Total all scenarios						1,009,100	1,759,500

+Total area based on statistics, but area available for bioenergy is based on a series of assumptions which are set out later in the report.

*The max figure given for cereal surplus is the average surplus of wheat and barley over 5 years, rather than the actual maximum as the maximum figure is not considered realistic of actual practices.

**A total of 144,000 ha of economically marginal land is present in the UK but only 87,000-98,000 ha is considered suitable for bioenergy crop production. These figures are not included in the total row of Table 4 to avoid double counting as it is assumed that these figures are already included in the estimates of land available under cereal and oilseed rape overproduction.

*** No figures were given for EFA's inclusion of 2G bioenergy crops in EFA requirements has the potential to stimulate uptake of bioenergy crops, but these would be on land already identified (e.g. economically marginal land).

****White land area is calculated over 5 years as it is unclear exactly how much land will be made available annually.

Existing land used for bioenergy crops (1G and 2G)

Total land area (ha)	Area potentially available to bioenergy production (ha)	Land accessibility score (detailed scores in Appendix 1)
122,000	122,000	13/14

Key Assumptions:

- 100% of land remains available to bioenergy production - the current area of bioenergy crops will remain under bioenergy production despite some uncertainties regarding end-user sourcing of bioenergy feedstocks.

Defra statistics (Defra 2015a) identify **122,000 ha** of land currently used in the UK to produce bioenergy crops. Of this area, 83,000 ha is identified as wheat or oilseed rape which is used for bioethanol/biodiesel, 29,000 ha is maize grown for anaerobic digestion and, in England only, **10,000 ha** of short rotation coppice (SRC) and Miscanthus. Industry estimates also identify an additional **500 ha** of SRC currently grown in Scotland, Wales and Northern Ireland (E4tech, 2013). For this study it is assumed that the available area is the same as the current area.

It must be noted that there are uncertainties associated with whether the current level of bioenergy cropping will continue. In particular Drax power station, a previous major outlet for Miscanthus and SRC grown in the UK, has stated that it is focusing on imported rather than home grown sources of bioenergy in the future (Drax, 2015). In 2014, around 25,000 tonnes of Miscanthus and 6,150 tonnes of SRC willow were used by Drax (Drax, 2015), representing 1,900 ha of Miscanthus and 650 ha of SRC using average Miscanthus and SRC yields (Defra, 2015a). The loss of this existing market could result in some farmers removing their 2G bioenergy crops unless they find an alternative outlet for their crop. With contracts coming to an end removal of SRC and Miscanthus plantations have been observed.

Where land is already used to grow bioenergy crops it is considered that there are few constraints to the use- with the land having an accessibility score of 13/14 (see Appendix 1 for detailed breakdown of scores). The main areas of bioenergy crops at present are in South of England, East Midlands and Yorkshire and Humber, although ETI have identified scope to expand this to other areas with SRC production favoured in the west/north-west of the UK and Miscanthus in the south and east of the UK (ETI, 2015). 'Scale' was the only factor that received a score of 1 as bioenergy crops tend to be spatially located on smaller, widely distributed pockets of land rather than large scale plantations, and therefore this could limit development of markets in the short term.

Cereal over production

Total land area (ha)	Area currently used for bioenergy (ha)	Additional area potentially available to bioenergy production (ha)	Land accessibility score (detailed scores in Appendix 1)
UK cereal area 2.9M	62,000*	314,000-494,000	13/14
Pro rata assumption on OSR area 0.6M	13,000*	69,000-166,000	
Total 3.5M	75,000	383,000-660,000	

*Data for 2014 (Defra 2015a)

Key Assumptions:

- The yields of cereal crops grown in the UK remain relatively constant
- UK demand for cereals and oilseed for food and feed remains constant
- Approximately 2 Mt of surplus wheat, 1 Mt surplus barley and (making pro rata assumptions) 0.6 Mt surplus oilseed rape are grown annually.
- 2.8% of cereal and oilseed area already used for bioenergy
- Additional 8-19% of cereal area – could be spared for bioenergy crop production

Wheat is the main arable crop grown in the UK accounting for 1.8-2.0M ha each year (Defra, 2015b), based on crop areas over the last 5 years. Barley (winter and spring) accounts for the second largest area of arable crops at 1.0-1.1M ha. Wheat and barley are sold on a commodity market, and rarely grown for a specific purchaser, therefore many farmers will plant an area that suits their rotation, and expect to find a market at harvest. Grains are a global commodity and the price tends to reflect the global supply and demand, although there are some local effects, for example in years where the wheat area is high and yields are good this can mean that there is more wheat available than is needed to meet UK food and feed demand. This can cause a downwards pressure on prices and leaves an increased volume of grain available for export, if the market exists. Wheat and barley account for 65% of the total UK arable area (Defra, 2015b) and there is robust data available from Defra and AHDB on supply and demand, therefore calculations relating to supply and demand were focused on these crops. It should be noted that oilseed rape is the third main crop in UK arable rotations with about 0.6M ha (Defra, 2015b), although areas have been declining in recent years in response to poor prices and increased challenges in managing pests. Similar supply and demand pressures act on this market, with seed from this crop potentially being available for use as a 1G bioenergy crop. However, supply and demand balance sheets are less readily available for this crop to calculate the level of surplus that could be diverted to bioenergy. As a result no accurate figures were calculated in this assessment, instead the calculations made on the cereals were applied pro rata to oilseed rape meaning any estimates of land spared are highly uncertain.

Average wheat and barley demand in the UK is around 19.7 M tonnes (AHDB, 2016) providing grain for bread, brewing, malting, other food production, animal feed and existing biofuel production (5 year average 2011-2015). The UK typically uses 19.7 M tonnes of wheat and barley grain with a typical surplus of 3.5 M tonnes based on the five year average wheat and barley surplus, between 2011-2015 (AHDB, 2016). It should be noted that in most years a surplus was present, but in poor years, e.g. where drilling was impacted by weather resulting in reduced areas or where yields were poor this surplus was eroded. In order to convert the 'surplus' into an area the average UK surplus of wheat and barley for each year (Defra, 2015b) was divided by the average yield (t/ha) in that year for each of wheat and barley to give an area of wheat and barley that was considered 'surplus'. This figure was averaged to give a five year average of **494,000 ha** with a range from **314,000 ha** in 2013 to **647,000 ha** in a good year like 2015. Data has not been accessed to complete a similar study for the oilseed rape area, however if similar proportions of oilseed rape were 'surplus' **69,000 ha – 166,000 ha** could be spared (AHDB Cereals and Oilseeds, 2015). This is considered to be highly uncertain and quite possibly an over estimate as the oilseed rape industry and markets are different to cereal markets. All of this area could potentially be used to source 1G bioenergy crops within one year as the crop is already there, it just needs to be sold into a different market. The constraints are that the costs of transporting to bioethanol/biodiesel plants is not prohibitive (either economically or in terms of GHG emissions), a stable market exists for selling bioethanol/biodiesel and the returns from growing crops for 1G bioenergy are greater than or equal to that of selling crops on conventional food and feed markets. In addition it is considered that if the supply and demand drivers were right some of this land could be converted to 2G bioenergy crops, with the economically marginal land the most likely area to be converted (**87,000-103,000 ha**), see separate section for discussion on marginal land),

although this process would take longer than the simple switch of market required to enable this surplus grain to be sold into bioenergy markets.

Table 5 Range in yield ‘surplus’ for wheat and barley between 2011-2015- calculated based on average annual yield (Defra statistics) and yearly surplus (tonnes) based on AHDB Supply and Demand data (AHDB, 2016)

	Wheat			Barley			Cereals
	Yield (t/ha)	Surplus (t)	Area (ha)	Yield (t/ha)	Surplus (t)	Area (ha)	Surplus area (ha)
2015	9.0	2,865,000	318,000	6.7	2,202,000	329,000	647,000
2014	8.6	940,000	109,000	6.4	1,836,000	287,000	396,000
2013	7.4	1,473,000	199,000	5.8	668,000	115,000	314,000
2012	6.7	2,643,000	394,000	5.5	1,032,000	188,000	582,000
2011	7.7	2,830,000	368,000	5.7	941,000	165,000	533,000
5 year average		2,150,000	278,000		1,336,000	217,000	494,000

The accessibility of the surplus UK area of wheat and barley is considered to be high, with a score of 13/14. Practicality of conversion, location, scale, physical availability, quality and legal were considered to have minimal constraints associated with them as the land is already growing arable crops that could be sold as 1G bioenergy crops given the right market incentives. The main constraint to the conversion of ‘surplus’ cereal production (land) into 1G bioenergy is considered to be economic, as the size of the bioethanol market and the demand for cereal crops for bioethanol production is not currently sufficient to cause a largescale switch in markets (milling, feed, export, industrial uses etc) that UK wheat and barley are currently sold to. In the main surplus grain is either exported or held as stocks for future years if an export market is not available at a suitable price. There is some flexibility in the feed industry to take more wheat if it is sufficiently cost effective, but there is a limit to the amount of additional wheat that can be taken into the livestock sector. In order to achieve a switch there needs to be an increase in the attractiveness of the bioenergy market to UK farmers.

Economically marginal arable land

Total land area (ha)	Area potentially available to bioenergy production (ha)	Land accessibility score (detailed scores in Appendix 1)
144,000	87,000-98,000*	10/14

*The available area identified (87,000-98,000 ha) is already included in the areas identified in the above section on cereal and oilseed rape over production and so are not included in final available area estimates for bioenergy crop production.

Key Assumptions:

- Economically marginal land area coverage in Scotland and Ireland is similar to England and Wales.
- 32-40% of economically marginal arable land that could be converted to 2G given favourable market conditions (gross margin for bioenergy is better than gross margin for food or feed production)

- The economically marginal land that is 'available' for bioenergy crop production is included in the overall potential land area for bioenergy crop production identified under cereal overproduction (see section above) and as such are not included in final area estimates.

Economically marginal land refers to arable land of 'typically low agricultural productivity, which is likely to change use based on economic and social drivers' (Defra, 2009). Agricultural land use is to some extent driven by financial return of different agricultural enterprises and as such economically marginal land may be of interest for 2G bioenergy production where the financial returns from arable cropping are less than could be obtained from growing bioenergy crops on the same land. It is considered that the supply and demand mechanism above could support a conversion of economically marginal land to bioenergy crop production, particularly 2G bioenergy crop production (therefore figures in this section are already included in the overall potential land area available for bioenergy identified under surplus cereal production). However, the conversion of the economically marginal land to 2G bioenergy production would take longer than an instant switch to 1G bioenergy production.

