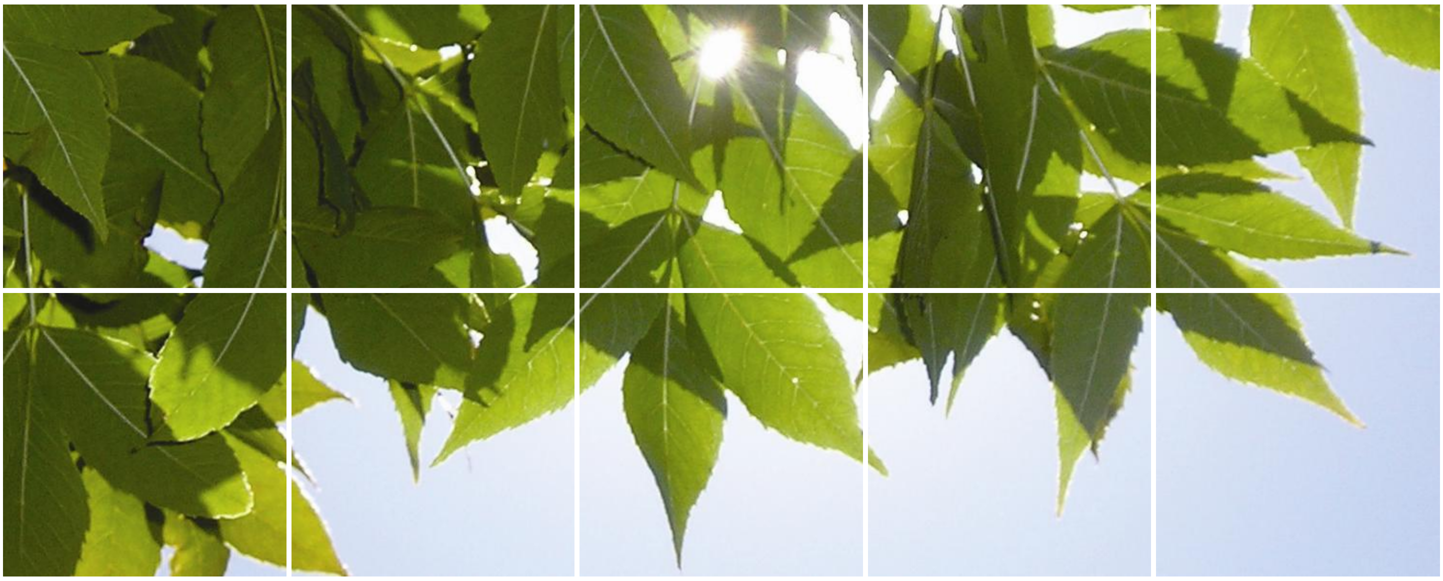

UK and Global Bioenergy resource – Annex 1 report: details of analysis

Report to DECC

Restricted Commercial

ED 56029

Final

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	Date	March, 2011

Summary

This report is the Annex to the report “UK and Global Bioenergy resource” written by AEA for DECC, December 2010.

It provides details of the general methodology for the work presented in that report and more information on the data used in the report and the results for each feedstock.

For each UK biomass feedstock it presents details of the main assumptions used to estimate the supply, a summary of the constraints analysis and a detailed summary of the results.

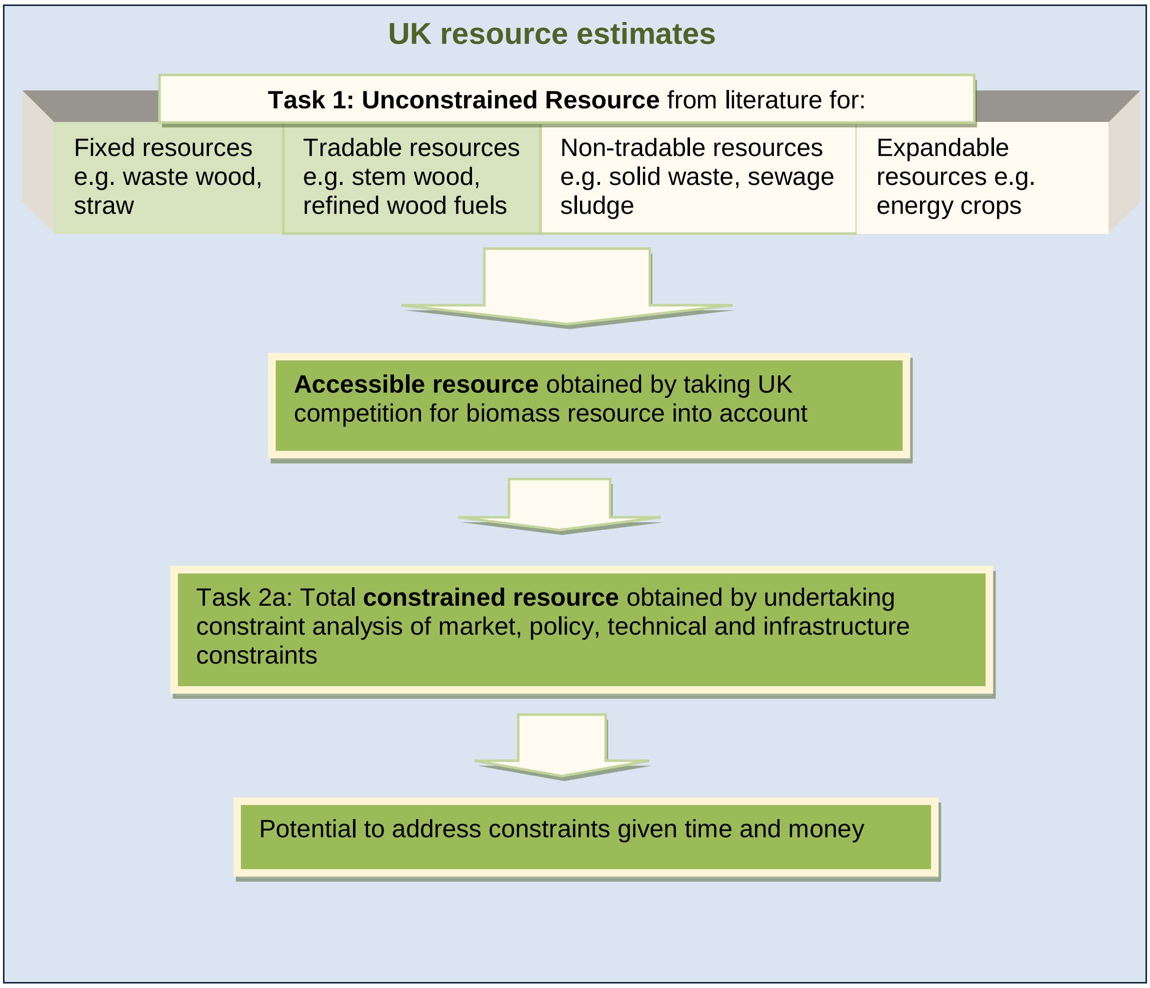
The Global analysis provides details the main assumptions in estimating supply.

Annex 1 - Contents

UK Feedstock: Methodology

Figure 1 provides a schematic of the methodology used for the UK feedstock analysis.

Figure 1 Diagrammatic presentation of the methodology for UK resource estimates



Constraint analysis for UK feedstock

The starting point for the analysis of the supply of UK sourced feedstocks was to estimate the ‘unconstrained’ potential. Competing demands – for example food, or feedstocks used by industry – were then taken into account, providing a UK bioenergy sector ‘accessible’ potential. How much of this could actually come to market depends on the ability of the supply side to overcome barriers – which gives a ‘constrained’ supply potential.

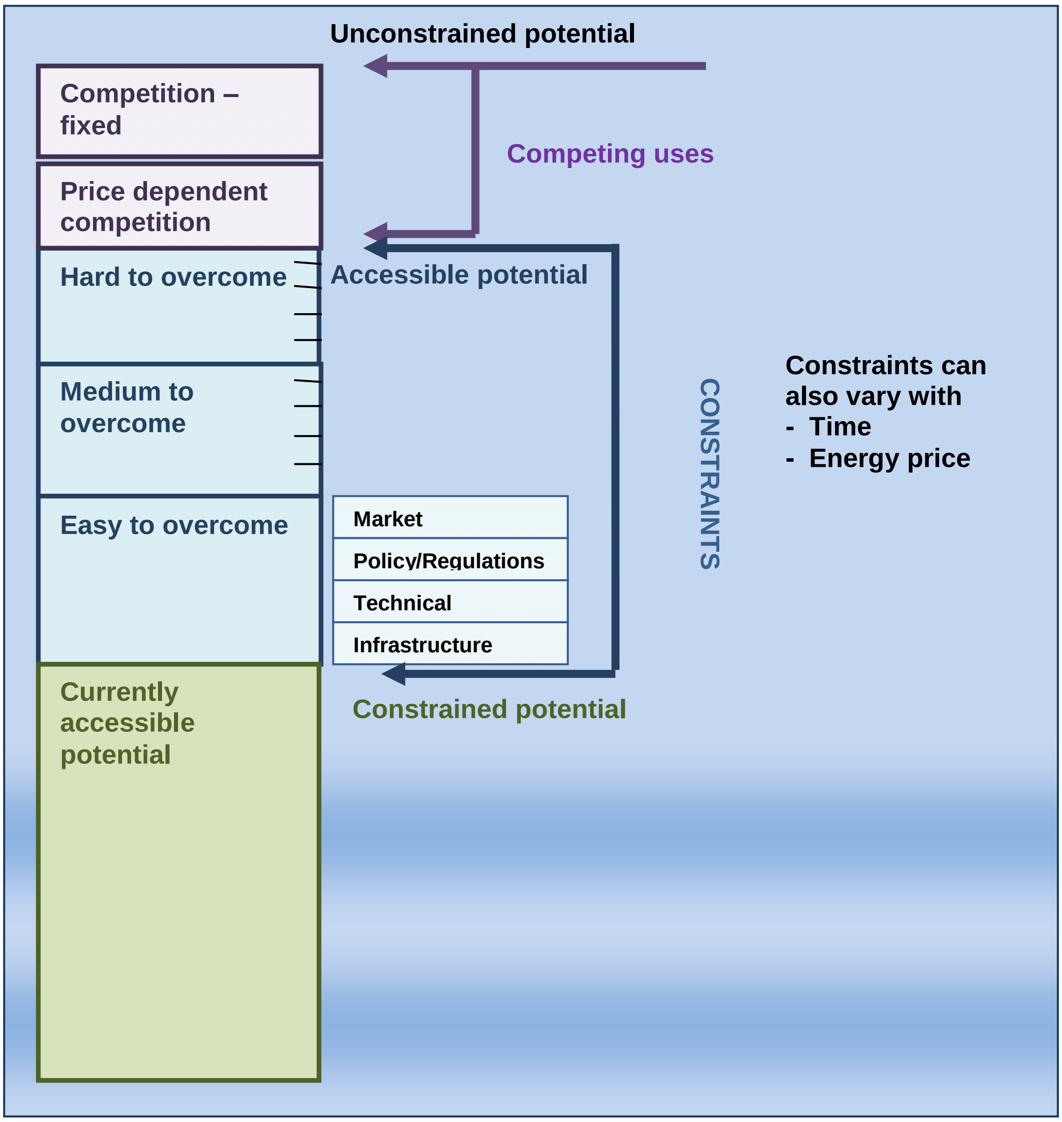
The unconstrained resource was estimated from data in the literature. The starting point for all estimates in this work was the E4Tech (2008) analysis, unless additional data had been made available in the intervening period. For example, WRAP has just completed a more extensive survey of waste wood that was used in our analysis but not available to E4Tech in 2008 (WRAP, 2009). In addition, in some cases we interpreted or extrapolated data using different assumptions in order to ensure that they were in line with other estimates we were using (for example, landfill gas, food waste for AD and energy recovery from the renewable fraction of waste were estimated so that there was no double counting of the same resource; and our analysis of landfill gas production was based on different assumptions to E4Tech’s). The sources of data are listed in the modules for each feedstock in this Annex.

Having obtained figures for the unconstrained resource, we then subjected the estimates to constraint analysis (see Figure 2). Starting from the unconstrained resource, a view was taken on the competing uses and whether or not this competition is price dependent. Competition for biomass feedstocks includes the use of agricultural land for food, feed and other non-food uses; the use of wood for timber, paper, pulp and panel board; the use of waste in recycling or compost; and the use of biomass for biomaterials. Estimates were based on data from the literature, from Government statistics or from sector associations, together with expert judgement based on our experience of the sectors and examination of the prices paid by competing sectors. Only the price dependent resource was considered to be potentially available to the bioenergy sector (i.e. the unconstrained resource minus the price-independent competing uses provides an indication of the "**accessible potential**" for bioenergy).

A view was then taken on how much of the accessible potential is likely to reach market under different assumptions about how far barriers are overcome, resulting in an estimate of the "**constrained potential**" for bioenergy use.

This approach simplifies the situation somewhat in that sometimes constraints affect competing use as well. However, this effect was not considered significant for this work.

Figure 2 Diagrammatic representation of unconstrained and various constrained resource potentials



Estimation of competing uses

Competing uses were estimated using data from the literature, from Government statistics or from sector associations. They were based on real data where ever possible. An expert view was then taken on how much of this competition was sensitive to price, and, therefore, available to the bioenergy sector at higher prices. These estimates were based on knowledge of the competing sectors (from literature and from our experience of these sectors), and examination of the prices paid for the feedstock by competing sectors. In some cases there are examples of competing uses where a proportion of the biomass will never be available to bioenergy. Details are provided in the feedstock modules in this Annex.

Constraints estimates

Although there are data available on factors that constrain the use of biomass, sometimes with an indication of how much of the resource is constrained in this way, on the whole this is an area where expert opinion is required and the analysis is less certain.

Constraints were estimated using a combination of information from the literature and our own expert opinion, drawing on technical reports and our own experts' experience of bioenergy. Expert experience is based on work in the sector over a period of years, experience of consultations and discussions with key stakeholders[1] and a general knowledge of barriers to development of biomass resources. Many of the sources of information (e.g. the first year of the RTFO (RFA) and WRAP analysis of the waste processing sector (WRAP2007-2009) indicate important barriers that need to be overcome for the full resource to be supplied.

Together these sources provide us with good knowledge of the policy environment (including the impacts of policy changes), a good level of understanding of technical and infrastructure development in all bioenergy sectors, knowledge of sector needs and an understanding of the uncertainties and perceptions of suppliers.

The analysis concentrated on understanding how the accessible potential might be achieved and what the constraints that need to be addressed are. The constraints assessed were:

- Market constraints
- Policy and regulatory constraints
- Technical and
- Infrastructural constraints

The analysis considered the importance of each constraint (in terms of the relative amount of resource it influences), how difficult the constraints are to address (easy, moderately hard or hard), and which are the ones that might enable fastest returns if addressed.

Constraints that acted on only a portion of the supply, or that could be addressed providing relatively low investment was made, were considered easy to address. Likewise, policy issues that could be addressed by stable UK policy or by clarification of specific points were also regarded as easy to address, as it is within the power of Government to influence these issues.

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[1] For example, AEA have been involved in consultations and work with the waste sector, the biofuels sector and biomass users and suppliers as part of other work over the past two years. Examples of this include a review of the impact of the RTFO in which the biofuel sector were consulted, our work on collection of Renewable Energy Statistics for DECC; and regional work in Yorkshire and the South West in which we were involved in consultations with relevant sectors. We are also involved in work in both the public and private sector in the waste area. In addition we worked on this project with Forest Research, who run the Biomass Energy Centre and have a good understanding of forestry in the UK and globally.

Technical and infrastructure issues requiring investment or a degree of research were assessed as easy or medium constraints, depending on the level of investment required and the extent of the problem.

Constraints that require considerable change in current practices (e.g. in waste management), new technical development were considered to be hard to overcome. Other constraints are by definition very difficult to address (e.g. terrain can sometimes provide a very significant barrier to development of forestry residues). These may not be possible to address in the time scale under consideration.

We then considered how the impact of each constraint may change over time For example, some logistical issues, such as planting material and equipment for energy crops, provide a constraint that may be overcome within the timescale being considered, but restrict the resource available in the near term.

The impact each constraint had on each feedstock was a matter of judgement, based on information available and the expert's own experience of the sector. This means that the results are somewhat subjective and uncertain. The details of how the constraints were decided for individual feedstock are given in the feedstock modules in this Annex.

Price points assessed.

Finally we considered how the impact of each constraint may change depending on the price achievable for the feedstock. As well being a function of technical availability and non-financial barriers, supply is also a function of price – with higher prices, some of the constraints discussed above will be overcome by the market. We considered 3 price levels: £4/GJ, £6/GJ and £10/GJ representing prices for the supply of the feedstock in bulk, and for woody fuels assuming supply as chips for biomass heat. The lower bound was chosen to be broadly consistent with current prices of bulk chips, while the mid and upper price points were chosen to show how supply might increase if prices for feedstocks increased in the future. A high price of £10/GJ was chosen as the upper bound, so that the full impact of price in determining availability could be seen (for example previous estimates by E4Tech (2010) considered £9.4/GJ to be a 'very high' estimate of bulk prices for chips in 2020). £6/GJ was considered to be a more realistic estimate of the level that prices might rise to in the short to medium term.

The methodology for each UK feedstock and the results obtained is presented below.

This is followed by detail on the international feedstocks.

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Chapter 1: UK Wood Fuels

UK wood fuels – Summary of assumptions and results

This section contains a summary of the main assumptions made in the analysis of UK clean wood based biomass feedstocks, and the results for the specific feedstocks. A summary is presented for each feedstock, followed by additional details, results and a summary of constraints.

Feedstocks for clean wood fuels in the UK could be supplied from forestry residues, small round wood, sawmill residues, arboricultural arisings and short rotation forestry. Waste wood is also a significant wood resource, but we have included it in the waste feedstock results.

Figures 3 and 4 show the wood fuel resource at £4/GJ (no constraints addressed) and £10/GJ (easy and medium constraints addressed). These indicate that there is a large potential to increase some of the wood resources including forestry residues, stemwood and arboricultural arisings; and that there is a potential for a significant contribution from short rotation forestry in 2030. These resources are increased with price (from 23PJ/y at £4/GJ in 2010 to 113PJ/y at £10/GJ in 2010) and time (to 46PJ/y at £4/GJ in 2030 and to 121PJ/y at £10/GJ in 2030).

Figure 3 Clean wood fuel availability in the UK at £4/GJ, no constraints addressed.

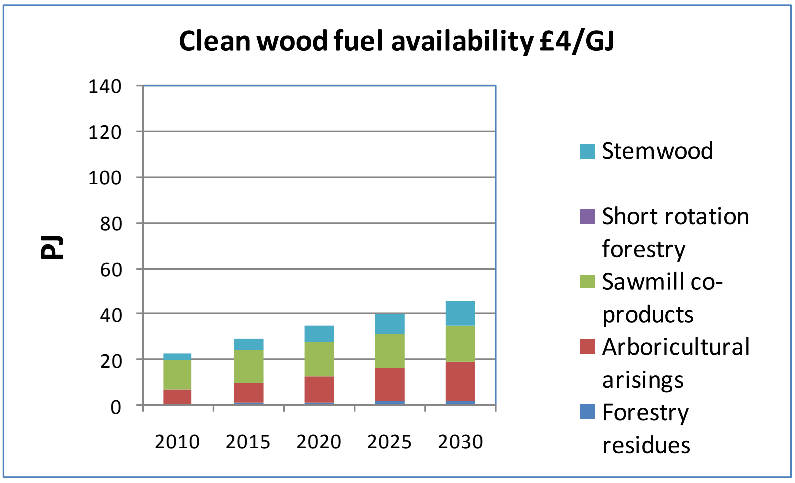
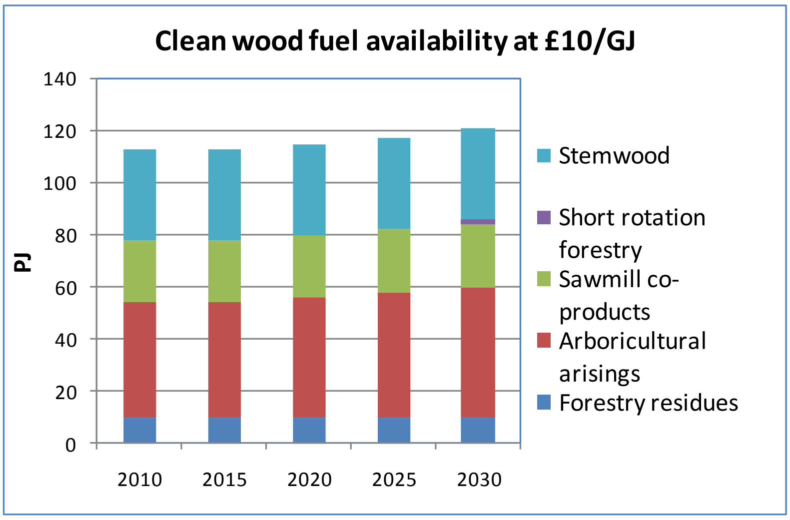


Figure 4 Clean wood fuel available in the UK at £10/GJ with all easy and medium constraints addressed.



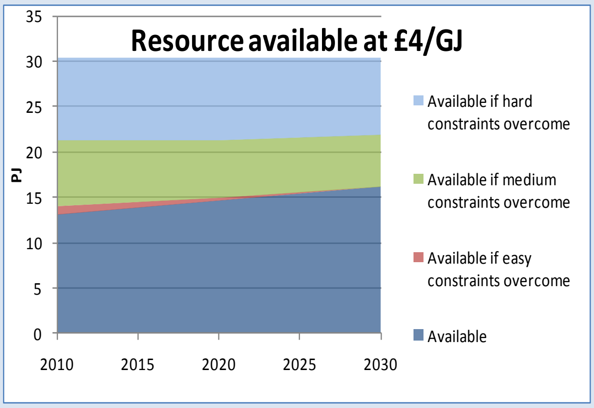
Sawmill residues

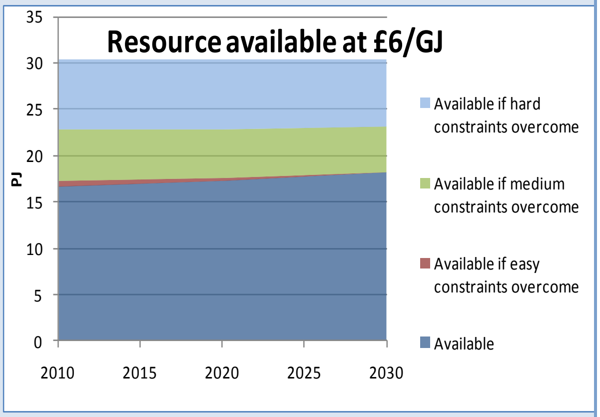
Summary of assumptions and results

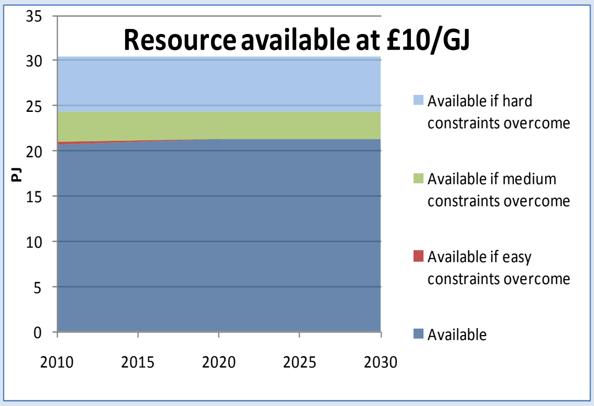
Unconstrained Potential 1.6M odt 30PJ	Assumptions • Clean wood residues from timber processing (chips, slabs, sawdust and bark). • Finite resource. • Current uses include animal bedding and panel board manufacture. The latter represent the largest current users of this resource (about 50% of resource) • Most resource comes from large sawmills, although there are also a number of small hardwood mills scattered around the country. • The unconstrained potential does include competing uses for panel board and pulp mills. • Source of data: Forestry Commission. Physical constraint: finite resource, dependent on wood processing in UK. Unconstrained potential assumed not to increase between 2010-2030 on the basis that UK timber processing tends to remain stable (CONFOR 2010).
Cost	Drying, processing (to fuel), transport. Wrap estimate cost of raw material £15-£30/t at mill. Costs of processing not included in this analysis.
Competing uses	Assumptions on competing uses: Horticultural wood chips and animal bedding are high value products. Panel board manufacture is dominant market (assumed that half of sawmill co-product goes to this route). Result: Competition accounts for up to 50% of unconstrained potential.
Constraints:	Low: - Incomplete or immature supply chain - Cost of certification for sustainability Medium: - Volume of sawlogs coming to mills - Returns insufficient - Achieving appropriate fuel specification - Bark content - Processing capacity (for pellets or briquettes) - Collection from small dispersed processors. High: - Volume of sawlogs coming to mills - Returns insufficient - Inertia/disinterest Competing feedstock uses that are dependent on energy price

Results - Half supply available at £4/GJ, increasing to over two thirds supply at £10/GJ. Likely that competing uses will also increase price willing to pay, so total resource never available

- Competing markets are very important in impacting price and supply (and vice versa)







Additional details

Timber for saw logs is removed from the forest for timber processing, but there is also a considerable residue resource available from sawmills:

- **Sawmill residues** – these include bark, off cuts and sawdust, which are currently used in energy in the UK. They are a finite resource, the production of which is dependent on timber production in the UK. Current competing uses include the manufacture of panel board and animal bedding. These current uses represent the main constraints on the use of sawmill residues for energy.

Current estimates of the sawmill resource are shown in the Table above. Forest Research has updated this estimate using its own data to provide an unconstrained resource of 1.6M odt/y. We have assumed that just under half of this resource (0.7Modt/y) has a competing use, all of which is dependent on price.

Constraints

The major constraints on this resource, accounting for a decrease of some 50% in supply, are:

- The volume of sawlogs coming to mills – any potential for increase comes from the non Forestry Commission managed wood land. Bringing these woodlands into management also involves overcoming barriers such as insufficient returns and inertia/disinterest in managing the woodlands. Even if this were achieved there would be a time lag before the full potential for good quality sawlogs could be realised.

- Competing feedstock uses that are dependent on energy price.

In addition there are technical considerations which constrain supply by less than 5%:

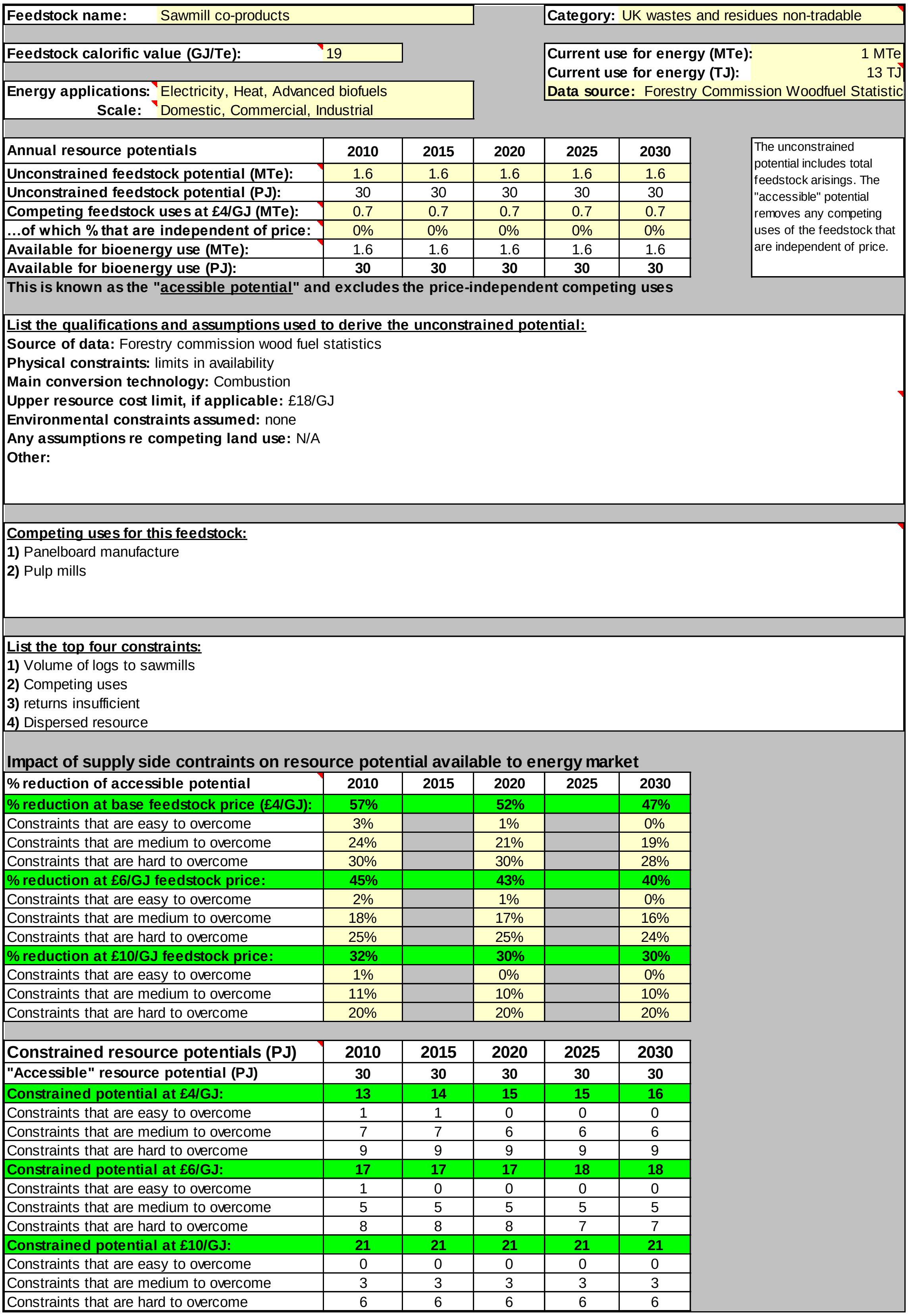
- Achieving specifications for wood fuel requirements (e.g. the need for high quality chip, low bark content and drying to the right moisture content).

Other important but more minor constraints, accounting for less than 5% of supply constraint are:

- The need to establish a market supply chain and to stimulate demand
- The cost of compliance with sustainability certification

These constraints are difficult to overcome even at high price and up to 2030 at all prices we consider. In our analysis the market remains constrained to about 70% of accessible potential. To overcome the major constraints would require major investment in under managed woodland and a change in the market for competing uses. Unless the price of bioenergy feedstock rises significantly we do not think this will happen.

Detailed Results



Feedstock name: Sawmill co-products
Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te): 19

Current use for energy (MTe): 1 MTe
Current use for energy (TJ): 13 TJ
Data source: Forestry Commission Woodfuel Statistic

Energy applications: Electricity, Heat, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	**2010**	**2015**	**2020**	**2025**	**2030**
Unconstrained feedstock potential (MTe):	1.6	1.6	1.6	1.6	1.6
Unconstrained feedstock potential (PJ):	30	30	30	30	30
Competing feedstock uses at £4/GJ (MTe):	0.7	0.7	0.7	0.7	0.7
...of which % that are independent of price:	0%	0%	0%	0%	0%
Available for bioenergy use (MTe):	1.6	1.6	1.6	1.6	1.6
Available for bioenergy use (PJ):	**30**	**30**	**30**	**30**	**30**

This is known as the "acessible potential" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: Forestry commission wood fuel statistics
Physical constraints: limits in availability
Main conversion technology: Combustion
Upper resource cost limit, if applicable: £18/GJ
Environmental constraints assumed: none
Any assumptions re competing land use: N/A
Other:

Competing uses for this feedstock:
1) Panelboard manufacture
2) Pulp mills

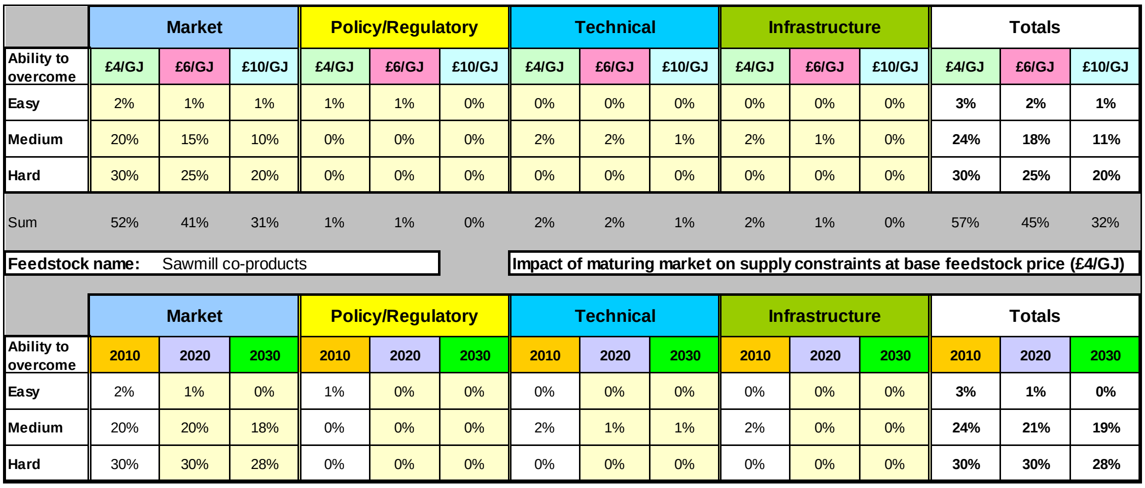
List the top four constraints:
1) Volume of logs to sawmills
2) Competing uses
3) returns insufficient
4) Dispersed resource

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	**2010**	**2015**	**2020**	**2025**	**2030**
% reduction at base feedstock price (£4/GJ):	**57%**		**52%**		**47%**
Constraints that are easy to overcome	3%		1%		0%
Constraints that are medium to overcome	24%		21%		19%
Constraints that are hard to overcome	30%		30%		28%
% reduction at £6/GJ feedstock price:	**45%**		**43%**		**40%**
Constraints that are easy to overcome	2%		1%		0%
Constraints that are medium to overcome	18%		17%		16%
Constraints that are hard to overcome	25%		25%		24%
% reduction at £10/GJ feedstock price:	**32%**		**30%**		**30%**
Constraints that are easy to overcome	1%		0%		0%
Constraints that are medium to overcome	11%		10%		10%
Constraints that are hard to overcome	20%		20%		20%

Constrained resource potentials (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**
"Accessible" resource potential (PJ)	**30**	**30**	**30**	**30**	**30**
Constrained potential at £4/GJ:	**13**	**14**	**15**	**15**	**16**
Constraints that are easy to overcome	1	1	0	0	0
Constraints that are medium to overcome	7	7	6	6	6
Constraints that are hard to overcome	9	9	9	9	9
Constrained potential at £6/GJ:	**17**	**17**	**17**	**18**	**18**
Constraints that are easy to overcome	1	0	0	0	0
Constraints that are medium to overcome	5	5	5	5	5
Constraints that are hard to overcome	8	8	8	7	7
Constrained potential at £10/GJ:	**21**	**21**	**21**	**21**	**21**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	3	3	3	3	3
Constraints that are hard to overcome	6	6	6	6	6

Constraints



	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	**3%**	**2%**	**1%**
Medium	20%	15%	10%	0%	0%	0%	2%	2%	1%	2%	1%	0%	**24%**	**18%**	**11%**
Hard	30%	25%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**30%**	**25%**	**20%**
Sum	52%	41%	31%	1%	1%	0%	2%	2%	1%	2%	1%	0%	57%	45%	32%

Feedstock name: Sawmill co-products

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	2%	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	**3%**	**1%**	**0%**
Medium	20%	20%	18%	0%	0%	0%	2%	1%	1%	2%	0%	0%	**24%**	**21%**	**19%**
Hard	30%	30%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**30%**	**30%**	**28%**

Forest Residues and Small Round wood

Summary of assumptions and results

Forest residues

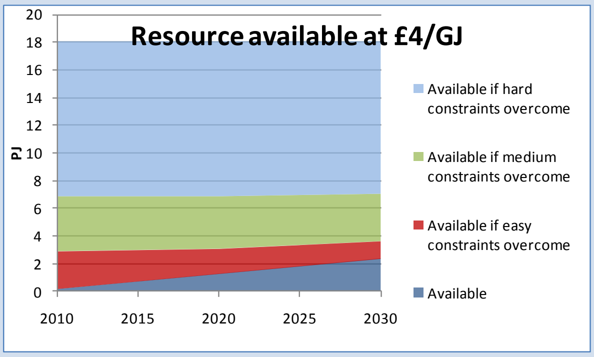
Unconstrained Potential 1M odt/y (18PJ)	Assumptions • Estimate of resource comes from a combination of sources including forestry commission statistics, Carbine and ADAS (2008) data. The Forestry Commission (Ref: Woodfuel resource in Britain) estimated around 0.95 M odt/y and this figure has been updated to 1M odt/y using the other, more recent references. • Forest residues comprise brash, stumps and small round wood not suitable for other purposes. • Some of this resource is important to forestry operations, maintenance of the environment of the forest and structural stability of soil. This has assumed to be 50% of the resource and has been excluded from the estimates in this work. Physical constraints: terrain, forestry operations (determined by demand in other sectors).
Cost	Factors affecting cost: • Harvesting costs, need to purchase specialist equipment. • Need to dry and store timber • Need to meet fuel specifications. • Potential cost of certification • Cost of investment in uncertain policy environment • Transport (and cost of transport infrastructure in under-managed wood lands)
Competing uses	Assumptions on competing uses: None Assumed that environmental constraints result in up to half resource not being available. This resource is not included in our estimates.
Constraints:	Low: - Lack of local demand - Cash flow issues - Immature/incomplete supply chain - Planning constraints - Lack of capital grants for investment in supply - Lack of long term stable policies to enable investment. - Achieving fuel specifications - Availability of harvesting equipment. - Lack of transport infrastructure. Medium: - Returns insufficient - Supply chains for under managed wood land. - Cost of harvesting equipment (substantial up- front investment required. - Cost of certification for sustainability - Timber drying space and facilities High: - Returns insufficient - Inertia/disinterest - Competition from existing applications - Terrain difficult to access and harvest. - Environmental constraints. - Use of brash for matting for ground protection.

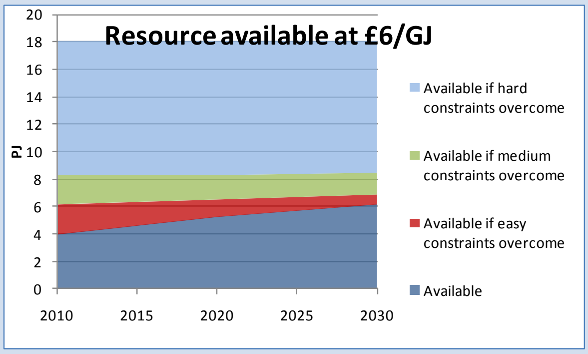
- Small round wood expensive to harvest

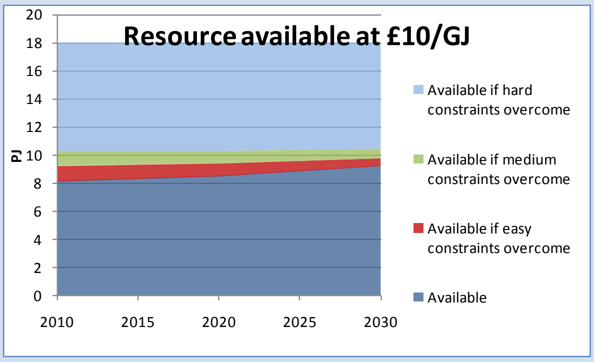
Results Insufficient returns, lack of interest on part of forestry owners, investment costs and difficulties in obtaining resource due to lack of infrastructure and terrain mean that even at £10/GJ only half of the resource is accessible by 2030.

At £4/GJ less than 12% resource is accessible.

Long term, stable policy and investment environment is important







Small round wood (SRW)

Unconstrained Potential 3.3Modt/y (63PJ/y) Constant over time period of report.	Assumptions • Produced as part of the first pass forestry operation • Only produced if there is a market. • More small roundwood could be taken from the forest and could be used as a fuel wood supply. • Small round wood is currently produced to meet market demand, so the major constraint on the use of what is currently produced is related to competition from other markets Physical constraints: Terrain constraints will make it difficult and expensive to harvest timber.
Yield rates	Current yield rates t/hectare by land type and for different crops. Improvement assumed in yield rates over time.
Cost	Factors that influence costs include investment in harvesting machinery, need to overcome terrain and infrastructure issues.
Competing uses	Assumptions on competing uses: Panel board manufacture, pulp mills, fencing. Assumed that competition is price dependent and that increased demand might change harvesting practice to obtain more supply from forest and also might bring more forest land into management. Result: Potentially 1M odt/y would go to competing uses, depending on price.
Constraints	Low:

- Lack of local demand
- Cash flow
- Immature supply chain
- Planning constraints
- Lack of grants for capital investment
- Lack of long term, stable policies to enable investment.
- Achieving fuel quality specifications.
- Low bulk density
- Lack of understanding of fuel quality standards
- Convenient, low cost basic fuel standards testing
- Lack of transport infrastructure

Medium:

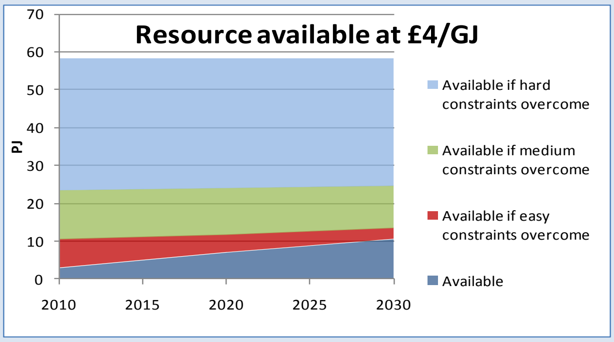
- Returns insufficient
- Requires substantial up-front investment.
- Cost of certification for sustainability
- Difficult terrain
- Lack of timber drying and storage facilities
- Lack of harvesting and collection infrastructure.

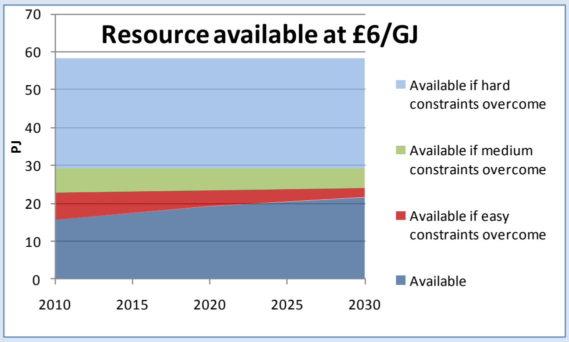
High:

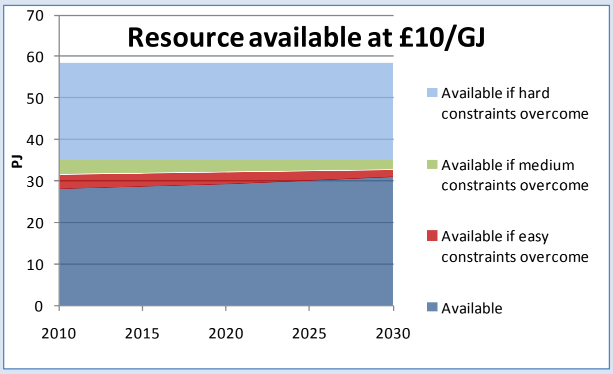
- Returns insufficient
- Inertia/disinterest
- Competition from existing markets
- Difficult terrain
- Small woods expensive to harvest
- Risk of ground damage
- Harvest site access

Results Accessible resource increases with time, but increases more rapidly with cost, showing that price dependency is important. Total resource is never accessed. This is because some of the hard to overcome constraints are never

Long term, stable policy and investment environment is important addressed.







Additional details for forestry residues and SRW.

There are two main potential sources of wood for bioenergy from forests:

- **Forestry residues** – comprise small stem wood not suitable for other purposes, small branches, and brash usually left on the forest floor. These could be obtained as part of current forestry operations, but to do this there is a need for additional investment to enable their collection either as part of the first pass forestry operations or for collection from the forest in a second pass operation. Some of this resource is important to maintenance of biodiversity and soil structure and carbon. In this analysis it is assumed that 50% of the brash remains in the forest, for use as matting and for environmental reasons. It was also assumed that roots were not removed for bioenergy purposes. The main constraints on the current use of forest residues include terrain and other land/soil issues that make it difficult to harvest and collect the residues; a need to invest in equipment for harvest and collection; and the establishment of a supply/market chain for the product. Our results indicate that there is an unconstrained resource of around 1M odt/y from this source (McKay et al 2008, updated by figures available to Forest Research).
- **Small round wood (SRW)** - produced as part of the first pass forestry operation. Generally SRW is only produced if there is a market. Forestry operations could be altered to obtain more SRW from the forest, which could be used as a fuel wood supply. The major constraint on what is currently produced is related to competition from other markets. Our results indicate that there is an unconstrained resource of 3.3 M odt/y of small round wood that could be used for bioenergy (McKay et al 2008, updated by figures available to Forest Research).

Estimates from the literature include:

Table 1 Estimates of forest residues in the UK

Reference	Current resource (M odt)	Future resource (M odt)	Competing uses
McKay *et al* (2003)	0.9 – residues 2.1 - SRW 0.9 – Sawmill co-products	Not estimated	Panel board, pulp mills, fencing and other – 2.26 M odt total.
Kilpatrick *et al* (2008)	4.2 – includes all forest resource (i.e. includes SRW and sawmill co-products).	4.2	

The resource available is suitable for use in the heat and power sectors. Currently use of this resource is in small to medium scale heat generation (often in the locality of the source) and in large scale power generation.

Constraints

The main barrier to forestry residues for bioenergy is that it is not harvested or because woodlands are either under managed, or not managed at all. The main reasons for this are:

- Insufficient returns – it is simply not economically attractive to manage the woodland as the current price for bulk woodfuel is approximately equal to the cost of harvesting, processing (drying, chipping), transport, etc., with the landowner typically getting negligible income. Harvesting small areas of woodland can be particularly expensive.
- Inertia/disinterest – the woodland was not bought, or held, for production purposes. It may have been bought for investment purposes, or held for sporting reasons, or owned as part of a farm or estate. In some cases some periodic clearing of rides might be undertaken to allow access, but a management plan has never been drawn up and there is no intention to try and extract any timber. There can also be a perception that unmanaged woodland is more “natural” and that allowing harvesting operations will damage the woodland.

- Access – Road access to and into the woodland.
- Environmental constraints – risk of soil damage from harvesting

Other barriers to managing/harvesting existing stocks include:

- Difficult terrain – including slope, thus driving up costs

These are major barriers that are difficult to overcome and we have constrained the resource considerably (up to 62%) to account for these issues. Although some of them might be tackled if the price for forestry residues was high, the constraints remain significant (43%).

Where harvesting/management are being undertaken there can still be barriers to exploiting the material obtained for fuel (this generally also applies to arboricultural arisings):

- Moisture content – chipped on site for bulk reduction for removal, it can be then difficult/ expensive to dry efficiently in chip form.
- Space to dry (& store) wood, as either roundwood or chip, can be unavailable or insufficient.
- Chip quality – unless a specialist (relatively expensive) woodfuel quality chipper is used then chip quality can be insufficient for small and medium scale boilers.
- Lack of knowledge/understanding of fuel standards required
- (Lack of) Availability of low cost, convenient test stations for basic parameter testing (moisture content; chip size/quality)
- Planning restrictions on using farmland/rural/green belt land for drying roundwood
- Lack of local demand (in some places)
- Cash flow (drying wood is time consuming)
- Lack of specialist (chip) delivery vehicles required for some installations
- Uncertainty/variability of chip volume and energy parameters

The constraints above are considered to be much lower than those in the first list and can be addressed much more easily with time and increased price for the wood fuel.
Additional constraints for small round wood (and sawmill residues)

- Competition with existing markets

Detailed Results – Forest residues and SRW

Forest Residues

Feedstock name: Forest residues

Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te): 19

Current use for energy (MTe): 0 MTe
Current use for energy (TJ): 5 TJ
Data source: Forestry Commission Woodfuel Statistic

Energy applications: Electricity, Heat, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (MTe):	1.0	1.0	1.0	1.0	1.0
Unconstrained feedstock potential (PJ):	18	18	18	18	18
Competing feedstock uses at £4/GJ (MTe):	0.0	0.0	0.0	0.0	0.0
...of which % that are independent of price:	100%	100%	100%	100%	100%
Available for bioenergy use (MTe):	1.0	1.0	1.0	1.0	1.0
Available for bioenergy use (PJ):	**18**	**18**	**18**	**18**	**18**

This is known as the "acessible potential" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

List the qualifications and assumptions used to derive the unconstrained potential:

Source of data: Forestry Commission Statistics Unit, CARBINE, Woodfuel resource in Britain study, ADAS report for NNFCC

Physical constraints: Difficult terrain limits resource

Main conversion technology: Combustion

Upper resource cost limit, if applicable: £18/GJ

Environmental constraints assumed: Limits on recovery of residues from forest (50% is assumed to remain in forest)

Any assumptions re competing land use: Based on current land areas devoted to forestry

Other:

Competing uses for this feedstock:

1) **Brash mats in harvesting**
2) **Forest soil quality preservation**
3) **Mulch**

List the top four constraints:

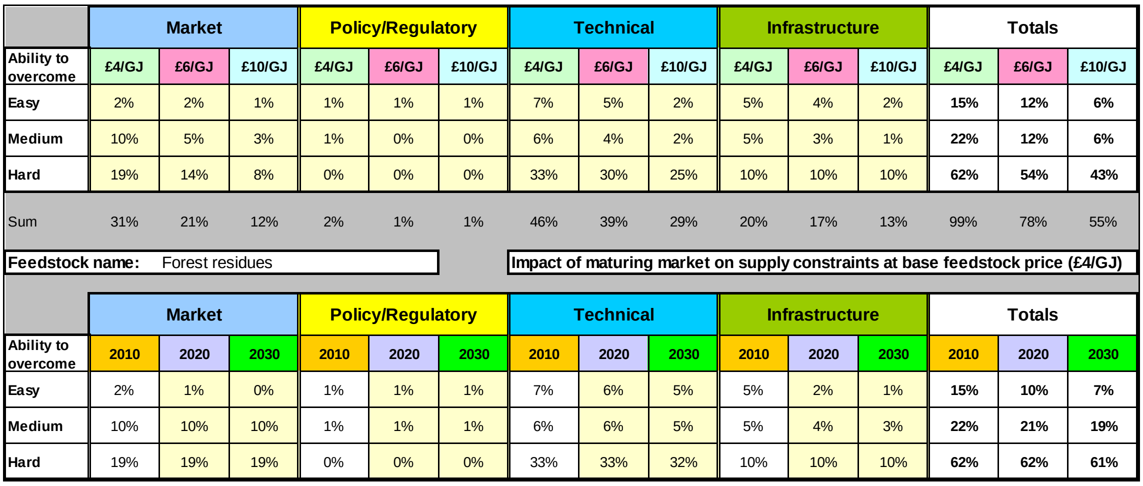
1) **Insufficient financial returns**
2) **Inertia/distinterest (exacerbated by constraint No. 1)**
3) **Moisture content**
4) **Achieving suitable chip quality**

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base feedstock price (£4/GJ):	**99%**		**93%**		**87%**
Constraints that are easy to overcome	15%		10%		7%
Constraints that are medium to overcome	22%		21%		19%
Constraints that are hard to overcome	62%		62%		61%
% reduction at £6/GJ feedstock price:	**78%**		**71%**		**66%**
Constraints that are easy to overcome	12%		7%		4%
Constraints that are medium to overcome	12%		10%		9%
Constraints that are hard to overcome	54%		54%		53%
% reduction at £10/GJ feedstock price:	**55%**		**53%**		**49%**
Constraints that are easy to overcome	6%		5%		3%
Constraints that are medium to overcome	6%		5%		4%
Constraints that are hard to overcome	43%		43%		42%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	**18**	**18**	**18**	**18**	**18**
Constrained potential at £4/GJ:	**0**	**1**	**1**	**2**	**2**
Constraints that are easy to overcome	3	2	2	2	1
Constraints that are medium to overcome	4	4	4	4	3
Constraints that are hard to overcome	11	11	11	11	11
Constrained potential at £6/GJ:	**4**	**5**	**5**	**6**	**6**
Constraints that are easy to overcome	2	2	1	1	1
Constraints that are medium to overcome	2	2	2	2	2
Constraints that are hard to overcome	10	10	10	10	10
Constrained potential at £10/GJ:	**8**	**8**	**8**	**9**	**9**
Constraints that are easy to overcome	1	1	1	1	1
Constraints that are medium to overcome	1	1	1	1	1
Constraints that are hard to overcome	8	8	8	8	8

Constraints



	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	2%	2%	1%	1%	1%	1%	7%	5%	2%	5%	4%	2%	**15%**	**12%**	**6%**
Medium	10%	5%	3%	1%	0%	0%	6%	4%	2%	5%	3%	1%	**22%**	**12%**	**6%**
Hard	19%	14%	8%	0%	0%	0%	33%	30%	25%	10%	10%	10%	**62%**	**54%**	**43%**
Sum	31%	21%	12%	2%	1%	1%	46%	39%	29%	20%	17%	13%	99%	78%	55%

Feedstock name: Forest residues

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	2%	1%	0%	1%	1%	1%	7%	6%	5%	5%	2%	1%	**15%**	**10%**	**7%**
Medium	10%	10%	10%	1%	1%	1%	6%	6%	5%	5%	4%	3%	**22%**	**21%**	**19%**
Hard	19%	19%	19%	0%	0%	0%	33%	33%	32%	10%	10%	10%	**62%**	**62%**	**61%**

]

Small Round wood

Feedstock name: Small roundwood

Category: Internationally tradeable/imports

Feedstock calorific value (GJ/Te): 19

Current use for energy (MTe): 0 MTe
Current use for energy (TJ): 7 TJ
Data source: Forestry Commission Woodfuel Statistic

Energy applications: Electricity, Heat, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	**2010**	**2015**	**2020**	**2025**	**2030**
Unconstrained feedstock potential (MTe):	3.3	3.3	3.3	3.3	3.3
Unconstrained feedstock potential (PJ):	63	63	63	63	63
Competing feedstock uses at £4/GJ (MTe):	1.0	1.0	1.0	1.0	1.0
...of which % that are independent of price:	25%	25%	25%	25%	25%
Available for bioenergy use (MTe):	3.1	3.1	3.1	3.1	3.1
Available for bioenergy use (PJ):	**58**	**58**	**58**	**58**	**58**

This is known as the "acessible potential" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: Forestry Commission Statistics Unit, CARBINE, Woodfuel resource in Britain study, ADAS report for NNFCC
Physical constraints:
Main conversion technology: Combustion
Upper resource cost limit, if applicable: £18/GJ
Environmental constraints assumed:
Any assumptions re competing land use: Based on current land areas devoted to forestry
Other: Market constraints - SRW only produced if there is a market.

Competing uses for this feedstock:
1) Panelboard manufacture
2) Pulp mills
3) Fencing

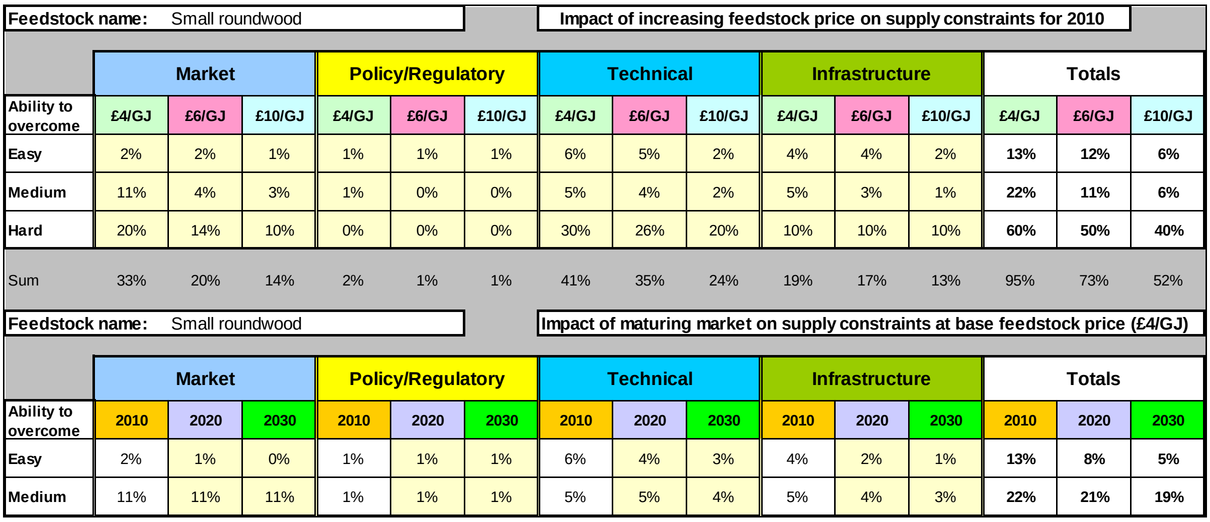
List the top four constraints:
1) Insufficient financial returns
2) Inertia/distinterest (exacerbated by constraint No. 1)
3) Much of the resource is difficult to harvest economically
4) Achieving suitable chip quality

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	**2010**	**2015**	**2020**	**2025**	**2030**
% reduction at base feedstock price (£4/GJ):	**95%**		**88%**		**82%**
Constraints that are easy to overcome	13%		8%		5%
Constraints that are medium to overcome	22%		21%		19%
Constraints that are hard to overcome	60%		59%		58%
% reduction at £6/GJ feedstock price:	**73%**		**67%**		**63%**
Constraints that are easy to overcome	12%		7%		4%
Constraints that are medium to overcome	11%		10%		9%
Constraints that are hard to overcome	50%		50%		50%
% reduction at £10/GJ feedstock price:	**52%**		**50%**		**47%**
Constraints that are easy to overcome	6%		5%		3%
Constraints that are medium to overcome	6%		5%		4%
Constraints that are hard to overcome	40%		40%		40%

Constrained resource potentials (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**
"Accessible" resource potential (PJ)	**58**	**58**	**58**	**58**	**58**
Constrained potential at £4/GJ:	**3**	**5**	**7**	**9**	**11**
Constraints that are easy to overcome	8	6	5	4	3
Constraints that are medium to overcome	13	13	12	12	11
Constraints that are hard to overcome	35	35	34	34	34
Constrained potential at £6/GJ:	**16**	**18**	**19**	**20**	**22**
Constraints that are easy to overcome	7	6	4	3	2
Constraints that are medium to overcome	6	6	6	6	5
Constraints that are hard to overcome	29	29	29	29	29
Constrained potential at £10/GJ:	**28**	**29**	**29**	**30**	**31**
Constraints that are easy to overcome	4	3	3	2	2
Constraints that are medium to overcome	4	3	3	3	2
Constraints that are hard to overcome	23	23	23	23	23

Constraints for small round wood



Feedstock name: Small roundwood

Impact of increasing feedstock price on supply constraints for 2010

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	2%	2%	1%	1%	1%	1%	6%	5%	2%	4%	4%	2%	**13%**	**12%**	**6%**
Medium	11%	4%	3%	1%	0%	0%	5%	4%	2%	5%	3%	1%	**22%**	**11%**	**6%**
Hard	20%	14%	10%	0%	0%	0%	30%	26%	20%	10%	10%	10%	**60%**	**50%**	**40%**
Sum	33%	20%	14%	2%	1%	1%	41%	35%	24%	19%	17%	13%	95%	73%	52%

Feedstock name: Small roundwood

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	2%	1%	0%	1%	1%	1%	6%	4%	3%	4%	2%	1%	**13%**	**8%**	**5%**
Medium	11%	11%	11%	1%	1%	1%	5%	5%	4%	5%	4%	3%	**22%**	**21%**	**19%**

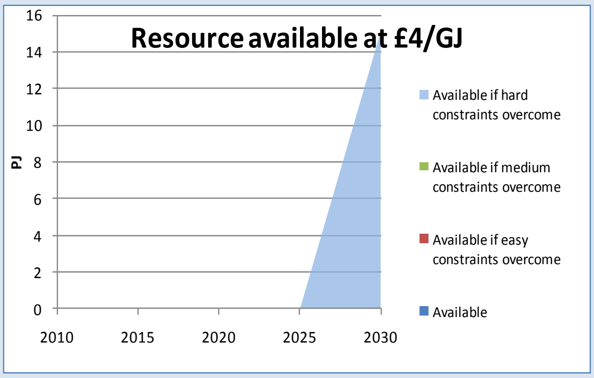
Short rotation forestry (SRF)

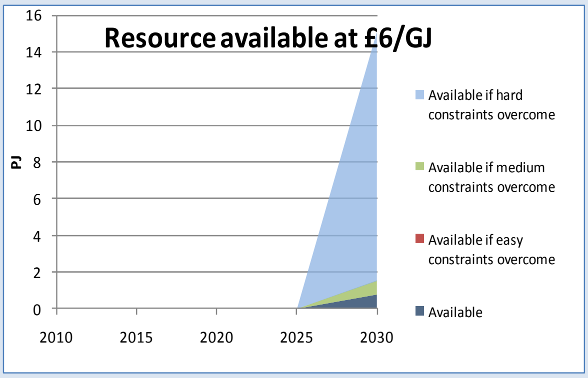
Summary of assumptions

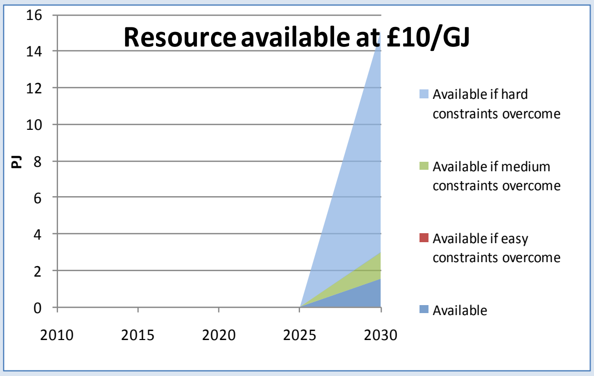
Unconstrained Potential: O in 2010-2025, rising to: 0.8Modt/y (15PJ) in 2030.	Assumptions • Assume current trials are successful and planting on larger scale begins in 2015. Very little resource realised within timescale of this work. We have assumed 2000 ha planted in 2015 and a further 1000ha each year thereafter, resulting in 17,000ha by 2030 and producing 102,000 odt/y by 2030 at the most. At £ 4/GJ price is insufficient to stimulate planting of SRF. • Assume first harvest in 2030 • Land available: Livestock density increased to allow access to land Physical constraint: Planting rate and rotation time. Typical rotation likely to be 8-20 years. Need completion of current trials to plug knowledge gap. Result: proposals are for planting on rough grazing land in West, NW Scotland and upland areas of north, west and SW England. Estimate conversion of 10% permanent pasture and 20% rough grazing to SRF. (Kilpatrick *et al* 2008). Total: 1.8Mha availability that would produce 7.5Modt if it were all planted.
Yield rates	4.18 - 6 odt/ha/y
Cost	Main cost issues relate to investment costs and returns. There are key uncertainties, relating to long lead time and policy stability etc.
Competing uses	Assumptions on competing uses: assumed no competing uses
Constraints:	Low: - Public perception issues related to amenity value of land. - Not all suitable species covered by grant programme - Regulatory and political uncertainty - Level of complexity and long term nature of investment not recognised in market incentives. - Research programme into potential impacts incomplete. Medium: - Significant knowledge gaps which increase risk and uncertainty - Need for long term, stable market for fuel to underpin economics of production. - Insufficient returns High: - Insufficient returns - Inertia/disinterest - Long lead time Environmental constraints (e.g. water demand, invasiveness)
Results	Results indicate that no resource is available until 2030. Long term, stable policy and investment environment is important. Long term impact information is important.

Support for development of sustainable management is important.

Constraint is that return is insufficient on price







Additional Details

Short rotation forestry allows more intensive production of wood, with an estimated yield of up to 4.18 odt/ha/y at present. Typically fast growing species of trees would be grown on rotations of 8-20 years, depending on the species and the site. The trees would be gown primarily for the production of biomass for energy (Harrison 2010). Kilpatrick et al (2008) estimate that a future biomass resource of 7.52 M odt/y might be possible using short rotation forestry and suggest that this resource would be distributed similarly to permanent grassland and rough grazing in the upland areas of Waste, north west Scotland and the upland areas of north, west and south west England. They estimate that this would involve conversion of over 20% of rough grazing land and 10% of permanent pasture to wood land, and that this would have important implications that need careful consideration (both to livestock densities and on the amenity value of the land). We have used the figure of 7.52M odt/y for our unconstrained potential in 2030.

However, current trials are still underway and it is unlikely that any large scale planting will happen before 2018 at the earliest (Tubby 2010). This means that very little of the resource would be realised within the timescale of this work.

The potential for short rotation forestry will be clearer once the trials are complete, although more information is needed on growth and yields. A study on the potential for short rotation forestry (LTS 2006) found (subject to a number of important caveats) no serious issues relating to biodiversity, soils, hydrology, pests, diseases or landscape that would rule out SRF as a potential land use. This study found that the most critical issues related to the ‘economic benefits of the system for the producer’ and that there remain questions about ‘yields, density and other characteristics of wood grown under SRF systems.’

In this work we have assumed a yield of 6odt/ha/y. We have assumed that 2000ha are planted by 2015 and 1000 ha/y thereafter to 2030. This results in 17,000ha with a yield of 6 odt in 2030, or a resource of 102,000 odt in 2030.

Constraints

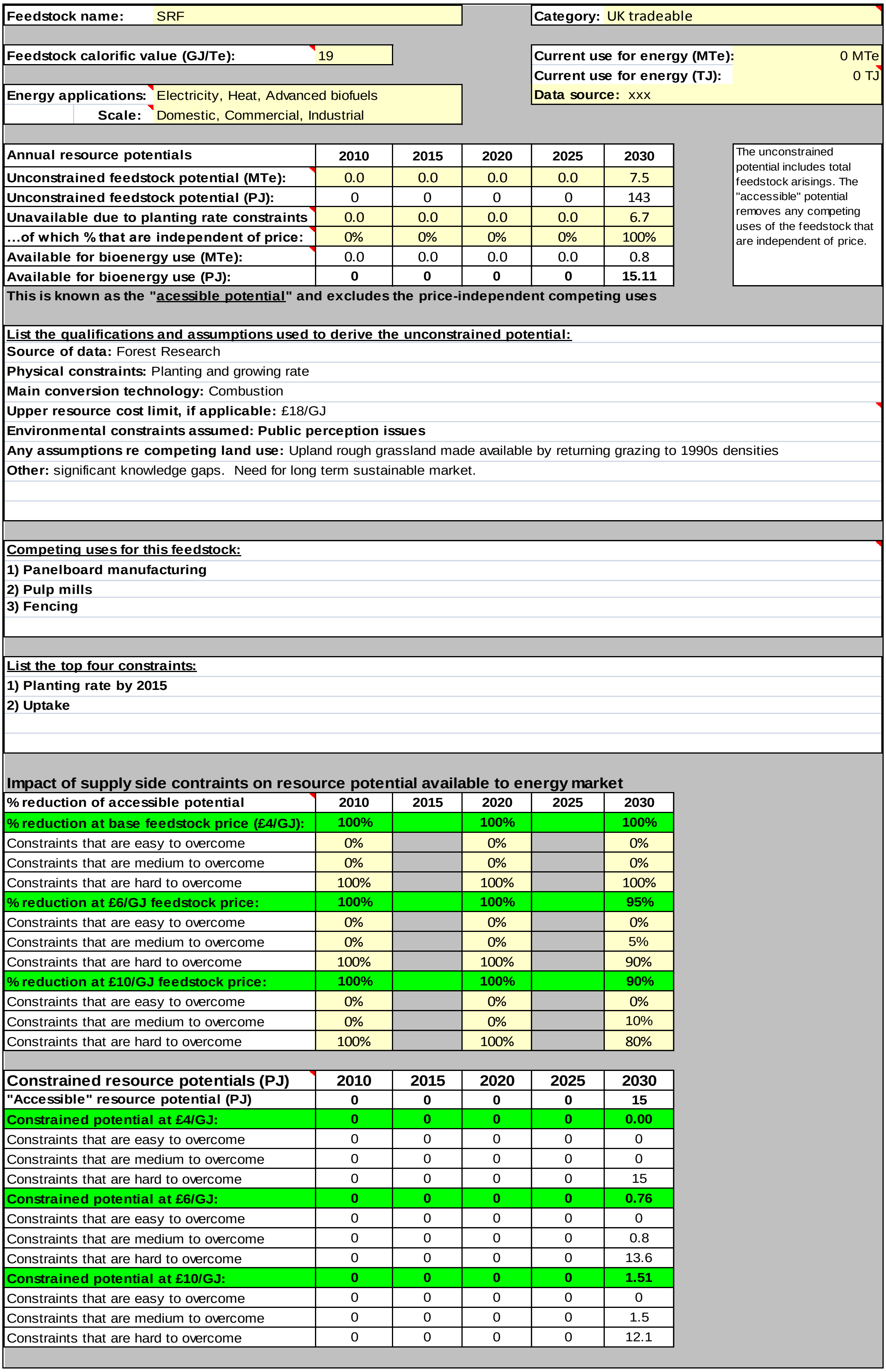
There are a number of significant constraints related to the lead time to develop SRF in the UK. In addition there are technical issues (such as water constraints or invasiveness) that will not be clear until the current trials are producing results. Currently we have assumed that these technical issues constrain the resource by 100% until 2030, where the constraints begin to shift to infrastructure issues.

The costs of establishment and the need for an adequate return will impact on the lead time for development. The level of disinterest within the forestry or energy sector will have important impacts.

Tubby (2010) also points out:

- There are significant knowledge gaps, which increase risk and uncertainty
- There is a need for a long-term sustainable market for the fuel to underpin the economics of production
- There may be public perception issues, particularly relating to the amenity value of the land on which the SRF is grown. Deforesting these areas would be difficult both legally and socially, therefore alternative forest management practices and 'new' species may be considered.

Results



Feedstock name:	SRF	**Category:**	UK tradeable
Feedstock calorific value (GJ/Te):	19	**Current use for energy (MTe):**	0 MTe
		Current use for energy (TJ):	0 TJ
		Data source:	xxx
Energy applications:	Electricity, Heat, Advanced biofuels		
Scale:	Domestic, Commercial, Industrial		

Annual resource potentials	**2010**	**2015**	**2020**	**2025**	**2030**
Unconstrained feedstock potential (MTe):	0.0	0.0	0.0	0.0	7.5
Unconstrained feedstock potential (PJ):	0	0	0	0	143
Unavailable due to planting rate constraints	0.0	0.0	0.0	0.0	6.7
...of which % that are independent of price:	0%	0%	0%	0%	100%
Available for bioenergy use (MTe):	0.0	0.0	0.0	0.0	0.8
Available for bioenergy use (PJ):	**0**	**0**	**0**	**0**	**15.11**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "acessible potential" and excludes the price-independent competing uses

List the qualifications and assumptions used to derive the unconstrained potential:

Source of data: Forest Research

Physical constraints: Planting and growing rate

Main conversion technology: Combustion

Upper resource cost limit, if applicable: £18/GJ

Environmental constraints assumed: Public perception issues

Any assumptions re competing land use: Upland rough grassland made available by returning grazing to 1990s densities

Other: significant knowledge gaps. Need for long term sustainable market.

Competing uses for this feedstock:

1) Panelboard manufacturing
2) Pulp mills
3) Fencing

List the top four constraints:

1) Planting rate by 2015
2) Uptake

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	**2010**	**2015**	**2020**	**2025**	**2030**
% reduction at base feedstock price (£4/GJ):	**100%**		**100%**		**100%**
Constraints that are easy to overcome	0%		0%		0%
Constraints that are medium to overcome	0%		0%		0%
Constraints that are hard to overcome	100%		100%		100%
% reduction at £6/GJ feedstock price:	**100%**		**100%**		**95%**
Constraints that are easy to overcome	0%		0%		0%
Constraints that are medium to overcome	0%		0%		5%
Constraints that are hard to overcome	100%		100%		90%
% reduction at £10/GJ feedstock price:	**100%**		**100%**		**90%**
Constraints that are easy to overcome	0%		0%		0%
Constraints that are medium to overcome	0%		0%		10%
Constraints that are hard to overcome	100%		100%		80%

Constrained resource potentials (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**
"Accessible" resource potential (PJ)	**0**	**0**	**0**	**0**	**15**
Constrained potential at £4/GJ:	**0**	**0**	**0**	**0**	**0.00**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	0	0	0	0	15
Constrained potential at £6/GJ:	**0**	**0**	**0**	**0**	**0.76**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0.8
Constraints that are hard to overcome	0	0	0	0	13.6
Constrained potential at £10/GJ:	**0**	**0**	**0**	**0**	**1.51**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	1.5
Constraints that are hard to overcome	0	0	0	0	12.1

Constraints

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	**0%**	**0%**
Medium	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	**0%**	**0%**
Hard	0%	0%	0%	0%	0%	0%	100%	100%	100%	0%	0%	0%	**100%**	**100%**	**100%**
Sum	0%	0%	0%	0%	0%	0%	100%	100%	100%	0%	0%	0%	100%	100%	100%

Feedstock name: SRF

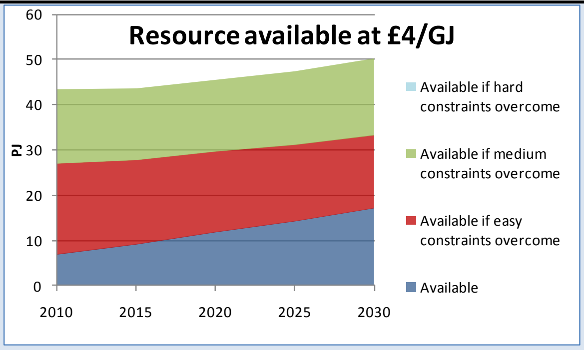
Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

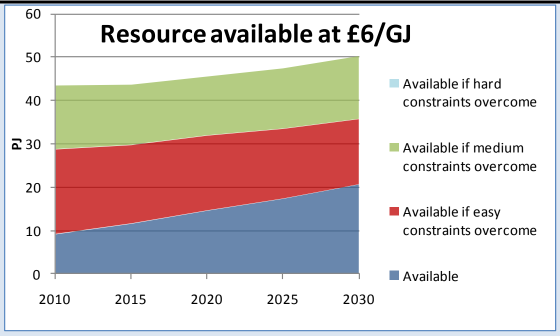
	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	**0%**	**0%**
Medium	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.00%	**0%**	**0%**	**0%**
Hard	0%	0%	0%	0%	0%	0%	100%	100%	100%	0%	0%	0%	**100%**	**100%**	**100%**

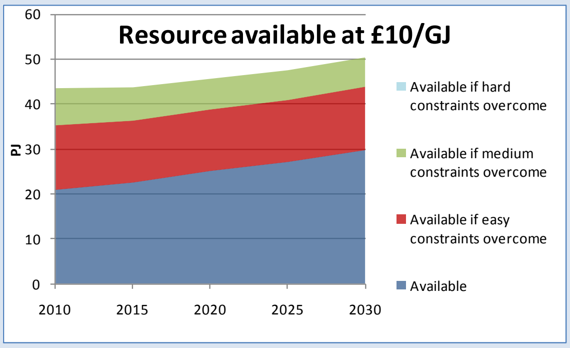
Arboricultural residues

Summary of assumptions

Unconstrained Potential	Assumptions
2.3M odt/y (44PJ/y) (2010), increasing to 2.7M odt/y (50PJ/y) in 2030	Resource from transport corridors and urban green space. Figures taken from NNFCC (Kilpatrick *et al* 2008). The estimate for transport corridors increases to 2030, resulting in the increased potential seen here. This is latest study of resource. Earlier estimates provide a much lower resource (0.4-0.56Modt/y). Physical constraints: Dispersed nature of resource; for significant proportion of resource it is easier to leave on site rather than collect and process.
Yield rates	3-5odt/ha assumed.
Cost	Costs incurred in chipping, meeting fuel specification, transport, drying and storage.
Competing uses	Assumptions on competing uses: Residues from urban green spaces may be chipped for mulch. It is assumed that this resource would be available if price were sufficient.
Constraints	Low: - Lack of local demand - Cash flow - Immature supply chains - Meeting fuel specifications - Lack of fuel quality standards - Lack of fuel standards testing facilities - Lack of transport infrastructure Medium: - Insufficient returns - Requirement for substantial up-front investment. - Cost of certification for sustainability - Low bulk density (high transport/storage costs) - Timber drying and storage facilities.
Results	Slow release of accessible resource at low price (only 16% potentially available now and at £4/GJ). Increases with time and cost to 60% accessible resource. Investment required in particular for collection, storage and drying faculties and for fuel preparation.







Detailed assumptions

There has been no need to gather statistics on arboricultural arisings and so little data is available. The main estimates are:

Table 2 Estimates of arboricultural arisings from the literature

Report	Estimate	Year
E4Tech (DECC)	0.4 M odt/y (7.8 PJ)	2020
E4Tech (DECC)	0.4 M odt/y (7.8PJ)	2030
ADAS (NNFCC)	2.3 M odt/y (44PJ) – 2.7odt/y (50PJ)	2008-2030
Forestry Commission (2003)	0.56M odt/y*	2003
AEA (NNFCC)	0.3 M odt/ 5.8PJ	Current

** The FC also gave an estimate of non-marketed arisings of 321,000t/y. These estimates were based on a survey of practitioners, the results of which were averaged and then multiplied across the whole sector in the UK.*

According to ADAS (2008) there is 3.5 M ha land in the UK used for urban, recreational and transport purposes. ADAS (2008) calculates their estimate from estimated yields now and improved yields in the future. This provides an estimate of 1.75Mt/y from urban green space now plus 0.54M odt/y from the transport network. Their figure for transport corridors increases to 0.9Modt/y for 2030. These are the figures that we have used for the unconstrained resource for arboricultural residues. However, not all of it is available for biomass fuel; much of this resource is managed in situ and left on site or chipped for mulch. Forest Research also estimates that around 0.5Mt in England currently goes to landfill. All of this is price dependent.

This means that of an unconstrained potential of 2.3M odt/y (2010), 100% of it is considered accessible. However, the use of arboricultural residues as mulch and the cost of collection constrains the resource considerably.

Constraints

The major constraints in developing this feedstock are technical; they involve preparation of the feedstock as a fuel (achieving fuel specifications) and the lack of facilities for collection, transport, drying and testing of the feedstock. These can be overcome with investment (i.e. at higher price), but substantial investment in infrastructure and facilities is required. We estimate that the effect of these constraints is a decrease in the resource of 60% at low price, decreasing to 40% at £10/GJ.

Other constraints have a less significant effect, but are still important:

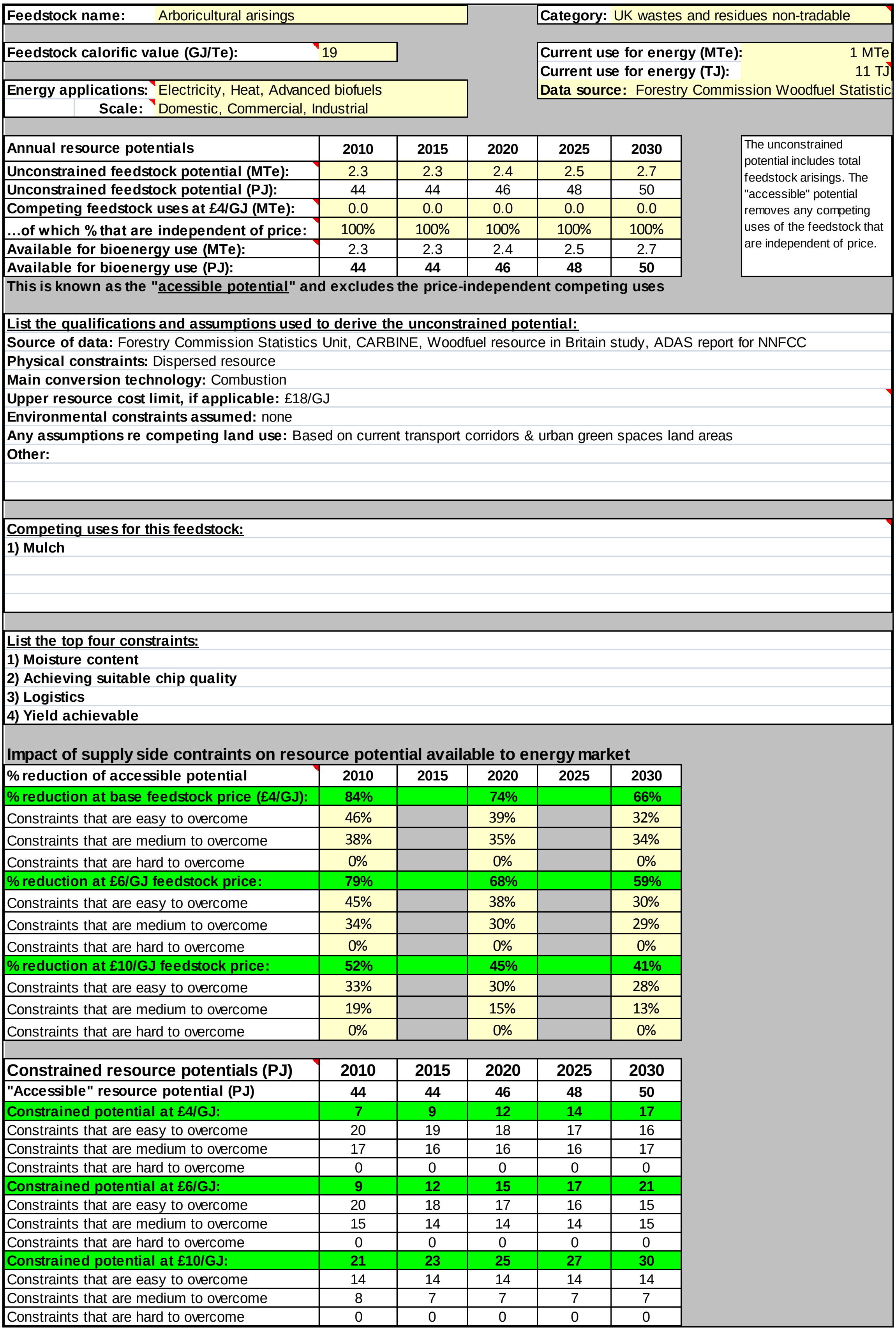
- Lack of local demand – this is the type of demand that might stimulate local investment in feedstock supply
- Cash flow issues
- Immature supply chain (mainly related to the dispersed resource and the lack of infrastructure for bringing it together for processing)
- Insufficient returns on the investment needed, related to substantial upfront investment. Lack of grants for capital investment
- Planning constraints (in particular related to the need to air dry the feedstock)
- Cost of certification for sustainability

The combined effect of these constraints is estimated to be 20% at £4/GJ, decreasing with time and price to 12%.

This means that to obtain this resource there will need to be a major investment in collection, in facilities for storage and fuel preparation and in ensuring that it is properly separated to ensure contaminants are minimal and the quality of material is reliable.

The immaturity of this option for arboricultural residues means that there are other associated constraints, such as planning issues for storage and processing facilities; the need for capital equipment for processing; the need for long-term stable policies to allow the supply change to grow; and the need to meet certification, sustainability and fuel specification. Although all small constraints they remain important in the short term.

Results



Feedstock name: Arboricultural arisings

Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te): 19

Current use for energy (MTe): 1 MTe
Current use for energy (TJ): 11 TJ
Data source: Forestry Commission Woodfuel Statistic

Energy applications: Electricity, Heat, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (MTe):	2.3	2.3	2.4	2.5	2.7
Unconstrained feedstock potential (PJ):	44	44	46	48	50
Competing feedstock uses at £4/GJ (MTe):	0.0	0.0	0.0	0.0	0.0
...of which % that are independent of price:	100%	100%	100%	100%	100%
Available for bioenergy use (MTe):	2.3	2.3	2.4	2.5	2.7
Available for bioenergy use (PJ):	**44**	**44**	**46**	**48**	**50**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "acessible potential" and excludes the price-independent competing uses

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: Forestry Commission Statistics Unit, CARBINE, Woodfuel resource in Britain study, ADAS report for NNFCC
Physical constraints: Dispersed resource
Main conversion technology: Combustion
Upper resource cost limit, if applicable: £18/GJ
Environmental constraints assumed: none
Any assumptions re competing land use: Based on current transport corridors & urban green spaces land areas
Other:

Competing uses for this feedstock:
1) Mulch

List the top four constraints:
1) Moisture content
2) Achieving suitable chip quality
3) Logistics
4) Yield achievable

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base feedstock price (£4/GJ):	**84%**		**74%**		**66%**
Constraints that are easy to overcome	46%		39%		32%
Constraints that are medium to overcome	38%		35%		34%
Constraints that are hard to overcome	0%		0%		0%
% reduction at £6/GJ feedstock price:	**79%**		**68%**		**59%**
Constraints that are easy to overcome	45%		38%		30%
Constraints that are medium to overcome	34%		30%		29%
Constraints that are hard to overcome	0%		0%		0%
% reduction at £10/GJ feedstock price:	**52%**		**45%**		**41%**
Constraints that are easy to overcome	33%		30%		28%
Constraints that are medium to overcome	19%		15%		13%
Constraints that are hard to overcome	0%		0%		0%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	**44**	**44**	**46**	**48**	**50**
Constrained potential at £4/GJ:	**7**	**9**	**12**	**14**	**17**
Constraints that are easy to overcome	20	19	18	17	16
Constraints that are medium to overcome	17	16	16	16	17
Constraints that are hard to overcome	0	0	0	0	0
Constrained potential at £6/GJ:	**9**	**12**	**15**	**17**	**21**
Constraints that are easy to overcome	20	18	17	16	15
Constraints that are medium to overcome	15	14	14	14	15
Constraints that are hard to overcome	0	0	0	0	0
Constrained potential at £10/GJ:	**21**	**23**	**25**	**27**	**30**
Constraints that are easy to overcome	14	14	14	14	14
Constraints that are medium to overcome	8	7	7	7	7
Constraints that are hard to overcome	0	0	0	0	0

Constraints

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	4%	4%	4%	3%	3%	2%	35%	35%	25%	4%	3%	2%	**46%**	**45%**	**33%**
Medium	8%	5%	3%	1%	0%	0%	25%	25%	15%	4%	4%	1%	**38%**	**34%**	**19%**
Hard	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	**0%**	**0%**
Sum	12%	9%	7%	4%	3%	2%	60%	60%	40%	8%	7%	3%	84%	79%	52%

Feedstock name: Arboricultural arisings

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	4%	3%	1%	3%	2%	1%	35%	32%	29%	4%	2%	1%	**46%**	**39%**	**32%**
Medium	8%	7%	6%	1%	0%	0%	25%	25%	25%	4%	3%	3%	**38%**	**35%**	**34%**
Hard	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	**0%**	**0%**

References for all wood biomass

E4Tech (2009) Biomass supply curves for the UK

Kilpatrick *et al* (2008). Addressing the land use issues for non-food crops, in response to increasing fuel and energy generation opportunities. NNFCC project 08-004

Forestry Facts and Figures 2009 Forestry Commission Economics & Statistics Unit www.forestry.gov.uk/pdf/fcfs209.pdf/$file/fcfs209.pdf

Forest Research Carbine model.

Halsall L, Gilbert J & Matthews R(2005) UK forecast of softwood availability www.forestry.gov.uk/pdf/pf2005.pdf/$FILE/pf2005.pdf

Harrison A. Short rotation forestry. Presented at the NNFCC event on the impacts of land use change: myth or reality January 2010. http://www.nnfcc.co.uk/NNFCC/ViewEvent.aspx?id=915

HMRC UK TradeInfo www.uktradeinfo.com

LTS (2006) A Review of the Potential Impacts of Short Rotation Forestry http://www.forestry.gov.uk/pdf/SRFFinalReport27Feb.pdf/$FILE/SRFFinalReport27Feb.pdf

McKay H, Hudson JB, Hudson RJ (2003) Woodfuel resource in Britain; Final report by Forest Research www.biomassenergycentre.org.uk/pls/portal/url/ITEM/79AC345DE5D9CDCAE04014AC08045CE3

Tubby, I (2010) Personal Communication.

Chapter 2: Agricultural resources

Agricultural resources – Summary of assumptions and results

Agricultural resources are those resources that would be produced by farmers on agricultural land. The first of these are residues that are already produced but would need to be harvested, collected and stored. The other agricultural resources are energy crops, which can be grown on spare agricultural land.

Figures 5 and 6 show the UK feedstock availability at £4/GJ and £10/GJ. They show that energy crops could become an increasingly important agricultural resource in the UK, particularly if a high price for the feedstock is available and if constraints are met. The reason for the lack of difference between energy crops (1) and (2) for £4/GJ is due to constraints on planting rate.

Figure 5 Agricultural feedstocks in the UK available at £4/GJ, no constraints addressed for: (1) energy crops maximum scenario; (2) 1G biofuels maximum.

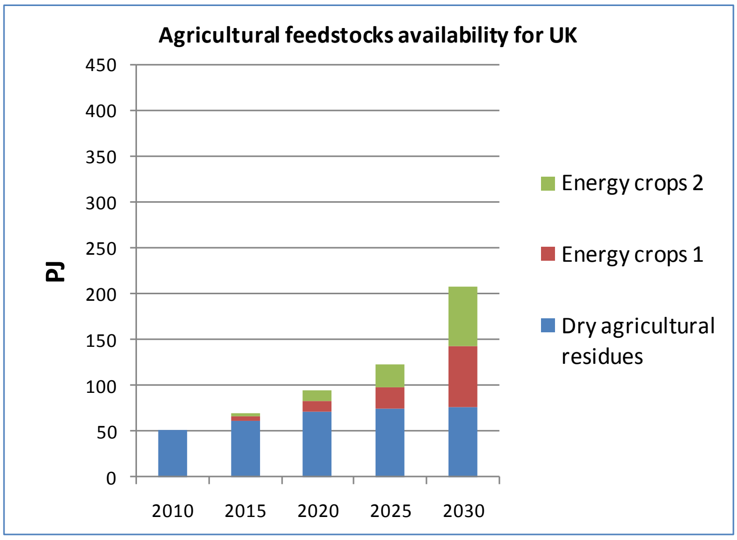
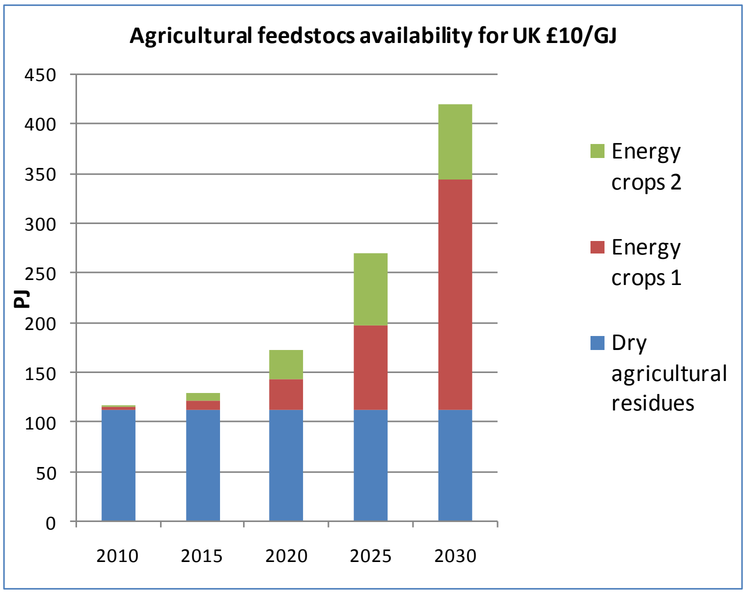


Figure 6 Agricultural feedstocks in the UK available at £10/GJ easy and medium constraints met for (1) energy crops maximum scenario; (2) 1G biofuels maximum.



Dry agricultural residues

Summary of assumptions and results

<table>
<tr><td>Unconstrained Potential

Total resource:

11.1Modt
(211 PJ)

Total avalable resource:

6.0Modt (113PJ)</td><td>Assumptions

Total Resource:

Dry agricultural residues that could be used for bioenergy and quantities produced are:

• Straw: 11.9 – 13.9 Mt
• Seed husks and hulls 1.4Mt
• Chicken litter 1.1 M odt

The above estimates for straw include oil seed rape straw. We have assumed that this straw would not be used because of its combustion characteristics. Taking 2.5mt of OSR from the total straw figures and then averaging the result provides an estimate of 10.4Mt. Assuming that this is 15% moisture leaves an estimated resource of 8.8Modt for straw.

Straw availability can vary as much as 30% with harvest.

We have also assumed 15% moisture for seed husks and hulls, leaving a resource of 1.2Modt.

Adding the dry agricultural resources together provides an unconstrained resource of 11.1Modt/y.

Total resource assumed to remain constant over time.</td></tr>
<tr><td>Competing uses</td><td>Competing uses are:

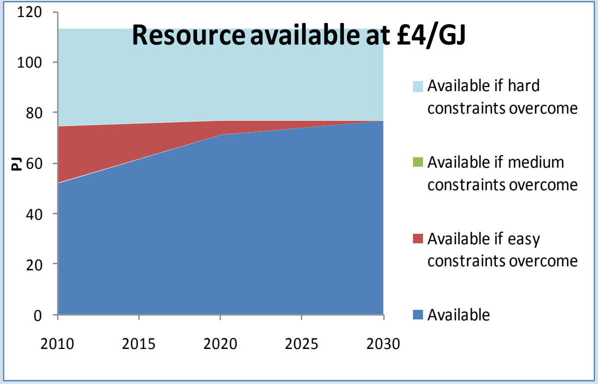
• Straw: animal bedding: 5.8Mt (4.9Modt/y)
• Straw: use for animal feed: 2Mt (1.7M odt/y)
• Seed hulls and husks: feed: all of the resource is used for feed
• Chicken litter – none.

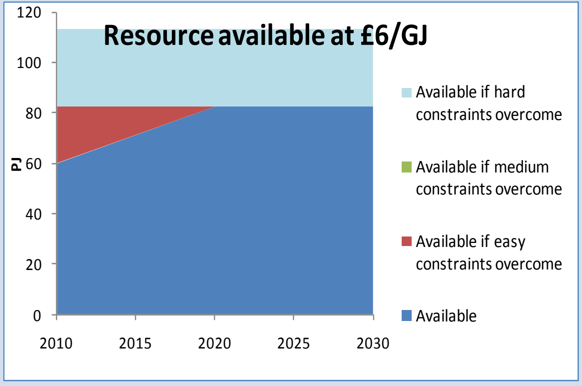
Assumed that of the competing uses for straw, 34% are price dependent, i.e. that portion could be made available for bioenergy at a price of £4/GJ or above</td></tr>
<tr><td>Constraints:</td><td><i><u>Easy to overcome</u></i>
Dispersed nature of resource compared to demand

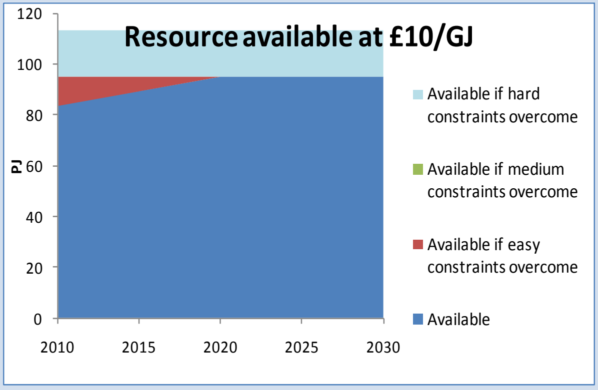
- Lack of long term stable policies to enable investment (perceived financial risks).
- Regulatory and political uncertainty
- Lack of grants for capital investment for supply (e.g. storage/processing facilities).
- Lack of storage and processing facilities.

Overall these constrain resource by 20% at price of £4/GJ in 2010; it is assumed that time and increased feedstock price would reduce these constraints</td></tr>
</table>

	Hard to overcome - Competition for feedstock - Poor yields in some years (straw) - Concerns about impact of bioenergy on prices of other uses. - Dispersed nature of resource that is not currently being utilised (poultry litter). Overall these constrain resource by 34% at price of £4/GJ in 2010; constraints are reduced by price (to 16% at £10/GJ) but do not decline with time.
Cost	Cost of harvesting, baling, storage and transport are major issues. ADAS estimated £35/t would bring half the straw resource to market (~£2.6/GJ) and that at £60/t (~£4.5/GJ) only 2% of farmers would not bale and remove straw.
Results	


Resource available at £4/GJ


Resource available at £6/GJ


Resource available at £10/GJ

Additional details

The feedstocks detailed here are:

- Dry agricultural residues such as straw and chicken litter
- Energy crops, which can be grown on fallow or low grade agricultural land.