In England and Wales, the total area of economically marginal land (including National Parks) is estimated to be **128,000 ha** (Defra, 2009). This figure is calculated in Defra (2009) and is based on situations where the enterprise margins for the perennial crops were greater than those estimated for arable production. The enterprise margin for wheat is shown below and was derived using average annual wheat price in the UK calculated from Defra's monthly wheat trade and price figures between 1996-2014 biomass prices in the UK market place (c £100/t for wheat). The wheat price used in the study is similar to current feed wheat markets, with milling wheat prices being slightly higher (£103-106/tonne) (Farmers Weekly, 2016). The average yield was calculated in Defra (2009) using data from Defra 2008 Cereal Production and Oilseed Rape Surveys and were plotted spatially to identify the relationship with data on underlying soil class and natural fertility factors, with an average yield taken. The wheat production cost (£482/ha) was based on earlier work undertaken by Fera to develop costing worksheets for farmers considering energy crop production. The additional £5.53/t (see enterprise margin below) is based on estimated wheat haulage costs (Defra, 2009).

$$\text{Wheat enterprise margin} = \text{market price (£/t)} \times \text{yield (t/ha)} - (\text{production cost (£/ha)} + \text{yield (t/ha)} \times \text{£5.53/t}).$$

The biomass enterprise margin was calculated for both Short Rotation Coppice (SRC) and Miscanthus using a similar method to the wheat enterprise margin, as shown below:

$$\text{SRC enterprise margin} = \text{market price (£/t)} \times \text{yield (t/ha)} - (\text{production cost (£/ha)} + \text{yield (t/ha)} \times \text{£34.50/t})$$

$$\text{Miscanthus enterprise margin} = \text{market price (£/t)} \times \text{yield (t/ha)} - (\text{production cost (£/ha)} + \text{yield (t/ha)} \times \text{£31.10/t})$$

The market price (£60/odt) for both SRC and Miscanthus was based on figures reported by industry and collated in bioenergy market statistics, such as monthly market reports by Enagri (Defra, 2009). SRC yields were mapped using models derived by Forest Research which took in to account factors such as annual rainfall, seasonal rainfall (March-October), growing degree days, frost days, soil pH and soil texture (sand, clay or loam). Miscanthus yields were based on a yield map developed by ADAS based on the following dry matter accumulation equation, applied on a daily basis for the length of the growing season, with the cumulative yield calculated at the end of the growing season (Defra, 2009).

$$Y_{P(k)} = \sum_{k=1}^n S_{t(k)} \epsilon_{i(k)} \epsilon_c d_{f(k)}$$

- Where, (Y_p) is the total above-ground dry matter yield at final harvest (g m⁻²).
- The argument (k) denotes the value of the associated variable on the k th day during the growing season;
- S_t is the daily incident solar radiation over the growing season (MJ m⁻² PAR);
- ϵ_i is the efficiency with which the crop intercepts that radiation (dimensionless);
- ϵ_c is the efficiency with which the intercepted radiation is converted into above-ground biomass (g d.m. MJ⁻¹ PAR intercepted)
- d_f is the drought reduction factor (dimensionless)
- n is the length of the growing season. For potential yield d_f is unity.

Base costs of production/hectare for each crop were derived from default values used in earlier work undertaken by Fera to develop costing worksheets for farmers considering energy crop production, which have been adopted and used by the biomass supply industry. These include all planting and input costs and account for machinery, depreciation and labour costs. Costs related to output per tonne of product were stripped out (e.g. haulage and drying costs). All costs for perennial energy crops were annualised over a 13-year period. The base costs of production were calculated as £187/ha for willow SRC and £159/ha for Miscanthus. Drying costs were then attributed to SRC and Miscanthus based on % dry matter, with a drying cost of £24.50/tonne attributed to SRC and £10.50/tonne to Miscanthus. Haulage costs of £10 per tonne were allocated to biomass crops to reflect the different bulk densities of bioenergy crops. A further baling cost of £10.60/tonne harvested was applied to Miscanthus.

An estimate of the economically marginal arable land for Scotland and Northern Ireland was not provided by Defra (2009) or found elsewhere. However, the economically marginal arable area stated in Defra (2009) of 128,000 ha accounts for 3.2% of the total arable area (land that is currently used to grow food, feed or fuel) in England and Wales and, if increased pro rata to the UK arable area) assuming a total UK arable crop area of 4.5 M ha, based on a ten year average – Defra, 2015b) this would give an estimated total area of marginal land equivalent to **144,000 ha**. In England and Wales, National Parks and Areas of Outstanding Natural Beauty are designated under the National Parks and Access to the Countryside Act 1949. The aim of this act is to ‘conserve and enhance the natural beauty, wildlife and cultural heritage of National Parks and promote opportunities for the understanding and enjoyment of the special qualities of those areas by the public’. The Act does not explicitly refer to bioenergy crops, however it is not considered likely that bioenergy crops would be considered to be appropriate in National Parks (Wang *et al.*, 2014) and as such the area of economically marginal land in National Parks (41,000 ha) has been excluded from the available land estimate- leaving **87,000 ha** of economically marginal land potentially available in England and Wales, with a pro-rata increase to include Scotland and Northern Ireland increasing this figure to **98,000 ha**.

There were considered to be minimal constraints (score of 2) with regards the practicalities of conversion, physical availability and legal issues to using economically marginal land for bioenergy crop production. Economically marginal land is already in crop production and is therefore considered to be readily accessible for conversion to 1G bioenergy crop production i.e. by selling crop outputs to the bioethanol and biodiesel markets. Its conversion to 2G bioenergy cropping could be scored as a 1 as it would require the farmers to understand the production of a new crop and either purchase machinery or source contractors for the planting and harvesting of the crop. Economically marginal land by definition is already cultivated and therefore there are no legal constraints to its conversion to bioenergy crops, apart from the need to carry out an Environmental Impact Assessment (EIA) if SRC is to be grown, but this is true of all land to be converted to SRC production.

For location, scale, quality and economic availability economically marginal land scored a 1, indicating that there are some constraints to its accessibility. Economically marginal land tends to be in dispersed, small parcels of typically low agricultural productivity e.g. due to slope of land, soil type, ground cover, field shape, topography etc., which could make accessing the land difficult. The land is already being used to produce food crops that could also serve as 1G bioenergy crops and therefore a market driver that established a more reliable market for grain going for bioenergy could result in a short term shift to 1G bioenergy crop production. However, this land could also be suitable for 2G bioenergy crop production, but in order for that to occur there would need to be a sufficient market driver and reliability of market to enable farmers to make the long term commitment that establishing 2G bioenergy crops warrants.

The main barrier to the conversion of economically marginal land to bioenergy crop production (especially 2G) is economic; to convert land to 2G bioenergy crops farmers need to make an initial investment for planting with a lengthy 3-5 year wait before they see any return on that investment. This makes the crop potentially seem more risky compared to conventional arable crops. Switching to the production of 2G bioenergy crops is also a change in farm practice which will impact on cash flow and will require new skills. For some farmers the risk of switching to 2G bioenergy crops will be too high, particularly given previous failed schemes and the rather uncertain market, restricting uptake. In addition some of these economically marginal areas may be included in agri-environmental schemes, for which bioenergy crops in England are not currently eligible. Whilst the land is in the environmental stewardship scheme this could prove a barrier to conversion, but as these schemes are transient in nature, lasting around 5 years, it should not be considered an absolute constraint on the land use. The conversion of economically marginal land to 2G bioenergy crop production would require a change in farmer perception to recognise the benefit of growing non-food crops, and a market change to make the change financially viable and minimise the risk associated with conversion.

Uncropped arable land (fallow)

Total land area (ha)	Area potentially available to bioenergy production (ha)	Land accessibility score (detailed scores in Appendix 1)
214,000	36,000-47,000	10/14

Key Assumptions:

- The proportion of rotational fallow to permanent term fallow is the same across the UK
- Approximately 78-83% of fallow is considered rotational and is therefore not available for conversion
- Approximately 17-22% of fallow is long-term and therefore available for conversion
- Assumes all permanent fallow land is suitable for growing bioenergy crops

Uncropped arable land (fallow) is land that has in the past been cultivated for arable crop production, but in the current season is not being used for crop production. In 2015 there were **214,000 ha** of uncropped arable land in the UK (Defra 2015c). Consultation with Associated Independent Crop Consultants (AICC) (AICC, personal communication) located in areas with larger amounts of fallow land indicate that 78-83% of the uncropped arable land is considered to be rotational fallow, where land is left uncropped for one or two seasons as part of a planned crop rotation. This can be used to aid pest, disease or weed management or is left unplanted because of weather conditions, logistics or market conditions. This rotational fallow land is part of the main cropping area and is considered to be a transient land use. An estimated 8,700 ha of this rotational fallow is un-utilised organic land that is part of the fertility building, pest and weed management process in organic systems. This rotational fallow is therefore not considered to be 'available' for bioenergy crop production. The other type of

fallow land is more permanent in nature, often in field corners or more difficult to access parts of the farm, e.g. areas that suffer waterlogging, steep slopes, poor access, or on field margins providing buffers to water courses. AICC estimate that 17-22% of the uncropped arable land is permanent fallow i.e. land that remains uncropped over numerous years. This is the area that is considered to be most likely to be available for conversion to bioenergy crops, equivalent to **36,000-47,000 ha**. These figures assume that the proportion of rotational to permanent uncropped arable land is similar across the UK, also assuming that all of the permanent fallow is suitable for growing bioenergy crops. However, numerous factors could affect the suitability including land drainage, previous land use (quarry etc.) or location in relation to urban areas (some fallow land is left as a buffer between urban areas and farmed areas due to challenges with farming close to urban areas). There is the potential that some of the uncropped arable land could also be considered to be economically marginal – however given that the economically marginal area has not been included separately from the supply and demand spared cereal area there should be no-direct overlap in the figures presented.

Uncropped arable land has few constraints to its practical conversion to bioenergy production as although the land is not currently used for crop production, under CAP greening rules (Defra, 2014a) the '*land must be maintained in a state which makes it suitable for grazing or cultivation*', therefore theoretically it would not take much time or economic input to convert uncropped arable land to either 1G or 2G (Miscanthus or short rotation coppice) bioenergy crops. There were also few constraints in terms of location or scale. The distribution of uncropped arable land reflects the arable area (ADAS, unpublished 2010-2015), with larger areas found in the East Midlands, South East and South West, areas which traditionally have a higher proportion of arable land, whilst the area of uncropped arable land is less in the more grassland dominated areas such as the West Midlands and North West. Where whole fields have been left as uncropped arable land the scale of plot for conversion to bioenergy crop production is sufficient for both 1G and 2G bioenergy crop production. Where the uncropped arable land is in awkward places, the conversion to 1G may be more practicable if the rest of the adjoining land is also in arable production.

For the other constraints uncropped arable land scored a 1, indicating that there are some constraints to the conversion to bioenergy. Quality of land can be mixed, as some of the land that is converted to permanent fallow is economically marginal and therefore has challenges associated with its use, either due to poor soils, or the shape and accessibility of the land. There are potentially legal/policy constraints to the conversion to bioenergy as some areas of uncropped arable land are included under the Countryside Stewardship scheme (Natural England, 2015) or as part of the Ecological Focus Area requirements under CAP (Defra, 2014a).

Reduction in waste

It is widely publicised that food waste is a serious problem, with an estimated 15 Mt of food wasted each year in the UK (WRAP, 2015) with an estimated cost to the UK food industry of approximately £5 billion each year (Defra, 2015d). A study by WRAP (2012) suggested that approximately 4.2 million tonnes of the total 7 million tonnes of consumer food waste in the UK is avoidable, which is equivalent to 6 meals per week for the average UK household. The main sectors affected by food waste in the UK are: fruit and vegetables (27%), drinks (17%), bakery (11%), meals (10%), dairy (10%) and meat (7%). This report focusses on UK produced commodities, which can easily be attributed to single products therefore meal waste and drinks are excluded.

Total land area (ha)	Area potentially available to bioenergy production (ha)	Land accessibility score (detailed scores in Appendix 1)
On farm food waste – 62,000	13,600 – 62,000	8/14
Consumer food waste - 196,000	49,000 - 98,000	6/14

Key Assumptions:

- Fruit and vegetable crops are most affected by on farm waste – with an estimated 30% of the area (62,000 ha) effectively wasted on farm due to failure to meet specification.
- **On-farm waste-** Changes to retailer specifications could increase crop utilisation by 5% – this change could spare 13,600 ha assuming that total production remains unchanged and growers didn't just capitalise on increased productivity by increasing total production.
- **Consumer waste-** A 50% reduction in consumer food waste would be equivalent to up to 98,000 ha of land being spared, which could potentially be utilised for bioenergy crop production.
- All tonnage to hectare conversions are based on standard yields (2014) calculated by taking the total UK production (tonnes) and dividing this figure by the total UK area of the crop.
- There are multiple steps required to get from a reduction in food waste through the supply chain to a reduction in volume of food produced and the potential for LUC to occur sparing land for bioenergy crop production and therefore these figures are highly uncertain as to whether the land would actually become available to bioenergy specifically.

There is an estimated 4.2M tonnes of avoidable food waste produced in the UK, a large proportion of that food is produced in the UK, and therefore a proportion of the agricultural and horticultural land area in the UK is currently being used to produce crops which are then wasted. If the amount of food wasted in the UK could be reduced it is assumed for the purpose of this report that there would be a subsequent reduction in demand for certain products, leading in theory to a reduction in the area required to produce the required crops/livestock. If the right market drivers were then in place this spared land could be converted to growing bioenergy crops. Assumptions around this area are therefore highly uncertain.

There are two key ways in which food waste could be reduced: the first is by reducing on-farm food waste, e.g. by adjusting retailer specifications on size and shape and preventing food being wasted before it reaches shelves, the second is to reduce the amount of food wasted by consumers. On farm food waste is potentially easier to target in the short term as it involves targeting a 'relatively small' number of purchasers to get them to agree to changes in specification, and then feeding those changes back to the suppliers. Reducing consumer food waste is more complex and requires a campaign to change practices in a vast number of households. These changes in practices then need to filter back to changes in purchasing, resulting in reduced demand for products, which then reduces the market for produce, causing a reduction in the required area of production. This means that there are multiple actions across a range of consumers, retailers, packers and growers that have to come together to get a reduction in area, before an additional action is needed to get that reduction in area focused towards bioenergy crop production, as opposed to increasing exports or diversification into other food crops. This process is likely to require comprehensive knowledge transfer schemes, incentives and a collaborative approach to waste management to enable it to occur.

Reducing on-farm waste assumptions

According to Feedback Global (Feedback Global, 2009) retailer specifications cause 20-40% of fresh vegetables and fruit to be wasted before they reach supermarket shelves. For the purpose of this study it was assumed that the middle range figure of 30% would be selected as the level of crop wastage due to retailer specifications.

Defra statistics (2014b) indicate that there are 204,000 ha used to grow fruit and vegetables in the UK, with potatoes accounting for about 141,000 ha and other fruit and vegetables [carrot, onion, lettuce, cabbage, cauliflower, apple, soft fruit (strawberries, raspberries and blackberries), stone fruit (cherries and plums) and pears] the rest. In total this area produces **7.4M tonnes** of marketable produce. A study by WRAP in partnership with Co-operative Food in 2013/14, highlighted that a 2mm screening size reduction for potatoes from 45- 43 mm, increased crop utilisation by 5 percentage points (WRAP, 2014). Assuming that the same level of increased crop utilisation could be achieved in all crops, it is calculated that in order to produce the same volume of UK fruit and vegetable production the land requirement could be reduced to **194,000ha**, a reduction in area of **13,600ha**.

Defra produce statistics for production and area (Defra 2014b) for each of the main horticultural crops. These were used to calculate the current marketable yield of each crop, the 5percentage point increase in utilised yield was applied to this yield figure and then a back calculation was made to identify how much land was required to maintain current production levels given higher utilised yield (reduction in on farm waste). If crop wastage could be removed all together (100% utilisation), an estimated area of approximately **62,000 ha** of land could be spared. It is expected that more complex changes to specifications would be required to achieve more of the 62,000 ha.

Table 6. Area of on-farm waste created as a result of retailer specifications (using 2014 data)

	Area (2014)	Production (2014)	Current marketable yield (70% utilised)	Marketable yield (75% utilised)	Marketable yield (100% utilised)	Spared area (75% utilised)	Spared area (100% utilised)
Commodity	(ha)	(t)	(t/ha)	(t/ha)	(t/ha)	(ha)	(ha)
Potato	141,000	5,452,000	39	41	55	9,400	42,000
Carrot	11,000	748,000	68	73	97	733	3,000
Onion	10,000	369,000	37	40	53	667	3,000
Lettuce	6,000	131,000	22	23	31	400	2,000
Cabbage	7,000	230,000	33	35	47	467	2,000
Cauliflower	9,000	87,000	10	10	14	600	3,000
Apple	9,000	226,000	25	27	36	600	3,000
Soft Fruit (incl Strawberries, Raspberries, Blackcurrants)	9,000	140,000	16	17	22	600	3,000
Stone Fruit (incl Plums, Cherries)	1,000	14,000	14	15	20	<100	300
Pear	1,000	24,000	24	26	34	<100	300
Total Area	204,000	7,400,000				≈13,600	≈62,000

NB: Yield data shown in table was calculated using area and production data from the Defra Basic Horticulture Statistics (Defra 2014b)

On-farm waste reduction was considered to have few constraints with regards location, scale and quality – with each being scored as a 2. The location of land will largely be focussed in areas/regions where the majority of horticultural production occurs e.g. the East Midlands, Eastern and South East regions, with additional areas in parts of the West Midlands and Lancashire. There were considered to be some constraints with regards physical availability and legal/policy issues. Major constraints were considered to be in place for practicalities of conversion and economic availability. In theory if a change to retailer specifications could be achieved quickly, then land is already cultivated and could be converted for production of bioenergy crops relatively easily. However, without the right incentives/markets many farmers may decide to continue with their current levels of production, in the expectation of being able to sell more crop for the same level of input and export any surplus produce. The economic barrier is bigger in the case of fruit and vegetable production than with cereals due to the high value of the crop, bioenergy crops would have to be highly profitable or confer wider business benefits in order to displace highly profitable fruit and vegetable production systems. The initial barriers to sparing this land, in order to make conversion to bioenergy crop production possible, are consumer and retailer attitudes to outside specification produce. Given the choice of unblemished produce over ‘wonky’ vegetables consumers are still more likely to select the ‘perfect’ produce. Progress is being made in this area with a number of major retailers now trialling outside specification or ‘wonky’ vegetable boxes (Guardian, 2015), however, real progress on consumer food selection practices and retailer specifications is unlikely to be achieved in the short-term, therefore the timescale for the reduction in food waste will be in the mid-long term with incremental improvements anticipated over the next 10 years.

Reducing consumer waste assumptions- crop waste

A recent WRAP report (WRAP, 2012), identified that a total of 7.0 M tonnes of food and drink were wasted in the UK in 2012, with approximately 60% or 4.2 M tonnes of that waste avoidable. The main components of this avoidable waste were identified to be bakery products (450,000 tonnes), fresh fruit and vegetables (1.16 M tonnes), dairy products (395,000 tonnes) and beef and lamb meat products (41,000 tonnes). Other components which make up the remaining 2 M tonnes of avoidable waste and which are not covered in this report include, drinks, meals (pre-prepared and homemade), cakes and desserts, condiments, processed fruit and vegetables, confectionary, staple foods and oil and fats.

Bakery: There are a wide range of bakery products and therefore a 600g white loaf was used as a proxy for all bakery products. A typical white loaf is made from a 5:3 ratio of flour to water. Therefore of the total 450,000 t bakery waste, 282,000 t will be flour. An estimated 75% (211,000 tonnes) of the flour used in the UK is home grown (Nabim, 2015) with the remaining 25% imported wheat. Based on an average historical wheat yield of 7.9 t/ha (Defra, 2015b) this is equivalent to 27,000 ha of wheat.

Potatoes: The WRAP (2012) survey reported 320,000 t of consumer potato waste, of which 75% (240,000 t) is assumed to be from home grown potatoes (Defra, 2015c). Using a 39t/ha average yield (Defra 2014b), the area required to produce the tonnage of potatoes was calculated to be equivalent to 6,000 ha.

Fresh vegetables and fruit (exc potatoes): The WRAP (2012) report includes both UK and imported fruit and vegetables, as well as produce grown under protection. All imported produce such as bananas and citrus were excluded from this assessment as they are not grown in the UK, as were any protected edibles such as tomatoes and peppers as it is unlikely that a glasshouse facility would be removed to grow bioenergy crops. Crops included in the food waste calculations were: carrot, onion, lettuce, cabbage, cauliflower, apple, soft fruit (strawberries, raspberries and blackberries), stone fruit

(cherries and plums) and pears. The total area under each crop and total production volume figures were used (Defra 2015e) in order to calculate the yield of crops. The ratio of exports to imports was calculated for each crop based on figures from the Basic Horticultural Statistics 2014 (Defra 2014b) and the Agriculture in the United Kingdom 2014 (Defra 2015e) publications. As with wheat and potatoes the tonnage of total consumer waste (total vegetable and fruit approx. 364,000 tonnes) was multiplied by the proportion of the crop that was home grown and this gave the tonnage of UK consumer waste produced (total vegetable and fruit waste approx. 194,000 tonnes). This estimated tonnage of wasted UK vegetable and fruit production was then divided by the yield of the crop, to give an equivalent total UK area of vegetables (excl. potatoes) or fruit crop wasted of approximately **6,800 ha**. For crop specific details see Table 7 below.

Table 7. Reduction in waste- Tonnage and equivalent area of key arable and horticultural crop waste

Commodity	Area	Yield	Annual Production	Total Consumer Avoidable Waste	Proportion Home Production Market	UK Consumer Avoidable Waste	Area equivalent of UK consumer waste
	(ha)	(t/ha)	(t)	(t)	(%)	(t)	(ha)
Bakery (wheat part) *	1,832,000	7.9	14,473,000	450,000 (of which 282,000 flour)	75%	211,000 (flour)	27,000
Potato	141,000	39	5,452,000	320,000	75%	240,000	6,000
Carrot	11,000	68	748,000	73,000	96%	70,000	1,000
Onion	10,000	37	369,000	55,000	48%	26,000	700
Lettuce	6,000	22	131,000	44,000	41%	18,000	800
Cabbage	7,000	33	230,000	22,000	93%	20,000	600
Cauliflower	9,000	10	87,000	14,000	36%	5,000	500
Apple	9,000	25	226,000	59,000	34%	20,000	800
Soft Fruit (incl Strawberries, Raspberries, Blackcurrants)	9,000	16	140,000	44,000	61%	27,000	2,000
Stone Fruit (incl Plums, Cherries)	1,000	14	14,000	32,000	15%	5,000	300
Pear	1,000	24	24,000	21,000	13%	3,000	100
Total				1,134,000		645,000	40,000

* Due to the wide range of bakery products a 600g white loaf was used as a proxy for all bakery products figures presented represent the proportion of a white loaf represented by wheat.