Dry agricultural residues

Resource assumptions

The main dry agricultural residue available in the UK is straw. However, there are also quantities of residue produced during the processing of grains and oils in the UK. These include wheat milling residues, seed husks (such as pea and bean hulls and oat husks) and other materials and screenings etc (including linseed chaff, lupin pods etc). In addition there is also a significant amount of chicken litter which can be used as an energy feedstock.

Each of these feedstock is examined separately below and then the total available and the assumptions made in our analysis is summarised.

Seed husks and hulls

ADAS have examined the availability of seed husks and hulls for work being undertaken for NNFCC (ADAS 2010, which draws on sources such as Nabim, Defra and feed statistics). This analysis estimates the total annual volume of see husks/bran and milling co-products to be 1.4Mt. In addition there are some 4000t of bean hulls.

Currently the majority of this resource has a market as animal feed, valued at around £70-90/t. However, it is ADAS' view that competition from the fuel market would simply result in high feed prices, particularly where the feed is a valuable source of protein (such as wheat milling co-products). Thus there is no practical resource available in the current market.

In our analysis in we have assumed a CV of 18 GJ/t, and a moisture content of 15%, taking this assumption from data on straw.

Straw

There have been a number of studies on the availability of straw for bioenergy, starting in 1995 with work by Northern Straw and most recently work by ADAS (2008). The issue with straw is that the yield varies according to harvest conditions and, as wheat yields have been improved, the yield of straw has not necessarily improved in line with grain yields (because the improvements have resulted in higher grain, but shorter straw). Thus there is a potential variation year on year of up to 30% in the availability in straw.

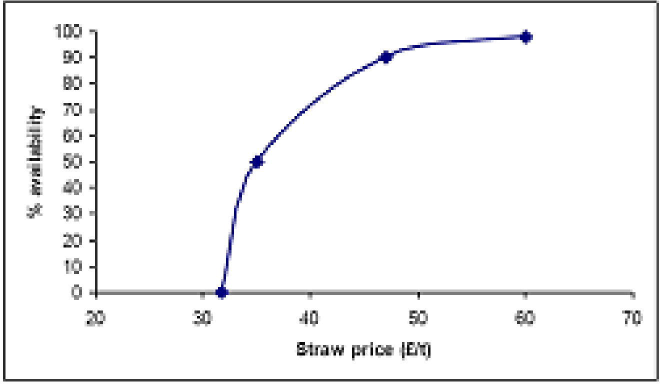
ADAS (2008) indicate that the average harvestable yield of straw in the UK over the past five years is 8.4Mt/y for wheat, 3.2Mt/y for barley and 2.3Mt OSR (total: 13.9Mt/y). Around 5.8Mt/y is used for livestock feed and bedding. The remainder is mostly incorporated into the soil and represents a resource of 8.1 M odt/y (ADAS 2008). We have assumed that straw has a CV of 18GJ/t and is available at 15% moisture (although Northern Straw (1995) state it varies between 15 and 25% moisture).

ADAS also point out that there are important issues with the logistics of collection and labour requirements and that poor weather affects use and can influence the amount available significantly. In addition the value of straw as a source of fertiliser is important and represents cost savings to the farmer. ADAS estimate that an average price of £35/t would bring approximately half the straw (~4Mt/y) to market. Even at £60/t there would be some growers (2% of growers would not bale and remove straw because of the beneficial effect its incorporation has on soil quality).

Although there are significant quantities of oil seed rape (OSR) straw produced, it is a difficult straw to harvest and most of it is incorporated into the soil. Data on its combustion characteristics also mean that it is not a good fuel for combustion, so we have excluded OSR straw from our analysis. However, ADAS do point out that it could be a useful residue (ultimately) for second generation biofuels production.

Major competition may come from fertiliser value in straw, as the cost of artificial fertiliser is increasing. This means when the value of straw is low on the open market it may not be worth harvesting it. ADAS analysis of the effect of fertiliser value on wheat straw availability is shown in Figure 7 (barley and OSR straw is worth more). As they point out, if artificial fertiliser prices increase this supply curve may change.

Figure 7 Example wheat straw price supply curve (ADAS 2008).



In addition ADAS note an interesting statistic from 2008. In this year set aside was set to 0% and the amount of straw increased by 1.19Mt. They estimate that if the same area were to be brought back into simple wheat/OSR rotation assuming straw yields of 4 and 4.2 t/ha this could result in an additional future resource of 1.21 m odt/y (592000t wheat straw and 621,000t OSR straw).

In another recent analysis CSL (2008) provide an estimate for straw production in the UK of around 11.9 Mt/y, of which 54% is wheat straw; 21% is oil seed rape straw; 20% is barley straw; and 4% come from oats. Their estimates are similar to ADAS, but they estimate lower livestock use at around 3.7Mt (presumably this is because ADAS include the whole bedding and feed market). Taking out the livestock use, this leaves an availability of around 5.7 Mt/y. CSL also estimate that mushroom growers use a further 40,000t/y. They conclude that ‘even if a significant proportion of the available barley straw went into animal diets it’s likely that around 2-3Mt of straw are surplus to current animal and biomass energy demands and is available for further bioenergy use.’

These figures can be compared to those from (Stott, 2003), which found that between 7 and 11.6 Mt of straw are produced in the UK, depending on estimated yield per ha (estimated yields ranged from 3.4 to 5.8/ha). Taking account of straw baled for sale and ploughed in this study estimated that 30% of straw is potentially available for energy use, some 2.1 to 3.5Mt/y. These figures are in line with those estimated above. Further information from Northern Straw (1995) indicated that in that year 12.5Mt straw was produced and competing uses (bedding, feed etc) were 8.56 Mt. This leaves a resource of around 3.9Mt/y for potential energy use.

To obtain an estimate of straw availability we have assumed:

- The resource of OSR straw (equivalent to around 2.5Mt/y) is not available for energy
- We have taken 2.5Mt/y of OSR straw from the above estimates and the averaged the amount of straw produced to obtain an unconstrained resource estimate of 10.4Mt. Assuming that this is 15% moisture, this provides an unconstrained resource of 8.8M odt/y.

Competing uses are:

- Animal bedding, assumed to use around 5.8Mt/y (4.9M odt/y)
- Feed: assumed to be 2Mt/y (1.7M odt/y)

Of these competing uses we have assumed that 34% are price dependent (i.e. would become available if the price were right).

Chicken litter

The other dry agricultural residue that is used for energy in the UK is chicken litter. Estimates of the amount of chicken litter vary: the Biomass Energy Centre (BEC, 2010) provides a figure of around 3.5Mt of poultry droppings produced in the UK each year, although this probably includes wet manures that are more suited to anaerobic digestion. The Biomass Strategy provides an estimate of 1.1Mdry t/y for poultry litter (at 60% dry matter) and this is similar to earlier estimates that indicated that there are some 1.4Mt (Dagnall, 1993) of chicken litter that can be considered for energy use in the

UK. For this report we have used the Biomass Task Force figures, which equate to 15,385 TJ. Table 3 shows that a significant proportion of the resource is already used (0.76Mt).

The combustion technology for the use of chicken litter must take the characteristics of the chicken litter into account (issues include the high ash content, relatively high moisture content and low CV as delivered), but this technology is well proven and has been demonstrated in the UK. In our analysis we have assumed the CV for chicken litter on dry weight basis is 19GJ/odt (Net CV (as received) 13.5 GJ/t) (DTI 1999).

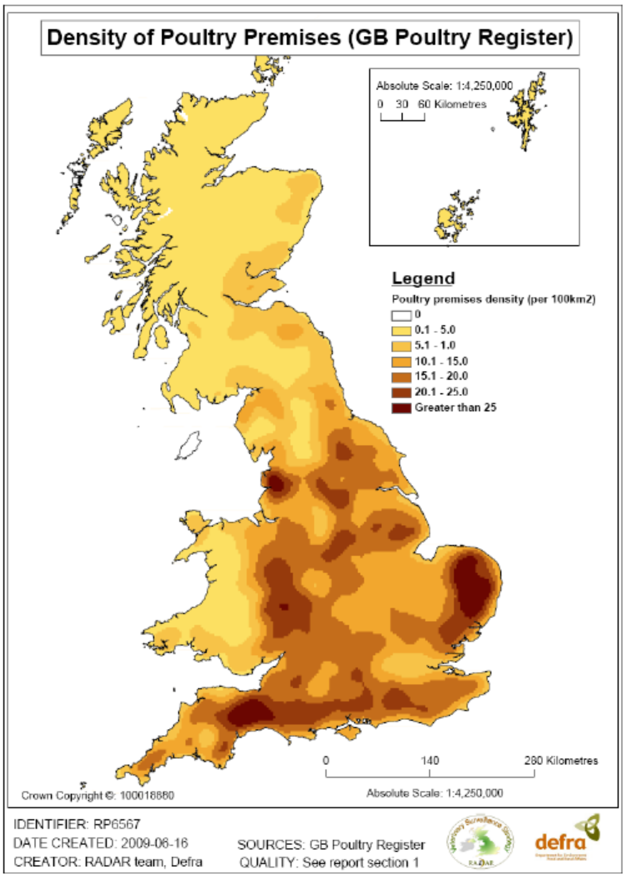
The material is less dense than straw and in the region of three times as many vehicle movements are required. In addition, because of the odour issues, the current plant operators have specially designed vehicles to prevent odour issues in transport. Thus the price of feedstock is highly dependent on transport costs; material is typically gathered from within 40km and an indicative price for poultry litter is £10/odt.

Poultry litter comes under the Waste Incineration Directive for the purposes of combustion. This also adds to the capital cost of plant development, but for the current plants has enabled the operators to co-combust the chicken litter with other similar wastes that also come under WID, so income can be gained from the gate fee.

There are large differences in poultry numbers across the country (see Figure 8). However, this does not differentiate between layers and broilers and it is not possible to understand the density of chicken litter from this map.

The current chicken litter plants are situated in the areas where the poultry population is highest, and these plants have contracts with the major producers. According to Defra and UK Agriculture figures the population of poultry in the UK has not changed significantly over the past 10 years. Consequently we have assumed that poultry litter will not increase over the 2010-2030 period.

Figure 8 Density map of poultry keeping premises (Defra 2009)



Current use of dry agricultural residues for energy

Table 3 Use of dry agricultural residues in the UK

Plant	Capacity (MWe)	Tonnage/y (Chicken litter unless otherwise stated)
Eye	12.7	140,000
Thetford	38.5	420,000
Glanford	13.5	89,000 Meat and bone meal (MBM)
Westfield	9.8	110,000
Ely	38	200,000 Straw
Total resource demand	**760,000t chicken litter, 200,000t straw and 89,000t MBM**	

Constraints for dry agricultural residues

There are a number of constraints on the availability of dry agricultural residues, some of which have been hinted at above. For example, the resource tends to be highly dispersed and there are competing uses. Transport constraints are particularly important for chicken litter. These constraints may be affected by the price that is paid for the feedstock.

In addition there are issues with public perception of the combustion plants, which means that it may not always be possible to site a plant in the most convenient location for the resource (or even to get planning permission at all) (Howes et al, 2001). These factors add to the perception of risks by farmers/suppliers and financiers. In this case it is important to have a clear and stable policy environment to encourage bioenergy in order to provide stability and decrease the perceptions of risk.

We have divided these risks into those that are relatively easy to address and those that are more intransigent and may have long term impact on supply:

Constraints that are easy to overcome

- Dispersed nature of resource compared to demand
- Lack of long term stable policies to enable investment (perceived financial risks).
- Regulatory and political uncertainty
- Lack of grants for capital investment for supply (e.g. storage/processing facilities).
- Lack of storage and processing facilities.

Overall these constrain resource by 20% at price of £4/GJ in 2010; it is assumed that time and increased feedstock price would reduce these constraints

Constraints that are hard to overcome

- Competition for feedstock – there are good traditional markets for some of these agricultural residue feedstocks, some of which are integrated into agriculture and represent a significant constraint on availability.
- The poor yields of straw in some years, which affects all uses and results in rapid price increases.
- Concerns about impact of bioenergy on prices of other uses i.e. the impact of bioenergy demand on straw prices, which may result in significant lobbying.
- Dispersed nature of resource that is not currently being utilised (this is particularly important for poultry litter).

Overall these constrain resource by 34% at price of £4/GJ in 2010; constraints are reduced by price (to 16% at £10/GJ) but do not decline with time.

Results

Feedstock name: Straw and dry agricultural residues

Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te): 19

Current use for energy (MTe): 0.9Mt
Current use for energy (TJ): 17,100 TJ
Data source: EPRL

Energy applications: Electricity, Heat,
Scale: Domestic, Commercial, Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (MTe):	11.1	11.1	11.1	11.1	11.1
Unconstrained feedstock potential (PJ):	211	211	211	211	211
Competing feedstock uses at £4/GJ (MTe):	7.8	7.8	7.8	7.8	7.8
...of which % that are independent of price:	66%	66%	66%	66%	66%
Available for bioenergy use (MTe):	6.0	6.0	6.0	6.0	6.0
Available for bioenergy use (PJ):	**113**	**113**	**113**	**113**	**113**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "acessible potential" and excludes the price-independent competing uses

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: ADAS 2008, UKERC 2010, Defra 2007
Physical constraints: logistics of collection, labour requirements, poor weather; transport for chicken litter.
Main conversion technology: Combustion
Upper resource cost limit, if applicable: £45/t (£2.5/GJ) - when straw reaches this price and above there is likely to be a shortage of
Environmental constraints assumed: Incorporation of approximately 30% of straw for fertiliser value and to aid soil structure
Any assumptions re competing land use: None as straw is residue from arable crops.
Other:

Competing uses for this feedstock:
1) Livestock feed and bedding.
2) Soil incorporation
3) Mushroom growers

List the top four constraints:
1) Competition for feedstock from other uses limits availability to energy. Particularly as the competition is either not price constrained or is
2) Lack of stable renewable energy policy - nobody will invest in straw energy without a stable policy regime.
3) Concerns about logistics of collection and storage
4) Concerns about transport of straw, ralated to restrictions on how far it can be transported.

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base feedstock price (£4/GJ):	**54%**		**37%**		**32%**
Constraints that are easy to overcome	20%		5%		0%
Constraints that are medium to overcome	0%				
Constraints that are hard to overcome	34%		32%		32%
% reduction at £6/GJ feedstock price:	**47%**		**27%**		**27%**
Constraints that are easy to overcome	20%		0%		0%
Constraints that are medium to overcome	0%				
Constraints that are hard to overcome	27%		27%		27%
% reduction at £10/GJ feedstock price:	**26%**		**16%**		**16%**
Constraints that are easy to overcome	10%		0%		0%
Constraints that are medium to overcome	0%		0%		0%
Constraints that are hard to overcome	16%		16%		16%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	**113**	**113**	**113**	**113**	**113**
Constrained potential at £4/GJ:	**52**	**62**	**71**	**74**	**77**
Constraints that are easy to overcome	23	14	6	3	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	38	37	36	36	36
Constrained potential at £6/GJ:	**60**	**71**	**83**	**83**	**83**
Constraints that are easy to overcome	23	11	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	31	31	31	31	31
Constrained potential at £10/GJ:	**84**	**89**	**95**	**95**	**95**
Constraints that are easy to overcome	11	6	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	18	18	18	18	18

Constraints

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	10%	10%	5%	5%	5%	3%				5%	5%	3%	**20%**	**20%**	**10%**
Medium													**0%**	**0%**	**0%**
Hard	25%	20%	10%	5%	5%	5%				4%	2%	1%	**34%**	**27%**	**16%**
Sum	35%	30%	15%	10%	10%	8%	0%	0%	0%	9%	7%	4%	54%	47%	26%

Feedstock name: Straw and dry agricultural residues

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	10%	0%		5%	5%		0%			5%			**20%**	**5%**	**0%**
Medium	0%			0%			0%			0%			**0%**	**0%**	**0%**
Hard	25%	25%	25%	5%	5%	5%	0%			4%	2%	2%	**34%**	**32%**	**32%**

References for dry agricultural residues

ADAS (2008) Addressing the land use issues for non-food crops, in response to increasing fuel and energy generation opportunities. NNFCC08 - 004

CSL (2008) National and regional supply/demand balance for agricultural straw in Great Britain. Report for NNFCC

Defra (2007) UK Biomass strategy

Defra (2009) Density of Poultry and Poultry Premises Registered on the GB Poultry Register http://www.defra.gov.uk/foodfarm/farmanimal/diseases/vetsurveillance/poultry/documents/poultry-registered090616.pdf

Dagnall S (1992) Poultry litter as a fuel. Presented at a WPSA UK Branch Symposium held in London on 9 April 1992. World's Poultry Science Journal (1993), 49:175-177

DTI (1999) Energy from biomass: Summaries of biomass projects. Volume 5: Straw, poultry litter and energy crops as energy sources. ETSU BM/04/00056/REP/3

P S Howes *et al*.(2001) Comparison of public acceptability of energy from waste and energy from biomass in 5 EU states. Available from AEA Technology (P S Howes) or Environment Agency R&D Technical Report P1-404

Stott (2003) Straw availability in the UK

Energy Crops

Summary of assumptions and results

Unconstrained Potential

Total resource:

4 to 15 M odt

(76 to 282 PJ) in 2030 depending on land availability scenario

Assumptions

Land availability

Land availability for the period up to 2020 is based on an estimates of land not required for food or feed from Kilpatrick (2008) and for 2030, an estimate of ex-arable i.e. land and which becomes available as yields increase and less land is required to meet food and feed demands. No planting of energy crops on pasture land is considered.

Two scenarios for future use of this 'spare' land are considered:

- Scenario 1: production of arable crops for biofuels (wheat and OSR) are maximised and energy crops are only grown on land that is unsuitable for energy crops (derived from Kilpatrick, 2008)
- Scenario 2: all spare land is used for energy crops

Area available for planting ('000 ha)		2020	2030
Scenario 1 (max biofuels)	Land for energy crops	296 kha	296 kha
	Land for biofuels	359 kha	644 kha
Scenario 2 (max energy crops)	Land for energy crops	655 kha	1,100 kha
	Land for biofuels	0 kha	0 kha

Yields:

50% of land is assumed to be planted with SRC and 50% with miscanthus. Yields assumed are shown below

Yield (odt/ha)	2010	2020	2030
SRC	9	11	12
Miscanthus	10	13	15

This gives a total potential resource, if all land identified above could be utilised, of:

Resource potential		2010	2015	2020	2025	2030
Scenario 1	Modt:	0.1	3.2	3.6	3.8	4.0
	PJ	2	60	67	72	76
Scenario 2	Modt:	0.1	7.0	7.9	11.2	14.9
	PJ	2	134	149	213	282

Competing uses

No competing uses assumed for feedstock, although this could potentially change if the biomaterials market developed in the future.

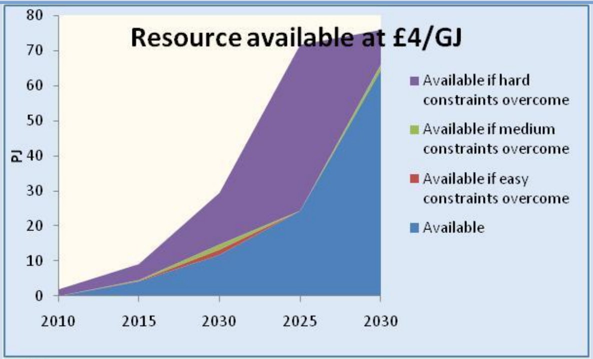
As land availability estimates are based on 'set-aside' or land which is not required to meet food and feed requirements, there is no completion with food and feed. Competing use of the land for biofuels feedstocks production has been

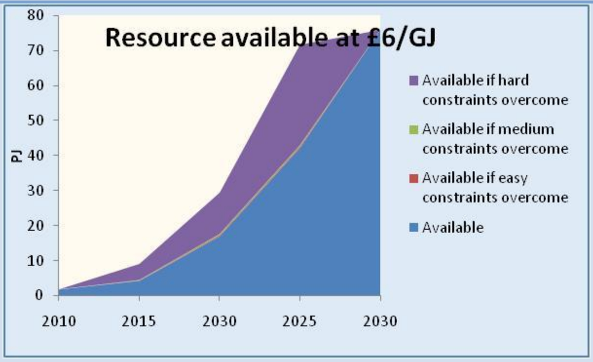
<table>
<tr><td></td><td>considered through the use of two scenarios.</td></tr>
<tr><td>Constraints:
Constrained resource at £4/GJ:
24 to 90 PJ (depending on land availability scenario)
Rises to:
76 to 231 PJ at £10/GJ</td><td>The main constraint, particularly in Scenario 2 where land availability is high, is the maximum rate at which energy crops could be planted. Based on availability of equipment and planting material in the UK, it is estimated that 4,000 ha/year could currently be planted. It is considered that the maximum rate at which this part of the industry could expand, would result in this annual planting area increasing by 20% each year. This would allow planting of the areas shown below
<table>
<tr><th></th><th>2015</th><th>2020</th><th>2025</th><th>2030</th></tr>
<tr><td>Cumulative area planted '000 ha</td><td>42</td><td>131</td><td>352</td><td>902</td></tr>
</table>
Exceeding these planting rates is considered to be difficult and planting rate constraints are considered to be independent of the delivered cost of the biomass. This constraint is therefore included in the modelling as a reduction to the unconstrained feedstock potential. Once the planting rate constraint is included, the available bioenergy potential is obtained.
The available bio-energy potentials calculated are shown in the following table:
<table>
<tr><th colspan="2">Available potential</th><th>2010</th><th>2015</th><th>2020</th><th>2025</th><th>2030</th></tr>
<tr><td>Scenario 1</td><td>Modt:</td><td>0.1</td><td>0.5</td><td>1.6</td><td>3.8</td><td>4.0</td></tr>
<tr><td></td><td>PJ</td><td>2</td><td>9</td><td>29</td><td>72</td><td>76</td></tr>
<tr><td>Scenario 2</td><td>Modt:</td><td>0.1</td><td>0.4</td><td>1.6</td><td>4.5</td><td>12.2</td></tr>
<tr><td></td><td>PJ</td><td>2</td><td>8</td><td>30</td><td>85</td><td>231</td></tr>
</table>
Available bio-energy potentials once planting rates are taken into account
In Scenario 1, the planting rate is a significant constraint up to 2020, but not after this. In Scenario 2, where more land is available for energy crops, planting rates significantly constrain the resource up to 2025, and even in 2030, only allow planting of 80% of the potential land available.
There are few constraints for energy crops that fall into the easy/ medium to overcome category. The main other constraints are the attitude of farmers to energy crops due to the long term nature of the crops and their past poor experiences with energy crops, and the uncertainty in the market associated with changes to policy and unknown way in which sustainability requirements will develop. These constraints are thought to be hard to overcome, but can be influenced by the price paid for the biomass. In general terms, £4/GJ is considered to be insufficient to encourage energy crop production even with otherwise supportive policies and market. At £6/GJ farmers would consider the crops if the policy and market was otherwise advantageous. However, uptake is likely to be quite slow, as farmer wait to see how the crop performs and market develops. At £10/GJ farmers are likely to think the crop may be worth the risk. At 310/GJ production in both scenarios will therefore be constrained only by planting rate.</td></tr>
<tr><td>Cost</td><td>At present this resource is typically available (when supplied in bulk) at about £6/GJ. As discussed above, £6/GJ is considered to be marginal for the farmer to consider it profitable, and production will only occur where this is low risk. To</td></tr>
</table>

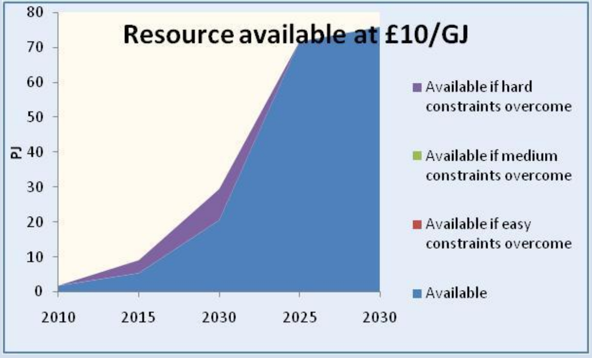
	obtain substantial increases in capacity in the short term, higher prices are therefore required for energy crops in the UK.

Results

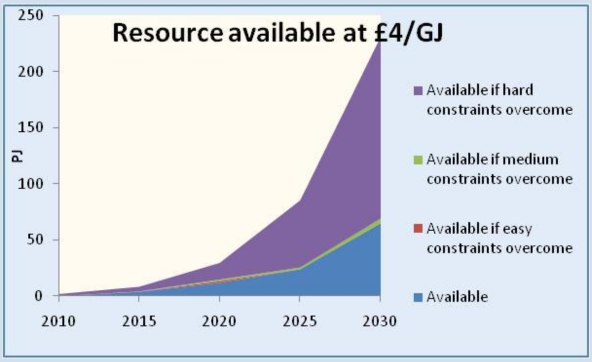
Graphs showing results for £4, £6 and £10/GJ for energy crops, scenario 1

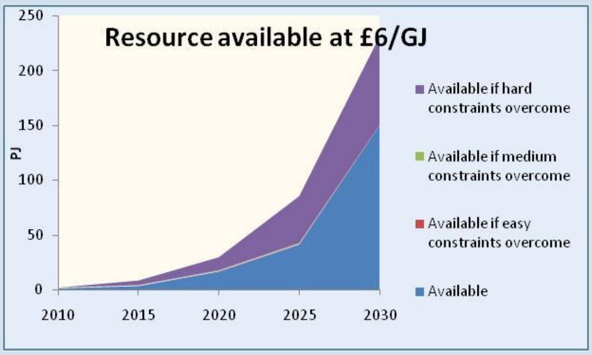


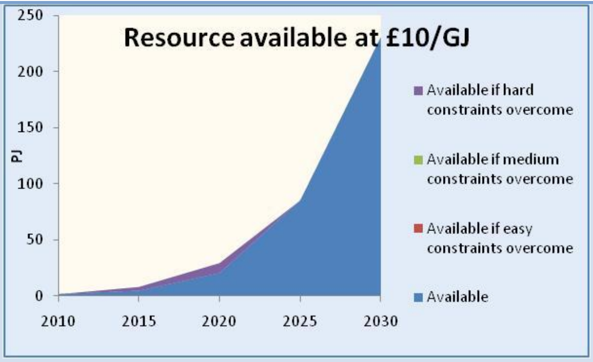




Graphs of results for £4, £6 and £10/GJ for Energy crops, scenario 2







Additional details

Energy crops

Resource estimates

Energy crops have been considered as a feedstock for bioenergy in the UK since the early 1990s. Energy crops in the UK fall into 2 categories:

- Perennial woody/ grassy crops grown on short rotations (1-3 years)
- Single stem trees grown on short rotation, Short Rotation Forestry. (10-20 years)

Perennial woody/ grassy crops are not currently widely grown in the UK, despite a number of initiatives from the Government to promote production. This suggests there are a number of constraints to energy crop production, and these are discussed in the constraints section below.

SRF is at an early stage of development in the UK. Trials are in progress, and current advice is that SRF could be grown on rough pasture or existing forestry land. It will therefore not compete for land with perennial woody/ grassy crops which could be grown on arable land or temporary pasture, and can be considered an additional resource in the UK. This resource is assessed elsewhere (in the wood fuel section).

In addition there are annual food, feed or fodder crops that can be grown for energy purposes if the price is right. These have been considered for their potential use for biofuels elsewhere in this report (in the biofuels section).

Perennial energy crops under consideration in the UK

AEA has recently reviewed the perennial energy crops suitable for production in the UK (AEA 2010). This confirmed that SRC willow, SRC poplar and miscanthus, the best developed energy crops to date, are still the most suitable for energy crop production in the UK. These are the crops that will be considered in this section. In addition, it was noted that the energy grasses switchgrass and reed canary grass also had potential.

Switchgrass and RCG have similar agronomic requirements to SRC and miscanthus. If energy crops were grown on all suitable and available land were, switchgrass and RCG would not increase the total potential area of energy crops grown, although their inclusion would lead to greater crop diversity. Currently yield of switchgrass is similar to that of miscanthus, and RCG shows lower yields, so total biomass production would not increase by switching from SRC/ miscanthus to these crops.

The energy crop potential assessed using SRC/ miscanthus would therefore not change significantly if switchgrass/ RCG were included in the energy crop mix.

Important parameters determining energy crop potential in the UK

The technical potential for energy crops in the UK is determined by

- Amount of suitable land available for energy crop production
- The yield/ ha achievable for the energy crop at a specific location and time.

Amount of suitable land available

The energy crops SRC, miscanthus, switchgrass and reed canary grass can all be grown on arable land or temporary pasture land in the UK, which gives a theoretical upper limit on the area of energy crops in the UK.

A number of recent studies have estimated the amount of suitable land that would actually be available in the UK for energy crops. These estimates include varying levels of environmental constraints, and various assumptions about alternative land uses. A summary is given in the table below.

Table 4 Summary of available land for energy crops

Study	Available land in England and Wales, million ha	Major assumptions
Bond, 2009. RELU	0.5-1	Available land is in ALC categories 3 and 4, with added constraint of no pasture land included. No timeframe given.
ADAS 2008. Bioenergy mapping review for EA	0.4	10% of agricultural land available for energy crops
Aylott 2008. Yield and supply of SRC	1.3	10% arable land+ 20% improved grassland+ 100% abandoned grassland. No timeframe given.
Kilpatrick 2008. Land use of non- food crops	0.7	5% arable land+ land in bare fallow+ excess temporary grassland. Also estimates 1.8 million ha of permanent grassland/ rough grazing would be available for SRF.
E4Tech, 2008. Biomass supply curves in the UK. (data from EU Refuel project)	1.1 from excess arable land 1.2 from excess pasture	These are estimates for 2030.

Although the assumptions made very from case to case, the estimates are generally made up by

- assuming that arable land/ temporary pasture is suitable for energy crops
- estimating excess arable land and allocating this to energy crops (this tends to be in ALC 3 and 4)
- Adding environmental constraints- the most important of which is whether grassland can be converted to energy crops.

If grassland is excluded, as seems likely post RED implementation, then a range of 0.4-1.3 M ha is available. For the E4Tech (2008) work this corresponds to scenarios central RES and High sustainability, which give a more realistic potential for energy crops for 2030.

Timescales are not given, but we have interpreted these as estimates for up to 2030.

Yields

Current estimates of yields of energy crops in the UK are based on data from a limited number of field trials and empirical modelling. Empirical modelling of yields includes the effects of soil type and climate. Current ranges for yield are large, as shown below.

Table 5 Summary of yields for energy crops

Study	Energy crop	Yield range, odt/ha/y	Comments
ADAS 2008. Bioenergy mapping review for EA	Miscanthus	6.9-24.1	ADAS model
FR, 2009	SRC	8-10	
Aylott 2008. Yield and supply of SRC	SRC	4.9-10.7 9 average for willow 6.3 average for poplar	Measured yields less than 50% of potential yield.
Richter, 2008.	Miscanthus	5-18 9.6 national average	Empirical model based on UK field data. Yield v sensitive to water availability.
NIX 2009	Miscanthus	12-15 Average 13	Yield for mature crop
	SRC	7-9 Average 8.3	Yield for mature crop

Current average yield is estimated to be 10odt/ha/y for miscanthus and 9 odt/ha/y for SRC willow. It should be noted that achieving or exceeding these yields depends on

- Good establishment, especially weed control and ground preparation.
- Suitable land and climate for crop, especially water availability.

The energy crops are relatively unimproved and current and modelled yields of SRC are less than 50% of potential yield (Aylott, 2008). There is therefore potential for steep increases in yields of energy crops on a time frame up to 2050. This would depend on continued investment in breeding programmes and field trials. Table 4 shows the yield increases used in this work.

Table 6 Yield increases assumed in this analysis

Yield (odt/ha)	2010	2020	2030
SRC	9	11	12
Miscanthus	10	13	15

Estimates of potential

Current levels of Energy crop production in the UK are very low. Latest estimates are 6,000ha miscanthus (NIX, 2010), and 3,000ha SRC (FR, 2009). At current yields this gives 60,000odt/y miscanthus and 27,000 odt/y SRC, or less than 0.1 million odt/y energy crops in total.

The following assumptions are made to calculate resource in 2020 and 2030

- 50% of the available and suitable land is used for SRC and 50% for energy grasses
- the current average yield for miscanthus is 10 odt/ha/y and for willow is 9 odt/ha/y
- 0.7 million ha of land is available in 2020, rising to 1.1million ha in 2030

- SRC yield rises to 11odt/ha/y by 2020 and 12 odt/ha/y by 2030
- Miscanthus yield rises to 13odt/ha/y by 2020 and 15odt/ha/y by 2030

Table 7 Estimates of energy crop potential in 2020 and 2030.

Energy crop	2020 potential, million odt	2030 potential, million odt
Miscanthus	4.6	8.3
SRC willow	3.8	6.6
Total	**8.4**	**14.9**

The potential land available for energy crops is also limited by competition for some of the land identified as suitable for energy crops with the potential for growing biofuels crops on this land. We have taken this into account by examining two scenarios in this work:

- **Scenario 1** maximizes the potential to grow first generation biofuels crops. In this scenario the land allocated to SRC and miscanthus is land not suitable for the other crops: the remaining available land is used for OSR and wheat production. For 2030, the total potential for OSR, sugar beet and wheat in scenario 1 is the current production for bio-energy plus the additional production for the extra land available (as indicated above).

- **Scenario 2** maximizes the potential to grow lignocellulose energy crops. For this scenario, all suitable land is used for energy crops; no additional land is used for wheat, sugar beet or OSR, and the energy potential is based on current production for biofuels and the current wheat surplus.

The total areas assumed for energy crops and biofuels crops are shown in Table 8.

Table 8 land availability for energy crops or biofuels in the scenarios examined in this work

Area available for planting ('000 ha)		2020	2030
Scenario 1 (max biofuels)	Land for energy crops	296 kha	296 kha
	Land for biofuels	359 kha	644 kha
Scenario 2 (max energy crops)	Land for energy crops	655 kha	1,100 kha
	Land for biofuels	0 kha	0 kha

In reality these scenarios provide for two extreme positions and the reality will lie between the two.

Table 9 shows the results for the unconstrained resource potential based on the assumptions outlined above.

Table 9 Unconstrained resource potential

Resource potential		2010	2015	2020	2025	2030
Scenario 1	**Modt:**	0.1	3.2	3.6	3.8	4.0
	PJ	2	60	67	72	76
Scenario 2	**Modt:**	0.1	7.0	7.9	11.2	14.9
	PJ	2	134	149	213	282

Constraints for energy crops

We have identified a number of constraints on energy crops. Most important of these are the availability of land (and the type of land) and the attitude of farmers to planting the crops. A further important constraint is the rate at which land could be planted with energy crops. These and other constraints are listed below.

- Amount of arable land available. The above estimates start from the assumption that energy crops can be grown on arable land and that up to 10% of arable land would be available for energy crops. This is based on assumptions on land required in the future for food/ fodder production which normally include assumptions about increased yields of food crops. It also assumes that land not required for food crops is available for perennial energy crops. This is debatable since wheat / OSR/ sugar beet for energy and other non-food crops for non- energy purposes will be competing for the same land resource.

- Use of grassland for energy crops. Current interpretation of RED is that grassland cannot be used for energy crop production. Work in the UK for RELU/ TSEC also states that conversion of grassland to energy crops is counterproductive from a GHG emissions savings perspective. I have therefore assumed that no grassland will be used for energy crops. However, if agreement can be reached on the use of temporary or improved grassland for energy crops, then the land potentially available is much larger, as shown by the E4 Tech analysis. However, this analysis assumes that excess grassland becomes available due to intensification of livestock production.

- Farmer resistance. The Government has been supporting development of energy crops for 15 years in the UK, and to date less than 10,000ha has been planted. There are a number of reasons for this, including wariness of the energy market, poor cash flow and returns on crops, SRC being a very different crop for farmers and bad past experience with crop establishment and yields. However, without farmer acceptance the potential will not be achieved on the timescales required. This constraint is thought to be hard to overcome, but can be influenced by the price paid for the biomass. In general terms, £4/GJ is considered to be insufficient to encourage energy crop production even with otherwise supportive policies and market. At £6/GJ farmers would consider the crops if the policy and market was otherwise advantageous. However, uptake is likely to be quite slow, as farmers wait to see how the crop performs and market develops. At £10/GJ farmers are likely to think the crop may be worth the risk. At £10/GJ production in both scenarios will therefore be constrained only by planting rate.

- Technical ability to plant energy crops at rates required. To achieve 0.7 million ha by 2020, 100,000ha/y of energy crops must be planted. To put this in perspective, oilseed rape planting in the UK was 613,000ha in 2007, so by 2017 energy crops would be as prevalent as OSR in the landscape. Specialist equipment is required for both miscanthus and SRC planting, and for SRC harvesting. Although this is now commercially available, production of such equipment would need to increase dramatically to enable each group of farmers to have access to the required machinery. We have assumed a planting potential of 4000ha/y, which is based on the current availability of equipment and planting material in the UK. It is considered that the maximum rate at which this part of the industry could expand, would result in this annual planting area increasing by 20% each year. This would allow planting of the areas shown in Table 8. Exceeding these planting rates is considered to be difficult and planting rate constraints are considered to be independent of the delivered cost of the biomass. This constraint is therefore included in the modelling as a reduction to the unconstrained feedstock potential. Once the planting rate constraint is included, the available bioenergy potential is obtained.

- On the positive side, energy crops grown in the UK are likely to meet all the environmental and sustainability requirements of RED, and farmers are well used to dealing with agro-environmental schemes.

Table 10 Planting rates for energy crops assumed in this analysis

	2015	2020	2025	2030
Cumulative area planted ‘000 ha	42	131	352	902

No competing uses were assumed for energy crop feedstock, but this could change if a market for biomaterials develops in the future. As the land availability is based on ex set aside or land not required for food and feed requirements, there is no competition for food and feed. Competition of the land for first generation biofuels feedstocks is considered using the scenario analysis described above.

The available bioenergy potentials calculated in the analysis are provided in Table 11. In Scenario 1, the planting rate is a significant constraint up to 2020, but not after this. In Scenario 2, where more land is available for energy crops, planting rates significantly constrain the resource up to 2025, and even in 2030, only allow planting of 80% of the potential land available.

Table 11 Available potential from energy crops in the UK

Available potential		2010	2015	2020	2025	2030
Scenario 1	**Modt:**	0.1	0.5	1.6	3.8	4.0
	PJ	2	9	29	72	76
Scenario 2	**Modt:**	0.1	0.4	1.6	4.5	12.2
	PJ	2	8	30	85	231

Summary

- There is good potential for perennial energy crops in the UK, and up to 8.4M odt/y energy crops could be produced in the UK by 2020.
- There are a number of constraints to energy crop development, including technical constraints and competition for land use. These can be addressed by policy initiatives, but the constraints make it unlikely that the potential can be achieved from the current base by 2020.
- To date farmers have not embraced the opportunity to grow energy crops. The reasons for this are well known, but the potential will not be achieved until farmers concerns and issues are addressed.

Results – Scenario 1

Feedstock name: UK energy crops: scenario 1 (max 1G biofuels c

Category: UK tradeable

Feedstock calorific value (GJ/Te): 19

Current use for energy (MTe): 0 MTe
Current use for energy (TJ): 0 TJ
Data source: xxx

Energy applications: Electricity, Heat, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (MTe):	2.80	3.18	3.55	3.77	4.00
Unconstrained feedstock potential (PJ):	53.20	60.46	67.49	71.71	75.92
Constrained by planting rate (Mte)	2.70	2.74	1.99	0.00	0.00
...of which % that are independent of price:	1.00	1.00	1.00	1.00	1.00
Available for bioenergy use (MTe):	0.10	0.44	1.56	3.77	4.00
Available for bioenergy use (PJ):	**1.90**	**8.38**	**29.64**	**71.71**	**75.92**

This is known as the "acessible potential" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: Kilpatrick 2008, Aylott, 2008
Physical constraints: Planting rate
Main conversion technology: Combustion, gasification or fermentation.
Upper resource cost limit, if applicable: Price of non-energy crop resource +subsidy £8/GJ
Environmental constraints assumed: Water availability
Any assumptions re competing land use: Food and feed crops will be produced first
Other:

Competing uses for this feedstock:
1) Biomaterials

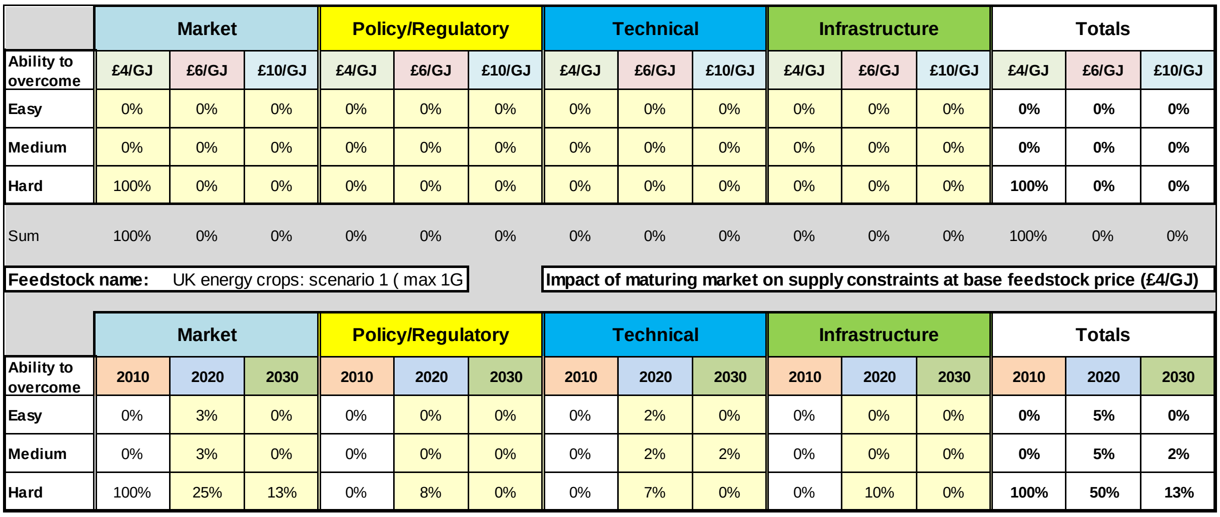
List the top four constraints:
1) Planting rates (material and equipment availability)
2) Farmer attitudes
3) Competition for land use.
4) Sustainability

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base feedstock price (£4/GJ):	**100%**	**54%**	**60%**	**66%**	**15%**
Constraints that are easy to overcome	0%	2%	5%	0%	0%
Constraints that are medium to overcome	0%	2%	5%	0%	2%
Constraints that are hard to overcome	100%	50%	50%	66%	13%
% reduction at £6/GJ feedstock price:	**0%**	**52%**	**42%**	**41%**	**0%**
Constraints that are easy to overcome	0%	1%	1%	1%	0%
Constraints that are medium to overcome	0%	1%	1%	1%	0%
Constraints that are hard to overcome	0%	50%	40%	40%	0%
% reduction at £10/GJ feedstock price:	**0%**	**40%**	**30%**	**0%**	**0%**
Constraints that are easy to overcome	0%	0%	0%	0%	0%
Constraints that are medium to overcome	0%	0%	0%	0%	0%
Constraints that are hard to overcome	0%	40%	30%	0%	0%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	2	8	30	72	76
Constrained potential at £4/GJ:	**0**	**4**	**12**	**24**	**65**
Constraints that are easy to overcome	0	0	1	0	0
Constraints that are medium to overcome	0	0	1	0	2
Constraints that are hard to overcome	2	4	15	47	10
Constrained potential at £6/GJ:	**2**	**4**	**17**	**42**	**76**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	0	4	12	29	0
Constrained potential at £10/GJ:	**2**	**5**	**21**	**72**	**76**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	0	3	9	0	0

Constraints – Scenario 1



	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	**0%**	**0%**
Medium	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	**0%**	**0%**
Hard	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**100%**	**0%**	**0%**
Sum	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%

Feedstock name: UK energy crops: scenario 1 (max 1G

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	0%	3%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	**0%**	**5%**	**0%**
Medium	0%	3%	0%	0%	0%	0%	0%	2%	2%	0%	0%	0%	**0%**	**5%**	**2%**
Hard	100%	25%	13%	0%	8%	0%	0%	7%	0%	0%	10%	0%	**100%**	**50%**	**13%**

Results – Scenario 2

Feedstock name: UK energy crops: scenario 2 (max energy crops)

Category: UK tradeable

Feedstock calorific value (GJ/Te): 19

Current use for energy (MTe): 0.1 MTe
Current use for energy (TJ): 0 TJ
Data source: Nix, Aylott 2008, ADAS, 2008.

Energy applications: Electricity, Heat, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	**2010**	**2015**	**2020**	**2025**	**2030**
Unconstrained feedstock potential (MTe):	6.20	7.04	7.86	11.19	14.85
Unconstrained feedstock potential (PJ):	117.80	133.78	149.34	212.57	282.15
Potential not realised due to planting constra	6.10	6.60	6.30	6.70	2.70
...of which % that are independent of price:	1.00	1.00	1.00	1.00	1.00
Available for bioenergy use (MTe):	0.10	0.44	1.56	4.49	12.15
Available for bioenergy use (PJ):	**1.90**	**8.38**	**29.64**	**85.27**	**230.85**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "<u>acessible potential</u>" and excludes the price-independent competing uses

<u>List the qualifications and assumptions used to derive the unconstrained potential:</u>
Source of data: Kilpatrick 2008, Aylott, 2008
Physical constraints: Planting rate. This is a major constraint that is deemed to be independent of price. It is used to constrain the
Main conversion technology: Combustion, gasification or fermentation.
Upper resource cost limit, if applicable: Price of non-energy crop resource +subsidy £8/GJ
Environmental constraints assumed: Water availability
Any assumptions re competing land use: Food and feed crops will be produced first
Other:

<u>Competing uses for this feedstock:</u>
1) Biomaterials could compete for use of energy crops or for land for other crops. Not included in these estimates

<u>List the top four constraints:</u>
1) Planting rates (material and equipment availability)
2) Farmer attitudes
3) Long term policy including sustainability requirements
4) Inconsistent yields

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	**2010**	**2015**	**2020**	**2025**	**2030**
% reduction at base feedstock price (£4/GJ):	**100%**	**54%**	**60%**	**72%**	**72%**
Constraints that are easy to overcome	0%	2%	5%	0%	0%
Constraints that are medium to overcome	0%	2%	5%	2%	2%
Constraints that are hard to overcome	100%	50%	50%	70%	70%
% reduction at £6/GJ feedstock price:	**0%**	**52%**	**42%**	**51%**	**35%**
Constraints that are easy to overcome	0%	1%	1%	0.5%	0%
Constraints that are medium to overcome	0%	1%	1%	0.5%	0%
Constraints that are hard to overcome	0%	50%	40%	50%	35%
% reduction at £10/GJ feedstock price:	**0%**	**40%**	**30%**	**0%**	**0%**
Constraints that are easy to overcome	0%	0.0%	0.0%	0%	0%
Constraints that are medium to overcome	0%	0.0%	0.0%	0%	0%
Constraints that are hard to overcome	0%	40%	30%	0%	0%

Constrained resource potentials (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**
"Accessible" resource potential (PJ)	**2**	**8**	**30**	**85**	**231**
Constrained potential at £4/GJ:	**0**	**4**	**12**	**24**	**65**
Constraints that are easy to overcome	0	0	1	0	0
Constraints that are medium to overcome	0	0	1	2	5
Constraints that are hard to overcome	2	4	15	60	162
Constrained potential at £6/GJ:	**2**	**4**	**17**	**42**	**150**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	0	4	12	43	81
Constrained potential at £10/GJ:	**2**	**5**	**21**	**85**	**231**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	0	3	9	0	0

Constraints – Scenario 2

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	**0%**	**0%**
Medium	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	**0%**	**0%**
Hard	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**100%**	**0%**	**0%**
Sum	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%

Feedstock name: UK energy crops: scenario 2 (max ener

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	0%	0%	0%	0%	3%	0%	0%	2%	0%	0%	0%	0%	**0%**	**5%**	**0%**
Medium	0%	0%	0%	0%	3%	0%	0%	2%	2%	0%	0%	0%	**0%**	**5%**	**2%**
Hard	100%	40%	60%	0%	8%	8%	0%	2%	2%	0%	0%	0%	**100%**	**50%**	**70%**

References for energy crops

ADAS (2008) Bioenergy review- mapping work ADAS for EA. SC070001/SR

AEA (2010) Applicability of UK derived feedstocks to specific fuel end uses. Report for NNFCC, in progress

Aylott (2008) Yield and spatial supply of bioenergy poplar and willow short rotation coppice in the UK. New phytologist (2008) 178.

Bond (2009) Impacts of UK energy crops. Presentation at RELU meeting

E4Tech (2008) Biomass supply curves for the UK. Report to DECC

Forests Research (2009)Biomass Energy Centre. Information Sheet 3: Short Rotation Coppice

Kilpatrick (2008) Addressing the land use issues for non-food crops, in response to increasing fuel and energy generation opportunities. NNFCC project 08-004

Richter (2008) Is UK biofuel supply from miscanthus water limited? Soil use and management September 2008, 24.

Chapter 3: Biofuels

Summary of assumptions and results

Biofuels resources examined for the UK include first generation biofuels crops (wheat, sugar beet for bioethanol and oil seed rape for biodiesel) and the two other feedstocks for biodiesel, tallow and used cooking oil. The crop resources were examined under two scenarios:
Scenario 1: maximum use of land available to grow first generation biofuels crops
Scenario 2: maximum use of land available to grow energy crops.

The assumptions behind these scenarios are explained under first generation biofuels below, which also shows how available land was calculated.

Summary of results

Results are shown in graphs 9 to 12 below. The graph for Scenario 1 with easy and medium constraints met shows that the UK could produce 48-80 PJ from first generation biofuels crops and up to 17PJ from tallow and UCO if easy and medium constraints are met at the high price modelled for biofuels. The amount produced from 1G crops is much lower in scenario 2 (29PJ, over the whole time period).

Figure 9 Graph showing biofuels availability at low price, no constraints met, Scenario 1 (maximised for first generation biofuel crops)

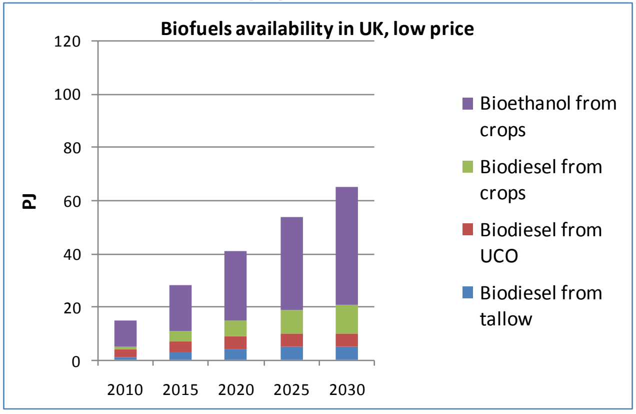


Figure 10 Graph showing availability of biofuels in the UK at high price with easy and medium constraints met, scenario 1.

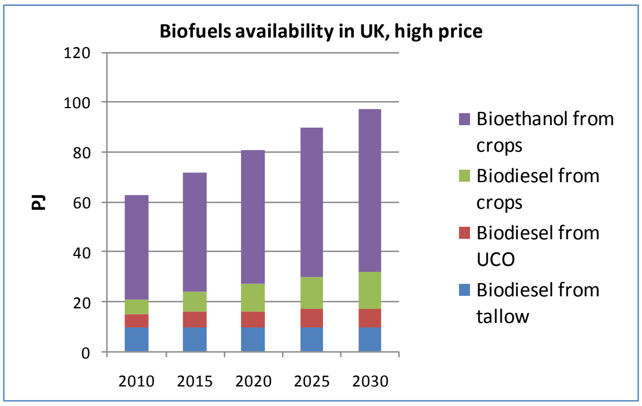


Figure 11 Graph showing biofuels availability in UK at low price, scenario 2 with no constraints addressed.

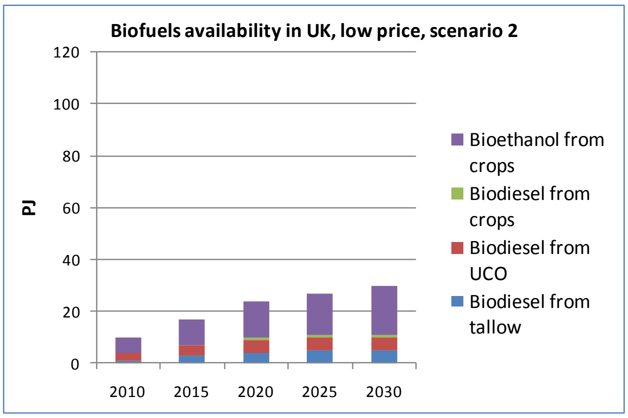
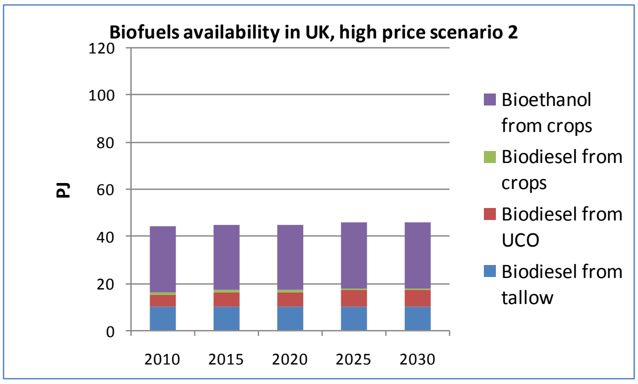


Figure 12 Graphs showing biofuels availability in UK at high price with easy and medium constraints met, scenario 2



Note on prices used in this analysis.

For these feedstocks it is unrealistic to use the price ranges that were used for solid biomass. Instead we have calculated a value based on market prices reported for biofuels crop feedstocks. For tallow and UCO we have pegged the prices to those of OSR –biodiesel, on the basis that biodiesel from plant oils are more likely to set biofuels prices than the price of biodiesel from a limited resource such as tallow or UCO.

The prices used are provided in Table 12.

Table 12 Prices used in analysis of first generation biofuels

Feedstock	GJ fuel/t feedstock	Feedstock price £/t	Feedstock price £/GJ fuel	Price range for model	
				£/t	£/GJ
Wheat	7.714	110	14.26	80 110 160	10.4 14.3 20.7
OSR	14.64	250	17.08	130 200 350	8.9 13.7 23.9
Sugar Beet	2.2078	31.5	14.27	18.9 26 37.8	8.6 11.8 17.1
Tallow	32.736			290.7	8.9

				447.2	13.7
				782.6	23.9
UCO	36.456			323.7	8.9
				498	13.7
				871.6	23.9

Sources: HGCA, Defra commodity prices, Farming On Line, NNFCC (2007), Farmers’ Weekly, AEA et at (2008)

First generation biofuels

Summary of assumptions and results

Unconstrained Potential	**Assumptions**
Scenario 1 OSR-Biodiesel: 0.42Mt (2010) to 1.01Mt (2030); Wheat and sugar beet – bioethanol: 4.8Mt (2010) to 7.8Mt (2030) ***Scenario 2*** OSR-Biodiesel: 0.08Mt Wheat and sugar beet – bioethanol: 3.65Mt	• UK biofuels are produced from: - Biodiesel: oil seed rape (OSR), tallow and used cooking oil - Ethanol: wheat and sugar beet. It is assumed that any increase in ethanol production in the future will be from wheat and not sugar beet. • Land currently used for food and feed will continue to serve these markets; but wheat currently exported for feed may represent a surplus that could be used for ethanol production • Processing capacity in the UK is not considered in this analysis. • Land use is assumed to be the same land that could be potentially used to produce energy crops. To ensure that we do not double count two scenarios were developed. Scenario 1: first generation biofuels dominate land use for biomass production. Scenario 2: energy crops dominate this land use. • We have assumed that arable land of marginal productivity for arable crops is represented by land set aside in the past. Kilpatrick et al (2008) indicate that there was an average of 480,000ha set aside in 2005-7 plus 175,000ha bare fallow land (= 655,000 ha of land, which we have assumed is potentially available for energy or biofuels crops). • Un-cropped arable land (fallow agricultural land or set aside) was estimated by using the amount of land that remained un-cropped despite set aside being set to zero in 2008. This amounted to 296,000ha. We have assumed that this land was unsuitable for wheat or OSR. • We have assumed that grassland will not be converted to first generation biofuels crops • We have assumed that the land resource not currently used for agricultural purposes is not of sufficient quality to grow first generation biofuels crops. • Prices are not at £4/GJ, £6/GJ and £10/GJ as for other biomass feedstock, but are related to the price of the crop. Result: Scenario 1 (480,000 ex set aside + 175000 bare fallow land) - 296,000 (un-cropped land) = 359,000ha hectares of available land by category in 2010. We assumed that 66% of this land is planted with wheat and 34% with OSR in rotation. In addition the crops already used or with the potential to be used for **first** generation biofuels remain, that is: - 3Mt of surplus wheat, most of which is usually exported (HGCA 2005). - Sugar beet, as currently used by British Sugar: 650,000 t (see: http://www.britishsugar.co.uk) - Oil seed rape, as indicated by the RFA (2010): 23,500ha Scenario 2 This scenario assumes that any marginal arable land, fallow land or un-cropped land would be used for energy crops. This means that only the 3Mt surplus wheat and current crops used for biofuels are available for biofuels production.

This can be summarised:

Crop	Yield (t/ha)	Land use (ha)	Tonnage (Mt)	Biofuel (t)	PJ biofuel
wheat	7.6	240,000	1.82	531,440	14.24
Oilseed rape (winter)	3.5*	120,000	0.42	171,570	6.38
Sugar beet	Crop used from British Sugar		0.65	48,880	1.3
Biofuels from additional surplus					
Wheat	3Mt feed wheat currently exported could be used for bioethanol.		3	876,000	23.3
Oilseed rape	According to RFA statistics 23,500ha were used for biodiesel production in 2009		0.08	33599	1.2

2030

For 2030 we have assumed that increases in the yield of food and feed crops result in additional spare land, which can be used for biofuels production. The increase in such land is from 655,000ha to 1.1Mha in 2030. We have also assumed increases in the yield of biofuels crops. Thus the land for first generation biofuels crops increases to:

1.1 M ha-296000ha = 804,000ha.

Assumptions and biofuels production for 2030:

Crop	Yield (t/ha)	Land use (ha)	Tonnage (Mt)	Biofuel (t)	PJ biofuel
wheat	9	530640	4.8Mt	1401600	37.3
Oilseed rape (winter)	3.7	273,360	1.01Mt	412585	15.3
Sugar beet	Crop used from British Sugar		0.65	48,880	1.3

In addition the surplus crop production indicated above is also assumed to be available in 2030.

Cost

The factors that determine how much is available at three different cost points are:

- Cost of production
- Competition for land and feedstock from other markets
- Government policy.

Competing uses

Assumptions on competing uses: food and non-energy uses.

It is assumed that land currently used for food and feed production continues to be used for this purpose.

It is assumed that there will be some competition with energy crops for the available land. This is modelled using scenario analysis as indicated above.

Constraints

Low:

- Lack of long term stable policies to enable investment
- Regulatory uncertainty, unclear policy (e.g. on sustainability and on the food-biofuels debate).
- Margins insufficient/farmer perception of market
- Lack of understanding on meeting current and future sustainability standards (and what these standards will be).
- Rotational constraints.

Medium:

- Yield of crop

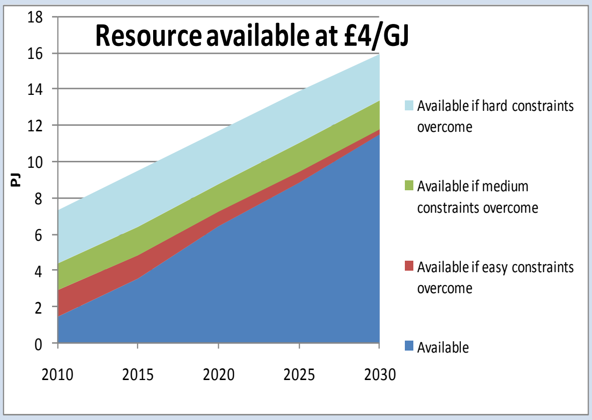
Hard to overcome:

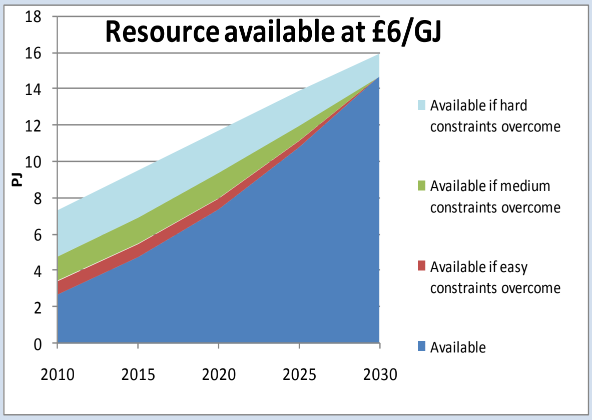
- Competition from overseas feedstock at cheaper price. This includes oils other than rapeseed oil
- Public perception of food versus fuel
- Concerns about the impact of biofuels on the prices of other commodities.
- Lack of processing facilities for OSR in UK.
- Sugar beet is at present.

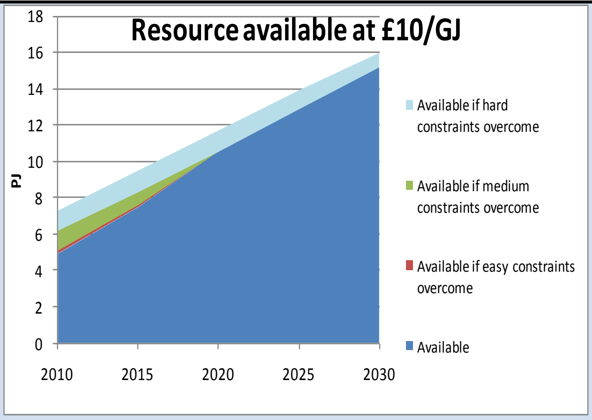
Results

- At high prices and over time a significant proportion of the full unconstrained potential can be achieved in the UK.
- At lower prices and fewer constraints addressed the resource available is much lower.

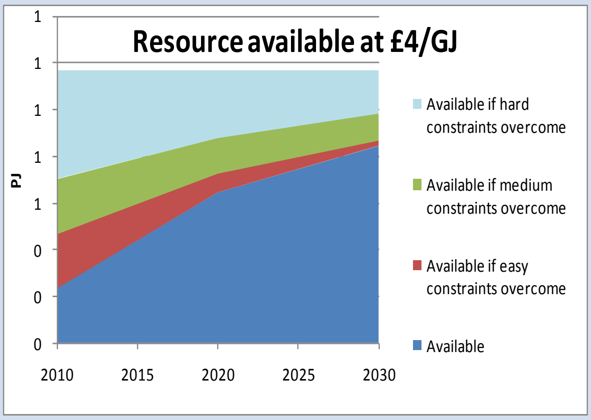
Graphs showing results for OSR, Scenario 1

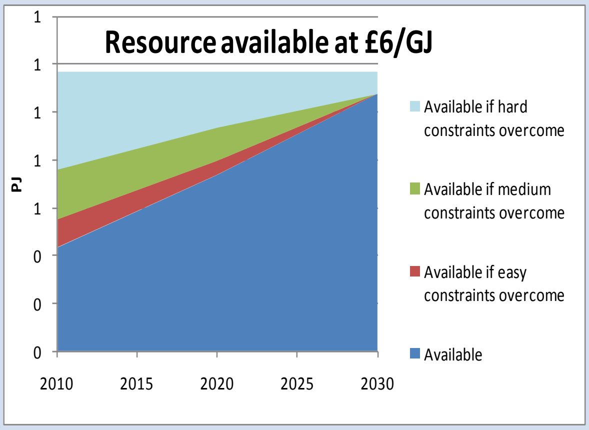


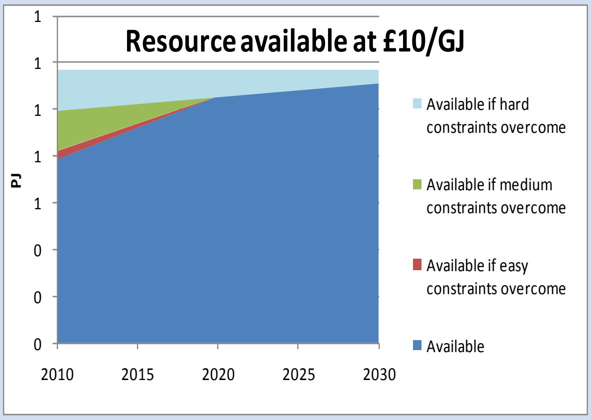




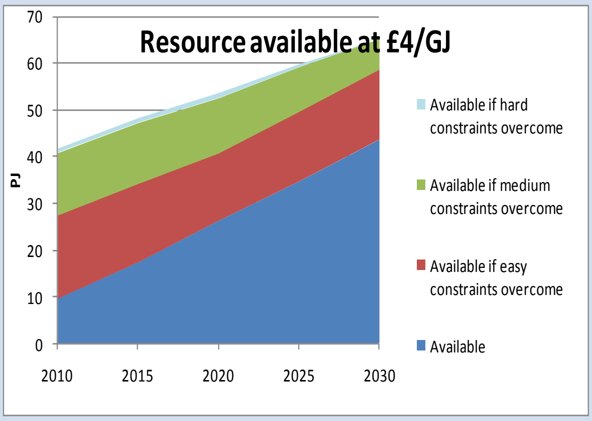
Graphs showing results for OSR, Scenario 2

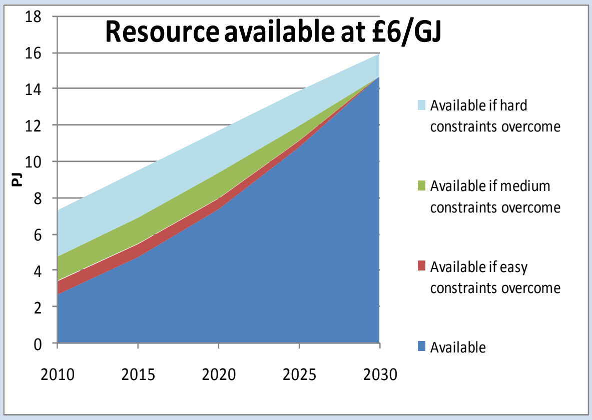


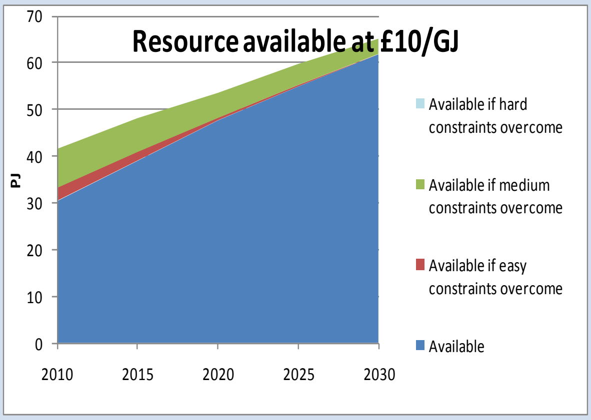




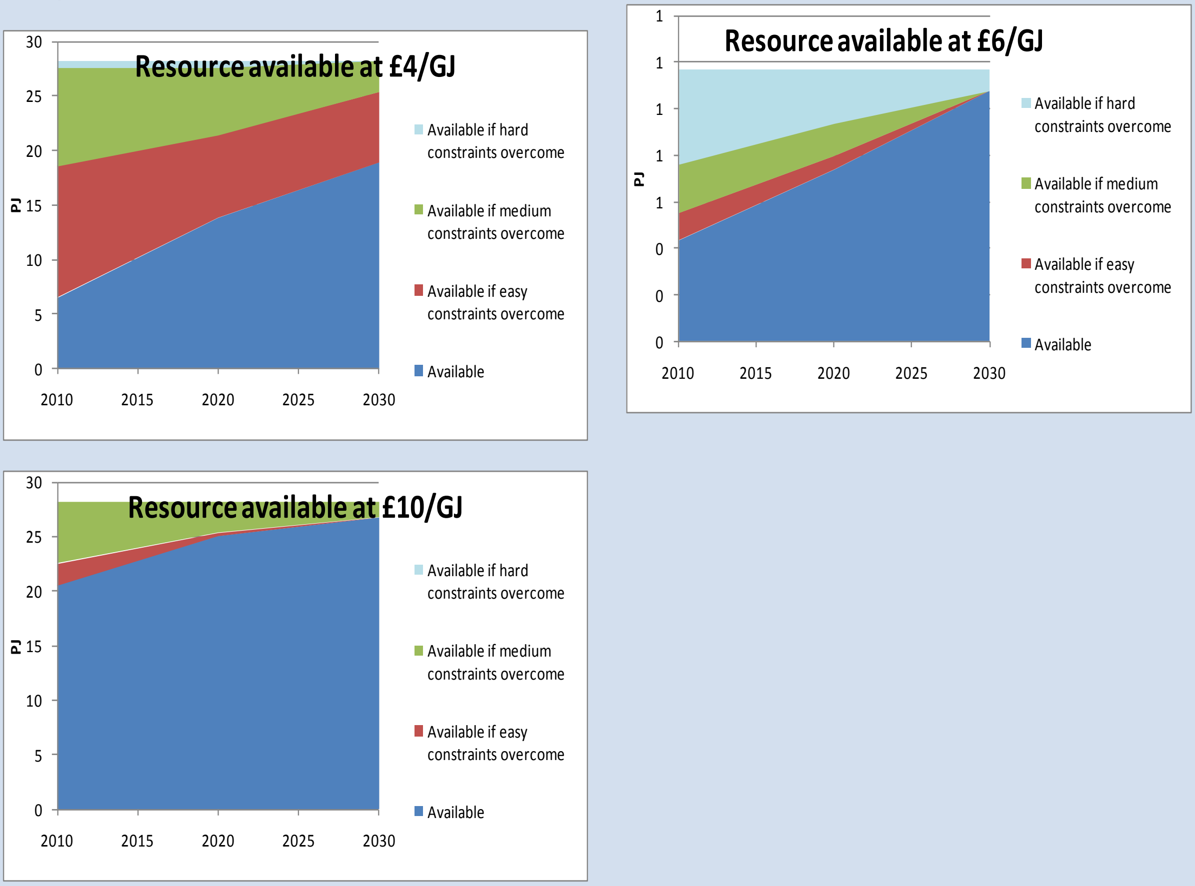
Graphs showing results for Wheat and sugar beet, Scenario 1







Graphs showing results for Wheat and sugar beet, Scenario 2



Additional Details

UK biofuels are currently produced from:

- Biofuels from first generation energy crops (wheat, sugar beet and oilseed rape, OSR).
- Biofuels from tallow and used cooking oil (UCO)

This summary discusses the assumptions made in our analysis of potential first generation biofuels in the UK and factors that constrain that production. It does not consider biofuels produced outside the UK or crops produced outside the UK but imported into the country to be processed.

First generation biofuel crops

Resource assumptions

Scenarios for production of biofuels from UK crops

To understand the potential for UK production of biofuels we have examined current production of suitable crops, potential production of additional crops and current and potential production of biofuels from tallow and used cooking oil (UCO). We have assumed that crops currently used for food and feed in the UK will continue to serve these markets; but that wheat currently exported for the feed market could be used for biofuels production in the UK instead. In addition we have estimated land availability to grow additional crops suitable for production of first generation biofuels in the UK. We have not considered the processing capacity for biofuels production in the UK.

The land allocated in this analysis to first generation biofuels crops could also be used to grow lignocellulose energy crops. Rather than make assumptions about the potential for these crops to be grown together, we have examined two scenarios: the first assumes that first generation biofuel crops dominate the use of the land ("high first generation crops"); the second that energy crops dominate ("High lignocellulose energy crops").

Scenario 1 High first generation crops

The UK is intensively cultivated, with little additional capacity for good quality arable land. Consequently there is a limit to potential increase in our capacity to produce first generation biofuel crops. In this analysis we have estimated additional land that could be used for growing first generation biofuels crops from past allocation of land to set aside. It was assumed that as this land was taken out of production for UK food and feed crops in the past it provides a representation of 'spare land' capacity in the UK. Analysis of set aside and fallow land from ADAS (Kilpatrick *et al* 2008) were used to estimate the maximum capacity for the UK to produce spare wheat and OSR for biofuels production to obtain an unconstrained potential for UK biofuels production. Kilpatrick *et al* (2008) indicate that there was an average of 480,000ha set aside in 2005-7 plus 175,000ha bare fallow land (= 655,000 ha of land, which we have assumed is potentially available for energy or biofuels crops). Set aside was set to zero in 2008, but, despite high wheat prices, 296,000 ha remained un-cropped (Kilpatrick *et al* 2008). In our analysis we have assumed that this is an indication that this land is unsuitable for wheat or OSR or, if it were planted, yields would be low. Therefore we have assumed that this land is not available for first generation biofuels crops. Thus in this scenario the potential land available for first generation energy crops is:

(480,000 ex set aside + 175000 bare fallow land) - 296,000 (un-cropped land) = 359,000ha.

As the crops are grown in rotation, we have assumed that 66% of this land is planted with wheat and 34% with oilseed rape in any one year. That is:

- Wheat area: 238,000ha (rounded to 240,000ha)

- OSR area: 122400ha (rounded to 120,000ha)

In addition the crops already used or with the potential to be used for first generation biofuels remain, that is:

- 3Mt of surplus wheat, most of which is usually exported (HGCA 2005).
- Sugar beet, as currently used by British Sugar: 650,000 t (see: http://www.britishsugar.co.uk)
- Oil seed rape, as indicated by the RFA (2010): 23,500ha

We have assumed that sugar beet-ethanol does not increase in the future (as indicated in NNFCC, 2007).

The remainder of the ex-set aside land (296,000 ha), is assumed not suitable for wheat or OSR production and would be used for perennial energy crops.

Scenario 2 High Lignocellulose energy crops

This scenario assumes that woody or grass energy crops for biomass are planted on set aside land, so that additional biofuels crops are available only due to yield increases. This means that the 3Mt of surplus wheat currently produced in the UK is available for biofuels production and the current use of sugar beet and oil seed rape continues, but there is no significant increase in the land planted with these crops.

The yields of wheat, OSR and sugar beet, land use and biofuels production assumed in this analysis is shown in Tables 13 for 2010 and 2 for 2030.

Table 13 Assumptions and biofuels production for 2010

Crop	Yield (t/ha)	Land use (ha)	Tonnage (Mt)	Biofuel (t)	PJ biofuel
wheat	7.6	240,000	1.82	531,440	14.24
Oilseed rape (winter)	3.5*	120,000	0.42	171,570	6.38
Sugar beet	Crop used from British Sugar		0.65	48,880	1.3

Biofuels from additional surplus				
Wheat	3Mt feed wheat currently exported could be used for bioethanol.	3	876,000	23.3
Oilseed rape	According to RFA statistics 23,500ha were used for biodiesel production in 2009	0.08	33599	1.2

Notes: current yields of wheat, sugar beet and OSR are taken from ADAS (2008), HGCA web site, NNFCC (2007) for sugar beet. Conversion rates: from RFA Carbon and Sustainability Guidance.

*SAC give a 5 year average yield for 1982-2004 of 3.52t/ha

Assumptions for 2030

We have assumed that increases in yield increases the land availability for first generation biofuels crops in Scenario 1. In addition it also increases the yield of biofuels crops.

The estimate of additional land availability from this source in 2030 is taken from E4Tech (2008). Using their analysis results in an increase in spare land for cultivation from 655000 ha to 1.1Mha. This increase comes from increases in yields, which frees land for energy crop production. It is assumed that all of this additional land could also be used to grow wheat or OSR. Thus for scenario 1 the land availability for first generation biofuels crops increases to 1.1 Mha- 296000ha= 804,000 ha. It is assumed that 66% of this land is planted with wheat and 34% of it with OSR (i.e. 530640 ha for wheat and 273360 ha for OSR).

In addition yields of crops used for first generation biofuels are also predicted to increase to 9t/ha for wheat in 2020 (HGCA 2010). Fisher *et al* (2009) predicted that OSR would increase in yield by 6-15% (by 2030) across the EU based on historical trends. We have assumed an increase of 6% by 2030 to provide an average UK yield of 3.7t/ha.

Table 14 Assumptions and biofuels production for 2030

Crop	Yield (t/ha)	Land use (ha)	Tonnage (Mt)	Biofuel (t)	PJ biofuel
wheat	9	530640	4.8Mt	1401600	37.3
Oilseed rape (winter)	3.7	273,360	1.01Mt	412585	15.3
Sugar beet	Crop used from British Sugar		0.65	48,880	1.3

In addition the surplus crop production in Table is also assumed to be available in 2030.

Table 15 Summary of energy crops production in 2030- Total available for bioenergy

Scenario	SRC/ miscanthus (PJ)	Wheat and SB (PJ)	OSR (PJ)	Total all crops (PJ)
1-Maximum wheat/ OSR/SB	76	60	15	151
2-Maximum SRC/ miscanthus	231	28	1.2	260

Table 16 Summary of energy crops production in 2030- Total unconstrained potential for bioenergy

Scenario	SRC/ miscanthus (PJ)	Wheat and SB (PJ)	OSR (PJ)	Total all crops (PJ)
1-Maximum wheat/ OSR/SB	76	60	15	151
2-Maximum SRC/ miscanthus	282	28	1.2	311

Constraints on first generation biofuels crops

HGCA (2005) examined the constraints on the use of UK first generation feedstocks to produce biofuels and came up with three sets of constraints:

- Uptake of biofuels is dependent on
  - ⇒ Market demand, itself a function of Government policy and the production capacity of the UK
- The extent to which UK crops will supply biofuels depends on:
  - ⇒ Profitability relative to food markets
  - ⇒ Cost of competitor feedstocks
  - ⇒ Import levels of raw materials and biofuels
- The production of UK feedstocks for biofuels is dependent on the land available, rotational constraints, and the demand for food and feed in the UK (which is a function of the price of food and feed). These issues could be overcome if high prices were available.
- Another important issue is how the market is perceived, particularly if varieties grown for biofuels production are required.

Constraints on OSR production

From the literature we have identified a number of constraints on OSR production:

- Yield increases – in general it is agreed that OSR yield increases rely on increased fertiliser input. If biodiesel is to be produced sustainability we are only interested in yield increases achieved without additional fertiliser input.
- Food demand – OSR is also a food crop. Its diversion into the biodiesel market may result in increased import of other crop oils into Europe (e.g. palm oil).
- Land availability: we have limited availability of land on the assumption that OSR production for food and other uses would remain and that not all ex-set aside land is suitable for profitable OSR at margins sufficient for farmers.

Constraints for Sugar beet

We have identified a number of constraints on expansion of sugar beet for bioethanol. These include:

- The higher cost compared to wheat bioethanol
- Logistics – both transport, short harvest season and storage difficulties
- Cost of extracting sucrose.
- Yield (improved yields might decrease costs)
- Closure of UK processing facilities
- Value of sugar beet to farmer compare to value of alternative crops
- Low value of co-products

General constraints

One major constraint relates to what the oil companies may decide to do in terms of biofuels production. For example, they may prefer the hydrogenation route for diesel and to use biobutanol instead of bioethanol. However, these are demand side constraints are not included in this analysis.

Summary

The most important constraints on the availability of first generation crops for biofuels in the UK are:

- Farmer margins and the competition with other crops that may present better margins for the land available
- Regulation and policy uncertainty, both for agricultural policy and transport fuel policy
- The technical and environmental constraints on yield and whether or not yields improve over the next 20 years.
- Competition from imported feedstock, which may be cheaper than UK feedstock.

Results

The results are shown below in the following order:

Biodiesel – Scenario 1

Biodiesel – Scenario 2

Bioethanol – Scenario 1

Bioethanol – Scenario 2

Results – Biodiesel Scenario 1

Feedstock name: Biodiesel - OSR scenario 1

Category: UK tradeable

Biofuel produced/Te feedstock (GJ/Te): 14.64

Current use for energy (MTe): 0.07 MTe
Current use for energy (TJ): 79 TJ
Data source: RFA

Energy applications: Electricity, Heat, Biofuels, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (Feedstock, MTe):	0.50	0.65	0.80	0.95	1.09
Unconstrained feedstock potential (PJ final biofuel):	7	10	12	14	16
Competing feedstock uses at £4/GJ (MTe):	0.0	0.0	0.0	0.0	0.0
...of which % that are independent of price:	0%	0%	0%	0%	0%
Available for bioenergy use (MTe):	0.50	0.65	0.80	0.95	1.09
Available for bioenergy use (PJ):	**7**	**10**	**12**	**14**	**16**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "acessible potential" and excludes the price-independent competing uses

List the qualifications and assumptions used to derive the unconstrained potential:

Source of data: SAC (2005), HGCA (2005) Kilpatrick (2008), Fisher et al (2009)
Physical constraints: Crushing facilities in UK
Main conversion technology: Transesterification
Upper resource cost limit, if applicable: Limits are set by price for OSR on the open market.
Environmental constraints assumed: For good yields fertilisers are required, but these may influence the carbon balance of the biodiesel
Any assumptions re competing land use: Have assumed that non-food crop land is used (based around wheat rotation on ex set aside
Other: yield increases assumed from literature. Increase in land available due to increase in yields of food and feed crops assumed from literature.

Competing uses for this feedstock:

1) Food
2) Other industrial uses
3) Export to elsewhere in EU for production of biodiesel.

List the top four constraints:

1) Competition from alternative biodiesel feedstock in UK
2) Land availability for OSR
3) Margins for farmers
4) Suitable biodiesel production capacity in UK

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base/low feedstock price:	**80%**		**45%**		**28%**
Constraints that are easy to overcome	20%		7%		2%
Constraints that are medium to overcome	20%		13%		10%
Constraints that are hard to overcome	40%		25%		16%
% reduction at medium feedstock price:	**63%**		**37%**		**8%**
Constraints that are easy to overcome	10%		5%		0%
Constraints that are medium to overcome	18%		12%		0%
Constraints that are hard to overcome	35%		20%		8%
% reduction at high feedstock price:	**33%**		**10%**		**5%**
Constraints that are easy to overcome	3%		0%		0%
Constraints that are medium to overcome	15%		0%		0%
Constraints that are hard to overcome	15%		10%		5%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	**7**	**10**	**12**	**14**	**16**
Constrained potential at low price:	**1**	**4**	**6**	**9**	**11**
Constraints that are easy to overcome	1	1	1	1	0
Constraints that are medium to overcome	1	2	2	2	2
Constraints that are hard to overcome	3	3	3	3	3
Constrained potential at medium price:	**3**	**5**	**7**	**11**	**15**
Constraints that are easy to overcome	1	1	1	0	0
Constraints that are medium to overcome	1	1	1	1	0
Constraints that are hard to overcome	3	3	2	2	1
Constrained potential at high price:	**5**	**7**	**11**	**13**	**15**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	1	1	0	0	0
Constraints that are hard to overcome	1	1	1	1	1

Constraints – Biodiesel Scenario 1

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**low**	**medium**	**high**	**low**	**medium**	**high**	**low**	**medium**	**high**	**low**	**medium**	**high**	**low**	**medium**	**high**
Easy	0%	0%	0%	20%	10%	3%	0%	0%	0%	0%	0%	0%	**20%**	**10%**	**3%**
Medium	0%	0%	0%	20%	18%	15%	0%	0%	0%	0%	0%	0%	**20%**	**18%**	**15%**
Hard	25%	20%	5%	5%	5%	0%	10%	10%	15%	0%	0%	0%	**40%**	**35%**	**20%**
Sum	25%	20%	5%	45%	33%	18%	10%	10%	15%	0%	0%	0%	80%	63%	38%

Feedstock name: Biodiesel - OSR scenario 1

Impact of maturing market on supply constraints at base feedstock price

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	0%	0%	0%	20%	7%	2%	0%	0%	0%	0%	0%	0%	**20%**	**7%**	**2%**
Medium	0%	0%	0%	20%	13%	10%	0%	0%	0%	0%	0%	0%	**20%**	**13%**	**10%**
Hard	25%	15%	10%	5%	2%	0%	10%	8%	6%	0%	0%	0%	**40%**	**25%**	**16%**

Results – Biodiesel Scenario 2

Feedstock name: Biodiesel - OSR scenario 2

Category: UK tradeable

Biofuel produced/t feedstock (GJ/Te): 14.64

Current use for energy (MTe): 0.07 MTe
Current use for energy (TJ): 79 TJ
Data source: RFA

Energy applications: Electricity, Heat, Biofuels, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (MTe):	0.08	0.08	0.08	0.08	0.08
Unconstrained feedstock potential (PJ):	1.2	1.2	1.2	1.2	1.2
Competing feedstock uses at £4/GJ (MTe):	0.0	0.0	0.0	0.0	0.0
...of which % that are independent of price:	0%	0%	0%	0%	0%
Available for bioenergy use (MTe):	0.08	0.08	0.08	0.08	0.08
Available for bioenergy use (PJ):	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "acessible potential" and excludes the price-independent competing uses

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: SAC (2005), HGCA (2005) ADAS (2008)
Physical constraints: Crushing facilities in UK
Main conversion technology: Transesterification
Upper resource cost limit, if applicable: Limits are set by price for OSR on the open market.
Environmental constraints assumed: For good yields fertilisers are required, but these may influence the carbon balance of the biodiesel
Any assumptions re competing land use: Have assumed that non-food crop land is used (based around wheat rotation on ex set aside
Other:

Competing uses for this feedstock:
1) Food
2) Other industrial uses
3) Export to elsewhere in EU for production of biodiesel.

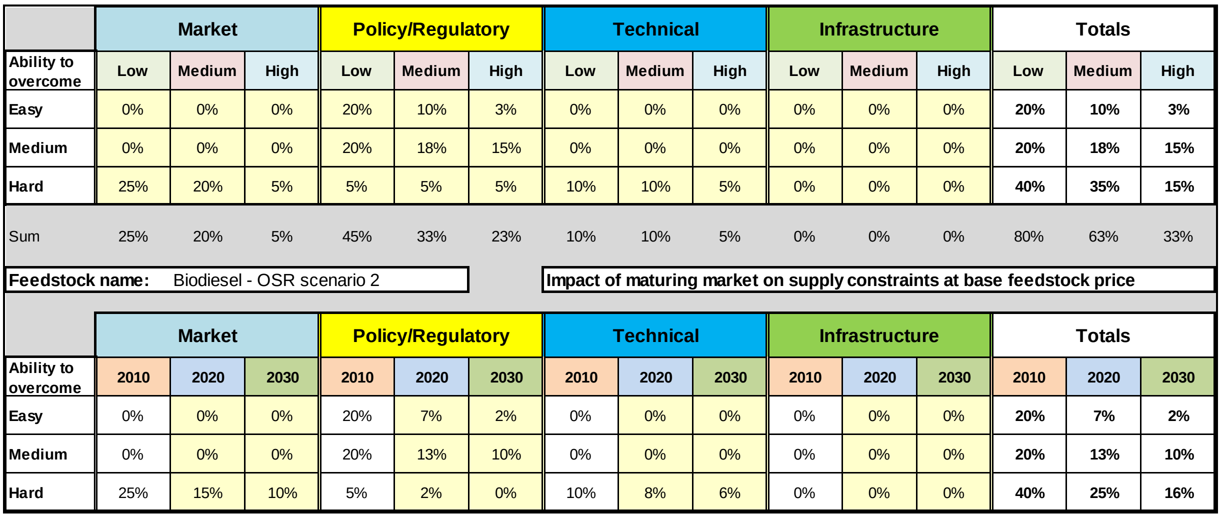
List the top four constraints:
1) Competition from alternative biodiesel feedstock in UK
2) Land availability for OSR
3) Margins for farmers
4) Suitable biodiesel production capacity in UK

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base/low feedstock price:	**80%**		**45%**		**28%**
Constraints that are easy to overcome	20%		7%		2%
Constraints that are medium to overcome	20%		13%		10%
Constraints that are hard to overcome	40%		25%		16%
% reduction at medium feedstock price:	**63%**		**37%**		**8%**
Constraints that are easy to overcome	10%		5%		0%
Constraints that are medium to overcome	18%		12%		0%
Constraints that are hard to overcome	35%		20%		8%
% reduction at high feedstock price:	**33%**		**10%**		**5%**
Constraints that are easy to overcome	3%		0%		0%
Constraints that are medium to overcome	15%		0%		0%
Constraints that are hard to overcome	15%		10%		5%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	1	1	1	1	1
Constrained potential at low price:	**0**	**0**	**1**	**1**	**1**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	0	0	0	0	0
Constrained potential at medium price:	**0**	**1**	**1**	**1**	**1**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	0	0	0	0	0
Constrained potential at high price:	**1**	**1**	**1**	**1**	**1**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	0	0	0	0	0

Constraints – Biodiesel Scenario 2



	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Easy	0%	0%	0%	20%	10%	3%	0%	0%	0%	0%	0%	0%	**20%**	**10%**	**3%**
Medium	0%	0%	0%	20%	18%	15%	0%	0%	0%	0%	0%	0%	**20%**	**18%**	**15%**
Hard	25%	20%	5%	5%	5%	5%	10%	10%	5%	0%	0%	0%	**40%**	**35%**	**15%**
Sum	25%	20%	5%	45%	33%	23%	10%	10%	5%	0%	0%	0%	80%	63%	33%

Feedstock name: Biodiesel - OSR scenario 2

Impact of maturing market on supply constraints at base feedstock price

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	0%	0%	0%	20%	7%	2%	0%	0%	0%	0%	0%	0%	**20%**	**7%**	**2%**
Medium	0%	0%	0%	20%	13%	10%	0%	0%	0%	0%	0%	0%	**20%**	**13%**	**10%**
Hard	25%	15%	10%	5%	2%	0%	10%	8%	6%	0%	0%	0%	**40%**	**25%**	**16%**

Results – Bioethanol Scenario 1

Feedstock name: UK bioethanol crops (wheat and sugar beet) S1
S1 is scenario 1

Category: UK tradeable

Biofuel produced per tonne feedstock (GJ/Te): 7.714

Current use for energy (MTe): 0.03 MTe
Current use for energy (TJ): 1 TJ
Data source: RFA 2010

Energy applications: Biofuels
Scale:

Annual resource potentials	**2010**	**2015**	**2020**	**2025**	**2030**
Unconstrained feedstock potential (Mte Feedstock):	5.4	6.3	7.0	7.8	8.5
Unconstrained feedstock potential (PJ final biofuel):	42	48	54	60	65
Competing feedstock uses at £4/GJ (MTe):	1.5	1.6	1.6	1.7	1.7
...of which % that are independent of price:	0%	0%	0%	0%	0%
Available for bioenergy use (MTe):	5.4	6.3	7.0	7.8	8.5
Available for bioenergy use (PJ):	**42**	**48**	**54**	**60**	**65**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "acessible potential" and excludes the price-independent competing uses

List the qualifications and assumptions used to derive the unconstrained potential:

Source of data: HGCA (2010), ADAS (2008), NNFCC (2007)
Main conversion technology: Fermentation
Upper resource cost limit, if applicable: Price of feedstock will be dependent on price of wheat for feed and food
Environmental constraints assumed: none
Any assumptions re competing land use: Have assumed that UK wheat produced for export is available and that only land that is not in current
Other:

Competing uses for this feedstock:
1) Food (export)
2) Feed (export)

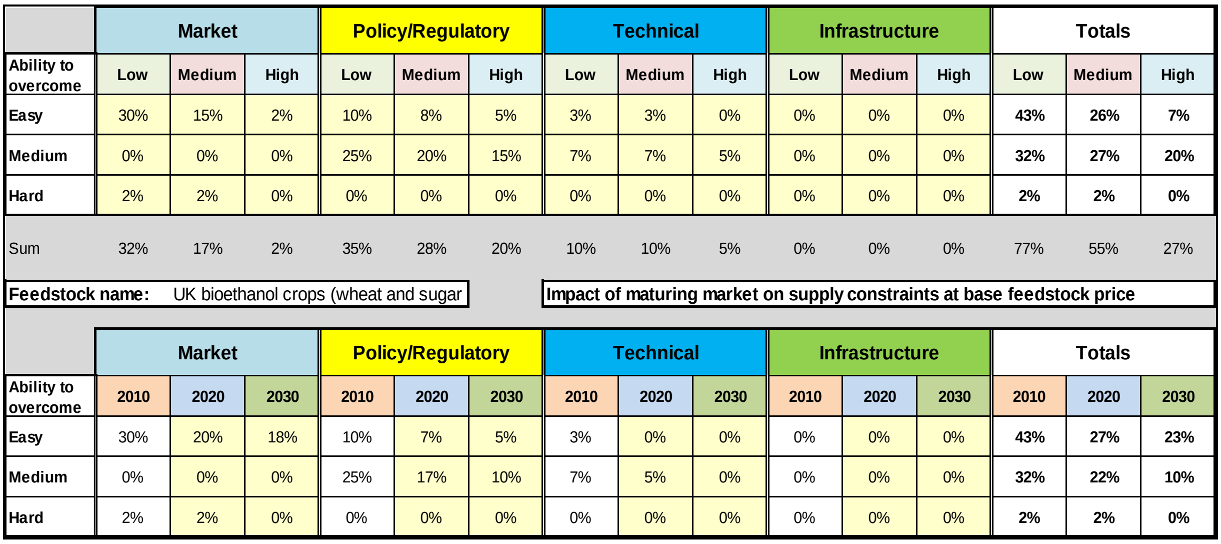
List the top four constraints:
1) Lack of long-term stable policy environment
2) Insufficient processing capacity in UK
3) Price of overseas feedstocks cheaper than UK feedstocks
4) Insufficient margin for farmers

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	**2010**	**2015**	**2020**	**2025**	**2030**
% reduction at base/low feedstock price:	**77%**		**51%**		**33%**
Constraints that are easy to overcome	43%		27%		23%
Constraints that are medium to overcome	32%		22%		10%
Constraints that are hard to overcome	2%		2%		0%
% reduction at medium feedstock price:	**55%**		**30%**		**20%**
Constraints that are easy to overcome	26%		15%		12%
Constraints that are medium to overcome	27%		15%		8%
Constraints that are hard to overcome	2%		0%		0%
% reduction at hight feedstock price:	**27%**		**11%**		**5%**
Constraints that are easy to overcome	7%		1%		0%
Constraints that are medium to overcome	20%		10%		5%
Constraints that are hard to overcome	0%		0%		0%

Constrained resource potentials (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**
"Accessible" resource potential (PJ)	**42**	**48**	**54**	**60**	**65**
Constrained potential at low price:	**10**	**17**	**26**	**35**	**44**
Constraints that are easy to overcome	18	17	14	15	15
Constraints that are medium to overcome	13	13	12	10	7
Constraints that are hard to overcome	1	1	1	1	0
Constrained potential at medium price:	**19**	**28**	**38**	**45**	**52**
Constraints that are easy to overcome	11	10	8	8	8
Constraints that are medium to overcome	11	10	8	7	5
Constraints that are hard to overcome	1	0	0	0	0
Constrained potential at high price:	**30**	**39**	**48**	**55**	**62**
Constraints that are easy to overcome	3	2	1	0	0
Constraints that are medium to overcome	8	7	5	4	3
Constraints that are hard to overcome	0	0	0	0	0

Constraints – Bioethanol Scenario 1



	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Easy	30%	15%	2%	10%	8%	5%	3%	3%	0%	0%	0%	0%	**43%**	**26%**	**7%**
Medium	0%	0%	0%	25%	20%	15%	7%	7%	5%	0%	0%	0%	**32%**	**27%**	**20%**
Hard	2%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**2%**	**2%**	**0%**
Sum	32%	17%	2%	35%	28%	20%	10%	10%	5%	0%	0%	0%	77%	55%	27%

Feedstock name: UK bioethanol crops (wheat and sugar

Impact of maturing market on supply constraints at base feedstock price

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	30%	20%	18%	10%	7%	5%	3%	0%	0%	0%	0%	0%	**43%**	**27%**	**23%**
Medium	0%	0%	0%	25%	17%	10%	7%	5%	0%	0%	0%	0%	**32%**	**22%**	**10%**
Hard	2%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**2%**	**2%**	**0%**