Reducing consumer waste assumptions- dairy and meat

The area of meat and dairy wastage was calculated using average milk yields (AHDB Dairy, 2015), and average slaughter weights (Defra 2015f) to calculate the number of stock impacted and then livestock units (Nix, 2016) and average stocking densities (Defra, 2010) to convert the number of stock into an area of grassland (details in Table 8).

Based on typical stocking densities and meat/milk yields it was estimated that the 436,000 tonnes of meat and dairy product waste is equivalent to **156,000 ha** of land that could be spared if all waste was reduced.

Table 8 Reduction in waste- Tonnage and equivalent area (livestock units) of meat waste

Stock	(a) Tonnage Wasted (t)	(b) Meat/Milk Yields (t/animal)	(c) Stocking Density (animals/ha)	(d) Livestock Units (LU)	Area equivalent (ha) [(a/b)/c*d]
Beef	34,000	0.34*	1.2	0.6	50,000
Lamb	7,000	0.02*	0.7	0.17	76,000
Dairy	395,000	7.6**	1.7	1.0	30,000
TOTAL	436,000		-	-	156,000

*3 month average (Defra 2015f)

**Five year average (AHDB Dairy, 2015)

d) A livestock unit is typically defined as, 'A Livestock Unit (LU) is usually defined in terms of feed requirements. These figures are based on metabolisable energy (ME) requirements. One LU is considered as the amount of feed energy needed for the maintenance of a mature black and white dairy cow.' (AHDB Beef & Lamb, 2013)

Consumer waste summary

Based on the calculations above consumer food waste in crop products is equivalent to 40,000 ha of crop land and meat and dairy product wastage accounts for a further 156,000 ha of direct land use (plus the additional land used to produce feed for these stock – not included in this assessment). This is equivalent to **196,000 ha** of land that is 'wasted' as food waste.

Current targets for food waste reduction are unclear (Defra, 2015d) and therefore the 'Waste Framework Directive target to recycle 50% of waste from households by 2020' (Defra, 2011) has been used to infer the level of potential of consumer food waste reduction. The European Commission have a commitment to half per capita food waste at the retail and consumer level by 2030 (EU, 2016), following on from a commitment to meeting the Sustainable Development Goals (SDGs, 2015). A 50% reduction in consumer food waste equates to a potential available area of up to **98,000 ha**. Assuming that only half of this spared land is converted to bioenergy production this gives a lower end estimate of **49,000ha**.

Tackling consumer food waste requires engagement with the whole of society and is therefore considered to be a long-term challenge. It is not only consumer practices to food waste and recycling which need to be changed. Incorporating food waste reduction strategies into the way retailers conduct their stock orders/checks and developing feed-back systems to primary producers, so that the land area which is no longer required for food production as a result of lower overall consumption, is available for other uses. In order to encourage uptake of conversion to bioenergy crops it may be necessary to incentivise farmers, as the current margins that can be obtained on arable/horticultural crops compared to bioenergy crops, present a barrier to conversion to 2G as they are more profitable (Nix, 2016).

Improved utilisation of grazed grassland

Total grassland area (ha)	Area potentially available to bioenergy production (ha)	Land accessibility score (detailed scores in Appendix 1)
Mid-term – 11,100,000 9,900,000 permanent 1,200,000 temporary	150,000-300,000	7/14
Long-term – 11,100,000 9,900,000 permanent 1,200,000 temporary	200,000-400,000 (additional)	4/14

Key Assumptions:

- Rough grazing area is excluded as it is considered unlikely to be converted to bioenergy cropping and is more challenging to intensify grazing on (e.g. due to impact on habitats).
- Due to the lack of available data, information on the total grazed area cannot be split for permanent and temporary grassland
- 90% of total UK permanent and temporary grassland area is grazed
- 1.5-7.0% of the grassland area could be spared through intensification of grazing management.
- Baseline figures assume that 5% of the grazed area is currently intensively managed under rotational grazing
- Mid-term estimates assume a further 5% of the grazed area will move to rotational stocking within 5-10 years
- Long-term estimates assume that in addition to the 10% of the grazed area under rotational stocking a further 5% will convert to paddock grazing in the next 10+ years

Temporary and permanent grassland covers approximately 11.1 Mha¹ of land across the UK. Temporary grassland (1.2 M ha) is land that has been in grass or other herbaceous forage for less than 5 years and permanent grassland (9.9 M ha) is grassland that has not been cultivated or used to produce any other crop, in the previous 5 years or more (Defra, 2014a; Defra, 2015c). Of the total area of grassland, an estimated 90% or 9.9 M ha is grazed by livestock (pers. comms Marc Jones, ADAS, 2016), with the remaining areas used for forage production (e.g. hay and silage).

There are two ways for releasing grassland for bioenergy production:

- *Improved utilisation of grassland*- It is estimated that the majority of the current UK grazed area is only 50% utilised (i.e. on most farms stock are only able to make use of 50% of the grass that is produced) (AHDB Beef and Lamb, 2013; pers. comms Marc Jones, ADAS, 2016), with the remaining grass wasted either through trampling, or just not grazing at the right time (AHDB Beef & Lamb, 2013). It is clear that there is scope to increase the intensity of grassland usage especially in the beef and sheep sectors - AHDB are currently doing research and knowledge transfer in these areas (AHDB Beef & Lamb, 2016). Increasing the intensity of grassland usage is likely to be possible mainly on temporary grassland and some improved

¹ Figure does not include rough grazing

permanent pasture where intensification of grazing can be supported with additional nitrogen applications and weed control.

- *Reduced livestock numbers*- The economics of livestock production in both the beef and sheep and the dairy sector are very tight in the present market (FBS, 2016), with a number of producers going out of business. Where intensification occurs elsewhere in the industry, those who are either unable or unwilling to intensify production will see their gross margins come under increasing pressure. Where this is the case farmers may start to look for diversification options such as bioenergy crops.

This study focuses on grazing system intensification to produce the same number of stock on a smaller area, assuming that some of the area that is spared, could be converted to a bioenergy crop production. The approach taken is to highlight at the current grazing management systems in place and the potential for switching to more intensive systems and using this to identify the potential reduction in area that could be achieved from doing this.

In the UK, there are three broad categories of grazing management system (AHDB Beef & Lamb, 2013);

1. **Set stocking** – Animals have unrestricted access over a wide area throughout the grazing season. Typical utilised grass yield per hectare is 4.3 tDM/ha (DM = dry matter).
2. **Rotational grazing** - Stock is moved around a small number of fields based on sward height or grass cover targets, or after a certain number of days. Typical utilised grass yield per hectare is 6.6 tDM/ha.
3. **Paddock grazing** - Livestock is moved frequently through a series of paddocks based on measured grazing heights or grass covers. Typical utilised grass yield per hectare is 8.2 tDM/ha.

The predominant grazing system is to use a set stocking approach, and it is estimated that 95% of the grazed area is currently managed in this way (pers. comm Marc Jones, ADAS livestock expert, 2016). The remaining 5% of the grazed land is assumed to be grazed more intensively using rotational or paddock grazing systems. Based on dry matter (DM) yields of 4.3 tDM/ha for set stocking and 6.6 tDM/ha for rotational grazing this gives an estimated utilised grazing volume of 43.5M tDM per year, across the 9.9M ha of grazed land.

In order to increase the availability of land for bioenergy crop production one approach would be to increase the intensity of grassland management. Expert opinion (Pers comms, Marc Jones ADAS livestock expert, 2016) suggests that it would be possible to increase the area grazed more intensively to 15% of the current grassland area over the next 10 years. Note there are legal restrictions on the conversion of permanent grassland in the Natura 2020 wild birds and habitats directive (Natural England, 2014) and on the proportion of permanent pasture that can be cultivated (no more than 5%, based on CAP rules), therefore the increased intensity of production would need to be focused on the permanent pasture, to enable more of the temporary grassland to be released for bioenergy production. In order to achieve this increased intensity of grazing management it would be necessary to implement farm practice change in the livestock sector to get farmers to adopt more intensive management activities, which is a slow process.

It is suggested that the changes needed to increase the intensity of grazing would occur gradually over time, with some changes possible in the mid-term (5-10 years) and further changes occurring through into the longer term (10+ years). These changes require effective knowledge transfer programmes to increase awareness of the benefits of improved grazing management and also a way of linking the spared land with bioenergy programmes, otherwise producers may just increase the size of their herds or flocks, rather than converting land to bioenergy production.

Improved utilisation of grassland- mid term

Table 9 sets out the changes in grassland management that could occur in the mid-term and links that to the amount of land this could potentially spare, assuming that livestock numbers, in keeping with current trends, remain relatively stable (AHDB Beef and Lamb, 2015a & 2015b). In the mid-term it is estimated that in addition to the 5% of the grazed land that is currently managed through rotational grazing an additional 5% of the grazed land in the UK could be switched to this system over the next 5-10 years. If this were to occur it would be possible to achieve the 43.5Mt DM of utilised grass required to support current UK livestock numbers on 9.6M ha of grassland, resulting in **0.3M ha** of land being spared. However, unless there is a strong link between the intensification of grazing programmes and promoting increased uptake of spared land for bioenergy production it is expected that only a proportion of this land would become available for bioenergy crop production, assumed to be 50% (ADAS expert opinion) equivalent to **0.15M ha** in the mid-term.

Table 9 Area of grassland under different grazing systems currently and in 5 years' time and the impact on area requirement

Grazing Strategy		Set-stocking	Rotational	Paddock	Spared land	Total
Yield	(t/ha)	4.3	6.6	8.2		
Current grassland area under each strategy	(%)	95%	5%	0%	0%	100%
Available DM	(Mt)	40.3	3.3	0.0	0	43.5
Area	(Mha)	9.4	0.5	0	0	9.9
Proportion of land under each strategy - mid-term		87%	10%		3%	100%
Available DM	(Mt)	37	6.5	-		43.5
Area	(Mha)	8.6	1.0	-	0.3	9.9
Area change	(Mha)	-0.8	0.5		0.3	

Improved utilisation of grassland- long term

Further changes to grassland utilisation are possible in the longer term and Table 9. shows the changes to grassland management practice and as with Table 10 links the management changes back to the amount of land this could potentially spared, assuming that livestock numbers remain relatively stable (AHDB Beef and Lamb, 2015a & 2015b). In the long-term it is estimated that 10% of land will remain under rotational grazing systems, as was the case in the mid-term, but that a further 5% of the grazed land in the UK could be switched from either set-stocking or rotational grazing systems to paddock grazing over the next 10 years. If this were to occur it would be possible to achieve the 43.5Mt DM of utilised grass required to support current UK livestock numbers on 9.2M ha of grassland, resulting in **0.7M ha** of land being spared, an extra **0.4M ha** over the long term. If it is again assumed

that only a proportion (50%, ADAS expert opinion) of the land spared will be converted, in the long term this would spare an additional **0.2M ha** of land.