Results – Bioethanol Scenario 2

Feedstock name: UK bioethanol crops (wheat and sugar beet) S2
S2 is scenario 2
Category: UK tradeable
Biofuel produced/Te Feedstock (GJ/Te): 7.714
Current use for energy (MTe): 0.03 MTe
Current use for energy (TJ): 1 TJ
Data source: RFA 2010
Energy applications: Biofuels
Scale:

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (Mte feedst	3.65	3.65	3.65	3.65	3.65
Unconstrained feedstock potential (PJ final bi	28	28	28	28	28
Competing feedstock uses at low price:	3.7	3.7	3.7	3.7	3.7
...of which % that are independent of price:	0%	0%	0%	0%	0%
Available for bioenergy use (MTe):	3.65	3.65	3.65	3.65	3.65
Availbale for bioenergy use (PJ):	**28**	**28**	**28**	**28**	**28**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "acessible potential" and excludes the price-independent competing uses

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: HGCA (2010), ADAS (2008), NNFCC (2007)
Main conversion technology: Fermentation
Upper resource cost limit, if applicable: Price of feedstock will be dependent on price of wheat for feed and food
Environmental constraints assumed: none
Any assumptions re competing land use: Have assumed that UK wheat produced for export is available and that only land that is not in
Other:

Competing uses for this feedstock:
1) Food (export)
2) Feed (export)
3)

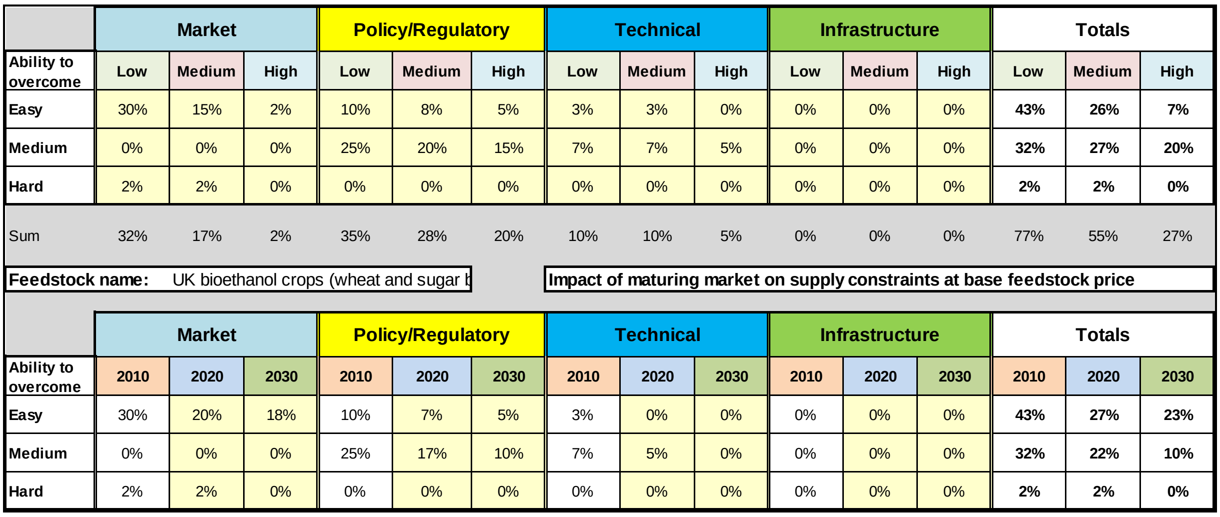
List the top four constraints:
1) Lack of long-term stable policy environment
2) Insufficient processing capacity in UK
3) Price of overseas feedstocks cheaper than UK feedstocks
4) Insufficient margin for farmers

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base/low feedstock price:	**77%**		**51%**		**33%**
Constraints that are easy to overcome	43%		27%		23%
Constraints that are medium to overcome	32%		22%		10%
Constraints that are hard to overcome	2%		2%		0%
% reduction at medium feedstock price:	**55%**		**30%**		**20%**
Constraints that are easy to overcome	26%		15%		12%
Constraints that are medium to overcome	27%		15%		8%
Constraints that are hard to overcome	2%		0%		0%
% reduction at high feedstock price:	**27%**		**11%**		**5%**
Constraints that are easy to overcome	7%		1%		0%
Constraints that are medium to overcome	20%		10%		5%
Constraints that are hard to overcome	0%		0%		0%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	**28**	**28**	**28**	**28**	**28**
Constrained potential at low price:	**6**	**10**	**14**	**16**	**19**
Constraints that are easy to overcome	12	10	8	7	6
Constraints that are medium to overcome	9	8	6	5	3
Constraints that are hard to overcome	1	1	1	0	0
Constrained potential at medium price:	**13**	**16**	**20**	**21**	**23**
Constraints that are easy to overcome	7	6	4	4	3
Constraints that are medium to overcome	8	6	4	3	2
Constraints that are hard to overcome	1	0	0	0	0
Constrained potential at high price:	**21**	**23**	**25**	**26**	**27**
Constraints that are easy to overcome	2	1	0	0	0
Constraints that are medium to overcome	6	4	3	2	1
Constraints that are hard to overcome	0	0	0	0	0

Constraints – Bioethanol I Scenario 2



	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Easy	30%	15%	2%	10%	8%	5%	3%	3%	0%	0%	0%	0%	**43%**	**26%**	**7%**
Medium	0%	0%	0%	25%	20%	15%	7%	7%	5%	0%	0%	0%	**32%**	**27%**	**20%**
Hard	2%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**2%**	**2%**	**0%**
Sum	32%	17%	2%	35%	28%	20%	10%	10%	5%	0%	0%	0%	77%	55%	27%

Feedstock name: UK bioethanol crops (wheat and sugar b

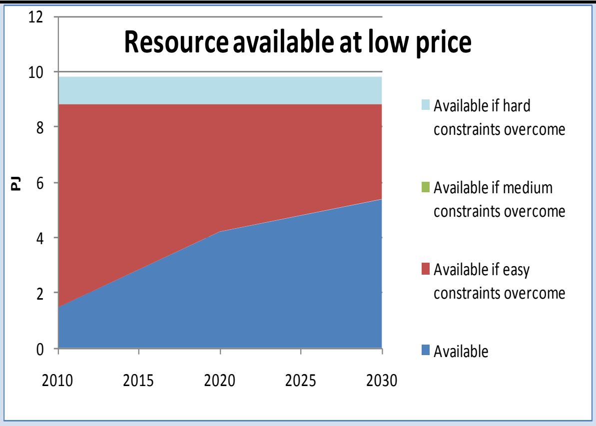
Impact of maturing market on supply constraints at base feedstock price

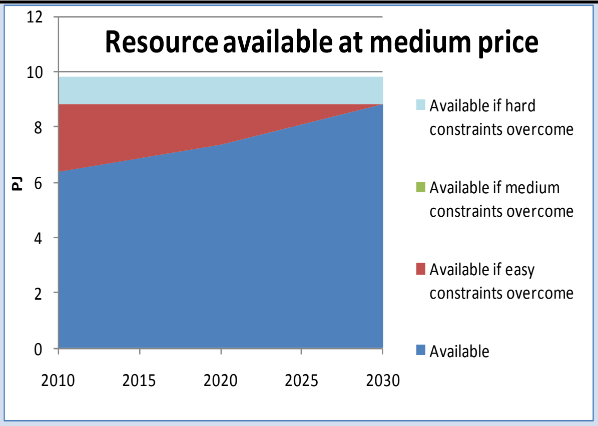
	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	30%	20%	18%	10%	7%	5%	3%	0%	0%	0%	0%	0%	**43%**	**27%**	**23%**
Medium	0%	0%	0%	25%	17%	10%	7%	5%	0%	0%	0%	0%	**32%**	**22%**	**10%**
Hard	2%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**2%**	**2%**	**0%**

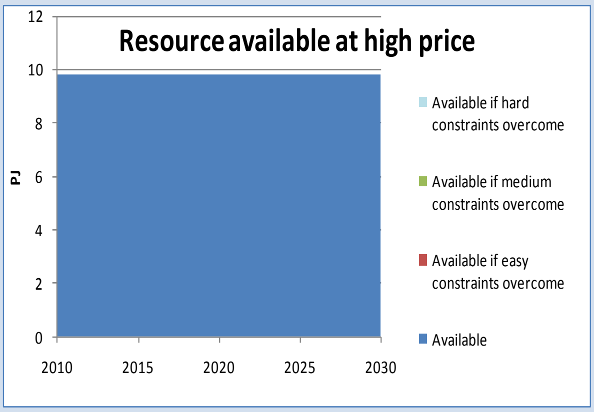
Tallow and Used cooking oil (UCO)

Tallow - Summary of assumptions and results

Unconstrained Potential	**Assumptions**
0.3Mt/y (10PJ/y) **Accessible potential** 0.23Mt/y, of which 0.064t is price dependent.	- Total quantity of tallow produced in UK is 200,000-290,000t. We have used 290,000t in this work. - 34.46GJ fuel is produced per tonne of feedstock. - Assumed that some 50,000t/y are used in feed and food, which are high value markets, but that the rest could be used for energy. Energy uses include heat and power on the producer's site as well as a feedstock for biofuels. - Biofuel production will be limited by conversion facilities, but this is not considered here. - Price range used in analysis is pegged to the price of biodiesel from OSR.
Cost	The factors that determine how much is available at three different cost points are: - The competition for tallow and the price people are willing to pay for the competing supply. - The amount of tallow going to the high value food and feed markets.
Competing uses	Assumptions on competing uses: - The 50,000t used in food and feed will only be used for biofuels if the price is high enough. - Tallow (category 3) can also be used for oleochemicals - We have assumed these uses are price dependent.
Constraints	Low: - Price of feedstock dictates the use of the feedstock. - Regulatory and policy uncertainty, particularly with respect to the combustion of tallow for heat on renderer's site - Restricted processing capacity in the UK. Hard to overcome: - Cheap imports of biodiesel may undermine the price that can be obtained for tallow biodiesel.
Results **Graphs of results for tallow**	


Resource available at low price


Resource available at medium price

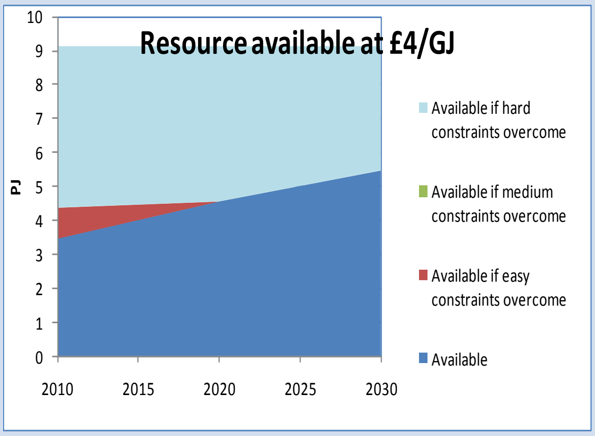

Resource available at high price

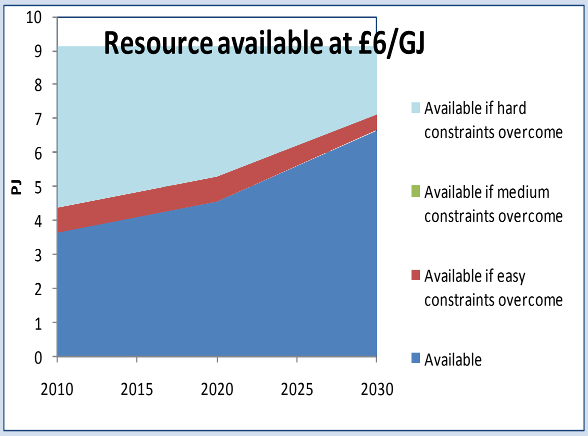
UCO – Summary of assumptions and results

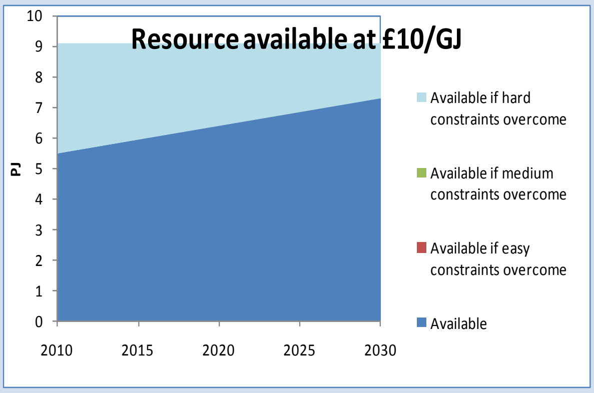
Unconstrained Potential 0.25Mt/y (10PJ/y) **Accessible potential** 0.25Mt/y, of which 0.03t is price dependent.	**Assumptions** - Main sources of UCO are catering, food factories and households. The latter represents the greatest resource, but would need to be collected separately from households if it is to be used. - Figures for UCO arisings are from WRAP (2008). Current use is for animal feed (food factory UCO only). The UK resource is limited by its use in food preparation. There is considerable potential to import, but this is not considered here. - The price range examined is pegged to the price of OSR-biodiesel.
Cost	The factors that determine how much is available at three different cost points are: - The competition for UCO from food factories. - Alternatives for its disposal
Competing uses	Assumptions on competing uses: Competing markets for this energy use include export and oleo chemicals (totalling 25,000t/y).

	UCO can also be exported.
Constraints	Low: - Regulatory and policy uncertainty. Hard to overcome: - Incomplete or immature supply chain (domestic UCO in particular)
Results	

Graphs of results for UCO







Additional details

Tallow and Used cooking oil (UCO)

Tallow is a by-product of meat processing. It is a limited resource in the UK, depending on the production of meat. As produced tallow is classified into a series of categories, dictated by the Animal By-products regulations:

- Category 1 can only be used for burning or fuel production
- Category 2 can be used for industrial applications
- Category 3 can be used for human contact (e.g. in soaps and cosmetics).

No tallow is disposed to landfill and all tallow produced has an economic use at present. The competing uses are mainly relevant to category 2 and 3 tallow and relate to its use in the oleochemicals industry. More information on this is available in AEA et al (2008).

The main sources of **UCO** in the UK are: catering premises, food factories and households. According to WRAP (2008) the quantities produced in each of these sectors are:

- Catering: 108,000t/y
- Food factories: 20,000t/y
- Households: up to 130000t/y

Most UCO is waste and was, until recently, sent to landfill or poured down the drain. The exception is food factory UCO, which attracts a premium price as an ingredient for animal feed.

WRAP (2008) estimated that across all sources total UCO arisings are at least 250Kt/yr. Their data shows that around 82,000 t/y goes to small scale biodiesel and around 1000t/y is incinerated. Competing markets for this energy use include export and oleo chemicals (totalling 25,000t/y).

Table 17 Summary of unconstrained resource of UK tallow and UCO for biofuels

Feedstock	Quantity (Mt/y)	Biofuel potential	Comments
Tallow	0.2 – 0.29 (AEA *et al* 2009). Amount assumed for unconstrained resource in this analysis: 0.3.	0.26Mt, assuming I t tallow produces 0.875t biodiesel	Not all of this is category 1 tallow, but the amount of category 1 tallow produced will vary with the price that users are willing to pay. We have assumed that, for the unconstrained resource, all of this tallow could be available and then constrained it by considering competing uses and price. Currently there is only one plant where tallow is converted to biodiesel in the UK, at Motherwell (45,000t/y), which also uses waste vegetable oil and can use virgin oil; and there is one plant in planning at Ellesmere Port, which will have a capacity of 170,000t biodiesel/y when it is built. This plant will use 150,000 t of cooking oil and tallow (Argent 2010).
UCO	0.25.	0.21Mt, assuming 0.875t biodiesel/t UCO	Figures from the RFA for year[2] and year 2 of the RTFO indicate that 36617 and 34937t of UCO were used for biodiesel production in these years. In addition to this it is likely that small producers also produce a significant quantity of their biodiesel from UCO.

Constraints on tallow and UCO

We have considered the following constraints on the use of tallow for biodiesel:

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[2] See: http://www.renewablefuelsagency.gov.uk/sites/renewablefuelsagency.gov.uk/. The RFA report that 36Ml biodiesel was supplied from UK UCO in 2008-9 and their unverified figures for 2009-10 indicate that supply was around 40Ml biodiesel from UK UCO. Assuming conversion factors of 0.875t biodiesel/t UCO and 0.89 kg biodiesel per litre (RFA C&S Guidance), this converts to 46230 and 51364t UK UCO respectively.

- The amount of tallow produced in the UK is limited by the production of meat and is not likely to increase significantly between 2010 and 2030. This is taken into account in our unconstrained resource.

- Competition: Tallow is already successfully used as a fuel by renderers. The major restriction on this use is the need for disposal in a WID-compliant combustion system. This is not restricting current combustion, but may restrict expansion in the future.

- Competition: The price the customer is willing to pay for tallow has a strong influence on how it is used and the competition from alternative uses. In other words, although there is an alternative market for tallow in feed, food and oleo chemicals, if the price being offered for tallow for biodiesel increases substantially (to £10/GJ), no category 2 and 3 tallow would be produced for these alternative purposes. The price for tallow in the UK is the major constraint for the use of this feedstock from UK sources.

- The price of biodiesel imported from abroad has a strong influence on the development of biodiesel plants in the UK and could restrict the development of further tallow biodiesel plants in the UK. This means that there are limited conversion facilities for tallow biodiesel at present in the UK. This is a downstream affect and is not considered in this analysis, but it does have important implications for the use of this feedstock.

We have considered the following constraints for UCO:

- The amount of UCO produced in the UK is limited by its use in food preparation. We have taken this into account by limiting the unconstrained resource in this analysis. However, under the animal by products regulations a significant amount of UCO which is contaminated with meat cannot be used as animal feed.

- Competition: there are a number of potential competing uses, such as use for heat and production of oleo chemicals. WRAP (2007) estimate that these uses represent a total of 26,000t/y.

- Production of UCO is not always straight forward. A significant resource (130,000t/y) is produced by households, which means that it is difficult to separate from general waste. However, local authorities are undertaking pilots to see if it is possible to collect UCO separately. In this analysis we have assumed that, given the right price, this is feasible.

- The use of UCO for biodiesel is limited by production facilities in the UK. We consider this a downstream constraint and have not considered it in this analysis.

Results – Tallow

Feedstock name: Tallow

Category: UK wastes and residues non-tradable

Biofuel produced per tonne feedstock (GJ/Te): 32.74

Current use for energy (MTe): 0.2 MTe
Current use for energy (TJ): 7,400 TJ
Data source: AEA *et al* 2008

Energy applications: Electricity, Heat, Biofuels,
Scale: Commercial, Industrial

Annual resource potentials	**2010**	**2015**	**2020**	**2025**	**2030**
Unconstrained feedstock potential (Feedstock MTe):	0.3	0.3	0.3	0.3	0.3
Unconstrained feedstock potential (PJ final biofuel):	10	10	10	10	10
Competing feedstock uses at £4/GJ (MTe):	0.10	0.10	0.10	0.10	0.10
...of which % that are independent of price:	0%	0%	0%	0%	0%
Available for bioenergy use (MTe):	0.3	0.3	0.3	0.3	0.3
Available for bioenergy use (PJ):	**10**	**10**	**10**	**10**	**10**

This is known as the "acessible potential" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: AEA *et al* 2008, Uniquema,
Physical constraints: Total tallow production is constrained by meat production in UK.
Main conversion technology: combustion for heat, although biodiesel production may be significant at higher prices.
Upper resource cost limit, if applicable: Price of oil/gas (for heat); price of imported biodiesel.
Environmental constraints assumed: none
Any assumptions re competing land use: none
Other: Based on analysis in AEA et al (2008) we have assumed that as the price increases the production of tallow is switched from category 2

Competing uses for this feedstock:
1) Heat use competes with biodiesel production at low prices
2) Animal feed
3) Soap and oleochemicals

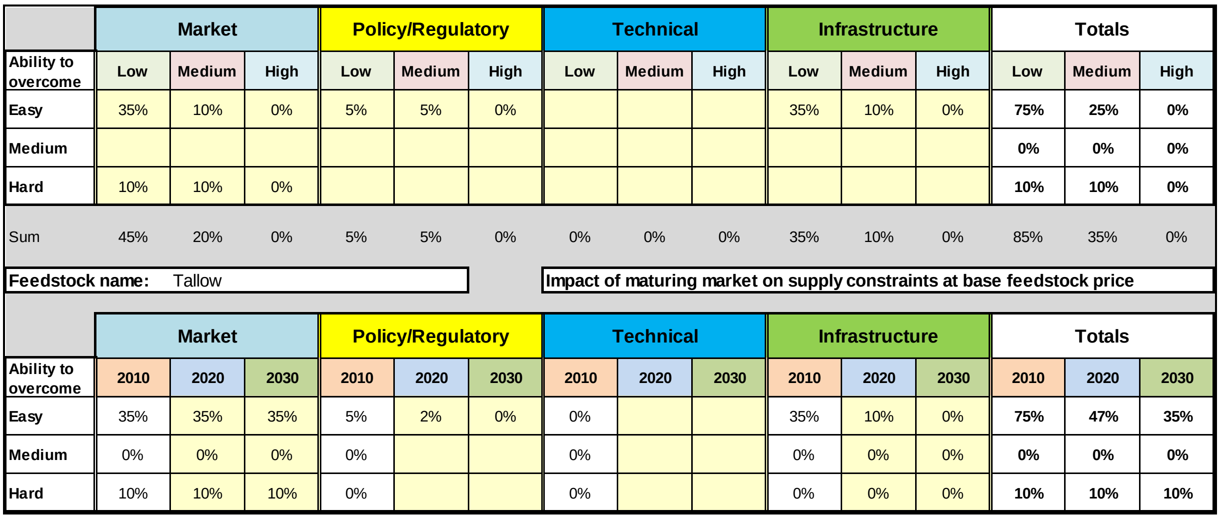
List the top four constraints:
1) Production of meat in UK
2) Need to treat category 1 tallow in WID compliant combustion systems
3) Limits in facilities available for conversion to biodiesel.
4) At low prices alternative uses are important constraint

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	**2010**	**2015**	**2020**	**2025**	**2030**
% reduction at base/low feedstock price:	**85%**		**57%**		**45%**
Constraints that are easy to overcome	75%	37%	47%	35%	35%
Constraints that are medium to overcome	0%	0%	0%	0%	0%
Constraints that are hard to overcome	10%	10%	10%	10%	10%
% reduction at medium feedstock price:	**35%**		**25%**		**10%**
Constraints that are easy to overcome	25%	15%	15%	15%	0%
Constraints that are medium to overcome	0%	0%	0%		
Constraints that are hard to overcome	10%	10%	10%	10%	10%
% reduction at high feedstock price:	**0%**		**0%**		**0%**
Constraints that are easy to overcome	0%	0%	0%	0%	0%
Constraints that are medium to overcome	0%	0%	0%	0%	0%
Constraints that are hard to overcome	0%	0%	0%	0%	0%

Constrained resource potentials (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**
"Accessible" resource potential (PJ)	**10**	**10**	**10**	**10**	**10**
Constrained potential at low price:	**1**	**3**	**4**	**5**	**5**
Constraints that are easy to overcome	7	6	5	4	3
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	1	1	1	1	1
Constrained potential at medium price:	**6**	**7**	**7**	**8**	**9**
Constraints that are easy to overcome	2	2	1	1	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	1	1	1	1	1
Constrained potential at high price:	**10**	**10**	**10**	**10**	**10**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	0	0	0	0	0

Constraints – Tallow



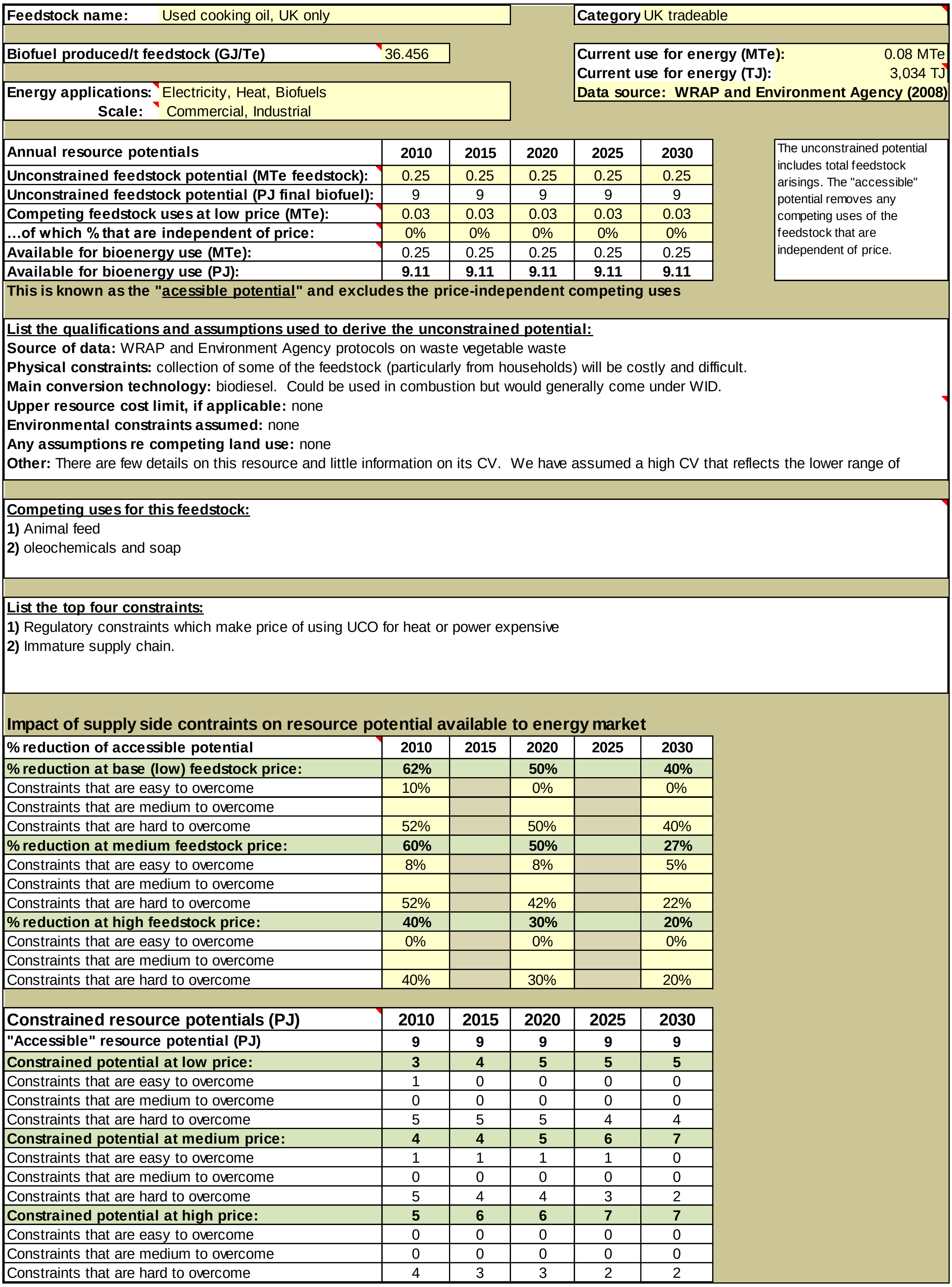
	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Easy	35%	10%	0%	5%	5%	0%				35%	10%	0%	**75%**	**25%**	**0%**
Medium													**0%**	**0%**	**0%**
Hard	10%	10%	0%										**10%**	**10%**	**0%**
Sum	45%	20%	0%	5%	5%	0%	0%	0%	0%	35%	10%	0%	85%	35%	0%

Feedstock name: Tallow

Impact of maturing market on supply constraints at base feedstock price

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	35%	35%	35%	5%	2%	0%	0%			35%	10%	0%	**75%**	**47%**	**35%**
Medium	0%	0%	0%	0%			0%			0%	0%	0%	**0%**	**0%**	**0%**
Hard	10%	10%	10%	0%			0%			0%	0%	0%	**10%**	**10%**	**10%**

Results – UCO



Feedstock name: Used cooking oil, UK only

Category UK tradeable

Biofuel produced/t feedstock (GJ/Te) 36.456

Current use for energy (MTe): 0.08 MTe
Current use for energy (TJ): 3,034 TJ
Data source: WRAP and Environment Agency (2008)

Energy applications: Electricity, Heat, Biofuels
Scale: Commercial, Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (MTe feedstock):	0.25	0.25	0.25	0.25	0.25
Unconstrained feedstock potential (PJ final biofuel):	9	9	9	9	9
Competing feedstock uses at low price (MTe):	0.03	0.03	0.03	0.03	0.03
...of which % that are independent of price:	0%	0%	0%	0%	0%
Available for bioenergy use (MTe):	0.25	0.25	0.25	0.25	0.25
Available for bioenergy use (PJ):	**9.11**	**9.11**	**9.11**	**9.11**	**9.11**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "acessible potential" and excludes the price-independent competing uses

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: WRAP and Environment Agency protocols on waste vegetable waste
Physical constraints: collection of some of the feedstock (particularly from households) will be costly and difficult.
Main conversion technology: biodiesel. Could be used in combustion but would generally come under WID.
Upper resource cost limit, if applicable: none
Environmental constraints assumed: none
Any assumptions re competing land use: none
Other: There are few details on this resource and little information on its CV. We have assumed a high CV that reflects the lower range of

Competing uses for this feedstock:
1) Animal feed
2) oleochemicals and soap

List the top four constraints:
1) Regulatory constraints which make price of using UCO for heat or power expensive
2) Immature supply chain.

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base (low) feedstock price:	**62%**		**50%**		**40%**
Constraints that are easy to overcome	10%		0%		0%
Constraints that are medium to overcome					
Constraints that are hard to overcome	52%		50%		40%
% reduction at medium feedstock price:	**60%**		**50%**		**27%**
Constraints that are easy to overcome	8%		8%		5%
Constraints that are medium to overcome					
Constraints that are hard to overcome	52%		42%		22%
% reduction at high feedstock price:	**40%**		**30%**		**20%**
Constraints that are easy to overcome	0%		0%		0%
Constraints that are medium to overcome					
Constraints that are hard to overcome	40%		30%		20%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	**9**	**9**	**9**	**9**	**9**
Constrained potential at low price:	**3**	**4**	**5**	**5**	**5**
Constraints that are easy to overcome	1	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	5	5	5	4	4
Constrained potential at medium price:	**4**	**4**	**5**	**6**	**7**
Constraints that are easy to overcome	1	1	1	1	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	5	4	4	3	2
Constrained potential at high price:	**5**	**6**	**6**	**7**	**7**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	4	3	3	2	2

Constraints – UCO

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Easy				10%	8%	0%							**10%**	**8%**	**0%**
Medium													**0%**	**0%**	**0%**
Hard	52%	52%	40%										**52%**	**52%**	**40%**
Sum	52%	52%	40%	10%	8%	0%	0%	0%	0%	0%	0%	0%	62%	60%	40%

Feedstock name: Used cooking oil, UK only

Impact of maturing market on supply constraints at base feedstock price

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	0%			10%	0%	0%	0%			0%			**10%**	**0%**	**0%**
Medium	0%			0%			0%			0%			**0%**	**0%**	**0%**
Hard	52%	50%	40%	0%			0%			0%			**52%**	**50%**	**40%**

References for all biofuels

ADAS (2008) Addressing the land use issues for non-food crops, in response to increasing fuel and energy generation opportunities. NNFCC project 08-004

ADAS (2009) Bioenergy review – mapping work. Science report SC070001/SR2

AEA *et al* (2008) Advice on the Economic and Environmental Impacts of Government Support for Biodiesel Production from Tallow.

AEA (2009) Bioenergy review SC07001/SR. Available from the Environment Agency.

Argent (2010) web site: http://www.argentenergy.com/articles/news/article_51.shtml

Beer et al Comparison of Transport Fuels. Final report EV45A/2/F3C Australian Greenhouse Office.

Uniquema, personal communication.

E4Tech (2010) Indirect land use change impacts of oilseed rape for biodiesel Working draft, February 2010.

Huete, S. and Flach R et al EU 27(2009) Biofuels Annual report: Netherlands-Germany EU27. US GAIN report number NL9014

HGCA (2010) Growing wheat for alcohol/bioethanol production Information sheet 11/Summer 2010. Available http://www.hgca.com/document.aspx?fn=load&media_id=6099&publicationId=7780

HGCA (2005) Environmental impact of cereals and oilseed rape for food and biofuels in the UK http://www.hgca.com/document.aspx?fn=load&media_id=1909&publicationId=2309

MVO (2009) Market analysis: Oils and fats for fuel. MVO is the Product Board for Margarine, fats and oils in the NL

NNFCC (2007) An Assessment of the Opportunities for Sugar Beet Production and Processing in the United Kingdom. NNFCC project 07-017

RFA (2009) Carbon and sustainability reporting within the RTFO. Technical Guidance part 2: Carbon reporting - Default values and fuel chains

RFA (2010) Year one of the RTFO 2008/9. Annual report to Parliament on the Renewable Transport Fuel Obligation.

RFA (2010a) Unverified figures for biofuels under the RTFO April 2009- April 2010. http://www.renewablefuelsagency.gov.uk/carbon-and-sustainability/rtfo-reports

SAC (2005) Economic Evaluation of Biodiesel Production from Oilseed Rape grown in North and East Scotland see: http://www.angus.gov.uk/ac/documents/sacreport.pdf

UK Agriculture http://www.ukagriculture.com/crops/oil_seed_rape.cfm

WRAP and Environment Agency (2008). Biodiesel: a financial impact assessment report for the production and use of biodiesel derived from cooking oil and rendered animal fat (tallow). Part of the Waste protocols project

WRAP and Environment Agency (2007). Waste Vegetable Oil: A technical report on the manufacture of products from waste vegetable oil. http://www.environment-agency.gov.uk/static/documents/Business/Waste_vegetable_oil_technical_report_.pdf

Chapter 4: Waste Fuels

UK waste fuels considered in this report included:

- Waste wood
- Solid waste: Municipal, industrial and commercial waste
- Wet waste suitable for anaerobic digestion

A description of the methodologies used for each of these is provided below.

Waste wood

Summary of assumptions and results

Unconstrained Potential	**Assumptions**
5Mt waste wood (85.3 PJ) from 2010 to 2030. **Available for energy use**: 3.5Mt (67PJ) 2010-2020.	Resource studies for recycling and recovery were used for statistics on waste wood production. Of these the most recent (WRAP 2009 and Defra 2009) contain the most up to date information on potential availability. Their figures only examine resource that could be accessed and not total resource. Assume whole resource is available to bioenergy and all types of waste wood could be used. Assume resource is available dry. Results: Resource comprises: Packaging – 1.2Mt Commercial &Industrial waste wood: 0.46Mt Construction and demolition waste wood: 2.32Mt MSW: 1.06Mt Resource remains stable from 2010 to 2030.
Competing uses	Assume that 1.2Mt of waste wood that goes to panel board industry and 0.3Mt that goes to high value products such as horticulture and animal bedding, leaving 3.5Mt
Yield rates	Currently only access easy to sort waste wood. However, all resource could be available. Requires investment and infrastructure to make this feasible.
Cost	Waste wood is by definition a discarded product and has traditionally been available at zero or negative price. However, as demand is outstripping supply the price has risen to up to £30/t or just under £2/GJ. The lowest price examined in this study should make all resource, except for highest value fraction (some 185,000t) available for bioenergy.
Constraints	Low: - Location of feedstock compared with demand - Substantial investment required for processing and handling.

- Lack of standards for wood fuel – particularly for waste wood that comes under WID[3] for purposes of combustion
- Planning and licensing requirements for WID feedstocks.

Total constraint: 25% in 2010 @ £4/GJ, reducing to 0% by 2020

Medium:

- Lack of suitable conversion equipment for difficult feedstocks
- Lack of cost effective advanced conversion systems.

Total constraint: 20% in 2010@ £4/GJ, reducing to 0% by 2020

High:

- Concerns about impact on prices of competing uses.

Total constraint: not included as it is a function of price and at £4/GJ the price is already sufficient to out price competition.

Competing uses

Assumptions on competing uses:
Only very high value products are not affected by price being offered for bioenergy.

Competing uses are:

Use	Tonnage
Panel board	1,119,000
Animal/poultry bedding	350,000
Equine surfaces	73,000
Mulches, soil conditioners and composting	95,000
Pathways and coverings	17,000

Results

- The accessible resource rises around threefold between 2010 and 2030, due mainly to the reduction of waste landfilled. The constraints are not strongly sensitive to the energy price and are mainly hard to overcome.

Graphs showing results for waste wood

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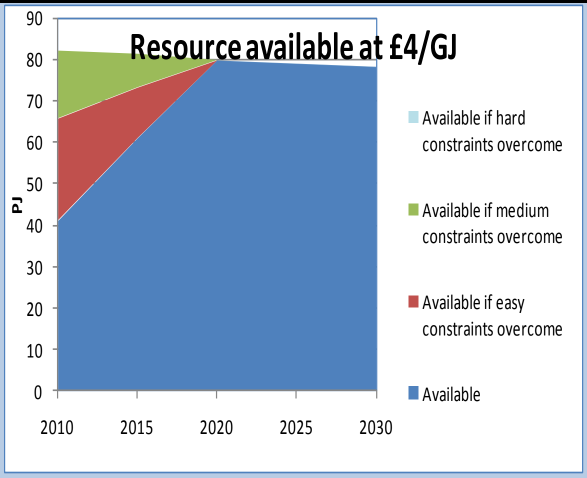
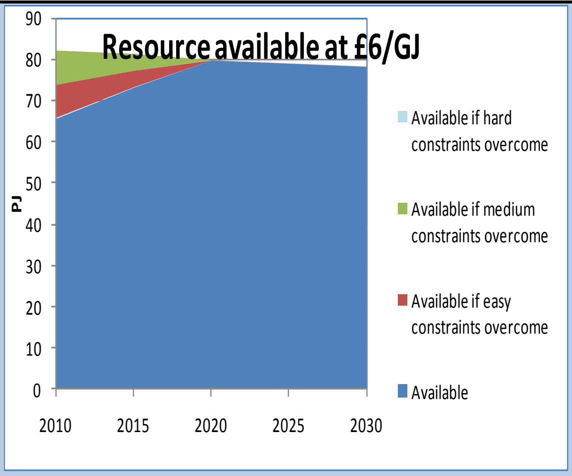
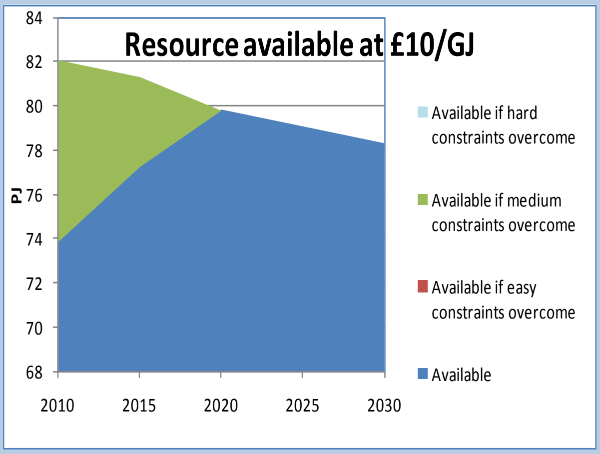
[3] WID: Waste Incineration Directive, which requires strict emissions compliance, which is adds cost to energy recovery.







Additional information - Waste wood

Introduction

The UK waste wood potential is not clearly known. There are no statistics on waste wood and the information that is gathered tends to be for recycling and recovery use or derived from surveys of the composition of various waste streams.[4] From this data the latest information for the UK is:

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[4] The amount of waste wood has been estimated in a number of studies. As the bulk of the waste wood stream arises in the industrial and construction and demolition sectors and these sectors are not subject to routine surveys of the composition of their waste all of these studies have had to rely on surveying of a relatively small proportion of sites and extrapolation of the results. This means that the results are subject to uncertainty. The data we present here shows the range of figures obtained. In a recent report CONFOR (2010) summed this up “Estimates of the size of the waste wood market vary quite considerably indicating that there are considerable uncertainties about the true size of the market because of the lack of accurate information about the quantity of material going into the different waste streams.”

Table 18 Overview of data on waste wood arising

Type of waste wood	Resource estimate (thousand t)	Comments and reference
Packaging	1,169	WRAP (2009)
Industrial waste wood	462.5 (1800-3500)	WRAP (2009) (ERM 2006, TRADA 2002 and BRE 2004)
Construction and demolition waste wood	1,184.5 +1,137.4 (resp.) (900-3,300)	WRAP (2009) (ERM 2006, TRADA 2002 and BRE 2004)
Municipal	1,056.7 (618.7-2,500)	Defra (2009) (WRAP 2009, ERM 2006, TRADA 2002 and BRE 2004)
Total	**5018** **(range: 3150-10469)**	Most industry experts believe the technical resource to be in the region of 5 Mt, i.e. the WRAP potential of around 4Mt from all streams apart from MSW, plus a further 1 Mt from MSW.

The range in the figures is in part due to what is included and what was intended by the study. In this study we have chosen to work with the latest data (WRAP 2009). This is because previous studies were considered to provide figures that gave a false impression of the amount available and the ease with which it could be separated from mixed waste streams providing an overestimate of the waste wood resource. The WRAP (2009) study was focussed on what could actually be accessed and ignored the difficult to separate fractions of mixed waste. The other figures shown in the Table above and summarised below are used to show the uncertainty and controversy surrounding these figures and the great range in figures obtained on waste wood. Separate consultation with the Wood Recycling Association indicates that the industry prefers the latest WRAP figures. In particular the early WRAP study (WRAP &MEL 2005) is thought to provide an over optimistic estimate of waste wood availability.

However, we feel that the WRAP (2009) estimate for municipal solid waste is low and related only to what can be achieved from waste transfer or civic amenity sites. We think it should be possible to collect more wood from municipal sources and have therefore used the higher Defra estimate (Defra 2009).

There may be more waste wood available, but it will be difficult to separate and may well be contaminated with other materials that are difficult to remove. This wood waste is in reality part of the mixed waste stream and has not been included in our totals.

Assuming that all of the above are reasonably dry waste,[5] the conversion to GJ at ~17GJ/t (assuming ~10% moisture):

5,018,000t= 85306000GJ = 85.31 PJ or 0.085EJ

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[5] Most waste wood sourced from post-consumer or treated waste is dried in production and remains reasonably dry through the waste chain.

Table 19 Summary of the results of various studies

Stream	ERM/DTI (2006/2007)	WRAP&MEL (2005)	TRADA (2002)	BRE/Hurley (2004)
Municipal	1.1	1.1	2.5	0.8
Industrial/Commercial	3.5	4.5	1.8	3.3
Construction/Demolition/Remodelling	2.9	5.0	0.9	3.3
Total	7.5	10.6	5.2	7.4

Use of waste wood for energy

Waste wood frequently forms part of a power station or boiler's demand, the remainder being made up with clean waste wood. There are 112MW of dedicated biomass power plants using waste wood plus other fuels at present, 14MW under construction, 100MW with consent awaiting construction and 70MW in planning. This adds up to a demand for over 3Mt of waste wood if all of the plants are built. In addition it has been estimated that another 65MW of thermal capacity exists in industrial premises (consuming over 580,000t waste wood) and that this is set to double over the next two years (DUKES, 2009). There are also a considerable number of biomass plants being built with the intention of using wood chips from abroad (~10Mt in addition to the tonnage indicated above) and many of these plants could use clean waste wood if required.

Constraints

As indicated above, there is high demand for waste wood at present and the technology for re-processing and handling large quantities of waste wood exists. This means that most of the resource in the North of England (just under 2Mt) is currently being reprocessed. This resource goes to panel board manufacture, horticultural and agricultural use and wood energy plants. The horticultural and agricultural market has the best ability to pay, but needs the cleanest grades of waste wood. WRAP (2009) estimated that around 0.5 Mt goes to horticultural and agricultural use and that the maximum availability of suitable waste wood for this market is 1.2Mt. Using data from WRAP (2009), the CONFOR (2010) report estimates that the wood processing industry can use a maximum of 2.32 Mt of waste wood and the wood energy plants could use up to 4.5 Mt of this resource. Currently around 60% of the recycled wood is used by wood panel manufacturers.

Statistics for use of reprocessed waste wood in 2008 are:

Table 20 Reprocessing of waste wood in 2008

Use	Tonnage
Panel board	1,119,000
Animal/poultry bedding	350,000
Equine surfaces	73,000
Mulches, soil conditioners and composting	95,000
Pathways and coverings	17,000
Biomass energy	370,000
Total reprocessed	2,024,000

Source: Wood Recyclers association statistics from web site (June 2009).

From this we conclude that there are two major constraints on waste wood for energy:

- Competition for the resource from other users. Of these it is unlikely that energy users can compete with the use of clean waste wood for bedding or horticultural use, but they will be able to compete on price with panel board manufacture.

- Lack of re-processing capability – the infrastructure required to enable waste wood to be separated from mixed waste. For many sectors this is simply a case of separation at source, followed by processing to an appropriate form for bioenergy. For other sectors, such as the municipal sector a new collection and processing sector will need to be developed if we are to obtain all suitable wood from municipal waste. For the purposes of this analysis we have assumed that 1.2Mt of waste wood goes to the panel board industry in the UK and 0.3Mt to high value products.

Other constraints are:

- Location of feedstock compared to demand and the need to develop infrastructure to address this.
- Lack of standards for wood fuel, particularly to distinguish fuels that need to be combusted in Waste Incineration Directive compliant plants.[6]
- Planning and licensing requirements for WID feedstock
- Lack of suitable small-scale combustion plants for contaminated waste wood. This holds up the market for these fuels and will prevent them being used separately to mixed waste streams.

The effect of the recession

According to figures provided by WRAP (2009) suggests that output from industries that produce waste wood was around 14% below peak levels at the time of their report. This means that the figures above could increase once the recession is over. However, this was estimated by WRAP to be more than 5 years' time. Consequently we have retained the level of 5Mt for the waste wood resource to 2030. In reality, once the recession is over this could increase to 5.7Mt.

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[6] Defra and the Environment Agency are doing some work on this, but it remains a constraint at present.

Results –Waste Wood

Feedstock name: Waste Wood

Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te): 19

Current use for energy (MTe): 1.1Modt
Current use for energy (TJ): 19,000 TJ
Data source: WRAP 2009, CONFOR 2010, Defra 2009

Energy applications: Electricity, Heat,
Scale: Commercial, Industrial

Annual resource potentials	**2010**	**2015**	**2020**	**2025**	**2030**
Unconstrained feedstock potential (MTe):	5.0	5.0	5.0	5.0	5.0
Unconstrained feedstock potential (PJ):	95	95	95	95	95
Competing feedstock uses at £4/GJ (MTe):	1.7	1.8	2.0	2.1	2.2
...of which % that are independent of price:	40%	40%	40%	40%	40%
Available for bioenergy use (MTe):	4.3	4.3	4.2	4.2	4.1
Available for bioenergy use (PJ):	**82**	**81**	**80**	**79**	**78**

This is known as the "acessible potential" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: WRAP (2009), Defra (2009)
Physical constraints: Amount of waste wood produced in the UK and the fraction of that amount that can be recovered in a form suitable
Main conversion technology: Combustion
Upper resource cost limit, if applicable: Dictated by cost of clean wood.
Environmental constraints assumed: A proportion of waste wood resource must be burnt in WID compliant plant.
Any assumptions re competing land use: None
Other: Waste wood availability is restricted by economic activity (e.g. demand for timber, construction and demolition activity)

Competing uses for this feedstock:
1) Panel board mills
2) Animal bedding
3) Horticultural Mulch

List the top four constraints:
1) Location of feedstok compared to fuel demand and processing facilities
2) Lack of clear standards/guidance on WID compliant feedstocks
3) Lack of small-scale WID compliant combustion systems.
4) Perception of impact of use on other commodities and on environment

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	**2010**	**2015**	**2020**	**2025**	**2030**
% reduction at base feedstock price (£4/GJ):	**50%**		**0%**		**0%**
Constraints that are easy to overcome	30%		0%		0%
Constraints that are medium to overcome	20%		0%		0%
Constraints that are hard to overcome	0%		0%		0%
% reduction at £6/GJ feedstock price:	**20%**		**0%**		**0%**
Constraints that are easy to overcome	10%		0%		0%
Constraints that are medium to overcome	10%		0%		0%
Constraints that are hard to overcome	0%		0%		0%
% reduction at £10/GJ feedstock price:	**10%**		**0%**		**0%**
Constraints that are easy to overcome	0%		0%		0%
Constraints that are medium to overcome	10%		0%		0%
Constraints that are hard to overcome	0%		0%		0%

Constrained resource potentials (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**
"Accessible" resource potential (PJ)	**82**	**81**	**80**	**79**	**78**
Constrained potential at £4/GJ:	**41**	**61**	**80**	**79**	**78**
Constraints that are easy to overcome	25	12	0	0	0
Constraints that are medium to overcome	16	8	0	0	0
Constraints that are hard to overcome	0	0	0	0	0
Constrained potential at £6/GJ:	**66**	**73**	**80**	**79**	**78**
Constraints that are easy to overcome	8	4	0	0	0
Constraints that are medium to overcome	8	4	0	0	0
Constraints that are hard to overcome	0	0	0	0	0
Constrained potential at £10/GJ:	**74**	**77**	**80**	**79**	**78**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	8	4	0	0	0
Constraints that are hard to overcome	0	0	0	0	0

Constraints –Waste Wood

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	25%	7%	0%	5%	3%	0%							**30%**	**10%**	**0%**
Medium	20%	10%	10%	0%									**20%**	**10%**	**10%**
Hard	0%	0%	0%										**0%**	**0%**	**0%**
Sum	45%	17%	10%	5%	3%	0%	0%	0%	0%	0%	0%	0%	50%	20%	10%
Feedstock name:	Waste Wood						**Impact of maturing market on supply constraints at base feedstock price (£4/GJ)**								

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	25%			5%			0%			0%			**30%**	**0%**	**0%**
Medium	20%			0%			0%			0%			**20%**	**0%**	**0%**
Hard	0%			0%			0%			0%			**0%**	**0%**	**0%**

References for Waste Wood

BRE, 2003. Best practice of timber waste management .

CONFOR (2010) Wood fibre availability and demand in Britain 2007 to 2025. Prepared for Confederation of Forest Industries (Confor), UK Forest Products Association (UKFPA), Wood Panel Industries Federation (WPIF), by John Clegg Consulting Ltd.

WRAP (2009) Wood Waste Market in the UK. Project MKN022. Available from WRAP website.

Defra (2009) Municipal Waste Composition: A Review of Municipal Waste Component Analyses. Project WR0119. Available from Defra Web site.

DUKES 2009 Digest of UK energy statistics, available from DECC web site.

ERM, 2006. Carbon Balances & Energy Impacts of the Management of UK Wastes.

Hurley, J.W., 2004. United Kingdom. National Summary Reports. COST E31-Recovered Wood.

TRADA, 2002 Part2: Research Findings

Trada (2008) Recovering and minimising wood waste. Wood information sheet 2/3 Sheet 29. Revised June 2008. See: http://www.trada.co.uk/techinfo/library/view/1E2E90AD-240E-4458-B1B8-C6D28F0FDCAD/Recovering+and+minimising+wood+waste/index.html?hl=waste+wood%2Cwaste%2Cwastes%2Cwood%2Cwoods%2Cwaste%2Cwastes%2Cwood%2Cwaste%2Cwastes%2Cwood%2Cwood%2Cwood%2Cwaste%2Cwastes%2Cwood%2Cwoods

WRAP (2005) Reference document on the status of wood waste arisings and management in the UK. M.E.L Research Ltd. ISBN: 1-84405-200-1. Available from the WRAP website.

Solid waste

Introduction

This section covers two potential ways of generating energy from solid waste:

- Recovery of energy from solid waste through combustion technologies
- The use of landfill gas.

These are dealt with separately below. The first section includes a general discussion of trends in waste arisings and waste management and the second discusses the future of landfill gas.

Renewable fraction of solid waste

Summary of assumptions and results

Unconstrained Potential	**Assumptions**
58.7 MTe in 2010 (330PJ) rising to 60.8 MTe (342PJ) in 2030.	Wastes included are MSW (including the wet fraction) and the mixed waste stream of commercial/industrial waste (CIW). Other CIW streams (waste wood, food waste) are covered in other modules or have no real energy generation potential. The unconstrained potential assumes that the resource is available in full for energy use, i.e. no recycling and no landfilling. It is assumed that MSW arisings grow at 0.3% per annum to 2025 whilst CIW arisings remain steady to 2030.
Available resource: 5.1 MTe (29PJ) in 2010 rising to 12.5 MTe (70PJ) in 2030.	Physical constraints: none Main energy from waste (EfW) conversion technology is mass burn incineration. The energy production potentials are factored by 62.5%[7] to reflect the renewable fraction of the input waste. Accessible potentials are based on a paired scenario with landfill gas to avoid double-counting. It assumes that UK recycling targets take precedence and are achieved, and that uptake of EfW accelerates in line with MSW 'recovery' targets to 2020 (75% in 2020, rising to 80% in 2025). We have assumed that the share of the residual waste going to EfW after recycling rises from their values in 2009 (16% MSW and 1% CIW respectively) to reach 50%[8] in 2025, with the balance going to landfill.
Yield rates	Not applicable
Cost	The prospects for EfW are affected mainly by the cost of competing waste disposal options, rather than the value of the energy in the energy market. Hence the rising cost of landfill is the single biggest driver. Some of the constraints are sensitive to energy price (such as the returns and availability of suitable technology for smaller-scale plant)
Competing uses	Assumptions on competing uses: Landfill and recycling/reuse are the principal competing uses for MSW and

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[7] We have used this percentage as it is the one cited in the RED and was used for recording energy from waste contribution to RESTATS until 2010 (when the figure was changed to 63.5% after this work was complete). However, the current Renewable Obligation level is 50%, decreasing in time to 35%. This would make a difference to the energy value that can be claimed for waste and could decrease the figure quoted here by almost half.

[8] This may be optimistic for C&I waste, but is based on assumptions that the cost of landfill continues to rise.

CIW, leaving only 9% for EfW in 2009, rising to 21% in 2030.

We have assumed that Government recycling targets for MSW (increasing linearly to 60% by 2025) and CIW (increasing to 70% by 2025) effectively remove those proportions of waste from EfW or landfill, though in practice some of this is likely to be price dependent (specific to individual materials). 36% of MSW but only 3% of CIW mixed waste was recycled/reused in 2009.[9]

It is assumed that anaerobic digestion of the wet fractions of MSW and CIW are counted as part of the recycling fraction (provided the digestate produced meets the necessary end of waste protocol/quality standard).

We have adopted a scenario consistent with the Government's waste strategy, whereby 75% of MSW is diverted from landfill by 2020, rising to 80% in 2025. To achieve this the fraction of post-recycling residual MSW going to EfW rises from 16% in 2009 to 50% in 2025, thus the balance going to landfill decreases from 84% to an equal 50% in 2025. CIW reaches a similar 50:50 split of residuals in 2025.

Constraints

Hard to overcome:

The main constraint on EFW is its relatively low position in the waste disposal hierarchy, whereby materials recycling will generally take precedence even if it more costly.

Waste disposal contracts are often very long-term, especially if treatment is involved, so the waste may be tied up for long periods.

EFW projects are often subject to strong local opposition, making them politically unpopular choices. It is arguable whether or not this is hard to overcome for all projects; but it probably adds to the cost of development and results in time delays for many proposals.

Medium to overcome:

EFW is strongly subject to economies of scale and tends to be adopted mainly in larger urban areas with significant waste arisings, though returns will improve as landfill tax rises.

Results

- The accessible resource rises around threefold between 2010 and 2030, due mainly to the reduction of waste landfilled. Higher recycling targets may offset this further, but this has not been taken into account in this work. The constraints are not strongly sensitive to the energy price and are mainly hard to overcome.

Graphs showing results for the renewable fraction of solid waste

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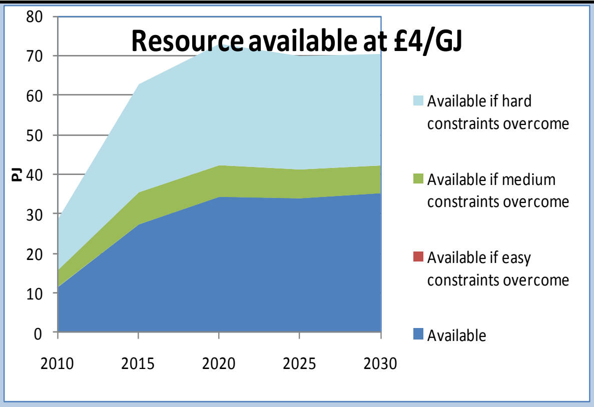
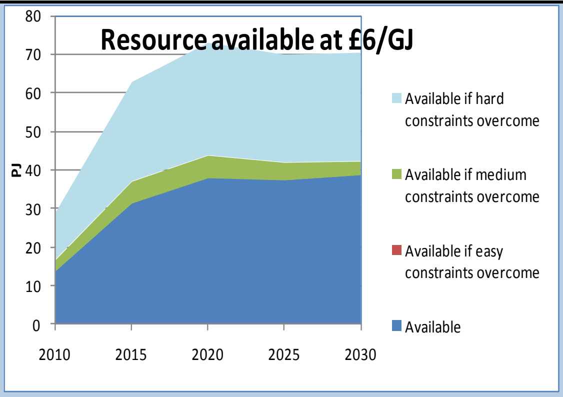
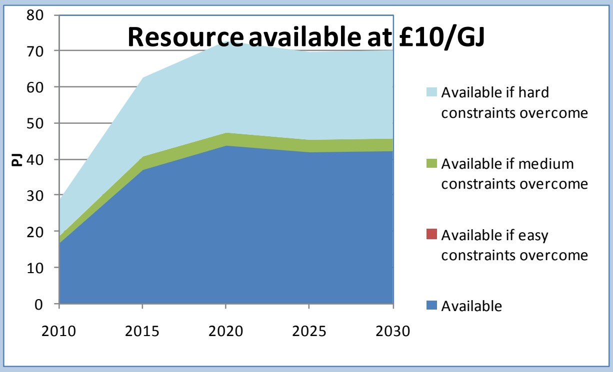
[9] This is a difficult statistic. Once C&I waste is segregated for recycling it is no longer counted as mixed waste and therefore the recycling of C&I mixed waste looks low, but probably more is being achieved in practice.







Additional details

Solid waste arisings and management

We have assumed that two waste streams are most relevant to recovery of energy from the renewable content of waste - municipal solid waste (MSW) collected by local authorities and commercial & industrial (C&I) wastes, collected by private waste contractors. The UK Government has recently enlarged the definition of MSW to included C&I wastes for the purposes of the Landfill Directive to bring the UK in line with other EU countries. This has roughly doubled the amount of “MSW” and consequently the amount of biodegradable municipal waste (BMW) to be diverted from landfill. The achievement of the reduction of the C&I derived BMW landfilled is likely to fall on the waste industry rather than Local Authorities with the current LATS system remaining in place for the proportion of BMW collected by Local Authorities. For the purposes of this report wastes collected by Local Authorities are described as MSW and wastes collected by private waste contractors as C&I wastes, although in the new definition a proportion of C&I waste collected by private companies will also be described as MSW.

Municipal solid waste

MSW covers household and non-household waste that is collected and disposed of by local authorities. It includes regular household collections, specific recycling collections, special collection of bulky items, waste received at household waste recycling centres, and waste collected from non-household sources (such as small businesses).

Table 21 shows that the total arising of MSW in the UK in 2008/09 was 33.4 million tonnes. 36% was either recycled or composted, 10% was sent to an energy recovery facility, and 53% was landfilled.

Table 21: Arisings ('000 tonnes) and management of MSW in the UK in 2008/09

	Recycled	Energy recovery	Other treatment	Landfilled	Total
England[10]	10,082	3,325	204	13,784	**27,395**
Wales[11]	647	32	12	1,035	**1,726**
Scotland[12]	1,127	84	-	2,076	**3,287**
Northern Ireland[13]	322	-	-	695	**1,017**
Total	**12,178**	**3,441**	**216**	**17,590**	**33,425**

Future arisings of bio-energy feedstock

The two factors which will affect future arisings of bio-energy feedstock from MSW are growth in arisings, and meeting future recycling targets.

Growth in MSW arisings

It is difficult to forecast future waste arisings. Waste arisings were shown to grow in line with, or even above, the level of economic growth for much of the latter part of the 20th century, but currently waste arisings are lower than they were ten years ago. A 3% p.a. growth in waste (as seen in the 1990s) would result a doubling of waste arisings in 20 years. However, the continuation of this trend is now considered to be unsustainable, and thus the sixth Environment Action Programme set an objective to achieve a decoupling of resource use from economic growth through significantly improved resource efficiency, dematerialisation of the economy and waste prevention.

The growth in household waste (and hence MSW) is due to two key factors:

- An increase in the number of households, and
- Growth in waste produced per household due to increased consumption.

Waste minimisation and re-use initiatives (Enviros 2004) aim to tackle the growth in waste produced by a household. However, even if these initiatives were to reduce the growth in waste per household to zero, then arisings of household waste would still increase as a result of an increase in the number of households.

One European study[14] has assessed the factors affecting household consumption, and the effects on the environment (resource use, energy use and waste). Another European study[15] developed a model which assesses the effects of food, recreation, 'infotainment', care, clothing, and housing on waste growth and used this to model four scenarios which all assumed continued economic growth but had different future lifestyles. The results showed that waste continued to grow - sometimes at a rate considerably higher than GDP growth rate, sometimes in line with GDP growth rate, and sometimes at lower than GDP growth rates.

Data[16] on MSW arisings from a number of European countries from 1997 to 2003 indicate that in some countries (e.g. Belgium and the Netherlands) waste arisings are growing more slowly than GDP growth. Waste growth in the UK between 1997 and 2003 appears to have been similar to growth in GDP.

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[10] Municipal Waste Management Statistics 2008/09. Defra, November 2009.
[11] Municipal Waste Management Report 2008/09. Welsh Assembly Government, December 2009.
[12] Landfill Allowance Scheme Data – April 2008 to March 2009. Scottish Environment Protection Agency, 2009.
[13] Northern Ireland Environmental Statistics Report. Northern Ireland Department of the Environment, January 2010.
[14] Household Consumption and the Environment. European Environment Agency Report 11/2005.
[15] Scenarios of Household Waste Generation in 2020. Report by Joint Research Centre for the European Commission, June 2003.
[16] Eurostat - ec.europa.eu/eurostat

There are a number of predictions for future MSW arisings; for example:

- A model (Defra 2006) that assesses the impact of lifestyle changes on household waste arisings in the UK. This model has a base case scenario in which waste quantities grow at an average of over 2% per year from 2005 to 2020.

- A model (Oakdene Hollins 2005) that predicts future waste arisings based on national waste strategies and the need to meet various legislative targets. This model has a base case growth rate of 2% per year from 2005 to 2020.

Arisings of MSW in England increased from 24.6 million tonnes in 1996/97 to 29.4 million tonnes in 2002/03, an average growth rate of about 3% per year. However, there has been little growth in arisings since then, and the overall arisings of 27.3 million tonnes in 2008/09 were lower than the arisings of 29.4 million tonnes in 2002/03. MSW arisings in Wales, Scotland and Northern Ireland were also lower in 2008/09 than they were in 2004/05.

There are a number of possible reasons why the measured arisings are lower than those predicted in existing models; these include waste minimisation campaigns, restrictions on the types of waste taken to household waste recycling centres, and possible impact of the current economic situation. A number of studies [17] on longer term trends in waste growth have been conducted, and a review (Fell et al 2010) of the findings from these determined that existing models and forecasts of the future growth of waste were largely speculative. As future waste growth will depend on both hard (i.e. fiscal, regulatory and service provision) and soft (i.e. behaviour change) measures, as well as environmental, behavioural, economic and political factors, the review concluded that further data accumulation and conceptual work to improve modelling and forecasting were required.

The Waste Strategy published in 2007 (Defra 2007a) developed four growth scenarios for MSW in order to assess a range of possible future outcomes to 2020:

1. 2.25% per annum reflecting recent trends in growth in consumer spending;

2. 1.5% per annum in line with national waste growth in the five years to 2004/05;

3. 0.75% per annum, in line with current projections of household growth and reflecting more closely national waste growth in the five years to 2005/06; and

4. 0% growth, representing the possibility that waste growth will be decoupled from household and economic growth.

Although MSW arisings have reduced in recent years, it is unlikely that scenario 4 (0% growth) will occur due to Government and Regional policy regarding future house building (even if a waste minimisation programme reduces the level of growth of waste in a household to 0%, the arisings of MSW will increase because of the increase in the number of houses). The available data, together with the probable impacts of future policies, suggests that whilst MSW arisings will increase, the average longer term growth rate for MSW is likely to be less than the 0.75% per year used in Scenario 3 of the waste strategy. A recent estimate (ERM 2009) for the South East Regional Partnership Board used an average growth rate of 0.3% per year up to 2025, and this estimate has been used to predict future arisings in this report.

The total MSW arising in the UK in 2008/09 (see Table 1) was 33.4 Mt. An average growth rate of 0.3% per year would result in an arising of 35.5 Mt in 2030. However, the amount of MSW which could be used for renewable energy will be lower due to recycling targets.

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[17] For example; Understanding Waste Growth at Local Level. Report (WR0121) by Resource Futures for Defra's Waste and Resources Evidence Programme (WREP), 2009.

Waste policy/strategy

The three main policy areas that will have an impact on MSW management are:[18]

- Recycling targets – the English Waste Strategy sets a target for recycling/composting 50% of MSW (and recovering 75% of MSW) by 2020. Wales has set an MSW recycling target of 70% by 2025, and Scotland is considering a similar target. The Northern Ireland Waste Management Strategy (published in 2006) set a target that 35% of household waste should be recycled or composted by 2010.
- The Landfill Directive – this will require the amount of biodegradable municipal waste which is landfilled to be reduced to 35% of that produced in 1995 by 2020.
- Landfill Tax - The Landfill Tax escalator is the mechanism through which the UK Government increases landfill tax in order to discourage business and local authorities from disposing of waste to landfill. This escalator will increase by £8 per tonne per year to 2014 when it will reach £80/t. As the landfill tax increases, local authorities will come under even greater financial pressure to divert waste from landfill.

Two potential further policy initiatives are:

- Biowaste Directive - The European Commission has been considering the introduction of a Biowaste Directive since 1999, and had indicated it may publish a draft Directive before the end of 2010. If implemented, this Directive would require Member States to encourage the separate collection and treatment of biowaste (food/kitchen waste and garden waste), and drive the demand for new biowaste treatment facilities, such as anaerobic digestion (AD) plants. However a recent communication has indicated the Biowaste Directive has been abandoned and policy is to be based on existing legislation and initiatives (EC 2010).[19]
- Landfill bans – The Government was considering introducing bans on landfilling materials that can be either readily recycled, utilized as feedstock for composting and AD facilities or used to recover energy from waste. A consultation was be held during 2010. As a result the Government in England has stated that it is not minded to introduce landfill bans, but the issue will be considered further as part of the current review of waste policies.

Although landfill bans are likely to increase the tonnage of some materials which are recycled, the main factor which will affect the arising of bio-energy waste will be recycling targets. An average UK recycling rate of 60% by 2030 was assumed for modelling purposes.[20] As the current MSW recycling rate is 36%, then if MSW grows at an average of 0.3% per year to 2030, 21.3 million tonnes of MSW will need to be recycled to meet a 60% recycling target, which is an increase of 9.1 million tonnes on the tonnage recycled in 2008/09.

The current composition of MSW in the UK, using both a review (Resource Futures) of existing analysis data for MSW waste streams in England, and recently completed compositional analysis studies in Scotland (Waste works and AEA 2009a) and Wales, (Waste Works and AEA 2009b) is shown in Table 22.

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[18] This work took the 2007 Waste Strategy into account. The Government is currently reviewing policies and will issue preliminary findings in May 2011.

[19] This situation is not entirely straightforward. The Commission have started work on a consultation to carry out an impact assessment to look at the scope for setting a recycling target for biowaste.

[20] This rate was used for the whole of the UK and not broken down on a regional basis

Table 22: Composition (Wt %) of municipal solid waste in the UK

Category	Weight percent
Paper and Card	21
Plastic	10
Textiles	3
Other combustibles	11
Glass	7
Food waste	17
Garden waste	14
Metal	4
Other categories	13
Total	**100**

Current Government policy is promoting the recycling of food waste, but additional material would also need to be separated in order to meet a 60% recycling target. This would reduce the arising of residual waste that could potentially be used for energy recovery. **In order to assess the impact of higher recycling rates, two scenarios were modelled:**

- Scenario 1 – MSW recycling rate remains at the 2009 rate each year to 2030
- Scenario 2 – MSW recycling rate increases linearly to meet the 60% recycling target by 2025, and the recycling rate remains at 60% until 2030.

Table 23 shows the arising of food waste that could be collected as the UK meets the 60% recycling target for MSW, and Table 7 shows the amount of residual waste that could be used for energy recovery (achieving the 60% recycling target will require other combustible materials, such as paper and plastic, to be separated for recycling). The energy potential from both streams is discussed later.

Table 23: Arisings (million tonnes per year) of food waste from MSW for potential anaerobic digestion *(figures show the amount that would be available after different rates of recycling are achieved)*

Year	At current (2009) recycling rate (Scenario	Recycling target of 60% achieved by 2025 (Scenario 2)
2010	0.8	0.8
2015	0.8	2.0
2020	0.8	2.8
2025	0.8	3.4
2030	0.8	3.4

Table 24: Arisings (million tonnes per year) of residual waste from MSW for potential energy recovery *(figures show the amount that would be available after different rates of recycling are achieved. In other words this is the residual waste after recycling).*

Year	At current (2009) recycling rate (Scenario 1)	Recycling target of 60% achieved by 2025 (Scenario 2)
2010	21.2	21.2
2015	21.5	18.5
2020	21.8	16.6
2025	22.2	15.0

2030	22.5	15.1

It should be noted that 3.4 Mt of residual MSW is currently being sent to energy recovery facilities.

Additional details for Commercial and Industrial waste

The UK Government has recognised that a lack of information on the arisings of commercial and industrial (C&I) waste streams and their growth rates is hampering both the development of an effective waste strategy and the ability to measure and monitor progress effectively. A number of surveys have been conducted, and a programme which will use administrative data (such as that collected by the Environment Agency), together with legislative changes, should enable good quality data on the yearly arisings and management of C&I waste to be available by 2012. However, Defra has identified the need for current information on C&I arisings and management in order to develop policy. Consequently, it announced (Defra 2009) in October 2009 that it would be commissioning a survey of C&I arisings in England; the findings from this should be available in 2011.

The published surveys and studies of commercial and industrial (C&I) waste in each country in the UK are as follows:

England:

- Surveys by the Environment Agency in 1998/99 and 2002/03
- Survey by Urban Mines (2007) of arisings in North West England in 2006/07
- Report prepared by ADAS (2009) for East of England Regional Assembly in 2009; this used results from the survey by Urban Mines conducted in the North West region of England in 2006/07 to predict arisings in each of the other English regions in 2007/08.
- The EU Waste Statistics Regulation report[21] for the United Kingdom in 2006 (published by Defra) also contains an estimate for C&I arisings in England in 2006.
- Survey by Urban Mines (2010) of arisings in the North West region in 2009.

Wales:

- Environment Agency Wales – 2002/03 survey of C&I waste in Wales (spreadsheet information)
- Survey of Industrial & Commercial Waste Arisings in Wales. Report by Urban Mines for Environment Agency Wales, May 2009 (survey conducted in 2008/09).

Scotland:

- Estimation of commercial and industrial waste produced in Scotland in 2004. Report by Napier University for the Scottish Environment Protection Agency (SEPA), November 2006.
- Estimation of commercial and industrial waste produced in Scotland in 2006. Report by Napier University for the Scottish Environment Protection Agency (SEPA), November 2008.
- SEPA Commercial and Industrial Waste Producer Survey 2007.

Northern Ireland:

- Commercial & Industrial Waste Arisings Survey 2004/05. Report by Environment & Heritage Service (EHS), March 2007. This report includes findings from previous[22] surveys conducted in 2000 and 2002.

These data can be used to estimate the total arising of C&I waste in the UK, its composition, and current management (such as percentage recycled). This will enable the current arisings of bio-energy feedstock to be estimated.

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[21] http://www.defra.gov.uk/evidence/statistics/environment/waste/wreuwastestats.htm

[22] References listed in 2004/05 report

Current arising of C&I waste as potential bio-energy feedstock

The total arising of C&I waste in the UK was estimated using the following sources:

- England – ADAS 2009 report (based on 2007 Urban Mines survey in North West)
- Wales – Urban Mines 2009 report for Environment Agency Wales
- Scotland – 2007 estimate by SEPA
- Northern Ireland – Survey in 2004/05.

The reports for England and Wales provide data on the composition of the C&I waste stream, and the composition in both Scotland and Northern Ireland can be estimated using the data for England and Wales. Table 25 shows that the total arising in the UK was 71.9 Mt/y.

Table 25: Arising ('000 tonnes per year) of C&I waste in the UK

	England[23]	Wales	Scotland	Northern Ireland	Total	Wt %
Chemicals	7,641	127	499	42	**8,309**	**12**
Metallic	2,961	333	394	113	**3,801**	**5**
Non-metallic	12,930	866	2,286	363	**16,445**	**23**
Discarded equipment	424	38	90	19	**571**	**1**
Animal & plant	3,842	400	714	165	**5,120**	**7**
Mixed waste	19,974	1,134	3,503	595	**25,206**	**35**
Common sludges	1,914	80	113	30	**2,137**	**3**
Mineral wastes	8,972	595	495	233	**10,295**	**14**
Total	**58,658**	**3,573**	**8,093**	**1,560**	**71,884**	**100**

The most recent survey to cover the management of each of the C&I categories listed inTable 25 was the survey conducted in Wales that was published in 2009. Table 26 shows that 51% of C&I waste in the UK was recycled, 8% was treated (this includes energy recovery), and 41% was landfilled.

Table 26: Management ('000 tonnes per year) of C&I waste

	Reused or recycled	Treated	Landfilled	Total
Chemicals	2,576	4,653	1,080	**8,309**
Metallic	3,687	76	38	**3,801**
Non-metallic	14,636	329	1,480	**16,445**
Discarded equipment	337	177	57	**571**
Animal & plant	4,710	51	358	**5,120**
Mixed waste	756	252	24,198	**25,206**
Common sludges	1,282	299	556	**2,137**
Mineral wastes	8,648	103	1,544	**10,295**
Total	**36,632**	**5,940**	**29,311**	**71,884**

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[23] Interim results of the 2010 C&I survey have recently been released, see: http://www.defra.gov.uk/evidence/statistics/environment/waste/documents/stats-release2010.pdf These are roughly in line with the England numbers in this table.

The categories of C&I waste that could be used as a bio-energy feedstock are the mixed waste stream (this is mainly general waste from offices and canteens), the non-metallic wastes (this includes paper and cardboard) and the animal and plant waste stream. Table 26 shows that the arising of the mixed waste stream was 25.Mt, and that most (96%) of this was landfilled.[24] The arising of the non-metallic waste stream was 16 Mt, and 89% of this was recycled,[25] and the arising of the animal and plant waste stream was 5.1 Mt, of which 92% was recycled. The total amount of material that could potentially be used as a bio-energy feedstock is the tonnage of these three streams which is currently landfilled, and Table 26 shows that this is about 26 million tonnes per year.

Future arisings of C&I waste as bio-energy feedstock

The two factors which will affect future arisings of bio-energy feedstock from C&I waste are growth in arisings, and meeting future recycling targets.

The lack of yearly data on the arisings of C&I waste makes it difficult to predict future arisings using historic trends, but the findings from the surveys and studies conducted in England and Wales indicate that arisings of commercial waste are increasing and arisings of industrial waste are decreasing.

One projection (Defra 2006a) of future arisings has been made using the Regional Economy-Environment Input-Output (REEIO) model which was developed by Cambridge Econometrics for the Environment Agency and the Regional Development Agencies. The model integrates economic growth of 50 C&I sectors with a set of key environmental pressures which include waste arisings. After accounting for the impact of future increases in landfill tax, the model predicted that total arisings of C&I waste in England would increase from 67.5 million tonnes in 2002/03 to 84.5 million tonnes in 2019/20. This is equivalent to an average growth rate of about 1.3% per year. The percentage of industrial waste reduces from 58% in 2002/03 to 47% in 2019/20; this is because the model indicates that whilst the average annual growth in commercial waste will be about 2.5% per year, there will be no growth in industrial waste because of both the decoupling measures aimed at industrial waste and the expected continued shift towards a service based economy. However, Table 25 shows that the estimated arising of C&I waste in England had reduced to 58.6 million tonnes in 2008.

Another estimate (Oakdene Hollins 2005) of future arisings used information from four Regional Assembly Strategy reports (East Midlands, East of England, South East and North West which, between them, were estimated to account for about 40% of overall arisings) to estimate that C&I waste arisings in the UK would increase from 83 million tonnes in 2001 to 94 million tonnes by 2020 (based on Environment Agency survey data for 1998/99). This is equivalent to an average growth rate of 0.8% per year for the overall waste stream, which is lower than the estimated average growth rate of 1.3% determined using the REEIO model. However, Table 26 shows that the estimated arising of C&I waste in the UK had reduced to 71.9 million tonnes.

The continuing shift towards a service based economy means that industrial waste will continue to decline (as indicated by the findings from surveys in England and Wales), and whilst the arising of commercial waste may well grow following the end of the current economic recession, both continuing waste minimisation activities and future increases in landfill tax are likely to result in very little growth in arisings over the next 20 years. The December 2009 update (GLA 2009) of the London Plan significantly reduced the projected tonnage arisings for C&I waste from those published in February 2008 (the update used an average growth rate of 0.1% per year to 2031), and a recent estimate (ERM 2009) for the South East Regional Partnership Board used an average growth rate of 0% per year up to 2025.

Consequently, an average growth rate of 0% per year for C&I waste has been used in this study, and thus the arising in the UK to 2030 of material that could potentially be used as a bio-energy feedstock will be about 26 Mt/y.

The other main factor which will affect future arisings of bio-energy feedstock will be the requirement to meet future recycling targets for the C&I waste stream which are set as part of national or regional waste strategies. Current and proposed recycling targets for C&I waste are as follows:

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[24] As indicated above, this is a difficult statistic. C&I mixed waste that has been segregated for recycling is no longer classed as mixed waste, so it appears that the recycling figures are low.

[25] This includes most of the wood waste considered separately in this study

- England - No targets have yet been set by Defra, but the aims are to increase recycling and treat the food waste fraction using anaerobic digestion. The South East plan has a recycling target for C&I waste of 65% by 2020, and the London plan sets a 70% recycling target for C&I waste by 2020.
- Wales – Minimum of 70% recycling by 2025; there may also be limits on the maximum percentages that can be sent to either an energy recovery facility or landfill.
- Scotland – No specific targets, but a target of 70% will probably be set following the completion of consultation on the Zero Waste plan.
- Northern Ireland – 60% recycling of C&I waste by 2020.

The current recycling rate for C&I waste is just over 50%. Thus if England, Scotland and Northern Ireland adopt a similar (70%) recycling target to that set by Wales, then the amount of material which will need to be recycled to meet this target will need to increase from the current level of 36.6 Mt to 50.3 Mt/y by 2025, which is an increase of 13.7 Mt/y.

In addition, the landfill tax escalator, and both the potential biowaste Directive and potential landfill bans will also have implications for future management of commercial and industrial waste.

Although there is some scope to increase both the amount of non-metallic waste and animal & plant waste which is recycled, Table 26 shows that most of the additional recycling will need to come from increasing the current (3%) recycling rate of the mixed waste stream.

Table 27 shows the composition (SLR 2007) of the mixed waste stream. It has a higher paper & card content, and a lower food/kitchen waste content than the residual (dustbin) waste fraction of municipal waste, but still contains a significant proportion of material which could be separated for recycling (including food waste which could be treated using anaerobic digestion). The remaining material would also be suitable for treatment in the types of facilities that are able to treat, and potentially recover energy, from the residual fraction of household waste.

The arising of this stream is 24 Mt/y, of which about 8 Mt/y is paper & card and about 3 Mt/y is food waste. In order to assess the impact of higher recycling rates, two scenarios were modelled:

- Scenario 1 – C&I recycling rate remains at the 2009 rate each year to 2030
- Scenario 2 – C&I recycling rate increases linearly to meet the 70% recycling target by 2025, and the recycling rate remains at 70% until 2030.

It is likely that specific components of the mixed waste stream will be recycled (e.g. paper and card, metal and food). This is taken into account in the assumed calorific value of the residual waste. However, we have not changed the assumptions on renewable content, as we are assuming that the figure deemed renewable in the RED will not change.

Table 28 shows the arising of food waste that could be collected as the UK meets the 70% recycling target for C&I waste, and Table 29 shows the amount of residual waste that could be used for energy recovery (achieving the 70% recycling target will require other combustible materials, such as paper and plastic, to be separated for recycling). The energy potential from both streams is discussed later.

Table 27: Composition (Wt %) of mixed C&I waste stream

	Composition (Wt %) of mixed waste stream
Paper and cardboard	32
Plastic film	7
Dense plastic	8
Textiles	2
Other combustibles	16
Glass	4
Other non-combustibles	6
Food waste	13
Other organics	2
Metal	4
Household hazardous	1
WEEE	1
Fines	4
Total	**100**

Table 28: Arisings (million tonnes per year) of food waste collected from C&I waste for potential anaerobic digestion

Year	At current (2009) recycling rate	Recycling target of 70% achieved by 2025 (Scenario 2)
2010	0.9	0.9
2015	0.9	2.3
2020	0.9	3.3
2025	0.9	3.8
2030	0.9	3.8

Table 29: Arisings (million tonnes per year) of residual C&I waste for potential energy recovery

Year	At current (2009) recycling rate (Scenario 1)	Recycling target of 70% achieved by 2025 (Scenario 2)
2010	21.8	21.2
2015	21.8	14.6
2020	21.8	11.7
2025	21.8	10.6
2030	21.8	10.6

Total energy recovery potential (MSW + C&I Waste)

Table 30 shows the total arising (Mt/y) of food waste that could potentially be sent to anaerobic digestion plants, together with the estimated electricity generation[26] potential. The electricity generated increases from 1.2 million GJ/year in 2010 to 5.2 million GJ/year by 2030 due to the increasing amount of food waste which is collected in order to meet the recycling targets in Scenario 2. For Scenario 1, there would be no increase in current recycling levels for either MSW or C&I waste, and thus the arising of food waste in 2025 would be 1.7 Mt/y.

Table 30: Potential arisings of food waste suitable for anaerobic digestion

Year	Arising (million t/yr)	Energy content (GJ/year)
2010	1.7	1.2 million
2015	4.3	3.1 million
2020	6.1	4.4 million
2025	7.2	5.2 million
2030	7.2	5.2 million

There may also be potential to recover energy from the digestate product, but this would need to be dried.

Table 31 shows the total amount of residual waste (from both MSW and C&I waste) that could potentially be sent to an energy recovery facility under Scenario 2, together with its energy content (using an average net calorific value[27] of 9 MJ/kg), and the electricity generation potential (in GJ/y) if all of the waste was processed using a conventional (moving grate) energy from waste (EfW) facility, which has an electricity generation efficiency of 23%. If Scenario 2 was implemented, the electricity generation potential would reduce from 89 million GJ/year in 2010 to 53 million GJ/year in 2030 due to the increase in the amount of material that was recycled. Some of this reduction would be off-set by the electricity generated (see Table 10) from recycled (anaerobically digested) food waste.

Table 31: Potential arisings of residual MSW and C&I waste suitable for energy recovery under assumption of increasing recycling (Scenario 2)

Year	Arising (million t/yr)	Energy content (GJ/year)	Electricity potential (GJ/year)
2010	43.0	387 million	89 million
2015	33.1	298 million	69 million
2020	28.3	255 million	59 million
2025	25.6	230 million	53 million
2030	25.7	231 million	53 million

Table 31 shows the potential energy recovery if the EfW facility only generated electricity (efficiency of 23%). A combined heat and power (CHP) facility would have a higher efficiency (at least 40%), and thus would enable more of the potential energy to be recovered provided that suitable markets/uses were available for the heat that could be produced. Note that under the terms of the renewable energy directive energy only the “biodegradable fraction of industrial and municipal waste” can be counted as renewable. The Digest of United Kingdom energy statistics (DUKES[28]) uses a figure of

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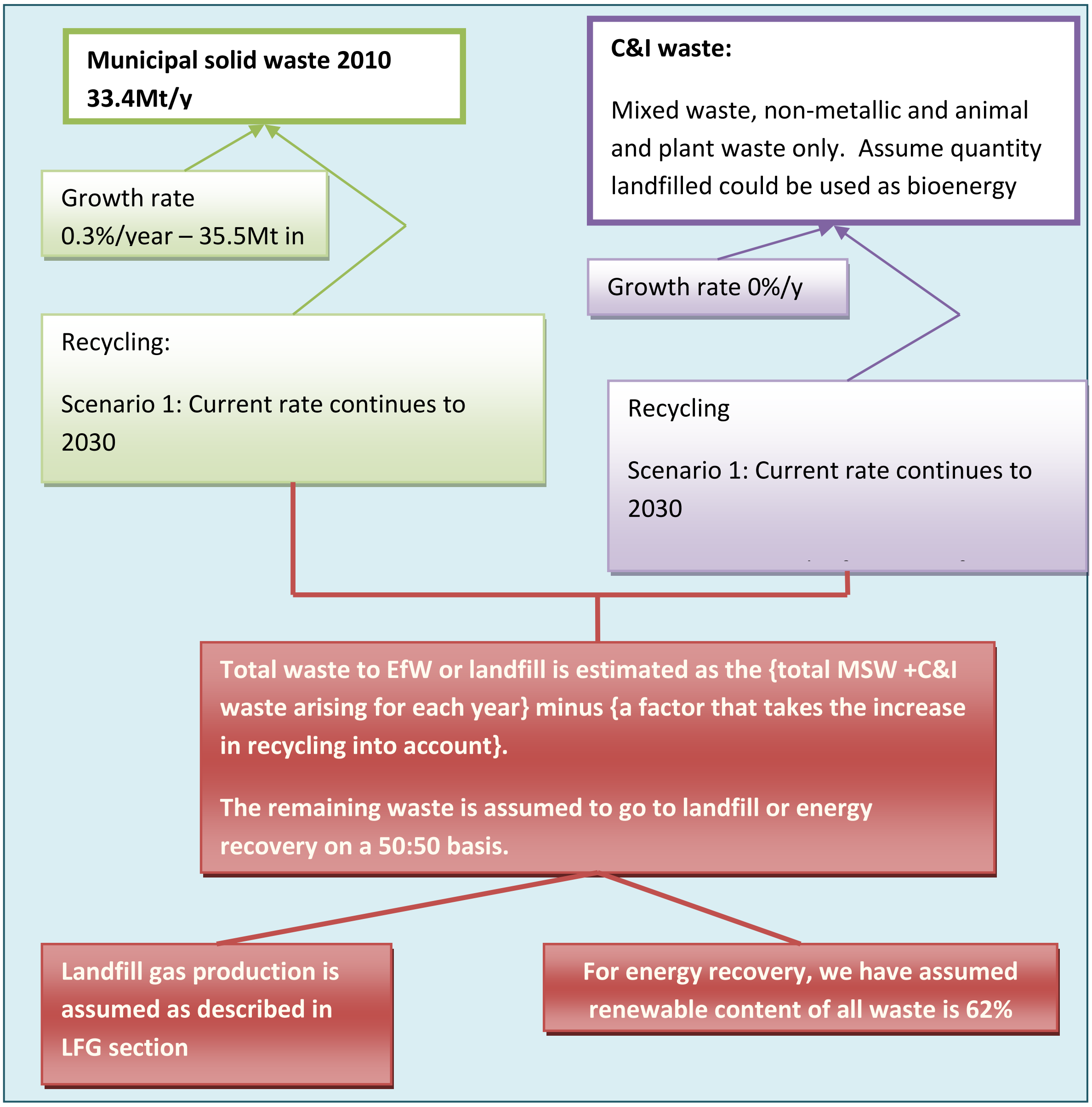
[26] Typical electricity generation of 0.2 MWh per tonne of food waste processed

[27] Net CV derived from data in the Environment Agency’s WRATE database
[28] See paragraphs 7.58 and 7.59 in
http://www.decc.gov.uk/assets/decc/statistics/publications/dukes/1_20090924085908_e_@@_dukes09ch7.pdf

62.5% based on waste analyses and the Renewables Obligation deems a figure of 50% unless evidence from waste analyses can justify a higher one.[29] We suggest that the DUKES figure of 62.5% be used to factor down the energy generation potential.[30] EfW can only receive support under the Renewables Obligation if converted via CHP or advanced thermal conversion (gasification/pyrolysis).

Figure 13: Summary of approach to Renewable Waste to Energy estimate



Total waste to EfW or landfill is estimated as the {total MSW +C&I waste arising for each year} minus {a factor that takes the increase in recycling into account}.

The remaining waste is assumed to go to landfill or energy recovery on a 50:50 basis.

Landfill gas production is assumed as described in LFG section

For energy recovery, we have assumed renewable content of all waste is 62%

Constraints and issues

There are many factors that will influence the amount of MSW and C&I waste used for energy production, not least any demand-side market incentives that are provided to encourage its uptake. The current incentives for electricity generation focus on CHP (limited by the lack of heat markets) and advanced conversion (not yet mainstream), so it is unclear how much market pull there will be for power production. The position may be improved if the RHI is able to support the heat fraction of a CHP plant (e.g. through an uplift for district heating).

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[29] See Chapter 9 of the Government Response to the Statutory Consultation on the Renewables Obligation Order 2009 at http://www.bis.gov.uk/files/file49342.pdf

[30] This is the figure used to calculate the UK targets. The figure changed in 2010 after this work was completed to 63.5 %. We have not changed this in our analysis.

However the current study is focusing on the supply-side constraints. It is difficult to quantify these accurately as they are very dependent on Government policy on waste. However it is clear that reuse and recycling/composting take precedence over energy recovery and that policy aims to maximise these over the period covered by this study. For MSW this preference is virtually independent of the value of the waste as an energy feedstock. For C&I waste the energy value will be a more important factor, as it is less influenced by recycling targets (though usually dependent on projects initially conceived to dispose of MSW). Recycling is much higher for C&I waste and energy recovery lower that MSW, so this indicates that the economics are stacked in favour of recycling, but there is still likely to be a residual fraction needing to be treated. The data above demonstrates that a combination of recycling and removal of non-combustible material[31] reduces the 'unconstrained' arisings of MSW and C&I waste by up to around 76% in 2030.

Of the remaining potential we anticipate that policy issues around the waste hierarchy will constrain a further 40%.[32] We believe that this is a hard constraint to overcome and that it will remain steady over the period in question. However it is worth noting that recycling can be a relatively expensive disposal option and that markets for recycled materials are often volatile. Higher recycling rates reduce the energy potential, but there will also be carbon savings from recycling that are almost always greater than from combustion, which should be taken into account.[33]

In addition the following constraints are likely to apply:

- Waste disposal contracts can often be long-term, rendering the waste inaccessible for other uses over the contract period. The UK has historically had a very heavy reliance on landfill and there are some in the waste disposal industry who are slow to contemplate other options. Both EfW and recycling alternatives should become increasingly financially attractive as the landfill tax rises from its current rate of £48/t to £80/t in 2014, however it is unclear what will happen after 2014.
- In order to achieve the economies of scale needed to make mass burn incineration of waste viable a critical mass of waste is required and this can be difficult to secure, especially if the MSW is committed largely to recycling. With the exception of the MSW held by the waste disposal authority, the waste is usually held and managed by many different parties. This means that EfW is generally seen as complex and rather risky, and why so many projects are driven primarily by a MSW 'base load'. There are waste treatment options that combine recycling and EfW to provide a more flexible mix and these are gaining popularity.
- Much of the potential lies at the relatively smaller scales for which mass burn incineration technology is not well geared. Whilst there are technologies being developed that can meet these market needs they are more likely to be seen as technically and commercially risky and not adopted in the UK generally for some time.
- In addition the following demand-side constraints have a direct effect on the supply potential:
- There are clear public perception/acceptance and planning approval issues for EfW which can act as a major constraint on demand. Public perception does not always prevent mass burn incineration plants being developed, but it may result in severe time delays for development. It is not clear whether advanced conversion plants would be similarly affected.
- Many recent EfW projects have been financed through "public–private partnerships" (PPPs). Some of these are just PPP (privately financed) but others have received support through the

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[31] It is important to note that these non-combustible materials still go into combustion plant as a portion of mixed waste, but just don't produce any energy

[32] Under the revised Waste Framework Directive it is possible to deviate from the waste hierarchy where this offers a better environmental outcome as demonstrated through life cycle assessment. We have not taken this into account in our calculations.

[33] Some energy from waste technologies, such as anaerobic digestion and potentially some of the advanced conversion processes may demonstrate higher savings than recycling.

private finance initiative (PFI), which provided support by a revenue grant from central government. This programme of revenue support is now over. 11 projects are still in procurement supported by PFI revenue grant – after that there will be no more grant and hence no more PFI. In future all large scale waste treatment projects will be procured as PPPs, using private finance.

Results – Renewable fraction of solid waste

Feedstock name: Renewable fraction of wastes (dry MSW & CIW)

Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te): 9.0

Current use for energy (MTe): 3.69 MTe
Current use for energy (TJ): 20,773 TJ
Data source: UK waste statistics (see report)

Energy applications: Mainly electricity, limited potential for CHP
Scale: Industrial

Annual resource potentials	**2010**	**2015**	**2020**	**2025**	**2030**
Unconstrained feedstock potential (MTe):	58.7	59.2	59.8	60.3	60.8
Unconstrained feedstock potential (PJ):	330	333	336	339	342
Competing feedstock uses at £4/GJ (MTe):	53.6	48.1	46.8	47.9	48.3
...of which % that are independent of price:	100%	100%	100%	100%	100%
Available for bioenergy use (MTe):	5.1	11.1	13.0	12.4	12.5
Available for bioenergy use (PJ):	**29**	**63**	**73**	**70**	**70**

This is known as the "<u>acessible potential</u>" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

<u>List the qualifications and assumptions used to derive the unconstrained potential:</u>

Source of data: UK waste statistics for MSW and commercial/industrial waste (CIW - "mixed waste" stream only). See report for details.

Physical constraints: none - these are the total waste arisings for MSW, including the wet fraction. CIW streams other than mixed waste are covered in other modules (waste wood, food waste) or have no real energy generation potential.

Main conversion technology: Mass burn incineration, which has a conversion efficiency to delivered electricity of 23%, based on electricity-only plant. Use of CHP would increase this to at least 40%, however the prospects for developing CHP are poor due to the limited heat applications available. There will also be some use of waste derived fuels.

Upper resource cost limit, if applicable: not applicable
Environmental constraints assumed: none
Any assumptions re competing land use: not applicable
Other: the unconstrained potential assumes that the resource is available in full for energy use, i.e. no recycling and no landfilling. It is assumed that MSW (municipal solid waste) arisings grow at 0.3% per annum to 2025 whilst CIW arisings (commercial and general industrial wastes) remain steady to 2030. Note that due to the multiple permutations for waste resource use available, energy yields are difficult to project with accuracy.

<u>Competing uses for this feedstock:</u>

1) 36% of MSW but only 3% of CIW mixed waste was recycled/reused in 2009.
2) We have assumed that Government recycling targets for MSW (increasing linearly to 60% by 2025) and CIW (increasing to 70% by 2025) effectively remove those proportions of waste from EfW or landfill, though in practice some of this is likely to be price dependent (specific to individual materials).
3) It is assumed that anaerobic digestion of the wet fractions of MSW and CIW are counted as part of the recycling fraction.
4) We have adopted a scenario consistent with the Government's waste strategy, whereby 75% of MSW is diverted from landfill by 2020, rising to 80% in 2025. To achieve this the fraction of post-recycling residual MSW going to EfW rises from 16% in 2009 to 50% in 2025, thus the balance going to landfill decreases from 84% to an equal 50% in 2025. CIW reaches a similar 50:50 split of residuals in 2025.