Table 10. Area of grassland under different grazing systems currently and in the long term and the impact on area requirement

Grazing Strategy		Set-stocking	Rotational	Paddock	Spared land	Total
Yield	(t/ha)	4.3	6.6	8.2		
Current grassland area under each strategy	(%)	95%	5%	0%	0%	100%
Available DM	(Mt)	40.3	3.3	0.0	0	43.5
Area	(Mha)	9.4	0.5	0	0	9.9
Proportion of land under each strategy – long term		78%	10%	5%	7%	
Available DM	(Mt)	32.9	6.5	4.0		43.5
Area	(Mha)	7.7	1.0	0.5	0.7	9.9
Area Change	(Mha)	-1.7	0.5	0.5	0.7	

Improved utilisation of grassland has a relatively low availability score in both the mid and long term. The key barriers to the uptake of bioenergy crops on grassland, are livestock farmer perceptions on the cost and value of switching to more intensive grazing systems, and linking those changes in practice to converting spared land to bioenergy crop production. It is thought that due to the nature of the beef, lamb and dairy industries; where there are a large number of farms, each covering a small area, changes to current grazing strategies will have to occur over a longer timescale. For a farmer the move from set-stocking to rotational grazing, is often unattractive as it requires not only an economic investment e.g. fences, gates, water troughs, but also a greater time investment as the level of grazing has to be much more closely monitored (AHDB Beef and Lamb, 2013). In the mid-term, recruitment of farmers will tend to attract and focus on those who are either already implementing some of these strategies e.g. dairy farmers who tend to implement more intensive grazing strategies or those who are receptive to making changes, therefore, it is thought that although challenging, the economic and physical constraints to the availability of this grassland could be overcome with investment in knowledge transfer initiatives and incentives e.g. subsidies. In the longer-term with the move from either set-stocking or rotational grazing to paddock grazing (the most intensive grazing system), the costs and time requirements become even more significant and therefore potentially even less attractive to many farmers, who are used to low-input grassland management e.g. upland farmers. If many of the ‘easy win’ farmers have already been recruited the level of time and money required to convince others to change their management strategies will begin to increase, although if sufficient farmers can demonstrate that the practice is manageable and profitable others may follow their lead.

Ecological Focus Areas (EFA's)

Total land area (ha)	Area potentially available to bioenergy production (ha)	Land accessibility score (detailed scores in Appendix 1)
403,000 in England	Overlap with other estimates	4/14

Key Assumptions

- Changes in EFA requirements could support increase in bioenergy crop (especially SRC) area, but land types will overlap with those already identified e.g. surplus arable land, marginal land or uncropped arable land.

Since 2015, every farmer in the European Union who claims a direct payment and has more than 15 ha of arable land is obliged to have 5% of their arable land covered by Ecological Focus Areas (EFA's). The aim of EFA's is to bring benefits for the environment, improve biodiversity and maintain attractive landscapes (such as landscape features, buffer strips, afforested areas, fallow land, areas with nitrogen-fixing crops etc.). In England EFAs must be made up of buffer strips, catch crops, cover crops, fallow land, hedges or nitrogen fixing crops, whilst in Wales and Northern Ireland, Short Rotation Coppice (SRC) is included as an EFA option. To be eligible to contribute to the EFA requirement, when growing SRC there must be no use of mineral fertiliser and/or plant protection products beyond the end of the second growing season post planting. Some exceptions to the EFA rule apply, for example to farmers who have more than 75% of their area under grassland (Defra, 2014a) do not need to comply. There is very limited information about the EFA in the UK due to the newness of the scheme. In England it is estimated that 403,000 ha of land are managed under an EFA (Defra, personal communication) and in Northern Ireland 2,004 ha (Dardni, personal communication) but this type of information was not available for Scotland and Wales. A more accurate figure of the area of EFA's in the UK is expected in the Defra June 2016 Agricultural Survey (Defra, personal communication) but this is not likely to be available until September 2016.

The area of available EFA land for bioenergy crop production depends on whether the eligibility of SRC as an EFA option could be extended to England and Scotland. Currently, the total area of SRC grown in Northern Ireland is around 400 ha (AEA, 2008), with E4tech (2013) estimates suggesting that the area of SRC grown in Northern Ireland, Wales and Scotland is around 500 ha, although there is some uncertainty around this figure. Changing of UK Government policy to include SRC as an EFA option in England and Scotland it would provide additional motivation to farmers to switch land use to SRC. This is likely to be in areas that are economically marginal and therefore a separate figure for area released under EFAs is not provided in this report as it is likely to result in double counting.

Ecological Focus Areas (EFA's) received a relatively low availability score (4/14) for conversion to bioenergy crop production. This was because SRC only counts as an EFA option in Wales and Northern Ireland and does not currently count as an EFA option in England and Scotland. This difference arose because under the CAP Reform each devolved government of the UK could choose which options provided by the EU where suited to meet EFA requirements and both the English and Scottish government chose not to include SRC or SRF. Instead, under rules set by England and Scotland, SRC and SRF do not count as part of 'arable land' as they are permanent crops that occupy the land for 5 years or more and so are not factored into EFA requirements.

To combat this, lobbying of the English and Scottish governments would be needed to allow SRC and SRF to be included as an EFA option in these countries. This would involve demonstrating that SRC meets the requirements of EFAs in that it provides environmental benefits, improves biodiversity and maintains attractive landscapes. There is evidence to support the environmental benefits from growing SRC which include low inputs, minimal soil disturbance and reduced nutrient leaching (Dimitriou *et al.*, 2011; McKay, 2011). However, other research suggests that SRC can have negative visual impacts on a landscape, with a study of 13 SRC plantations finding that four sites (31%) resulted

in adverse effects on the quality of the visual landscape (DTI, 2000). As a result it is a legal requirement in the UK to carry out an Environmental Impact Assessment (EIA) before planting SRC. In addition, if SRC were to be included as an EFA requirement in England and Wales it must be weighted correctly against other options to encourage uptake. For example in Northern Ireland and Wales 1m² of short rotation coppice is given the weighting of 0.3 and worth 0.3m², whilst in comparison 1m buffer strips are given a weighting of 1.5 and a conversion factor of 6 meaning 1m of buffer strip is equivalent to 9m² of EFA land. This is important as to meet EFA requirements, which state that EU farmers who claim a direct payment and have more than 15 ha of arable land must have 5% of their arable land covered by Ecological Focus Areas (EFA's), a larger area of SRC needs to be entered as an EFA compared to other options such as buffer strips.

Idle land

Total land area (ha)	Area potentially available to bioenergy production (ha)	Land accessibility score (detailed scores in Appendix 1)
Brown field – 451,000	45,000	6/14
Verges & embankments – 145,000	15,000	4/14

- *Relates to England and Wales only.*

Key assumptions:

- For brownfield sites, the area potentially available to grow bioenergy crops is based on assumptions made in Defra (2009). This report states that whilst there is considerable uncertainty over what proportion of brownfield land is capable of being brought into bioenergy crop production, it is conceivable that brownfield land could be returned to agriculture- with an estimate of 10% of the current brownfield area being used to grow bioenergy crops in the future used in the report.

Based on assumptions from Defra (2009) it was assumed that 10% of roadside verges could be converted to bioenergy crop production. For roadside verges this is based on the assumption that for 90% of roadside verges the key requirement is that they maximise driver vision, and therefore only grass can be grown on them. However, there are parts of the system, equating to around 10% of all roadside verges, where trees are grown and in this instance, it could be possible to plant fast growing SRC or Miscanthus in order to maximise biomass production. This is particularly relevant where new roads are being developed or existing roads modified and bioenergy crops could be considered as an alternative to conventional plantings. Removal of existing trees to replace with alternative bioenergy crops could be counterproductive, but the use of thinning from existing plantings could, if managed appropriately, prove to be an alternative source of bioenergy. Note – verges have the potential issue of heavy metal contamination, therefore soils would need to be tested and road run off monitored to minimise the risk.

- No assumptions are made in Defra (2009) as to the proportion of embankment land that could be used for biomass production. The report states that embankments are similar to roadside verges but 'contain more trees' and as such a figure of 10% availability for biomass production (same as roadside verges) is used.

'Idle' land includes roadside verges, railway embankments, canal towpaths, golf courses, sports turf, hedgerows, and brownfield land. This land is made up of former or current agricultural land that will not otherwise be used for food production and other unused land that is potentially suitable for

agricultural production (Defra, 2009). Current estimates put the total other land area in England and Wales at **867,000** ha, of which 451,000 ha is brownfield sites, 145,000 ha is road verges, railway embankments and canal tow paths, 30,000 ha is lowland bracken and 239,000 ha is other uses such as golf courses, sports turf and hedgerows.

Brownfield sites and verges and embankments were seen as the most suitable for conversion to bioenergy crop production and are discussed in more detail below.

Brownfield sites

The total area estimated to be covered by 'other' land in the UK is estimated to be **867,000 ha**, with the majority (451,000 ha) being brownfield sites (Defra, 2009). When considering land available for bioenergy crops on brownfield sites it was considered feasible to grow bioenergy crops on 10% of the total area- **45,000 ha**. The availability figure of 10% was chosen based on Defra (2009) which states that due to the multiple land uses of brownfield sites there is uncertainty to how much brownfield land can be converted to bioenergy crop production, and as such further work is needed to define this further, but the report suggests it is feasible to consider 10% of the brownfield land being suitable for bioenergy crop production, given the right economic incentives for conversion.

It was considered that brownfield sites could be converted to bioenergy crops in the short term, although land availability was relatively low (6/14) due to the economic factors in cleaning up and making brownfield sites suitable for cultivation and the challenges associated with brownfield site location and scale which could make brownfield sites difficult to access for planting and harvesting. There are also legal constraints surrounding use of brownfield sites for bioenergy crop production as the UK Government, under the Landmark Housing and Planning Bill has an ambition to build one million homes by 2020 and to do this has granted automatic planning permission on brownfield sites (UK Government, 2015).

Verges and embankments

The total area covered by verges and embankments in England and Wales is estimated to be **144,000 ha** which has the potential, at least in part, to be suitable for bioenergy crop production. This 144,000 ha is made up of:

- Roadside verges - 126,000 ha
- Railway embankments-- 17,000 ha
- Canal margins- 1,000 ha

If it is assumed that 10% of each of the above land types are suitable for bioenergy crop production (based on assumptions made in Defra, 2009) this gives around **15,000 ha** of available land for bioenergy crop production.

Land availability of verges and embankments is low (land availability score of 4/14) due to the fact that verges are often formed from disturbed ground so may have poor soil structure and would require clearing and cultivating to be suitable for bioenergy crop production and this would require an economic incentive. In addition there is the risk of contamination from roadside litter, which could both damage equipment and impact on the quality of the end product.

However, the logistical feasibility of growing crops on roadside verges has already been demonstrated e.g. in the 1970's grass was harvested and made into hay across a significant proportion of the UK's

major roads (Defra, 2009). Land is also expected to be mostly accessible as verges, canal paths etc. need to be accessed for regular maintenance (hence score of 1).

There are also specific barriers to growing bioenergy crops on 'idle land' that affect the land availability score. These include:

- Safety issues surrounding planting and harvesting of bioenergy in close proximity to roads and railways.
- Possible negative visual effects either to road users or general public from growing bioenergy crops.
- Logistical difficulties in cultivation and harvesting close to roads/railways etc.
- Strong opposition from the public to conversion of idle land for bioenergy crop production.
- High cost of conversion to bioenergy crops e.g. cost of clearing some verges and making them suitable for cultivation.

White land

Total land area over the next 5 years (ha)	Area potentially available to bioenergy production (ha)	Land accessibility score (detailed scores in Appendix 1)
Surplus government land- 5,000	500	5/14
Forestry Commission land- 10,000	10,000	8/14

Key Assumptions:

- The same approximate area of land will be sold off by the government and its agencies for at least the next 5 years.
- 5-15% government land that becomes available will be converted to bioenergy crops
- Up to 100% of forestry commission land could be converted to bioenergy

White land is a general expression used to mean land (and buildings) without any specific proposal for allocation in a development plan, where it is intended that, for the most part, existing uses shall remain undisturbed and unaltered (Department for Communities and Local Government, 2016). The limited information available on future surplus Governmental land sales and the lack of a centralised database which details all available white land (NAO, 2015), means that current white land estimates are based on annual availability. The current estimated total area of white land sold annually is **3,000 ha** based on recent trends in land sales (Forestry Commission Scotland, 2015 & NAO, 2015). Made up of approximately 66% Forestry Commission land and 33% surplus Government land that is being sold off.

- Over the last five years it is estimated that **2,000 ha** of Forestry commission land was sold off each year, it is assumed for the purpose of this report that this trend will continue for at least the next five years. This figure is for Scotland only and was obtained from Forestry Commission Scotland (data on acquisitions and disposals - Forestry Commission Scotland, 2015). Very little information on Forestry Commission land sales could be found for England and Wales.

- Between the years of 2011-2015 approximately 5000 ha of surplus Government land was disposed of (NAO, 2015), which is equivalent to **1000 ha** per year. However area data was only available for 54% of assessed sites and therefore the actual available area is likely to be higher than this estimate.

The total available white land for conversion to bioenergy crops over the next 5 years is **10,500 ha** (Table. 10). This is based on the assumption that:

- A success rate of up to 100% could be obtained for Forestry Commission land equating to 2,000 ha of land being available each year. This high success rate is due to the fact that the land-use will remain the same/similar when converting from a commercial plantation to SRF or SRC requiring less investment/time and offering an attractive alternative. It should be noted, that it is unlikely that 100% of the potential available land will be converted to bioenergy production.
- Based on the proportion of agricultural land in previous government land sales (Government Property Unit, 2016) and incentives under the Housing and Planning Bill to turn to development on brownfield sites rather than to other uses such as bioenergy crops (Department for Communities and Local Government, 2015b), a success rate of between 5-15% is assumed for surplus Government land, giving a range of approximately **100 ha** of land available for conversion each year.

Table 11. Total and available white land area in the UK per year and over 5 years

Land type	Total (ha/year)	Total (ha/ 5 years)	% available	Available land (ha/year)	Available land (ha/5 years)
Forestry commission land	2,000	10,000	up to 100	2,000	10,000
Surplus Government land	1000	5,000	5-15	≈100	≈500
TOTAL land	3,000	15,000		2100	10,500

The availability score for government owned white land is low (5/14); this is largely due to the high competition for land from Government housing schemes and the unsuitability of surplus land which is coming onto the market (Government Property Unit, 2016), of which the majority is designated for industrial or housing uses and is often made up of old office blocks and carparks (Homes and Communities Agency, 2016). Other factors which have affected the availability score include, the variability in the location e.g. majority located near urban areas (NAO, 2015), size and quality of land parcels due for sale and the irregularity with which land comes onto the market, making it hard to estimate the potential scope for converting white land to bioenergy production. Therefore it is thought that white land is likely to only be available in the longer term if Governmental pressures for housing can be overcome.

As with the government owned white land, the overall availability score for Forestry Commission white land is relatively low (8/14) due to the unknown quality, scale and location of the land that will be available. However, Forestry Commission owned white land has been given a higher availability score, due to the land requiring fewer changes in order to convert it to bioenergy production. This is also reflected in the predicted higher success rate for obtaining land previously owned by the Forestry

Commission and it is therefore predicted that Forestry Commission land may become available for bioenergy production earlier than government owned white land.

Route map to target bioenergy production in the UK

To support the UK achieving its 2050 carbon target, it is estimated that between 1.3-1.4 Mha of land will need to be converted to bioenergy crops over the coming years. This report has identified that between **1.0 Mha - 1.8 Mha** of land is potentially available for conversion to bioenergy in the UK, of which the two largest contributors are diverting the surplus area of arable crops to 1G bioenergy processing as demand dictates (383,000-660,000 ha) and improved utilisation of grassland (350,000 to 700,000 ha). Table 4 summarises the categories of land that have been identified as potentially available and the quantity that is considered in this study to be available in the short, mid and long term. The detailed assumptions about what proportion of each land type is potentially available for bioenergy production are set out in previous chapters. The conservative end of these estimates fall short of the target land area required for bioenergy crop production. However, the higher end of the estimates indicates that if the right market drivers and practices are put in place there is the potential to access over 1.4 Mha of land for bioenergy crop production. In order for this to happen bioenergy markets will need to become more established, larger and trusted to drive further changes in practice in order to spare additional land and convert it to bioenergy crop production.

The route map takes the categories of land that have been identified in each of the short, mid and long term timeframe and then considers what barriers there are to conversion and what drivers need to be put in place to support the conversion to bioenergy production. The main driver for conversion of land to bioenergy production is the establishment of a suitable market.



Market – In order for farmers to produce bioenergy crops there needs to be a market for the end product. This market needs to be competitive with other potential uses of their land for food and feed.

In addition there are a number of barriers that need to be overcome in order to enable the conversion of land these include;



Stewardship – Neither the Countryside Stewardship scheme, nor the Common Agricultural Policy agreements promote or encourage the uptake of bioenergy crops. As a result there is limited incentive (outside of market drivers) for farmers to convert land to bioenergy production, especially 2G as bioenergy crops are not eligible to be included (and receive payment) in current agri-environment schemes and SRC is only classified as an EFA in Northern Ireland and Wales where very little area is grown. In England and Scotland bioenergy crops are not eligible to be granted funding under the CAP Greening rules. Adjusting the stewardship schemes to enable the inclusion of bioenergy crops could provide additional motivation for planting 2G bioenergy crops.



Competition - Although this study has identified a number of ways in which land currently under arable or grassland, plus a number of other land uses e.g. white land and idle land can be spared, there is still no guarantee that the spared land would be converted to bioenergy crop production. There are numerous other land uses that are competing with bioenergy crops, e.g. the demand for housing and renewable energy. In addition although we have identified ways in which the land area needed for specific crops or livestock for food production could be reduced, without sufficient market drivers there is the potential that farmers opt to grow more of the same as they are familiar with those crops and export if they have an excess. Therefore, although land could potentially be converted for the production of bioenergy crops, it may not due to pressures from other competing industries.



Legal – There are some legislative or policy barriers that make the conversion of certain land types more challenging. For example there is an EU requirement for no more than 5% of the permanent grassland area to be cultivated. Therefore there is a limit to the amount of grassland that can be spared and then converted to bioenergy production.



Practices – In order for a number of the land uses to become available there is a requirement for practices to change and until these practices change they will act as a barrier to conversion. These changes of practice could be relatively simple and targeted e.g. in a relatively small number of arable growers, encouraging them to sell surplus grain into bioenergy markets. However access to some of the land in the medium term requires changes in practice which would be more complex as livestock farms tend to be more numerous but each covering a smaller area than arable farms, meaning knowledge transfer schemes will need to be targeted at a larger number of small farmers (e.g. livestock farms tend to be smaller than arable farms, so to achieve intensification of livestock production more people have to be targeted) and will often require more significant changes in practice (changes in stocking system or exit from livestock production and switch to bioenergy crop production). In the longer timeframe there are changes in practice that need to be targeted more generally at society, such as the need to reduce food waste at the consumer level.



Safety – For the conversion of certain land types safety is a potential barrier. This is particularly the case when considering the conversion of idle land such as road verges and railway embankments.

The route map to land for bioenergy production is set out in Figure 3. The estimated area of land available in the short, mid and long term is shown in the bars, with the hatched area showing uncertainty. The pie charts show what the main barriers or drivers are for change in each of the time frames, indicating the proportion of the potentially available land that is affected by each barrier or driver. Where multiple barriers or drivers are acting on a single land type the dominant barrier or

driver was taken. The individual steps that are required to achieve the converted area are set out in the text below prioritised as quick wins and mid – long term goals.

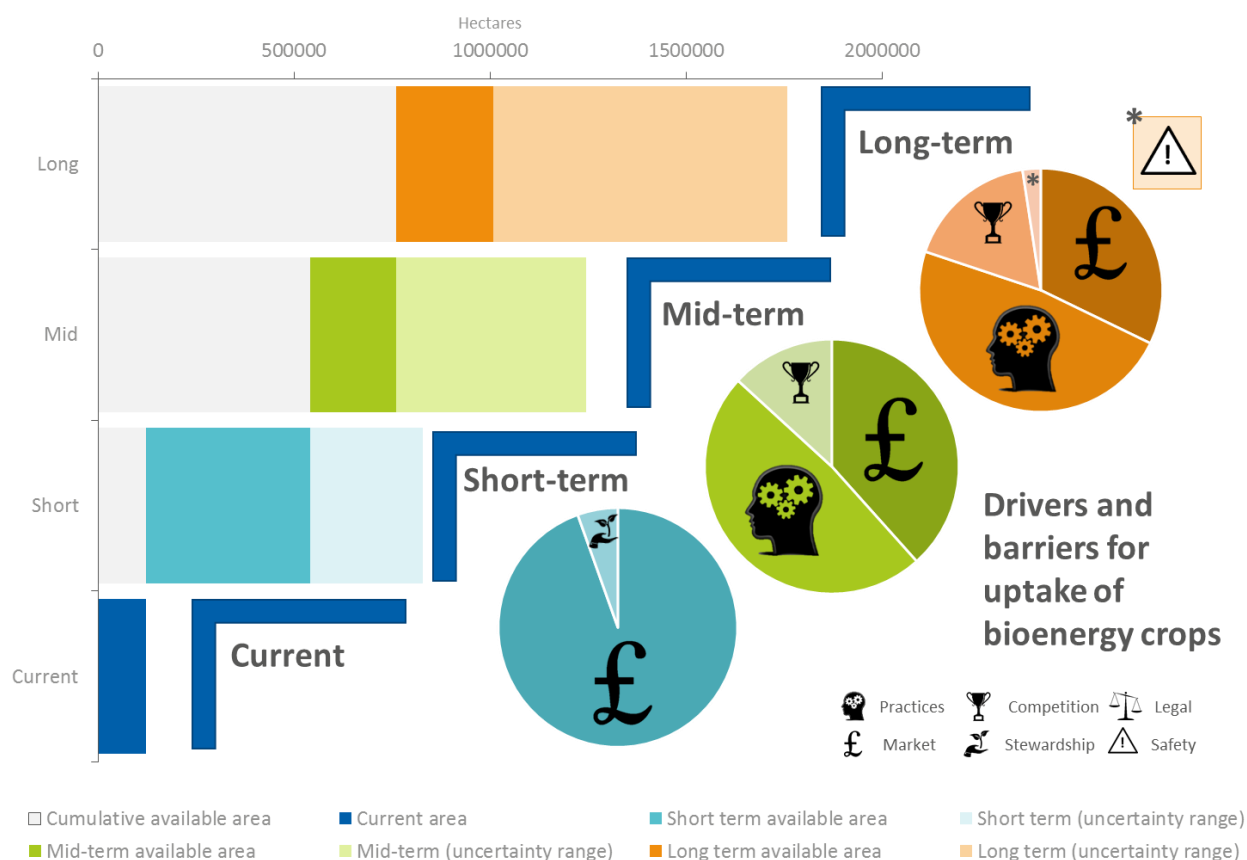


Figure 3. Route map to bioenergy crop production (uncertainty ranges are cumulative – with the long term uncertainty range picking up areas from short and mid term) – safety refers to the safety of production on road verges and embankments.