<u>List the top four constraints:</u>

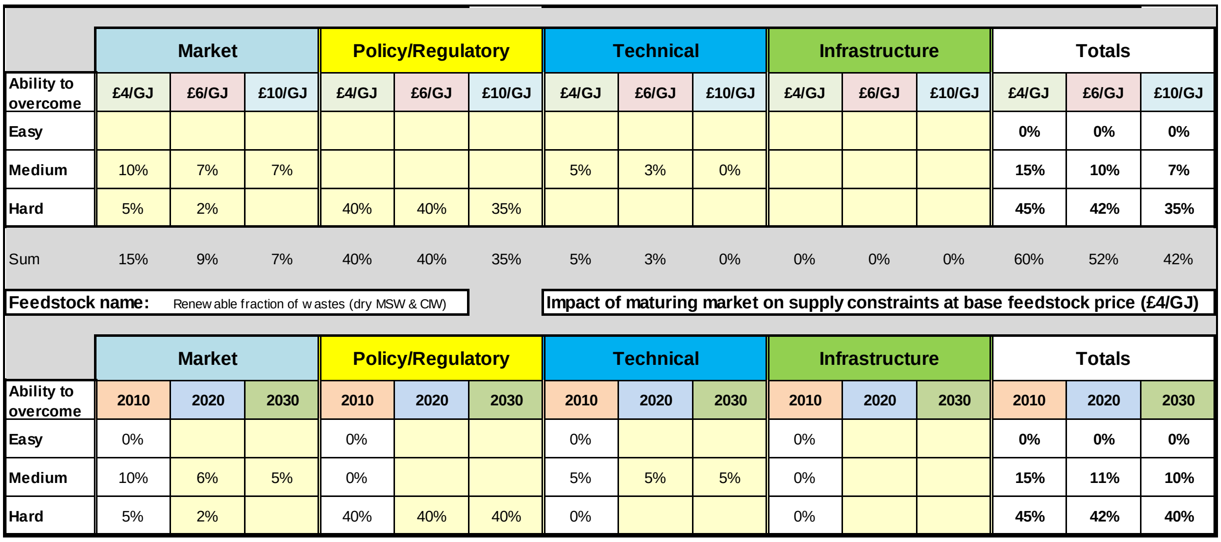
1) The main constraint on EFW is its relatively low position in the waste disposal hierarchy, whereby materials recycling will generally take precedence even if it more costly. Policy in this area is the subject of debate and is often seen as uncertain.
2) Waste disposal contracts are often very long-term, especially if treatment is involved, so the waste may be tied up for long periods.
3) EFW projects are often subject to strong local opposition, making them politically unpopular choices.
4) EFW is strongly subject to economies of scale and tends to be adopted mainly in larger urban areas with significant waste arisings.

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	**2010**	**2015**	**2020**	**2025**	**2030**
% reduction at base feedstock price (£4/GJ):	**60%**		**53%**		**50%**
Constraints that are easy to overcome	0%		0%		0%
Constraints that are medium to overcome	15%		11%		10%
Constraints that are hard to overcome	45%		42%		40%
% reduction at £6/GJ feedstock price:	**52%**		**48%**		**45%**
Constraints that are easy to overcome	0%		0%		0%
Constraints that are medium to overcome	10%		8%		5%
Constraints that are hard to overcome	42%		40%		40%
% reduction at £10/GJ feedstock price:	**42%**		**40%**		**40%**
Constraints that are easy to overcome	0%		0%		0%
Constraints that are medium to overcome	7%		5%		5%
Constraints that are hard to overcome	35%		35%		35%

Constrained resource potentials (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**
"Accessible" resource potential (PJ)	**29**	**63**	**73**	**70**	**70**
Constrained potential at £4/GJ:	**12**	**27**	**34**	**34**	**35**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	4	8	8	7	7
Constraints that are hard to overcome	13	27	31	29	28
Constrained potential at £6/GJ:	**14**	**31**	**38**	**37**	**39**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	3	6	6	5	4
Constraints that are hard to overcome	12	26	29	28	28
Constrained potential at £10/GJ:	**17**	**37**	**44**	**42**	**42**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	2	4	4	3	4
Constraints that are hard to overcome	10	22	26	24	25

Constraints – Renewable fraction of solid waste



	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	£4/GJ	£6/GJ	£10/GJ	£4/GJ	£6/GJ	£10/GJ	£4/GJ	£6/GJ	£10/GJ	£4/GJ	£6/GJ	£10/GJ	£4/GJ	£6/GJ	£10/GJ
Easy													0%	0%	0%
Medium	10%	7%	7%				5%	3%	0%				15%	10%	7%
Hard	5%	2%		40%	40%	35%							45%	42%	35%
Sum	15%	9%	7%	40%	40%	35%	5%	3%	0%	0%	0%	0%	60%	52%	42%

Feedstock name: Renewable fraction of wastes (dry MSW & CIW)

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030
Easy	0%			0%			0%			0%			0%	0%	0%
Medium	10%	6%	5%	0%			5%	5%	5%	0%			15%	11%	10%
Hard	5%	2%		40%	40%	40%	0%			0%			45%	42%	40%

References for Solid Waste

ADAS (2009) Study into Commercial and Industrial Waste Arisings. Report for the East of England Regional Assembly, April 2009.

Defra (2006) Modelling the Impact of Lifestyle Changes on Household Waste Arisings in the UK. Report by the Future Foundation and Social Marketing Practice for Defra.

Defra (2006a) Partial Regulatory Impact Assessment of the Review of England’s Waste Strategy.

Defra (October 2009) Commercial and Industrial Waste in England - Statement of aims and actions 2009.

EC (2010) Recent communication Brussels, 18.5.2010 COM(2010)235 final COMMUNICATION FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT on future steps in bio-waste management in the European Union

Enviros (2004) International Waste Prevention and Reduction Practice: Final Report. Report for Defra

ERM (2009) Regional Waste Management Capacity: Summary of modelling results. Report for South East England Partnership Board.

D Fell, J Cox, D Wilson. Future waste growth, modelling and decoupling. Waste Management & Research, 2010, pages 281–286

GLA (2009)Minor alteration to the consultation draft replacement London Plan. Greater London Authority, December 2009

Oakdene Hollins (2005) Quantification of the Potential Energy from Residuals (EfR) in the UK. Report for The Institution of Civil Engineers and The Renewable Power Association.

Resource Futures Municipal waste composition – A review of municipal waste component analyses. Report for Defra for project WR0119.

SLR (2007) Determination of the Biodegradability of Mixed Industrial and Commercial Waste Landfilled in Wales. Report for Environment Agency Wales

Urban Mines (2007) Study to fill Evidence Gaps for Commercial & Industrial Waste Streams in the North West Region of England. Report for the North West Regional Technical Advisory Board, May 2007.

Urban Mines (2010) North West of England Commercial and Industrial Waste Survey 2009. Report for the Environment Agency

WastesWork and AEA (2009a) The composition of municipal solid waste in Scotland. Report for Zero Waste Scotland.

WastesWork and AEA (2009b) The composition of municipal solid waste in Wales. Report for WRAP, May 2009

Landfill gas fraction of solid waste

Summary of assumptions and results

Unconstrained Potential	**Assumptions**
58.7 MTe in 2010 (235PJ) rising to 60.8 MTe (243PJ) in 2030. Available resource: 39.3 MTe (166PJ) in 2010 reducing to 12.5 MTe (69PJ) in 2030.	Unconstrained potential is the total MSW arisings and commercial/industrial (CIW) wastes that have gas generation potential. Other CIW streams (waste wood, food waste) are covered in other modules or have no real energy generation potential. The unconstrained potential assumes that the resource is available in full for landfill, i.e. no recycling and no incineration. It is assumed that MSW arisings grow at 0.3% per annum to 2025 whilst CIW arisings remain steady to 2030. Physical constraints: Waste decomposes over many years in landfills, thus the generation potential in any given year is based mainly on historically deposited waste. The data presented above assume a ten year decay half-life and usable gas generated over a period of 20 years. Main landfill gas (LFG) conversion technology is electricity generation, with a 30% efficiency. Accessible potentials are based on a paired scenario with energy from waste (EfW) from the renewable fraction to avoid double-counting. It assumes that UK recycling targets take precedence and are achieved, and that uptake of EfW accelerates in line with MSW 'recovery' targets to 2020 (75% in 2020, rising to 80% in 2025). It is assumed that the share of the residual waste going to EfW after recycling rises from their values in 2009 (16% MSW and 1% CIW respectively) to reach 50% in 2025, with the balance going to landfill. The LFG resource is estimated using figures for landfill over the past 20 years and the next 20 years. It is assumed that LFG produces an energy yield of 4GJ/t and that this is released over 20years. The LFG production in any one year has then been estimated using a cumulative addition of the resource in that year. Further details are provided in the background section below.
Yield rates	Energy yield is based on 4GJ/T of waste landfilled over 20 years
Cost	Once the waste is in place in landfills, the main factors determining whether it is economic to recover the energy are environmental controls requiring the collection (or flaring) of the gas and the value of the gas in energy markets. The reduction of ROC income through low banding of LFG has reduced the economic incentive to exploit LFG.
Competing uses	Assumptions on competing uses: Recycling/reuse and EfW are the principal competing uses for MSW and CIW, accounting for only 29% in 2009 but projected to rise to 79% in 2030. We have adopted a scenario consistent with the Government's waste strategy, whereby 75% of MSW is diverted from landfill by 2020, rising to 80% in 2025. To achieve this the fraction of post-recycling residual MSW going to EfW rises from 16% in 2009 to 50% in 2025, thus the balance going to landfill decreases from 84% to an equal 50% in 2025. CIW reaches a similar 50:50 split of residuals in 2025. It is assumed that anaerobic digestion of the wet fractions of MSW and CIW are counted as part of the recycling fraction.

It is likely that the gas generation potential of waste going to landfill will fall over the period to 2030, due to the progressive removal of components with a high biodegradable content for AD and composting. However this is not taken into account in the modelling because we have assumed a constant LFG production rate over the time period considered. Further work on the modelling of LFG production and its likely tail off with time is required to understand this more fully.

Constraints

Hard to overcome:

The really significant constraint for landfill gas is the landfill directive which imposes demanding targets for the reduction of biodegradable municipal waste going to landfill compared with the base year of 1995. These are a 25% reduction by 2010, 50% by 2013 and 65% by 2020.

Government targets require that MSW recycling/recovery rises to 75% in 2020 (therefore landfill falls to 25%). We have assumed that this target rises further to 80% in 2025.

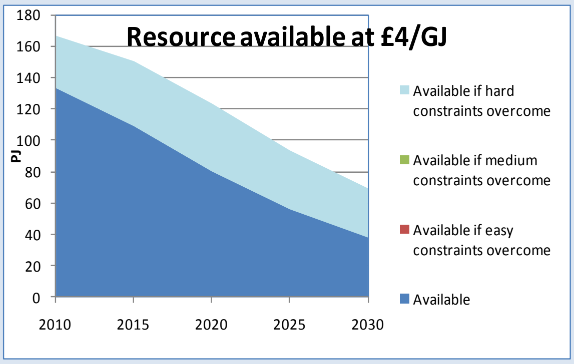
The landfill tax acts as a further deterrent to landfill. Currently set at £48/tonne (+VAT), the rate for active waste will continue to escalate by £8 per year until at least 2014/15, when it will reach £80 per tonne.

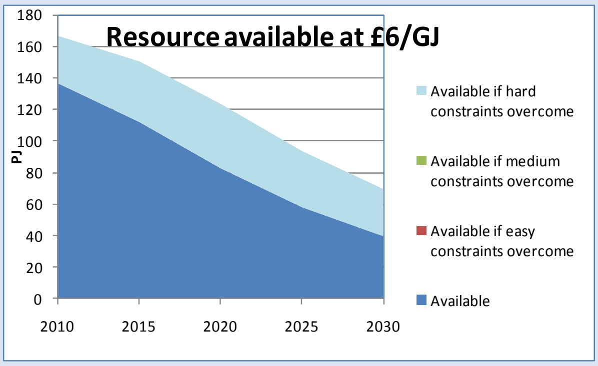
The Government is considering introducing bans on landfilling materials that can be either readily recycled, utilised as feedstock for composting and AD facilities or used to recover energy from waste.

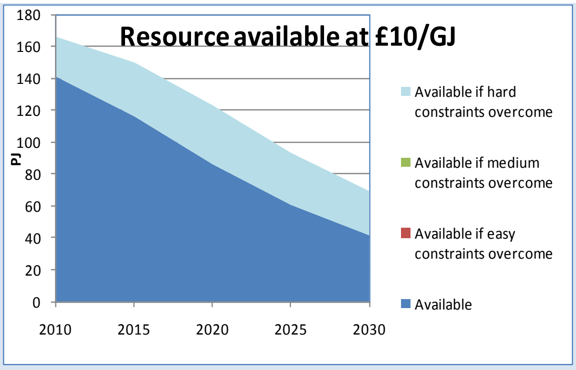
Results

- The accessible resource falls by 58% between 2010 and 2030, due mainly to the reduction of waste landfilled. The constraints are less sensitive to the energy price than to the other constraints, such as policy constraints and the landfill tax, that are hard to overcome.

Graphs showing results for landfill gas







Additional Information for Landfill gas

Resource assumptions

Landfill gas (LFG) is a combustible mixture of methane and carbon dioxide formed when biodegradable organic wastes decay in the airless (anaerobic) conditions of landfills. This process is also harnessed for digesting organic wastes in purpose-built vessels to generate methane-rich biogas from organic wastes, by means of anaerobic digestion (AD).

Landfill gas formation begins within a few months of organic waste being placed in the landfill and then increases rapidly over the following 5 to 10 years. Methane concentrations during this stage of waste decomposition are typically around 40-60% by volume, the rest being carbon dioxide and water vapour, plus a vast number of trace constituents. Gas formation peaks within about 5-10 years and then gradually tails off, although some methane may be detected after decades. As production falls, the methane content also decreases. Below about 30% by volume methane, energy recovery becomes problematic, and below about 17% the landfill gas cannot be flared without a pilot fuel. Most landfill gas energy schemes have a life of about 5-10 years.

Electricity generation is the predominant exploitation route of landfill gas. The technology is well-proven and there is now a great deal of industry experience in the field. Typical sizes range from 0.25 to over 3 MW_e per unit. A modular approach allows flexibility as, when gas production in one site starts to tail off, the superfluous capacity can be moved elsewhere to maximise recovery. In many respects LFG is one of the success stories of recent decades, with approaching 1GW of installed electricity generating capacity in place.[34] There is also a small amount of heat production from LFG but finding heat applications close to landfill sites is problematic and, in recent years, the support available under the NFFO/RO has encouraged electricity generation.

Landfill has been the mainstay of UK waste disposal for many years but recent policy has shifted towards minimising it, due to its wide range of environmental issues (not least emission of landfill gas to atmosphere). Defra's waste strategy[35] provides a clear hierarchy for waste disposal, with final disposal to landfill firmly at the bottom:

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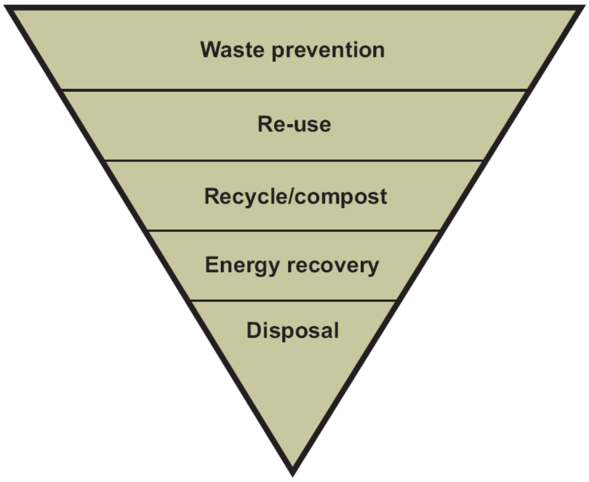
[34] An average of 32MW capacity has been installed per year for the last four years

[35] http://www.defra.gov.uk/environment/waste/strategy/strategy07/index.htm



The 1993 Landfill Directive requires the implementation of measures to reduce or eliminate the escape of pollutants and reduces the amount of biodegradable wastes that members states can landfill, setting targets for reduction based on 1995 levels: 25% by 2010, 50% by 2013 and 65% by 2020. In recent years there has been a strong trend towards recycling, with many collection authorities moving towards source separation. Recycling targets plus the deployment of composting and AD technologies, are gradually removing the material with high LFG production potential from the waste going to landfill. The Government's landfill tax is providing a further clear financial disincentive; currently standing at £48/tonne, it is due to continue to rise by £8/year until at least FY 2014/15, taking it to £80/tonne.

All this spells the eventual end of landfill for biodegradable material as a waste disposal option and, therefore, the eventual end of landfill gas as a major energy resource. However the decline is not easy to predict, partly because of the uncertainties associated with policy development and implementation, partly because LFG continues to be produced well after waste's placement in landfill. Without detailed modelling it is difficult to predict the decline with accuracy; we have balanced the various trends in waste management as indicated above, to provide reasonable estimates of the overall outcome. However, we have not done scenario analysis to examine the differences some of the assumptions in waste management might make.

We have not examined LFG in isolation, but have paired our analysis with the energy from waste (EfW) analysis to ensure no double counting of the renewable resource in solid waste. The unconstrained potential is taken as the full MSW arising plus the mixed waste fraction of commercial and industrial (C&I) waste. The scenario assumes that recycling targets are achieved and that, the uptake of EfW accelerates in line with MSW 'recovery' targets to 2020 (which include energy recovery). For both MSW and C&I waste it is assumed that the share of the residual waste after recycling rises from their values in 2009 (16% and 1% respectively) to reach 50% in 2025, with the balance going to landfill.

Summary of assumptions

In summary, the assumptions we have made in our calculations of landfill gas production include the following:

- Waste was deposited to landfill at a constant deposition until 2010. This mainly concerns waste deposited over the past 20 years, as we have assumed that all of the usable LFG is produced over a 20 year period.
- The reduction in waste to landfill in the future is assumed as part of the paired scenario with energy from solid waste explained above. Having taken recycling targets and potential increases in waste generation into account this scenario assumes that 50% of the residual goes to landfill and 50% to energy from waste.
- Landfill gas production has a half life of 10 years, i.e. production decreases by half in 10 years
- All of the usable LFG produced over a 20 year period after deposition.
- The CV of LFG converted back to tonne of waste is equivalent to 4GJ/t waste (see below)

Our estimate of the unconstrained LFG resource is based on the following assumptions. We have assumed the MSW arisings presented in the wastes module (from UK waste statistics, totalling 33.4 Mt in 2008/09) with an annual growth rate of 0.3% to 2025. For commercial and industrial (C&I) wastes, we have used only the tonnage for the ‘mixed waste’ stream as that with significant gas producing potential (25.2 million tonnes) and the assumption that arisings will remain steady to 2030. This gives a total **unconstrained resource of 58.7 million tonnes in 2010**, rising to **60.8 million tonnes in 2030**.

To calculate the energy supply potential associated with this, we have used a gas generation potential of 200m^3 per tonne of waste and an average calorific value of 20MJ/m^3 quoted by a FES report on renewable heat (FES 2005), which gives an energy production potential of 4GJ/tonne.[36] This results in an unconstrained energy supply potential of 235PJ in 2010, rising to 243PJ in 2030. This figure is only helpful in that it provides an upper limit on the resource; clearly much of this resource does not currently, and will not in the future, be disposed of to landfill. The next section therefore estimates the accessible resource, i.e. that remaining once the competing uses are removed.

The accessible LFG resource

The competing uses for landfill are those waste disposal options higher up the waste hierarchy. These are difficult to predict for the future as they depend on a wide range of factors: policy, market trends and technology development. Our analysis of EfW shows the impact of increasing recycling rates on the availability of waste for other disposal options. For MSW recycling is assumed to rise from the current rate of 36% to 60% by 2030; for the mixed waste stream of C&I wastes the rate rises from 3 to 57% by 2025. To this is added the tonnage that is assumed to be used by EfW plants (5.1 Mt in 2010 rising to 12.5 Mt in 2030).

The table below summarises the resulting ‘accessible’ energy supply potential and compares it with the data presented in E4tech’s report.

Table 32 LFG potential estimates compared with the E4Tech analysis.

Landfill gas potential (PJ)	2010	2015	2020	2025	2030
This study	166	150	123	93	69
E4tech report	54	39	29		15
Eunomia (2010)	154	127	107	92	82

Our figures are systematically higher than E4tech’s, but it is difficult to explain the differences as the basis for E4tech’s calculations were not provided. However it is possible to compare these figures with the current energy generation from LFG. Data from RESTATS and recent sources suggest that the installed capacity at the end of 2009 was 944MW, generating 5,170GWh (18.6PJ) at an average load factor of 62.5%. This is equivalent to an energy input of 62 PJ/y at a 30% energy conversion efficiency (typical for LFG electricity generation). The figures in Table 32 exceed this number, but they are an estimate of the maximum accessible potential, and do not take the difficulties in generating energy from LFG at low methane values into account.[37] An early draft of work being supported by Defra by Eunomia (see foot note 29) was made available during this project. This work showed that methane production in landfill decreases from 2010 and that methane recovery is approximately 70% of methane released by landfill sites. The results for the methane production predicted by Eunomia

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[36] Clearly this potential is released over a long period of waste decay but the annual generation potential is based on the approximation of a steady state supply of waste

[37] Note: There are various models of landfill gas potential, such as the Melmod model, which was developed to estimate potential landfill gas production for the UK GHG inventory (for reporting to the IPCC, and now carbon budgets). An update to this model is currently being undertaken for Defra & DECC by Eunomia. We have not used these models because they were not available to us in this work and because we were keen to ensure no double counting of waste, so our waste to landfill estimates had to be in line with the waste to energy recovery estimate. However, the model is designed to enable other figures to be input and allows estimates from these models to be obtained. It will also be important to understand the assumptions used in these figures and the impact they have on the residual combustible waste available for energy recovery as well.

are presented above and are of the same order as our estimates. Differences might be explained by some of the assumptions made about landfill waste and its biodegradable potential.

Constraints

The accessible resource described above takes into account estimates of the competing uses of waste that will take precedence over landfill. The value of waste on these alternative markets is therefore already taken into account. This means that, for waste going to landfill, we have assumed that sensitivity to price is not significant. There is some sensitivity to price for LFG exploitation, as there will be instances where gas recovery for energy is economically marginal and would be encouraged by a higher energy price.

The main factors that will constrain landfill gas supply, over and above the reductions for competing uses factored into the accessible potential, are as follows:

- Policy
    - The most significant constraint for landfill gas is the Landfill Directive, which imposes demanding targets for the reduction of biodegradable municipal waste going to landfill compared with the base year of 1995.
    - The landfill tax acts as a clear deterrent to landfill. The escalation in this tax improves the competitiveness of alternative treatment options and is designed to constrain the volume of waste going to landfill.
- The Government is considering introducing bans on landfilling materials that can be either readily recycled, utilised as feedstock for composting and AD facilities or used to recover energy from waste. This would significantly reduce the gas generating potential of the residual waste going to landfill.

Landfill gas is therefore subject to a considerable number of factors that will reduce both the volume of waste going to landfill and its gas generation potential. Most of the good sites are already exploited and the law of diminishing returns applies to the remaining potential. In 2009 the ROC income available to LFG stations under the RO was reduced from 1 ROC to 0.25 ROC/MWh with the introduction of banding, and this demand constraint will further limit the number of remaining landfill sites that could be tapped economically. Industry sources predict a decrease in landfill gas electricity capacity of between 20 and 40% of 2010 levels by 2020. Changes in technology may allow the operators to mitigate this downturn through site management improvements and the operation of small efficient generation kit. The reduction in generating capacity will not therefore be as rapid as suggested by the decrease in waste being deposited, due to the extended gas generation period.

Conclusions

Landfill gas will have been a success while it lasted, providing one of the major bioenergy contributions to electricity supply over the last two decades, whilst helping to limit landfill's damaging emissions to atmosphere. However it is a resource with a limited life, as market trends stimulated by a strong policy imperative seek to minimise the material that generates the fuel. In many respects the resource will not be lost, as the embodied energy may well be recovered (and more efficiently) by upstream treatment processes; lifecycle analysis may also show that recycling provides a more positive energy balance. The historic waste and the waste being deposited now will continue to generate gas for many years, thereby mitigating the decline in generation potential. So whilst it is unlikely that significant new LFG generation capacity will come on stream, it is likely that LFG will still be making a contribution in 2030, albeit significantly smaller than that at present.

Results – Landfill gas

Feedstock name: Landfill gas

Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te waste): 4

Current use for energy (MTe): 15.5 MTe
Current use for energy (TJ): 62,000 TJ
Data source: conversion from RESTATS data

Energy applications: Mainly electricity, limited heat and CHP
Scale: Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (MTe):	58.7	59.2	59.8	60.3	60.8
Unconstrained feedstock potential (PJ):	235	237	239	241	243
Competing feedstock uses at £4/GJ (MTe):	19.5	32.4	41.3	47.9	48.3
...of which % that are independent of price:	100%	100%	100%	100%	100%
Available for bioenergy use (MTe):	39.3	26.8	18.5	12.4	12.5
Available for bioenergy use (PJ):	**166**	**150**	**123**	**93**	**69**

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

This is known as the "acessible potential" and excludes the price-independent competing uses

List the qualifications and assumptions used to derive the unconstrained potential:

Source of data: UK waste statistics for MSW and commercial/industrial waste (CIW - "mixed waste" stream only). See report for details.

Physical constraints: None - this is the total MSW arisings and C&I wastes that have gas generation potential. Note however that waste decomposes over many years in landfills, thus the generation potential in any given year is based mainly on historically deposited waste. The data presented above assume a ten year decay half-life and usable gas generated over a period of 20 years.

Main conversion technology: Electricity generation, with an average conversion efficiency 30%. Use of CHP would increase this to at least 40%, however the prospects for developing CHP are poor due to the limited heat applications available. There are also a small number of heat-only applications with conversion efficiencies as high as 80%.

Upper resource cost limit, if applicable: not applicable

Environmental constraints assumed: none; the only relevant ones affect cost, not total potential.

Any assumptions re competing land use: not applicable

Other: the unconstrained potential assumes that the resource is available in full for energy use, i.e. no recycling and EfW. It is assumed that MSW (municipal solid waste) arisings grow at 0.3% per annum to 2025 whilst CIW arisings remain steady to 2030. Note that due to the multiple permutations for waste resource use available, energy yields are difficult to project with accuracy.

Competing uses for this feedstock:

1) 47% of MSW and 4% of 'mixed waste' CIW was disposed of by methods other than landfill in 2009 (reuse, recycling, EfW, etc).

2) We have assumed that Government recycling targets for MSW (increasing linearly to 60% by 2025) and CIW (increasing to 70% by 2025) are achieved and therefore remove those proportions of waste from landfill. Landfill is bottom of the waste hierarchy but has a strong historical basis in the UK.

3) It is likely that the gas generation potential of waste going to landfill will fall over the period to 2030 due to the progressive removal of components with a high biodegradable content for AD and composting, however this is not taken into account in the modelling.

List the top four constraints:

1) The really significant constraint for landfill gas is the landfill directive which imposes demanding targets for the reduction of biodegradable municipal waste going to landfill compared with the base year of 1995. These are a 25% reduction by 2010, 50% by 2013 and 65% by

2) Government targets require that MSW reuse/recycling/recovery rises to 75% in 2020 (therefore landfill falls to 25%). We have assumed that this target rises further to 80% in 2025.

3) The landfill tax acts as a further deterrent to landfill. Currently set at £48/tonne (+VAT), the rate for active waste will continue to escalate by £8 per year until at least 2014/15, when it will reach £80 per tonne.

4) The Government is considering introducing bans on landfilling materials that can be either readily recycled, utilised as feedstock for composting and AD facilities or used to recover energy from waste.

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base feedstock price (£4/GJ):	**20%**		**35%**		**45%**
Constraints that are easy to overcome					
Constraints that are medium to overcome					
Constraints that are hard to overcome	20%		35%		45%
% reduction at £6/GJ feedstock price:	**18%**		**33%**		**43%**
Constraints that are easy to overcome					
Constraints that are medium to overcome					
Constraints that are hard to overcome	18%		33%		43%
% reduction at £10/GJ feedstock price:	**15%**		**30%**		**40%**
Constraints that are easy to overcome					
Constraints that are medium to overcome					
Constraints that are hard to overcome	15%		30%		40%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	**166**	**150**	**123**	**93**	**69**
Constrained potential at £4/GJ:	**133**	**109**	**80**	**56**	**38**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	33	41	43	37	31
Constrained potential at £6/GJ:	**136**	**112**	**83**	**58**	**40**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	30	38	41	36	30
Constrained potential at £10/GJ:	**141**	**116**	**86**	**61**	**42**
Constraints that are easy to overcome	0	0	0	0	0
Constraints that are medium to overcome	0	0	0	0	0
Constraints that are hard to overcome	25	34	37	33	28

Constraints –Landfill gas

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	£4/GJ	£6/GJ	£10/GJ	£4/GJ	£6/GJ	£10/GJ	£4/GJ	£6/GJ	£10/GJ	£4/GJ	£6/GJ	£10/GJ	£4/GJ	£6/GJ	£10/GJ
Easy													**0%**	**0%**	**0%**
Medium													**0%**	**0%**	**0%**
Hard	10%	9%	8%	10%	9%	7%							**20%**	**18%**	**15%**
Sum	10%	9%	8%	10%	9%	7%	0%	0%	0%	0%	0%	0%	20%	18%	15%

Feedstock name: Landfill gas

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030
Easy	0%			0%			0%			0%			**0%**	**0%**	**0%**
Medium	0%			0%			0%			0%			**0%**	**0%**	**0%**
Hard	10%	15%	20%	10%	20%	25%	0%			0%			**20%**	**35%**	**45%**

References for Landfill gas

FES (2005) Renewable Heat and Heat from Combined Heat and Power Plants - Study and Analysis.

Wet feedstock resources for AD

There are three main resources that could be exploited for biogas in the UK: **wet manures**, **food and green waste** and **sewage sludge**. Landfill gas is already exploited in the UK and is discussed in the section on solid waste above.

The following section provides notes on the sources of key information and assumptions used in the derivation of supply constraints for:

1. Sewage sludge
2. Food waste and garden waste
3. Livestock slurry

All energy is reported in terms of the biogas generation (thereby obviating the need to comment on whether it is used for heat, power or upgrading for transport or gas grid injection). As such some of the energy recovery values may seem high as parasitic loads (on the AD plants and related activities) have not been deducted.

According to Defra (Jan, 2009) the UK produces over 100 Mt of organic material per year that could be used to produce biogas; which comprises:

- 12-20 million tonnes of food waste (approximately half of which is municipal waste collected by local authorities, the rest being hotel or food manufacturing waste);
- 90 million tonnes of agricultural material such as manure and slurry;
- 1.73 million tonnes of sewage sludge.

WRAP (2008) reports food waste amounting to around 18-20 million tonnes each year, of which 6.7 million tonnes is discarded from UK households. According to NNFCC (July 2009) the commercial and industrial sector contribute 1.6 Mt from retailers, 4.1 Mt from food manufacturers and 3 Mt from food service and restaurants. Biogas can also be produced from energy crops. In addition, the report (Defra, Jan 2009) suggested that the anaerobic digestion of food waste, livestock slurries, sewage sludge and energy crops could produce biogas to contribute approximately 10-20 TWh of heat and power by 2020, representing 3.8 – 7.5% the renewable energy required by 2020.

Wet manures

Summary of assumptions and results

Unconstrained Potential	**Assumptions**
66Mt (25PJ) **Accessible potential** **61Mt** (23PJ)	- We do not include farmyard manure because of its poor digestion characteristics and the cost of collection and transport. This is based on work we have undertaken with ADAS for Defra. If this feedstock was included in the resource estimates we believe that it would increase the resource by about 30 PJ. - Poultry litter: only included egg laying poultry houses. All other poultry types excluded. - Livestock waste based on 2004 Livestock Census data (Defra 2005). Assume livestock numbers have not changed significantly and are unlikely to in the future. - The slurry (or wet manure) estimates take account of the current farm practices (e.g. housing and % on slurry) for dairy cattle, other cattle excluding calves; dry sows; sows plus litters; fatteners 20-130 kg; weaners (<20 kg); and egg laying poultry. - The theoretical energy potential, of each livestock type, is derived by multiplying the livestock number with the volatile solid content of the waste and methane potential (Bo, m3 CH4/kg VS) and presented in terms of PJ/y. The technical potential takes account of the slurry that can be collected from the housed livestock and

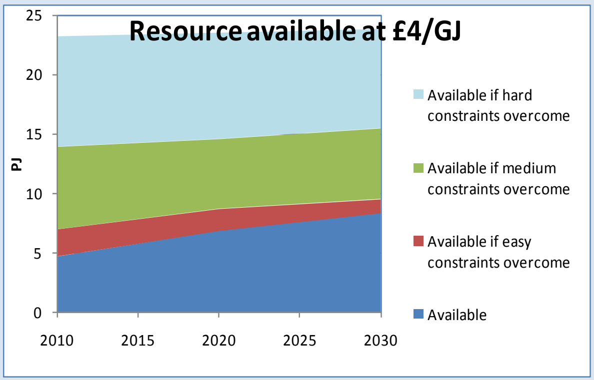
	applying a technical conversion efficiency of 75%. - Livestock slurries tend to be rather dilute and cannot be examined in isolation from other feedstocks. The scope provided in this module, alongside that in the food waste module, takes account of the need to co-digest with food waste from households, commercial and industrial categories. Other information and assumptions used in the derivation of the supply are: - Approximately one third of farms are rather small to be attracted to AD, unless the price of energy increases substantially above £15/GJ, whereby they could facilitate the collection of their slurry by AD plant operator and take back treated slurry for using on their land. - All livestock waste production is influenced by proportion of year the livestock is housed and from only those on slurry; as illustrated in Table 2. - In actual AD plants methane yield is assumed to be 75% of the theoretical yield. - The different livestock produce waste with a varying degree of organic and water content. For the purpose of this module all waste quantities are normalised and reported on 5% Volatile Solid basis. The ‘calorific value’ is derived by weighted average among all livestock slurry categories, 0.38 GJ/t. - Around 30% of livestock farms are considered rather small to benefit from AD and due to their remote locations (i.e. away from places of adequate energy demand) will face severe challenges to implement AD plants for their wastes. Physical constraint: Resource is constrained by farm locations and their livestock numbers in UK.
Competing uses	Assumptions on competing uses: There are no ‘competing uses’ but there are alternative disposal options. Our assumptions on these are explained above.
Constraints:	Low: - Perception of risks and uncertainty Medium: - Competing alternatives for disposal (e.g. management of waste on farm without AD) - Lack of collection and storage facilities (storage facility for livestock slurries) - Lack of transport infrastructure (road access needs to be sufficient and tankers must not transmit pathogens). High: - Requirement for substantial upfront investment. - Difficulty in obtaining project finance (low returns) - Location of feedstock compared with fuel demand (farmers cannot use all the heat generally produced from CHP) - For remote farms: integration into energy supply markets.
Cost	Cost of feedstock is zero or negative in this analysis, but there are costs in farmer’s time and transport. Consideration of AD option also must include consideration of downstream

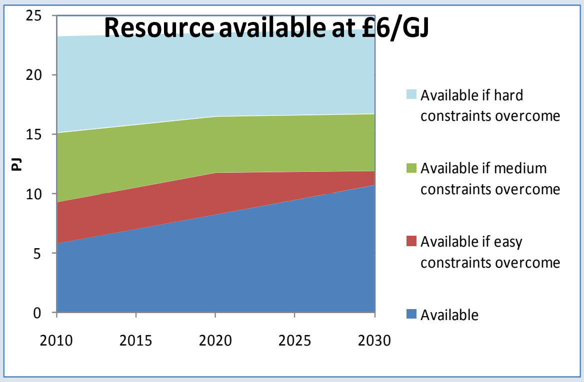
energy use, but this is not included in this analysis

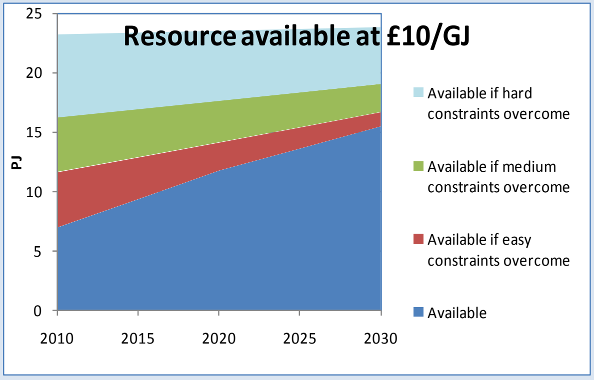
Results

- The accessible resource increases with price (from 5PJ at £4/GJ to 7PJ at £10/GJ in 2010) and with time (5PJ in 2010 to 8PJ in 2030 at £4/GJ). Highest resource estimated for 2030 at £10/GJ is 15PJ, around 62% of the unconstrained potential.

Graphs of results for wet manures for AD







Additional details for Anaerobic Digestion of wet wastes

Waste quantities for biogas

Anaerobic digestion of livestock farm slurries (i.e. a mixture of faeces, urine and water) can be achieved to produce methane as an energy source (while reducing or eliminating methane emissions at the spreading or storage phase). In principle it is also possible to recover methane from farm yard manure (FYM) that contains straw or other bedding materials for livestock. Research shows that FYM are prone to a great deal of problems when digesting. They have been studied in an accumulation system at a filling time of 60 days followed by about 50 days batch digestion at 40 and 50 oC (El Mashad et al., 2003) but poor mixing promotes stratification of the substrate and intermediate products along the reactor height, leading to inefficient or indigestible systems. In our assessment we have not taken the FYM into account; although we provide relative comparison of the energy recovery if this were to be included; see also comment about co-digestion below.

As far as poultry waste is concerned, we have only taken that from the egg laying poultry houses; specifically excluding waste from other poultry types (i.e. where they are housed on bedding material such as wood shaving and straw) as it is widely used in thermal energy plants (examples are 38 MW plant at Thetford, 13 MW plant at Eye and 10 MW plant at Westfield – all based on poultry litter as a fuel).

Livestock waste data have been based on 2004 Livestock Census data and as reported in Defra (2005). For the purpose this analysis it is assumed that the livestock numbers have not changed significantly and are unlikely to in the future. The slurry (or wet manure) estimates take account of the current farm practices (e.g. housing and % on slurry) for dairy cattle, other cattle excluding calves; dry sows; sows plus litters; fatteners 20-130 kg; weaners (<20 kg); egg laying poultry, as illustrated in Table 33 below. The theoretical energy potential, of each livestock type, is derived by multiplying the livestock number with the volatile solid content of the waste and methane potential (Bo, m^3 CH_4/kg VS) and presented in terms of PJ/y[38]. The technical potential takes account of the slurry that can be collected from the housed livestock and applying a technical conversion efficiency of 75% (an assumption; see below). These potentials are illustrated in Figure 14.

Table 33: Livestock slurry estimates (Defra, 2005) and the derived energy potentials

Livestock type	Bo $m^3 CH_4$ /kg VS	VS kg/hd /day	Livestock numbers (000's)	Theoretical potential (PJ/y)	Proportion of year housed	Proportion as slurry	Conversion efficiency	Technical potential (PJ/y)
Dairy cattle	0.24	3.48	2,664	**30.1**	59%	66%	75%	**8.8**
Other cattle	0.17	2.70	7,037	**43.6**	50%	18%	75%	**2.9**
Calves	0.17	1.46	3,552	**11.9**	45%	0%	75%	-
Dry sows	0.45	0.63	612	**2.4**	100%	35%	75%	**0.6**
Sows plus litters	0.45	0.63	149	**0.6**	100%	75%	75%	**0.3**
Fatteners 20-130 kg	0.45	0.49	3,882	**11.5**	90%	33%	75%	**2.6**
Weaners (<20 kg)	0.45	0.24	1,808	**2.6**	90%	53%	75%	**0.9**
Poultry	0.32	0.10	37,078	**16.0**	100%	73%	75%	**8.8**
Sheep etc.	0.19	0.40	45,018	**46.2**	0%	0%	75%	-
Total				**165.0**				**24.9**

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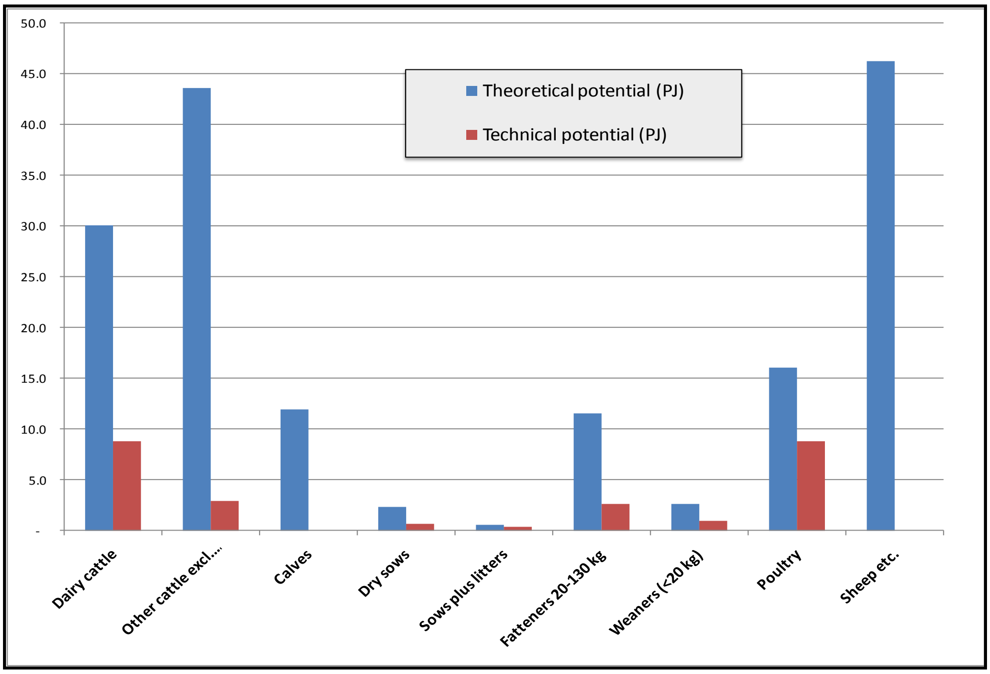
[38] We have not included farm yard manure in this, as work we are undertaking with ADAS for Defra indicates that it is unlikely that AD of farm yard manure would occur beneath £10/GJ and it is unlikely that it would happen in any case. However, if farmyard manure were added to the total it would bring it to 57.4PJ, which is about 30PJ than our estimates show here.

Figure 14: Illustration of the theoretical potential versus that obtainable due to current farm practices (derived from the data in Defra, 2005)



It should be noted that livestock slurries tend to be rather dilute and cannot be examined in isolation from other feedstocks. The scope provided in this module takes account of the need to co-digest with food waste from households, commercial and industrial categories. In contrast, the farm yard manures (FYM) are unlikely to be transported and are practically not available for AD plants.

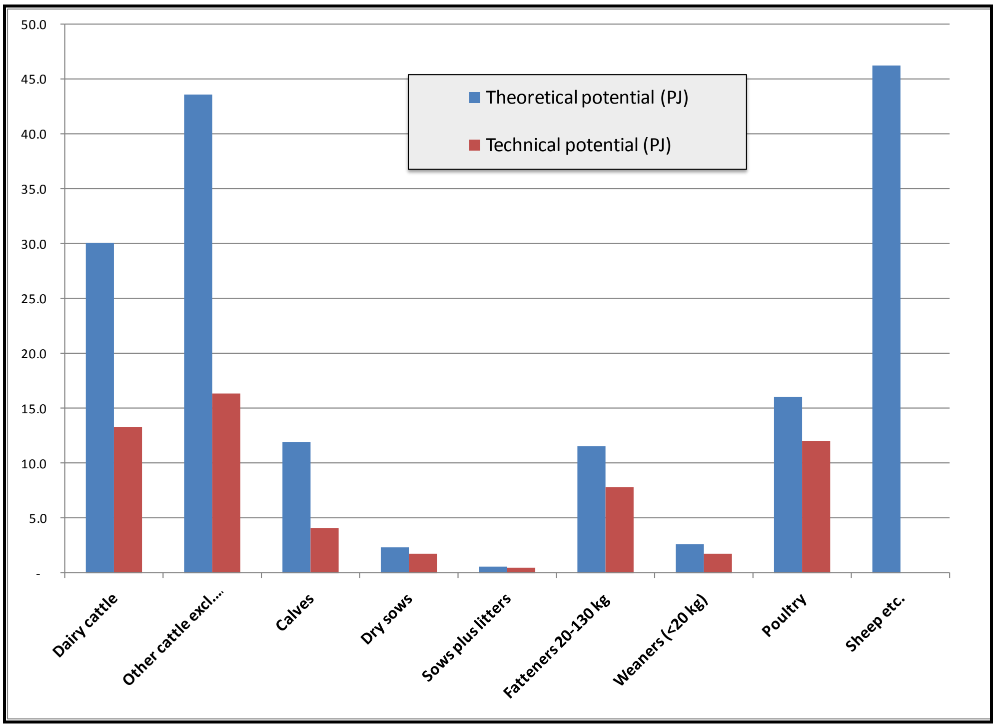
Other information and assumptions used in the derivation of the supply curves are:

- Approximately one third of farms are rather small to be attracted to AD, unless the price of energy increases substantially above £15/GJ, whereby they could facilitate the collection of their slurry by AD plant operator and take back treated slurry for using on their land.
- All livestock waste production is influenced by proportion of year the livestock is housed and from only those on slurry; as illustrated in Table 33.
- In actual AD plants methane yield is assumed to be 75% of the theoretical yield.
- The different livestock produce waste with a varying degree of organic and water content. For the purpose of this module all waste quantities are normalised and reported on 5%VS basis. The 'calorific value' is derived by weighted average among all livestock slurry categories, 0.38 GJ/t.
- Around 30% of livestock farms are considered rather small to benefit from AD and due to their remote locations (i.e. away from places of adequate energy demand) will face severe challenges to implement AD plants for their wastes.

Comparison with E4Tech estimates

E4Tech's estimate for wet manure is much higher (92 PJ) compared to that obtained above and we investigate the reasons for the disparity. Figure 15 illustrates the effect of including farm yard manure for AD.

Figure 15: Illustration of the theoretical potential versus that obtainable if FYM was also treated by AD (derived from the data in Defra, 2005)



The figure shows that if the FYM is also used for energy recovery by AD there would be a 130% increase in the potential resource, making it around 57 PJ/y.

We have assumed conversion efficiency (i.e. to technical methane yield as a fraction of theoretical methane yield) to be 75%; however, if this taken to be 100% then the potential resource would be 76 PJ.

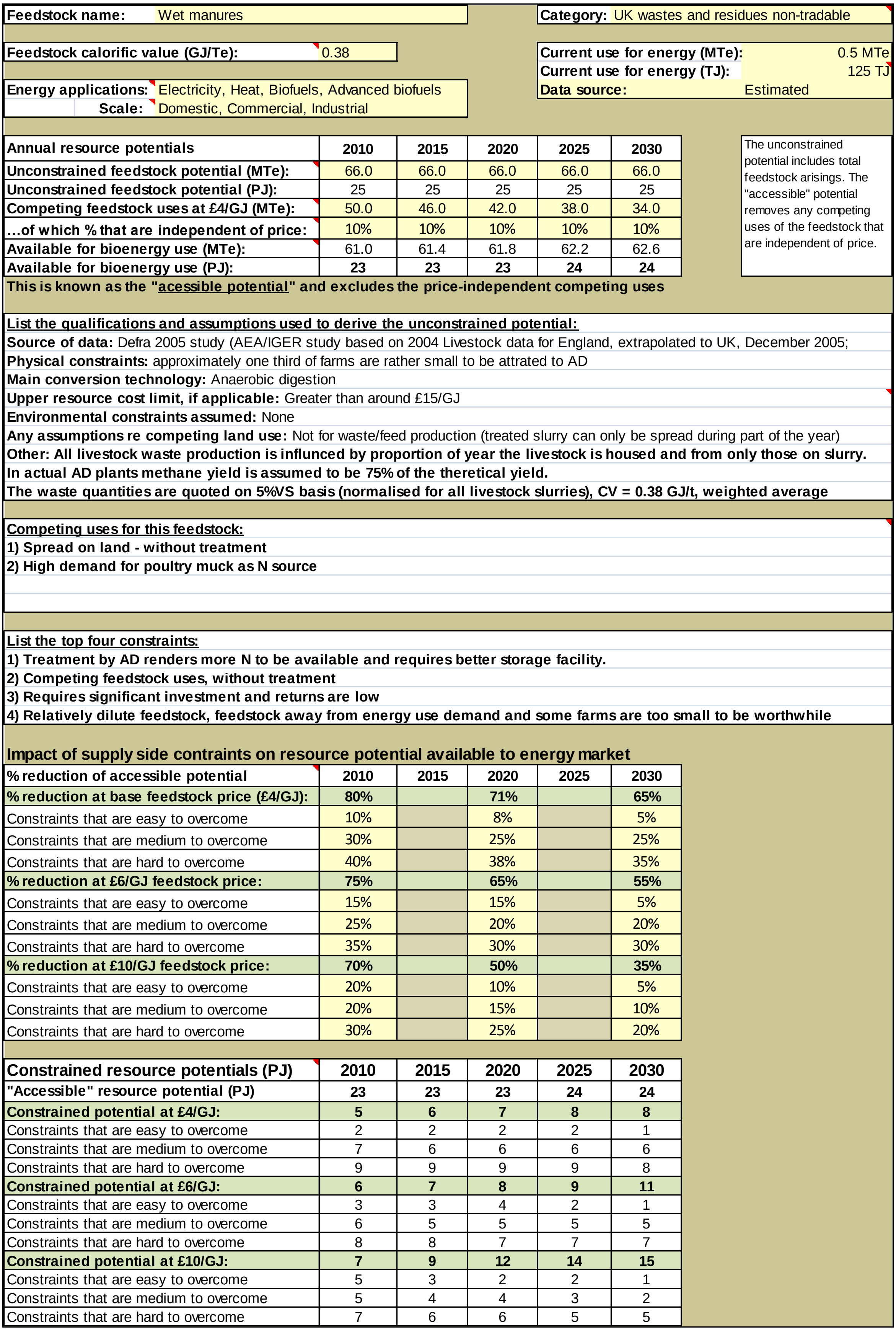
We are unable to attain or explain how the estimate given by E4Tech is as high as 92 PJ.