Short-term (up to 5yrs to achieve)

There are **541,000-829,000 ha** of land identified that could be available in the short-term given the correct market drivers and incentives and this is separated into quick wins (416,000-609,000 ha) and additional land-area (36,000-47,000 ha- from use of permanent uncropped arable land), with more details provided below.

Quick wins



This report has identified around **505,000 to 782,000 ha** of land to be available as soon as markets allow for bioenergy cropping (including land that is already in bioenergy crops). The key driver needed to ensure quick wins is the establishment of a suitable market for bioenergy crops. For 1G bioenergy crops this is relatively straight forwards as the feedstock for any refinery is already being widely produced across the UK. Therefore, assuming that the finances are available to build the refinery the access to feedstocks is possible, given the right market drivers. The production of 1G bioenergy crops on the existing arable area does not require any change in land use, and continues to use the established crop management practices and machinery used on the farm already.

1. **Maintain current area of 1G and 2G bioenergy crops** (122,000 ha) – ensure that the market is present to ensure that those crops currently grown are maintained
2. **Switch existing arable area to 1G bioenergy** (383,000-660,000 ha)- This is made up of 314,000-494,000 ha of land from converting surplus wheat and barley area to bioenergy crops (either 1G markets or growing 2G crops) and 69,000-166,000 ha of land from converting surplus oilseed rape to bioenergy cropping. The assessment above for wheat and barley is based on historical (5 year average) data from AHDB supply and demand surveys after taking into account domestic and industrial uses of grain (AHDB Cereals & Oilseeds, 2015). AHDB do not produce supply and demand surveys for oilseed rape, so in this case the same surplus proportions are taken into account as wheat and barley to provide the surplus oilseed rape area that could potentially be spared for bioenergy cropping.

Additional land available in the short term-

The development of a market for 2G bioenergy is likely to take longer than 1G as the feedstock for this market has to be purpose grown, it does not have an alternative food market. At current market prices the planting of 2G bioenergy crops and the subsequent gross margin does not compare well with conventional arable land. For example, the gross margins that can be typically obtained from conventional arable crops (winter wheat ≈£630/ha, winter barley ≈£480/ha, winter oilseed rape ≈£462/ha) are around three times those which can be obtained from 2G bioenergy crops, SRC (≈£176/ha) and Miscanthus (≈£139/ha) (Nix, 2016) which restricts uptake. However, on the more marginal arable land (Defra, 2014a) and in locations where the alternative is to rent land out for grazing (£100-175/ha) (Nix, 2016) the gross margin for 2G bioenergy is more comparable. Therefore for short term conversion to 2G bioenergy crops it is the economically marginal land that should be targeted.

3. **Economically marginal land** (land that is currently in arable production) (87,000-98,000 ha) the easiest option for farmers with economically marginal land is to convert it to 1G bioenergy due to farmers already having the equipment and facilities in place to handle these crops and the existence of bioethanol/biodiesel markets. However, the preferred option is that the land is used for conversion to Miscanthus, SRC or SRF, however this will require the development of suitable markets for the crops and therefore it is unlikely that this level of conversion would happen as quickly as could be the case for 1G bioenergy crops. *This area overlaps with the arable area identified above so is not presented separately in the route map graphic.*



In order to access the potential areas for bioenergy production on other areas of agricultural land it is necessary to understand the implications of conversion to bioenergy production on environmental stewardship, at present neither the Countryside Stewardship scheme, nor the Common Agricultural Policy agreements promote or encourage the uptake of bioenergy crops. For example, uncropped arable land (fallow) is eligible for inclusion under [EFA requirements](#) and there are [Countryside Stewardship](#) options for arable land e.g. skylark plots, field margins etc., but if the land was converted to bioenergy crop production, it could not be included in these schemes resulting in a reduction in payments (Defra 2014a). In order to support the increase in bioenergy crop area, especially 2G bioenergy from SRC, consideration should be given to how the crop provides benefits to the environment, e.g. early season pollen, nesting sites and how that could be included in future stewardship schemes as an incentive to increase the uptake of bioenergy crops.

4. **Uncropped arable land** (36,000-47,000 ha) (areas that are in permanent fallow). To be targeted for bioenergy crop production. These areas could be suited to either 1G or 2G bioenergy crop production as they potentially include areas that have been left fallow due to being economically marginal.

Mid-term goals (up to 10yrs to achieve)

There are **218,600 to 417,000 ha** of land identified that could be available in the mid-term given the correct market drivers and incentives.



In order to achieve mid-term goals action will need to be taken in the shorter term to start the process of changing practices. The development of markets identified under quick wins is expected to continue into the mid and even long term, with more established, larger, more trusted markets having the potential to support on farm changes in practice. If the market is present and the price is right farmers will have a greater incentive to convert land to bioenergy production, whether that is the simple conversion to 1G, or the need to learn how to grow 2G. There are however bigger changes in practice that are needed in order to spare some land. These changes in practice include the intensification of livestock production, with knowledge transfer and education programmes needed to drive uptake of new practices, such as more intensive grass monitoring and purchase of fencing etc. to enable more stock to be managed on smaller areas of land. This type of change in practice is expected to allow those that invest in the improved practice to become more profitable, and potentially increase the number of stock they have on the same area of land, whilst others who are either unable or unwilling to invest in intensification may leave livestock production due to the poor margins and switch to more profitable alternative land uses, e.g. 2G bioenergy crop production.

5. **Improved utilisation of grassland- mid-term** (150,000 to 300,000 ha)-Changing the intensity of grazing practices on permanent grassland, can spare grassland for growing both 1G and 2G bioenergy crops. Ideally it would be temporary grassland that would be spared as this will be more easily converted back into crop production, however there is the potential that some permanent grassland could also be converted to bioenergy crop production. In the mid-term it is expected that efforts to increase utilisation will tend to recruit those who are either already implementing strategies e.g. dairy farmers who tend to implement more intensive grazing strategies or those who are receptive to change and the accessibility of land for bioenergy crop production depends strongly on farmer willingness to alter their practices. Moving from less intensive to more intensive grazing strategies is costly both economically and with regards time management, as it requires economic investment in new fencing and water troughs etc. and also requires more active grazing monitoring by the farmer (AHDB Beef & Lamb, 2013). Therefore, the bioenergy crop market needs to be such to encourage farmers not only to switch to higher intensity grazing but also to utilise the land they free up to growing bioenergy crops. Without the clear incentives the new available land may instead be used for grazing more stock, or converted to cropped arable land so would not be available for bioenergy crop production.

Changes in practice will also be required to spare land through reductions in on farm food waste. The main areas affected by on farm waste are the fresh fruit and vegetable sector due to strict specifications on shape, colour and size, as well as the shorter term or more complex storage requirements for fresh produce. Cereals provided they are dried to a suitable moisture with store for

long periods in ambient conditions with minimal impacts on quality. Where full specification for grain is not met there are usually alternative markets such as the livestock feed market, minimising waste. However, difficulties in changing farmer and consumer practices and the requirement to engage supermarkets and other industry stakeholders in reducing waste make this a mid-term option. For example, research by Feedback Global (2009) has shown that about 30% of all fruit and vegetables produced in the UK are wasted (due to produce spoilage, produce shape etc.) before they reach the supermarket, this is equivalent to 58,000 ha. This waste is primarily due to strict supermarket product specifications which may not necessarily meet consumer needs. A number of the major retailers have already begun trials (Guardian, 2015) into selling below specification grade vegetables, but this has not yet been widely adopted. Consumer attitude to food waste poses a barrier to the conversion of 'wasted' arable, horticultural and grassland area to bioenergy crops and is likely to require significant investment in knowledge transfer schemes to change consumer and retailer perceptions to food waste (pers comms., Dan Wooley Feedback Global), as although reductions in avoidable food waste of 21% have been seen since 2007, the level of food waste is still high (WRAP, 2012).

Reduction in on farm waste fruit and vegetables (13,600 – 62,000 ha)- Reducing farm gate waste through changes in specification could spare 7-30% of the current fruit and vegetable area (204,000 ha). With suitable market drivers this land could be used for both 1G and 2G bioenergy cropping. However, it should be noted that for most fruit and vegetable businesses the gross margins per hectare are very high, so the expectation is that the businesses would tend to just utilise higher marketable yields to increase the profitability of their businesses, rather than to reduce the area they produce and put good vegetable producing land into lower value bioenergy crops meaning that this land would be difficult to access.



Competition for land acts as a barrier to accessibility. It is possible to identify land that could be spared from its current purpose, but just because that land becomes 'available' does not mean that it would be converted to bioenergy crop production. There are two key sources of competition for land; food production (farmers opting to increase production) and housing (alongside the need to provide habitats for wildlife). Competition for land from building development companies and other

renewable energy streams will also impact on the availability of land in the shorter-term and be a continuing barrier to conversion in the longer term. Developing strategies for accessing land and selecting land on which to bid will be critical in order to compete with current government housing and renewable energy targets.



Under the government Housing and Planning Bill the UK Government has pledged to build 1 million homes by 2020, which under the assumption that 20-40 houses can be built per hectare (calculated from figures in NAO, 2015) equates to an approximate land requirement of 25,000-50,000 ha. This is a considerable amount of land when compared to the calculated annual available area of government

owned white land (1,000 ha), showing that competition for this land will be high and due to this legislation, a housing land-use is likely to receive priority. One of the key aims of the bill is to increase development on brownfield sites and protect the green belt (Department for Communities and Local Government, 2015a and 2015b). Brownfield sites often require clearing before they are suitable for development or conversion to agricultural production which is often costly (Homes and Communities Agency, 2016). The Housing and Planning Bill incentivises land owners to turn to development on brownfield sites rather than to other uses such as bioenergy crops. Furthermore, the UK Government

recognises that the growing housing demand will not be met by building on brownfield sites alone and as such building on greenfield sites if sites meet certain conditions (Department for Communities And Local Government, 2012) is also supported, resulting in further competition with bioenergy crops for land. Selling greenfield sites on the edge of existing towns/villages for housing developments is often lucrative and further de-incentivises uptake of bioenergy cropping on that land.

6. **White land- forestry commission sites** (10,000 ha)- The land-use of these sites would be similar whether under commercial plantation or SRF. However, there will be competition for land from developers and private investors and the location, scale and quality of the land that will become available is unknown, as is the area of land that will be successfully obtained. Suitable for 2G bioenergy production only.
7. **Idle land – brownfield sites** (45,000 ha) – These sites are predicted to be brownfield sites that could be easily converted to agricultural production based on assumptions made in Defra (2009) which states that 10% of the total area of brownfield land (451,000 ha) could be available for conversion to bioenergy crop production. Where they do not have existing infrastructure present they represent a short term option for conversion to bioenergy, although with competition for other uses particularly high on this land there is uncertainty over just how much would actually be available for bioenergy production. Suitable for both 1G and 2G bioenergy crop production.

Long term goals

There is potentially **249,500 to 513,500ha** of land available for bioenergy crop production in the long term. This consists of further improvements in grassland utilisation (200,000-400,000 ha), reducing consumer waste (49,000-98,000 ha), and the higher risk / less viable options of buying government owned white land for conversion to bioenergy cropping (500 ha) and growing bioenergy crops on suitable verges and embankments (0-15,000 ha).



In order to spare these land areas there are significant changes in practice required across both the farming industry (further intensification of the livestock industry) and wider society through reductions in food waste. These changes in practice are considered to require a number of years to become established, through the implementation of knowledge transfer and awareness raising programmes. These changes in practice could result in land being spared. Market drivers then need to be present and working to ensure that the spared land is converted to bioenergy production.

8. **Improved utilisation of grassland- long term** (200,000- 400,000 ha)- In the long term it is considered feasible to switch 5% of current grassland area to highly intensive paddock grazing systems (see definitions in **Improved utilisation of grazed grassland** chapter) (pers. comms ADAS livestock expert Marc Jones). The change in grazing system requires significant time and cost requirements for farmers which make the change unattractive to farmers who are used to a low input grassland management system. There are also costs associated with knowledge transfer schemes to aid changing farmer practices. The spared land may not be created on the farms that are able to intensify, instead coming from less economically viable livestock enterprises, where diversification may be more appealing.
9. **Reducing consumer waste** (49,000-98,000)- An estimated 196,000 ha of land is used to grow food that is wasted by consumers and considered to be 'avoidable waste'. There is an EU

target to reduce consumer food waste by 50% by 2030 (EU, 2016), this is equivalent to 98,000 ha of land if all the spared land went to bioenergy crop production. However, it is assumed that only a proportion of the spared land (estimated at 50%) would actually be released for bioenergy production, giving a lower estimate of 49,000 ha available. Reducing consumer waste is a long term strategy as it involves changes to consumer practices by altering consumer attitudes to waste and recycling through targeted market campaigns and engagement with industry stakeholders i.e. supermarkets. This can be difficult as consumer behaviours can be largely unconscious, but Thaler and Sunstein (2008) suggest that interventions can 'nudge' habits in particular directions e.g. in this case to reduce waste.

Higher risk – less viable options



There is the potential to use idle land for the production of bioenergy crops, in particularly brownfield sites. However there are both safety and logistical barriers to the uptake of other types of idle land such as roadside verges and embankments for bioenergy crop production, for example, use of heavy machinery for cultivation and harvest of bioenergy crops at the side of either roads or railways poses safety concerns for both the machinery operators and the public using the roads and railways. In addition if tall crops such as SRC or Miscanthus are planted they might obstruct driver view- as such growing bioenergy crops on roadside verges has been considered in this report but found to have low viability for bioenergy crop production.

10. **Idle land- Verges and roadsides** (0-15,000 ha)- There are 150,000 ha of roadside verges and embankments in England and Wales, with 10% of these (15,000 ha) predicted to be potentially available for bioenergy cropping based on Defra (2009). As well as safety issues there are also logistical difficulties in cultivation close to railways/roads, with idle land typically being in narrow strips of land and cost of conversion could be high as it would require verges to be cleared and prepared for cultivation. There is also the risk of litter dropped from vehicles causing damage to cultivation and harvesting equipment or contaminating the end product.
11. **White land- government own (ex MoD)** (0-500 ha)- Accessing white land for bioenergy crop production is a long term goal as the majority of white land that comes onto the market is not suitable for conversion to bioenergy cropping e.g. residential land. There is also high competition for white land with housing developers and renewable energy companies making accessing white land for bioenergy crop production difficult.

Route map summary

In order for the UK to achieve the target of 1.3-1.4M ha of bioenergy crops there are a range of land use types that could be accessed – this assessment has identified between **1.0-1.8 M** ha of land that is potentially available. There are a number of constraints on these land uses that will require a series of actions to be put into place in order to access them. The first step is to continue to develop the market for bioenergy to ensure that bioenergy is considered alongside competing land uses so that land is allocated in most productive way. As the market develops the initial step is to target the more readily available land types for conversion to bioenergy production. The quickest win for this would be a matter of switching existing over production of cereals from a food to fuel market. Encouraging a switch of marginal land and uncropped arable land to 2G bioenergy would require greater farmer support. In order to access some of the potential land in the mid and long term early actions (knowledge transfer and awareness raising) around changes of practice in parts of the farming

community and also consumers will be needed. These practices will take time to embed and for the effects to be felt in terms of a reduction in the area needed for food production in order to spare land for conversion to bioenergy crops. There are some policy drivers that were identified that if adjusted could support the conversion of certain land types to bioenergy cropping such as consideration as to how bioenergy crops, especially SRC and SRF are treated in environmental schemes. Enabling the inclusion of land under bioenergy crops in Environmentally Favourable Areas (EFAs) or supporting them in Countryside Stewardship schemes could potentially provide additional motivation to farmers to convert some of their land.

It should be noted that there remains a great deal of uncertainty over the final areas of land that could be spared, and can actually be converted to bioenergy production as there is no direct link between some of the drivers for sparing land, e.g. intensification of livestock production or reduction in food waste and switching to bioenergy crop production. In order for the land to become available to bioenergy crop production consideration needs to be put into how conversion to bioenergy cropping can be linked to other incentives such as a drive to reduce food wastage that aims make more efficient use of land resources available, use whilst maintaining or improving current UK self-sufficiency in food production. The mechanisms for linking sparing of land to conversion to bioenergy are outside of the scope of this study, however ensuring that the market is sufficiently robust and inviting will be of importance in allowing bioenergy crop production to compete with other crops for spared land.

Conclusion

This study shows that if the right barriers are removed and drivers put in place that there is sufficient land that could potentially be made available to bioenergy crop production, without impacting on the ability of the UK to meet its current home produced food requirements. However, there are some serious challenges in actually removing the barriers and creating the drivers. The simplest driver for production of bioenergy crops is the development of a market, but this is not a simple process with many complex interlinking factors of supply and demand, as well as energy prices and financing linking together to impact on the time it takes to develop that market. Some policy or legislative drivers could be implemented, e.g. changes to EFA requirements or the inclusion of bioenergy crops in environmental stewardship schemes to help motivate farmers to plant crops, but the main driver for planting is expected to be a suitable, trusted market that pays prices that are comparable to those currently paid for food or feed.

In order to unlock a significant proportion of the area identified, programmes of work to change practice in areas unrelated to bioenergy crop production are needed. These include changes to consumer and supermarket behaviour to reduce food waste; and changes to livestock farmer practices to increase intensification on a proportion of the better livestock farms to enable more stock to be kept on a smaller area. These programmes of practice change would need to be run alongside programmes targeted at farmers to encourage the uptake of bioenergy crops, supported by an increasingly robust market for bioenergy crops, in order to ensure that the spared land is redirected to bioenergy crop production and no other competing uses for land.

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Appendix 1 – Scoring details on accessibility for each land type

The relative ease of conversion of land to bioenergy crop production is shown in Table 12. Table 12 sets out the total land area for each land type, the land area that is estimated to be accessible for bioenergy and the availability score for each land type. The assumptions around the land availability and specific barriers to access are discussed below.

Table 12 Current area, area available for bioenergy crops (ha), relative ease of conversion score (Max score-14) and other barriers to conversion

Source of land	Current area (ha)	Area potentially available for bioenergy (ha)	Practicalities of conversion	Location	Scale	Land Quality	Economic availability	Physical availability	Legal constraints	TOTAL	Other barriers
Bioenergy crops (1G and 2G)	122,000 ²	122,000	2	2	1	2	2	2	2	13	Uncertainty regarding Drax contracts, lack of market incentives, price of arable crops compared to bioenergy crops, market risk
Cereal over production	2,900,000	383,000-660,000 ³	2	2	2	2	1	2	2	13	Market drivers, Environmental stewardship
Economically marginal land	144,000 ⁴	87,000-98,000	2	1	1	1	1	2	2	10	Environmental stewardship
Uncropped arable land (fallow)	214,000	36,000-47,000	2	2	2	1	1	1	1	10	Environmental stewardship
Reduction in on-farm waste	62,000	13,600 – 62,000	0	2	2	2	0	1	1	8	Supermarket specifications
Improved utilisation of grassland – mid term	11,100,000	150,000-300,000	0	1	2	1	1	1	1	7	Farmer behaviour change & investment in improved stocking systems
Idle land (brownfield)	451,000 ⁵	45,000	1	1	1	0	1	1	1	6	Competition for housing

² Defra (2015a) Area of Crops Grown for Bioenergy in England and the UK: 2008 - 2014 [online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/483812/nonfood-statsnotice2014-10dec15.pdf [accessed 9 February 2016].

³ AHDB (2016) Supply & Demand [online]. Available at: <http://cereals.ahdb.org.uk/markets/supply-and-demand.aspx> [accessed 9 February 2016].

⁴ Defra (2009) Assessment of the availability of marginal or idle land for bioenergy crop production in England and Wales - NF0444 [online]. Available at: <http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16267> [accessed 16 February 2016].

⁵ Defra (2009) Assessment of the availability of marginal or idle land for bioenergy crop production in England and Wales - NF0444 [online]. Available at:

Source of land	Current area (ha)	Area potentially available for bioenergy (ha)	Practicalities of conversion	Location	Scale	Land Quality	Economic availability	Physical availability	Legal constraints	TOTAL	Other barriers
											Clean up costs / decontamination
Reduction in consumer food waste	196,000	49,000-98,000	0	2	1	2	0	0	1	6	Supermarket specifications
White land: Government land	5,000*	500	1	1	1	1	0	1	0	5	Competition for housing
White land: forestry commission	10,000*	10,000	2	1	1	1	1	1	1	8	Competition from developers, private land-owners
Idle land (verges & embankments)	145,000 ⁶	15,000	1	0	0	0	1	1	1	4	Safety
Improved utilisation of grassland – long term	11,100,000	200,000-400,000	0	1	2	1	0	0	0	4	Farmer behaviour change & investment in improved stocking systems
EFA's	Same as economically marginal land	Same as economically marginal land	0	2	1	1	0	0	0	4	Requires changes to England and Scotland EFA regs
TOTAL AREA		1.0-1.8 Mha									

*Five year average area made available, estimated annual white land area is 4,250 ha.

Note: Scores were used as a guide in order to assess potential timescales to availability, however land-use specific factors e.g. safety (verges and embankments), changes in practice e.g. food waste and grassland management etc. were also considered in timescale assessment.

<http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16267> [accessed 16 February 2016].

⁶ Defra (2009) Assessment of the availability of marginal or idle land for bioenergy crop production in England and Wales - NF0444 [online]. Available at:

<http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16267> [accessed 16 February 2016].