References

Defra (2005); Assessment of Methane Management and Recovery Options for Livestock Manures and Slurries; Joint report by AEA and IGER for Sustainable Agriculture Strategy Division, AEAT/ENV/R/2104; December 2005.

UK livestock numbers are based on 2004 Defra June Agricultural census.

Results – Wet manures



Feedstock name: Wet manures

Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te): 0.38

Current use for energy (MTe): 0.5 MTe
Current use for energy (TJ): 125 TJ
Data source: Estimated

Energy applications: Electricity, Heat, Biofuels, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (MTe):	66.0	66.0	66.0	66.0	66.0
Unconstrained feedstock potential (PJ):	25	25	25	25	25
Competing feedstock uses at £4/GJ (MTe):	50.0	46.0	42.0	38.0	34.0
...of which % that are independent of price:	10%	10%	10%	10%	10%
Available for bioenergy use (MTe):	61.0	61.4	61.8	62.2	62.6
Available for bioenergy use (PJ):	**23**	**23**	**23**	**24**	**24**

This is known as the "acessible potential" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

List the qualifications and assumptions used to derive the unconstrained potential:

Source of data: Defra 2005 study (AEA/IGER study based on 2004 Livestock data for England, extrapolated to UK, December 2005;
Physical constraints: approximately one third of farms are rather small to be attrated to AD
Main conversion technology: Anaerobic digestion
Upper resource cost limit, if applicable: Greater than around £15/GJ
Environmental constraints assumed: None
Any assumptions re competing land use: Not for waste/feed production (treated slurry can only be spread during part of the year)
Other: All livestock waste production is influnced by proportion of year the livestock is housed and from only those on slurry.
In actual AD plants methane yield is assumed to be 75% of the theretical yield.
The waste quantities are quoted on 5%VS basis (normalised for all livestock slurries), CV = 0.38 GJ/t, weighted average

Competing uses for this feedstock:

1) Spread on land - without treatment
2) High demand for poultry muck as N source

List the top four constraints:

1) Treatment by AD renders more N to be available and requires better storage facility.
2) Competing feedstock uses, without treatment
3) Requires significant investment and returns are low
4) Relatively dilute feedstock, feedstock away from energy use demand and some farms are too small to be worthwhile

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base feedstock price (£4/GJ):	**80%**		**71%**		**65%**
Constraints that are easy to overcome	10%		8%		5%
Constraints that are medium to overcome	30%		25%		25%
Constraints that are hard to overcome	40%		38%		35%
% reduction at £6/GJ feedstock price:	**75%**		**65%**		**55%**
Constraints that are easy to overcome	15%		15%		5%
Constraints that are medium to overcome	25%		20%		20%
Constraints that are hard to overcome	35%		30%		30%
% reduction at £10/GJ feedstock price:	**70%**		**50%**		**35%**
Constraints that are easy to overcome	20%		10%		5%
Constraints that are medium to overcome	20%		15%		10%
Constraints that are hard to overcome	30%		25%		20%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	23	23	23	24	24
Constrained potential at £4/GJ:	**5**	**6**	**7**	**8**	**8**
Constraints that are easy to overcome	2	2	2	2	1
Constraints that are medium to overcome	7	6	6	6	6
Constraints that are hard to overcome	9	9	9	9	8
Constrained potential at £6/GJ:	**6**	**7**	**8**	**9**	**11**
Constraints that are easy to overcome	3	3	4	2	1
Constraints that are medium to overcome	6	5	5	5	5
Constraints that are hard to overcome	8	8	7	7	7
Constrained potential at £10/GJ:	**7**	**9**	**12**	**14**	**15**
Constraints that are easy to overcome	5	3	2	2	1
Constraints that are medium to overcome	5	4	4	3	2
Constraints that are hard to overcome	7	6	6	5	5

Constraints – Wet manures

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	10%	15%	20%										**10%**	**15%**	**20%**
Medium	20%	15%	15%							10%	10%	5%	**30%**	**25%**	**20%**
Hard	30%	20%	20%							10%	15%	10%	**40%**	**35%**	**30%**
Sum	60%	50%	55%	0%	0%	0%	0%	0%	0%	20%	25%	15%	80%	75%	70%

Feedstock name: Wet manures

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	10%	5%	4%	0%			0%			0%	3%	1%	**10%**	**8%**	**5%**
Medium	20%	20%	20%	0%			0%			10%	5%	5%	**30%**	**25%**	**25%**
Hard	30%	25%	30%	0%			0%			10%	13%	5%	**40%**	**38%**	**35%**

Sewage sludge

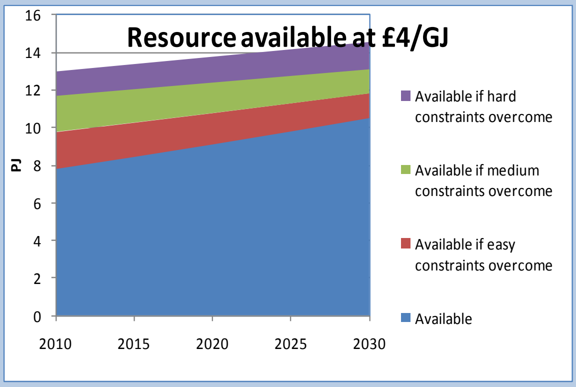
Summary of assumptions and results

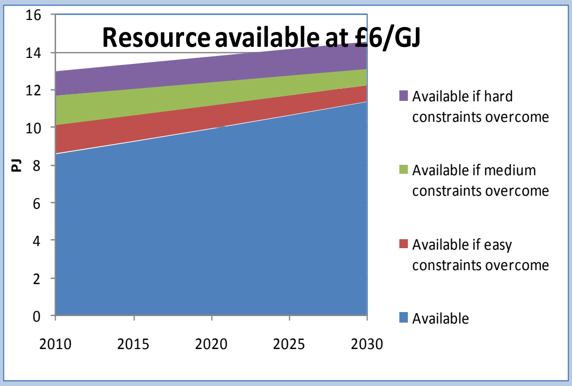
Unconstrained Potential	**Assumptions** - Sewage sludge is 4 wt% dry solids (also expressed as 4%DS). - The calorific value of sewage sludge (i.e. through the AD route) is taken as 0.40 GJ/t. This is based on the theoretical methane yield of sewage sludge of 0.242–0.273 gCH4/gVS added and the experimental yield is around 0.224 gCH4/gVS added. We have therefore taken a value of 0.2 gCH4/gVS added to give 0.40 GJ/t of sewage sludge at 4wt%. - Some 66% of sewage sludge is treated by AD at present (Water UK, 2008), which gives 9200 TJ of energy supply; however, not all may be exploited as useful energy. We have assumed that 85% of this methane is utilised effectively with the rest being flared. This assumption is slightly lower than E4Tech, who assumed that to be 90% rising to 100% from 2010. - Around 10% of sewage sludge cannot be accessed because it is produced in remote and small sewage treatment works. (We have taken easy and medium constraints, which could be overcome, as equal in proportion as it is difficult to differentiate between these). - The sludge incineration capacity of 18% for England & Wales, has been brought about to provide a secure disposal of sludge following the sludge disposal ban at sea, from 1998. In practice, this option is expensive and is a net energy user and therefore it is possible that some reduction in incineration capacity will take place with rising energy prices. Our view is that this capacity is likely to decrease if energy price was to rise around £10/GJ. We have therefore assumed that around 50% of the incineration capacity could be converted over to AD by 2030 and at £10/GJ Physical constraint: Finite resource
Competing uses	- 18% of sewage sludge in England and Wales goes to incineration and the rest goes to farmland (73%), land reclamation (6%), other uses (4%) (UK Waste Strategy, 2007). All methods would benefit from AD of the sludge, except incineration.
Constraints:	Low: - Returns insufficient (for all sewage sludge) - Perceptions of complexity of market (although there is some experience of use at sewage treatment plants) - Regulatory and policy uncertainty (changes due on Water Framework and Nitrate Directives) Medium: - Location of feedstock compared with fuel demand (sewage sludge produced at remote locations where AD treatment may not be economic). - Meeting current and future sustainability standards (and sludge matrix) High: - Cash flow issues (low payback on investment, restrictions placed on investment by OFWAT). - Lack of transport infrastructure (for remote and small quantities of sewage sludge).
Cost	Factors that influence cost are size of sewage treatment plant and transport. Future policy and regulation could be important.

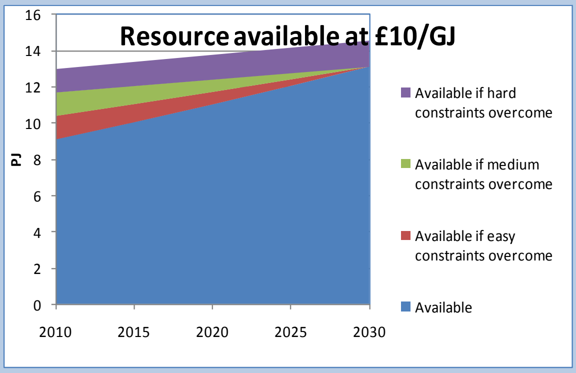
Results

- Results show that with time and money almost all (87%) of the accessible resource could be achieved.

Graphs of results for sewage sludge resource for AD







Additional details for Sewage sludge

Sewage sludge production in 2004 was around 1.37 million tonnes of dry solids per year or tDS/y (NNFCC, 2009), of which some 89% was from England and Wales. By 2030, this is expected to rise by 15%, giving the sludge production for the UK of 1.573 million tDS/y. This assumption differs from E4Tech's in that they assumed that growth in sewage sludge would slow after 2010.

The following information and assumptions are used in the derivation of the supply of biogas from sewage sludge:

- Sewage sludge is 4 wt% dry solids (also expressed as 4%DS).
- The calorific value of sewage sludge (i.e. through the AD route) is taken as 0.40 GJ/t. This is based on the theoretical methane yield of sewage sludge of 0.242–0.273 gCH_4/gVS added and the experimental yield is around 0.224 gCH_4/gVS added. We have therefore taken a value of 0.2 gCH_4/gVS added to give 0.40 GJ/t of sewage sludge at 4wt%.
- Some 66% of sewage sludge is treated by AD at present (Water UK, 2008), which gives 9200 TJ of energy supply; however, not all may be exploited as useful energy. We have assumed that 85% of this methane is utilised effectively with the rest being flared. This assumption is slightly lower than E4Tech, who assumed that to be 90% rising to 100% from 2010.
- 18% of sewage sludge in England and Wales goes to incineration and the rest goes to farmland (73%), land reclamation (6%), other uses (4%) (UK Waste Strategy, 2007). All methods would benefit from AD of the sludge, except incineration.
- Around 10% of sewage sludge cannot be accessed because it is produced in remote and small sewage treatment works. (We have taken easy and medium constraints, which could be overcome, as equal in proportion as it is difficult to differentiate between these).
- The sludge incineration capacity of 18% for E&W, as mentioned above, has been brought about to provide a secure disposal of sludge following the sludge disposal ban at sea, from 1998. In practice, this option is expensive and is a net energy user and therefore it is possible that some reduction in incineration capacity will take place with rising energy prices. Our view is that this capacity is likely to decrease if energy price was to rise around £10/GJ. We have therefore assumed that around 50% of the incineration capacity could be converted over to AD by 2030 and at £10/GJ.

Results – Sewage Sludge

Feedstock name: Sewage sludge

Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te): 0.4

Current use for energy (MTe): 20 MTe
Current use for energy (TJ): 7,800 TJ
Data source: Water UK (2008)

Energy applications: Electricity and Heat
Scale: Commercial, Industrial

Annual resource potentials	2010	2015	2020	2025	2030
Unconstrained feedstock potential (MTe):	35.4	36.4	37.4	38.3	39.3
Unconstrained feedstock potential (PJ):	14	15	15	15	16
Competing feedstock uses at £4/GJ (MTe):	5.7	5.7	5.7	5.7	5.7
...of which % that are independent of price:	50%	50%	50%	50%	50%
Available for bioenergy use (MTe):	32.5	33.5	34.5	35.5	36.5
Available for bioenergy use (PJ):	**13**	**13**	**14**	**14**	**15**

This is known as the "acessible potential" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: NNFCC (2009) and Waste Strategy 2007 (Annex C6 on sewage sludge)
Physical constraints: Around 10% of sewage sludge cannot be accessed due to its production in remote and small sewage treatment
Main conversion technology: Anaerobic digestion
Upper resource cost limit, if applicable: N/A (the incineration capacity provides secure disposal outlet from STW serving large conurbatio
Environmental constraints assumed: Possible that potentially contaminated SS unlikely to be treated by AD and will keep going to
Any assumptions re competing land use: Land available to dispose all sludge to land, after AD.
Other: • The sewage sludge is assumed to be 4%DS.
• 18% of sewage sludge in E&W goes to incineration of which 50% could be converted over to AD by 2030 and at £10/GJ.
• Around 10% of sewage sludge cannot be accessed due to its production in remote and small sewage treatment works.

Competing uses for this feedstock:
1) Incineration
(Other options such as land reclamation or application allow pre-digestion of sewage sludge.)

List the top four constraints:
1) Regulatory and policy constraints - recent and new changes (due to WFD)
2) Location of feedstock compared with fuel demand
3) Meeting current and future sustainability standards
4) Returns insufficient

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	2010	2015	2020	2025	2030
% reduction at base feedstock price (£4/GJ):	**40%**		**34%**		**28%**
Constraints that are easy to overcome	15%		12%		9%
Constraints that are medium to overcome	15%		12%		9%
Constraints that are hard to overcome	10%		10%		10%
% reduction at £6/GJ feedstock price:	**34%**		**28%**		**22%**
Constraints that are easy to overcome	12%		9%		6%
Constraints that are medium to overcome	12%		9%		6%
Constraints that are hard to overcome	10%		10%		10%
% reduction at £10/GJ feedstock price:	**30%**		**20%**		**10%**
Constraints that are easy to overcome	10%		5%		0%
Constraints that are medium to overcome	10%		5%		0%
Constraints that are hard to overcome	10%		10%		10%

Constrained resource potentials (PJ)	2010	2015	2020	2025	2030
"Accessible" resource potential (PJ)	13	13	14	14	15
Constrained potential at £4/GJ:	**8**	**8**	**9**	**10**	**11**
Constraints that are easy to overcome	2	2	2	1	1
Constraints that are medium to overcome	2	2	2	1	1
Constraints that are hard to overcome	1	1	1	1	1
Constrained potential at £6/GJ:	**9**	**9**	**10**	**11**	**11**
Constraints that are easy to overcome	2	1	1	1	1
Constraints that are medium to overcome	2	1	1	1	1
Constraints that are hard to overcome	1	1	1	1	1
Constrained potential at £10/GJ:	**9**	**10**	**11**	**12**	**13**
Constraints that are easy to overcome	1	1	1	0	0
Constraints that are medium to overcome	1	1	1	0	0
Constraints that are hard to overcome	1	1	1	1	1

Constraints – Sewage Sludge

	Market			**Policy/Regulatory**			**Technical**			**Infrastructure**			**Totals**		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	10%	10%	10%	5%	2%								**15%**	**12%**	**10%**
Medium	10%	10%	10%	5%	2%								**15%**	**12%**	**10%**
Hard	5%	5%	5%							5%	5%	5%	**10%**	**10%**	**10%**
Sum	25%	25%	25%	10%	4%	0%	0%	0%	0%	5%	5%	5%	40%	34%	30%

Feedstock name: Sewage sludge

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			**Policy/Regulatory**			**Technical**			**Infrastructure**			**Totals**		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	10%	10%	7%	5%	2%	2%	0%			0%			**15%**	**12%**	**9%**
Medium	10%	9%	6%	5%	3%	3%	0%			0%			**15%**	**12%**	**9%**
Hard	5%	5%	5%	0%			0%			5%	5%	5%	**10%**	**10%**	**10%**

References for Sewage Sludge

NNFCC (2009). Evaluation of Opportunities for Converting Indigenous UK Wastes to Fuels and Energy; report to the National Non-Food Crops Centre, funded by DECC; ED45551, July 2009.

Waste Strategy (2007); Annex C6 on Sewage sludge, as part of Waste Strategy for England 2007.

Water UK (2008); Sewage sludge production and disposal routes.

Food and green waste

Summary of assumptions and results

Unconstrained Potential	**Assumptions/Comments**
20.3 Mt/y **(80PJ)**	- Used data from WRAP and NNFCC on food and green waste availability. Analysis combines food waste from household, commercial and industrial premises and agro-industrial places. Have assumed 18Mt from these sources. - Does not include agricultural and livestock slurry. - Assumed overall the food waste arisings will be relatively stable. - Have assumed additional 2.3 Mt of green waste, mainly grass and soft biodegradables.
Constrained potential **15.8Mt/y (63 PJ/y)**	Physical constraint: The resource is limited by the collection schemes dedicated to food waste in the UK Result: 20Mt food and green waste available for AD 2010-2030
Yield rates	Food waste: 18-20 Mt/y (WRAP data) including : - Domestic food waste (6.7Mt/y), - Commercial and industrial waste: 1.6Mt/y from retailers, 4.1Mt/y food manufacturers and 3Mt/y from food service and restaurants. (Figures from NNFCC)
Competing uses	Assumptions on competing uses: (1) depend on quantity, quality and characteristics of different waste streams. (2) Depend on contracts for waste treatment already in place. Result: Food waste from households is subject to long term contracts which provide the long term guarantee to make AD plants viable/bankable. This means it is possible that 45% (6.7Mt FW and 2.3 Mt GW) is affected by the first competing use above and the rest (55%) depend on AD plants already in place.
	Constraints: - Vary with quantity and characteristics of waste. Low: - Perception of risks and uncertainty, linked to bankability of AD projects. - Lack of market experience (would be overcome by successful demonstration of schemes) - Lack of standards - Planning and licensing requirements - Lack of processing facilities for wastes (Need to facilitate separate collection of food waste) Medium: - Perception of market complexity (markets perceived as complex by financiers, particularly issues related to grid connection) - Difficulty in obtaining project finance (high return expected due to lack of experience with AD) - Regulatory and policy uncertainty (NIMBY issues). - Integration into energy supply markets (current use of biogas restricted

by access to heat demands and energy markets).

High:

- Competing cost-related feedstock uses (particularly where waste contracts in place already)
- Returns insufficient (needs generous gate fee, energy return not sufficient).

Regulatory and policy uncertainty (Quality standards for after use of residue)

Cost

Factors that determine how much supply assumed to be available at the 3 different cost points.

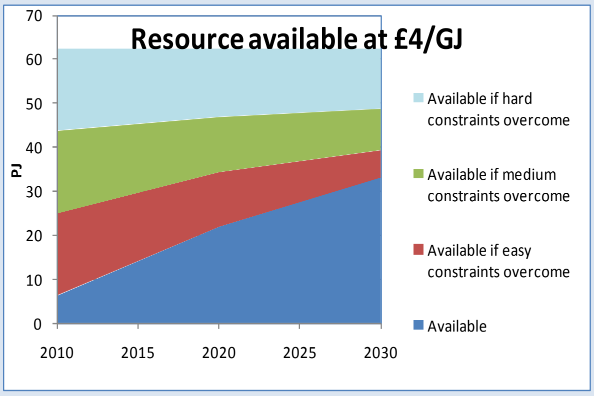
Cost of feedstock dependent on gate fee for organic waste, alternative disposal/treatment routes, cost of separate collection of domestic food waste and quality of feedstock to the AD plant.

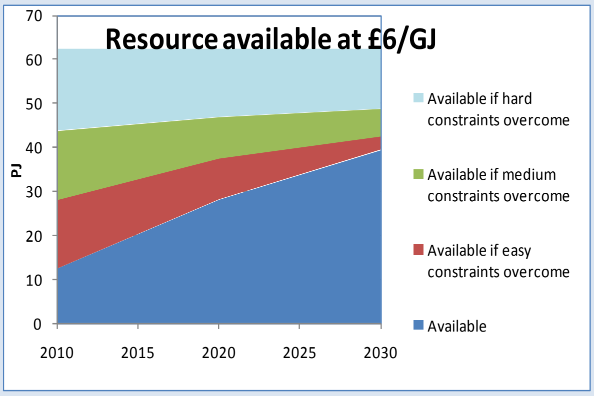
Consideration of AD option also must include consideration of downstream energy use, but this is not included in this analysis.

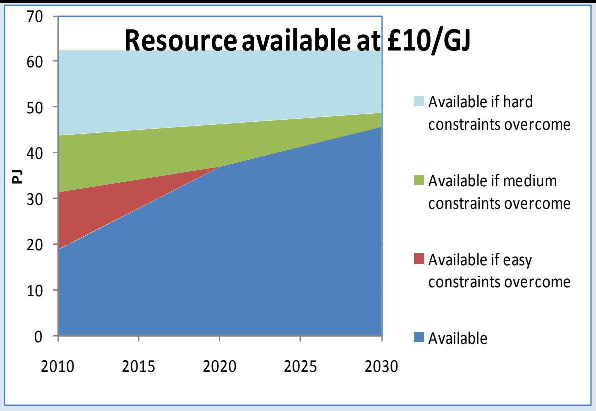
Results

- Our analysis shows a steadily increasing resource, both with price and time, but that both development of AD plants and increased price are important in stimulating supply of feedstock. Current availability is estimated to be of the order of 6PJ at £4/GJ, which is ~ 10% of the estimated unconstrained resource.

Graphs of results for food waste resource for AD







Additional information - Food and Garden Waste

In this section we estimate the scope for anaerobic digestion food waste. In our analysis we have considered the propagation of AD through the supply of separately collected food waste and that which arises relatively un-contaminated.[39]

Background

Predictions of future food waste arisings are difficult due to the multi-pronged approach on health, diet, and environment as well as on reducing and collecting pre-sorted food waste. In addition, there are several campaigns such as Love Food Hate Waste that take some time (typically five years) to have an impact. Therefore, any decrease in waste arisings will be small but gradual over several years.

In a recent meeting (EU Biowaste Conference, February 2010) WRAP charted the rise in the growth of composting schemes over recent years; the current quantities of waste composted are estimated to be around 5 million tonnes. This rise is expected to be thwarted by an increasing shift towards the use of AD plants in the UK due to the support for RE, but also AD in particular. In fact it is reported that there will be a significant increase in the proportion of food waste collected for recycling by AD (WRAP, Feb'10).

According to WRAP (2010) some 5% food waste is collected for recycling but this will rise to around 35%, amounting to 2Mt/y capacity for food waste alone by 2020. This target will be further enhanced by the Defra and WRAP's ambition of 1000 AD plants by 2020. Their strategy is based on waste prevention, collection and sorting, processing of biodegradable fraction, recycling and market developments. These are the plans that WRAP is focussed on to deliver the rising need for recycling food waste. It should be noted that at present agricultural or livestock slurry are not featured in their dealings.

Recent projections of commercial and industrial food waste from two categories of (1) retail and wholesale and (2) food and drink processing industry in England have been reported (ADAS, 2009), based on the aggregation and projections to 2030 of the waste categories from each of the regions in England. They show that the food waste from retail and wholesale sector is expected to increase while that from food and drink industry is expected to decline, but overall there will be a slight decrease in the food waste to 2030.

Based on the above evidence, and to keep the analysis presented here simple, we assume a constant value of food waste from these categories. In this category of waste for AD, we have combined food wastes from household, commercial and industrial premises and from agro-industrial places. The

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[39] Where the waste collected as whole or mixed, it is also possible to extract (mechanically) the biodegradable organic fraction for treatment by AD. While several WM contractors are considering this option, there are no such AD plants that are currently in operation, as they would not be able to produce marketable products from the residue (digestate) and thereby are likely to face substantial barriers.

latter is rarely measured but several estimates (including those from WRAP, 2008, 2010) show the total of these three categories as between 18-20 million; we have used 18 million tonnes.

For the purpose of looking at constraints each category needs to be understood with respect to the quantity and characteristics of the waste but also the competitive uses. At present the food waste from household is not collected widely; but this is changing due to local authorities' recycling targets and the need to reduce waste going to landfill. The short term future of large scale AD plants will be strongly influenced by this category, as any service contracts offered by the LAs tend to be long term and thereby lead to bankable projects.

The food waste from commercial and industrial premises is competed between composting and AD. In this category, any collection and disposal contracts tend to be short term (typically 1-2 years) and thereby bring vulnerability to the investors in AD plants. Concentrated effluents and sludges, especially from large food companies, also fall into this category.

Agro-industrial waste is rarely collected and thereby its quantities are unknown; we have estimated it by subtracting reported quantities of food waste (from HH and C&I sources) from WRAP's overall estimate of 18 million tonnes of food waste. However, we estimate that only around 50% will be accessible for energy price up to £10/GJ and by 2030.

Comparison with E4Tech data

As explained above, the quantitative estimates within different categories are uncertain, but the overall quantity of biodegradable food waste is reported to be around 18 million tonnes per year and this is what we have assumed in this report. Garden waste has also been included, as many of the local authorities are considering adding grass and soft plant materials into their waste streams for AD; see Table 34.

Table 34: Food waste and garden waste as categorised for use in the assessment

	Potential waste arising (t/y)	Feedstock potential (PJ)	Potential by 2030 (PJ)
Food waste (FW) from households	5,670,000	22.453	20.208
FW from commercial & industrial premises	6,330,000	25.067	22.560
FW – categorised as agro-industrial	6,000,000	23.760	11.880
Garden waste (50% of green waste)	2,330,000	9.227	8.304
Total	20,330,000	80.507	62.952

The above figures are broadly in line with those in E4Tech report: The table shows 55 PJ is recoverable by 2030, from the three categories of food waste; whereas that in E4Tech the equivalent value was 50 PJ. We predict that E4Tech's estimates are based on lower quantities of food wastes than ours. The garden waste provides the potential of around 9 PJ; 90% of which is assumed to be achievable by 2030.

Additional assumptions are used in the derivation of supply for AD:

- The food waste, from any category is assumed to be 25% DS.
- The garden waste is typically around 13-14% of the total MSW; whereas food waste is typically 18% (Defra, 2007)
- The calorific value of this food waste (through the AD route) is taken as 3.96 GJ/t. This is based on 55 GWh from 50,000 t/y AD plant (i.e. 110 m^3 methane per tonne of food waste).
- Currently around 12 AD plants are in operation, mainly in England, that use food waste. The quantities of food waste digested varies from around 10,000 t/y to 100,000 t/y. Our estimate is that around 0.5 M t/y of food waste is treated in these plants, which gives 2000 TJ of energy supply.

- Due to its production in remote and small communities, a proportion of food waste will not be available, as it will find its way to other competitive local uses.

Results – Food and Garden Waste

Feedstock name: Food waste
Category: UK wastes and residues non-tradable

Feedstock calorific value (GJ/Te): 3.96

Current use for energy (MTe): 0.5 MTe
Current use for energy (TJ): 2,000 TJ
Data source: Estimated

Energy applications: Electricity, Heat, Biofuels, Advanced biofuels
Scale: Domestic, Commercial, Industrial

Annual resource potentials	**2010**	**2015**	**2020**	**2025**	**2030**
Unconstrained feedstock potential (MTe):	20.3	20.3	20.3	20.3	20.3
Unconstrained feedstock potential (PJ):	80	80	80	80	80
Competing feedstock uses at £4/GJ (MTe):	9.0	9.0	9.0	9.0	9.0
...of which % that are independent of price:	50%	50%	50%	50%	50%
Available for bioenergy use (MTe):	15.8	15.8	15.8	15.8	15.8
Available for bioenergy use (PJ):	**63**	**63**	**63**	**63**	**63**

This is known as the "acessible potential" and excludes the price-independent competing uses

The unconstrained potential includes total feedstock arisings. The "accessible" potential removes any competing uses of the feedstock that are independent of price.

List the qualifications and assumptions used to derive the unconstrained potential:
Source of data: Jim Poll's notes for HH & C&I; made up to 18 Mt/y (WRAP, 2010); 50% of the green waste (mainly grass, leaves etc) is
Physical constraints: access to source separated ready resource - as collection systsems are not implemented widely or developed.
Main conversion technology: AD
Upper resource cost limit, if applicable: Over around £15/GJ to exceed competition with animal feed market
Environmental constraints assumed: None.
Any assumptions re competing land use: Only wastes considered
Other: All food wastes considered up to the limit of 18 miliion t/y and tonnes and 2.3 million t/y of GW (mainly grass and soft

Competing uses for this feedstock:
1) Other (assumed to be agro-industrial) goes to animal feed
2) Green waste to composting
3) Landfill and mixed waste management

List the top four constraints:
1) Separate collection of food waste from households - not widely applied
2) The contracts to receive waste for AD tends to be short term (1-2 years); except for LA food waste.
3) Cannot acccount for the quantity or composition of agro-industrial wastes as it is not generally measured
4) Perception of high risks and low returns.

Impact of supply side contraints on resource potential available to energy market

% reduction of accessible potential	**2010**	**2015**	**2020**	**2025**	**2030**
% reduction at base feedstock price (£4/GJ):	**90%**		**65%**		**47%**
Constraints that are easy to overcome	30%		20%		10%
Constraints that are medium to overcome	30%		20%		15%
Constraints that are hard to overcome	30%		25%		22%
% reduction at £6/GJ feedstock price:	**80%**		**55%**		**37%**
Constraints that are easy to overcome	25%		15%		5%
Constraints that are medium to overcome	25%		15%		10%
Constraints that are hard to overcome	30%		25%		22%
% reduction at £10/GJ feedstock price:	**70%**		**41%**		**27%**
Constraints that are easy to overcome	20%		0%		0%
Constraints that are medium to overcome	20%		15%		5%
Constraints that are hard to overcome	30%		26%		22%

Constrained resource potentials (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**
"Accessible" resource potential (PJ)	**63**	**63**	**63**	**63**	**63**
Constrained potential at £4/GJ:	**6**	**14**	**22**	**28**	**33**
Constraints that are easy to overcome	19	16	13	9	6
Constraints that are medium to overcome	19	16	13	11	9
Constraints that are hard to overcome	19	17	16	15	14
Constrained potential at £6/GJ:	**13**	**20**	**28**	**34**	**39**
Constraints that are easy to overcome	16	13	9	6	3
Constraints that are medium to overcome	16	13	9	8	6
Constraints that are hard to overcome	19	17	16	15	14
Constrained potential at £10/GJ:	**19**	**28**	**37**	**41**	**46**
Constraints that are easy to overcome	13	6	0	0	0
Constraints that are medium to overcome	13	11	9	6	3
Constraints that are hard to overcome	19	18	16	15	14

Constraints – Food and Garden Waste

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**	**£4/GJ**	**£6/GJ**	**£10/GJ**
Easy	20%	25%	10%	5%		5%				5%		5%	**30%**	**25%**	**20%**
Medium	20%	20%	15%	5%	5%					5%		5%	**30%**	**25%**	**20%**
Hard	20%	25%	20%	10%	5%	10%							**30%**	**30%**	**30%**
Sum	60%	70%	45%	20%	10%	15%	0%	0%	0%	10%	0%	10%	90%	80%	70%

Feedstock name: Food waste

Impact of maturing market on supply constraints at base feedstock price (£4/GJ)

	Market			Policy/Regulatory			Technical			Infrastructure			Totals		
Ability to overcome	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Easy	20%	20%	10%	5%			0%			5%			**30%**	**20%**	**10%**
Medium	20%	15%	10%	5%	5%	5%	0%			5%			**30%**	**20%**	**15%**
Hard	20%	20%	22%	10%	5%		0%			0%			**30%**	**25%**	**22%**

References for Food and Garden Waste

ADAS (2009); Study into commercial and industrial waste arisings; report prepared for the English regions; April 2009.

Defra (2007); Municipal Waste Statistics 2007, http://www.defra.gov.uk/environment/statistics/wastats/bulletin08.htm

Defra (Dec, 2005); Assessment of Methane Management and Recovery Options for Livestock Manures and Slurries; Joint report by AEA and IGER for Sustainable Agriculture Strategy Division, AEAT/ENV/R/2104; December 2005.

Defra (January 2009); Anaerobic Digestion - Shared Goals; Defra document setting out AD goals for businesses, regulators, and other stakeholders; http://www.defra.gov.uk/environment/waste/ad/pdf/ad-sharedgoals-090217.pdf

Defra(July 2009); Developing an Implementation Plan for Anaerobic Digestion, Defra's report published July 2009, produced by AEA.

E4Tech (2009); Biomass supply curves for the UK; report by E4Tech for DECC, March 2009.

NNFCC (2009); Evaluation of Opportunities for Converting Indigenous UK Wastes to Fuels and Energy; Report to the National Non-Food Crops Centre; This project was managed by the NNFCC and funded by DECC; ED45551; July 2009.

WRAP (2008) support for AD; presentation Nina Sweet at Bioenergy 2008; seminar organised by WAG, 8 October 2008.

WRAP (Oct 2009); Compost and Digestate Market Development in Wales; WRAP report OAV032; produced by AEA.

WRAP (Feb, 2010) Presentation by Nina Sweet 'Biowaste treatment in the UK - where are we and where do we need to go?' EU Biowaste Conference; Brussels, 16-17 February 2010.

Global Biomass supply analysis

Methodology

In addition to examining UK feedstock, global feedstocks that could be used in the UK were also examined. The analysis examined how significant this resource might be; and how it might interact with the UK resource (i.e. in terms of determining the market price).

Information on the total unconstrained global resource is not as easily available as for the UK, and we have generally had to model estimates of resource availability on a regional basis. Data used in this analysis is therefore subject to more uncertainties than that for the UK resources. In addition, examining the constraints on international supply in as much detail as for the UK would be extremely complex and an approach based on regional assessment was therefore adopted. Consideration was given as to potential infrastructure constraints, market and trade barriers and domestic demand, to estimate the quantity of feedstocks which might be available for export.

Four internationally traded resources were examined:

- Forestry products
- Agricultural residues
- Feedstocks for 1G biofuels
- 'Woody' energy crops.

The supply of these feedstocks in each of three general global scenarios – business as usual (BAU), BAU plus high investment, and low development was modelled. Consideration was then given to the constraints that there might be on development of these resources, and the impact of sustainability criteria on trade of these resources. An estimate of domestic demand in each region for the resources was then made, to allow the amount which would be available for export to be estimated.

A detailed description of how the four international feedstock resources were estimated is given below, but broadly the methodology was:

- **Forestry related feedstocks**: availability of forestry residues, small roundwood, and sawmill residues was modelled using CARBINE (by Forestry Research). This estimates production of these resources based on trends in afforestation and lumber production, with an allowance made for competing use of these resources in other industries such as pulp and paper and chipboard.
- **Energy crops and 1G biofuels feedstocks**: these were estimated on a 'bottom up' basis using scenarios of land availability and assumptions about yields, yield increases and planting rates. 1G biofuels feedstocks are expressed as the equivalent amount of biofuel they would produce.
- **Agricultural residues**: as many agricultural residues are not suitable for export, estimates were made, based on a literature review only of the amounts of agricultural residue that might be available for export.[40]

In all cases, resource availability was estimated on a regional basis. As there is some land which is suitable for both energy crops and 1G biofuels, two variants of each scenario were constructed. One in which production of 1G biofuels is maximised and energy crops are only grown on land which is not suitable for 1G biofuels (due to degradation or water scarcity), and one in which after biofuels demand has been met, preference is given to planting energy crops. In the latter case, planting of energy

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[40]

crops, is still often constrained, particularly in early years by the planting rate constraint and in these cases, remaining land can be utilised for biofuels production. This means that in some scenarios, particularly in early years there is little difference between the two scenarios as energy crop production is always limited by the planting constraint, and the area of land required for their cultivation can be satisfied from the pool of land which is not suitable for biofuels production.

Constraints on International Supply

For each of the feedstocks and regions we considered aspects that might constrain the development or extraction of the resource, and the ability to bring it to market. Two broad categories were considered:

- **Infrastructure constraints**: these relate to physical constraints on developing and exploiting the resource, such as:
    - Distribution and accessibility of land for crop production
    - Distribution and accessibility of forestry resource, and the nature of terrain
    - Transport infrastructure to move crops to storage/ distribution centres
    - Availability of facilities for international transport such as deepwater ports.
- **Market/ Trade constraints**: these relate to the ability to operate a reliable supply chain to bring the resource to the market for trading, both to supply the domestic and international market, and to develop arrangements for trading. Aspects considered included:
    - Political stability and ability to attract financial investment
    - Development and implementation of standards to define quality of feedstocks
    - Current market maturity for export of bulk goods including feedstocks.
    - Ability to demonstrate compliance with international technical standards and sustainability requirements.

For each region, an assessment was made as to whether the barrier to development in these two categories were very high, high, medium or low, for 2010, 2020 and 2030, under each of the three scenarios. This assessment was then used to estimate the percentage of the resource which would be likely to reach the market.

Impact of sustainability standards on supply

Biofuels used in UK (and the rest of the EU) are required to meet the sustainability requirements set out in the Renewable Energy Directive (RED) (EC 2009). As well as specifying that biofuels feedstocks should not be grown on converted land that previously had a high carbon stock, RED also specifies minimum GHG savings (compared to fossil fuels) that biofuels must achieve – 35% saving by 2013 and 50% saving by 2017 for existing production capacity and 60% by production capacity installed in 2018 and beyond. As we make the assumption that biofuels are grown on land that is ‘spare’ agricultural land, all biofuels would meet the first specification. To assess whether the required GHG savings would be achieved, typical values of savings for biofuel production from the crop/region combinations in the model were evaluated, and an assessment was then made of the percentage of biofuels produced in each region which would meet the RED criteria (see details in the tables detailing main assumptions below). For example, where the typical value for greenhouse gas savings for a particular supply are about 40%, it is judged that 20% of the supply might be far enough above this value to meet the 50% criteria. Typical greenhouse gas savings for most of the biodiesel supply modelled are below the 50% threshold set for 2020, and therefore the sustainability standards in the RED, severely limit the amount of biodiesel the EU can import in 2020 and beyond.

From April 2013 solid biomass and biogas electricity from plant >1MWe will need to have a carbon intensity of 285.12 kgCO2/MWh or lower to be eligible for ROCs (i.e. a saving >60% relative to the EU fossil fuel comparator) (DECC 2010a). This was announced after the analysis was undertaken for this report and has not been examined in detail in the report. It is difficult to quantify the impact that this would have on the quantities of biomass available to the UK. Wood chips from sustainably sourced forests, or from forest residues or sawmill waste, or energy crops, would all typically meet this criteria, even if transported from countries such as the US or Canada. However, pelleting of the wood (which is currently necessary to ensure that imported wood meets regulations) can substantially reduce the GHG savings such fuels can achieve if e.g. diesel fuel is used for drying the wood prior to milling and pelleting. The use of wood to fuel the drying process however leads to much lower emissions and it is likely that many pellets produced in this way would still meet the sustainability standard

Scenario development

In order to examine the impact of global economic, agricultural and technical development, three scenarios of global supply were developed. These focus on those aspects that we believe will have a significant impact on the availability of biomass on the global market to the UK. These include:

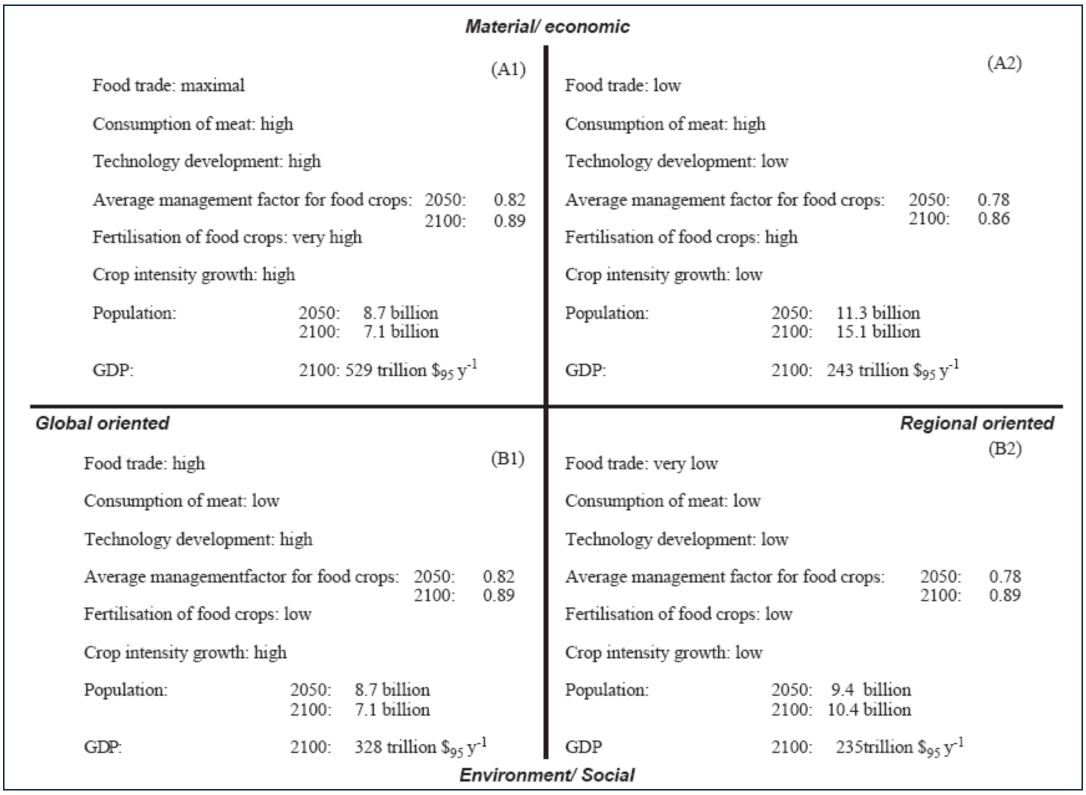
- Availability of land for bioenergy crops: This depends on both the global food/ feed requirements, estimated from population and diet and the amount of land needed to meet this requirement, based on the amount of intensification of existing agriculture and improvements in yield. We used scenarios from Hoogwijk et al (2003,2005) which include explicit assumptions for GDP, yield improvements and intensification of agriculture, see Figure 16. This analysis was extended by Van Vuuren *et al* (2009) to take constraints such as water availability into account.

- Yield improvements for energy crops. The amount of energy crops and current first generation biofuels crops depends on increased yields of these crops and we have allowed for this in the modelling. More details of how this was done are given in the results section below.

- Development of fuel quality standards: this could be a key requirement in allowing wide scale trading of biomass fuels for heat and power sector. Currently there are no agreed international fuel quality standards, which mean that specifications have to be agreed between each plant operator and supplier. Although some specifications are commonly used (such as Austrian, German and Scandinavian standards for wood fuels) this can mean that there is a proliferation of fuel specifications and that suppliers have to try to match them all. In addition in times of high demand/supply restrictions quality can fall. Development of agreed fuel quality standards would improve the standard of the fuels supplied and prevent this proliferation of different standards.

- Introduction of sustainability standards and the ability of suppliers to meet them and to demonstrate that they have met them.

Figure 16 From Hoogwijk (2005) Assumptions related to food demand and supply for the scenarios considered. The A1 and A2 scenarios are used as a basis for our scenario development.



(A1)

Food trade: maximal
Consumption of meat: high
Technology development: high
Average management factor for food crops: 2050: 0.82; 2100: 0.89
Fertilisation of food crops: very high
Crop intensity growth: high
Population: 2050: 8.7 billion; 2100: 7.1 billion
GDP: 2100: 529 trillion $\$_{95}\ y^{-1}$

(A2)

Food trade: low
Consumption of meat: high
Technology development: low
Average management factor for food crops: 2050: 0.78; 2100: 0.86
Fertilisation of food crops: high
Crop intensity growth: low
Population: 2050: 11.3 billion; 2100: 15.1 billion
GDP: 2100: 243 trillion $\$_{95}\ y^{-1}$

(B1)

Food trade: high
Consumption of meat: low
Technology development: high
Average managementfactor for food crops: 2050: 0.82; 2100: 0.89
Fertilisation of food crops: low
Crop intensity growth: high
Population: 2050: 8.7 billion; 2100: 7.1 billion
GDP: 2100: 328 trillion $\$_{95}\ y^{-1}$

(B2)

Food trade: very low
Consumption of meat: low
Technology development: low
Average management factor for food crops: 2050: 0.78; 2100: 0.89
Fertilisation of food crops: low
Crop intensity growth: low
Population: 2050: 9.4 billion; 2100: 10.4 billion
GDP 2100: 235trillion $\$_{95}\ y^{-1}$

The three scenarios developed were:

- Business as usual (BAU),
- BAU+ high investment
- Low development.

Each of these was based on the Hoogwijk/Van Vuuren land use scenarios described above, but were extended to include the additional constraints outlined above.

The main conditions for each of these scenarios is shown in Table 35 below.

Table 35 Summary of the main conditions in each scenario for global supply

Scenario	Technology development	Agricultural intensification	Agricultural yields for food crops	Global economy	trade	Infrastructure	Technology transfer	Quality standards	Population growth	Political stability in key producer countries
Business as usual (BAU)	**High**	**High**	**High**	**GDP grows**	**Enabled**	**Current trends**	**Current trends**	**Developed but not all countries can meet them**	**8.7 billion**	**Current trends**
BAU+ High investment	**High**	**High**	**High**	**GDP grows**	**Enabled**	**High investment**	**High**	**Developed and developing countries can meet them**	**8.7 billion**	**Good**
Low development	**Low**	**Low**	**Low**	**Low GDP growth**	**Restricted**	**Low development**	**Low**	**Not developed**	**11.3 billion**	**Poor**

Business as usual

This scenario is based on the Hoogwijk A1 Global Economic scenario (Figure 2.4). Under this scenario, there is high technology development, the world economy grows at an average of 2% per annum, and poorer regions of the world show good development and growth, becoming more stable politically. This encourages development of infrastructure, and food trade is maximal.

In this scenario current trends for bio-energy production prevail. We have assumed that development of agricultural resources and infrastructure will occur regionally on much the same basis as at present (i.e. those countries already successfully developing their infrastructure, technology and political stability continue to do so, but regions where this is not happening continue to lag behind). This means that much of the bio-energy potential of less developed regions will not be available under this scenario.

In the case of woody energy crops, regional average yields for energy crops were derived from the results in Hoogwijk (2005), and range from 5 odt/yr (e.g. in Southern Africa) to 10 odt/yr (in North America) and 11 odt/yr in Former Soviet Union. Yields are assumed to increase (as specified in Hoogwijk) at 1.6% per year in the BAU scenario, so are 37% above 2010 levels by 2030.

In the same way as for the modelling of UK energy crop resource, the maximum rate at which planting of energy crops could occur was estimated based on an assumption about the maximum rate at which the area planted each year could be expanded. This was 20% per year for developed economies, 10% per year for transition economies and 5% per year for emerging economies. Overall these planting rates constrain the area available to energy crops substantially: to 15% of the maximum area available in 2020 and 34% of the maximum available are in 2030.

In the case of 1G biofuels feedstocks, current yields were based on data from the RFA, or FAPRI data sets, which were found to be largely consistent with values in the Kline et al (2008), OFID (2009) and ADAS (2008a) studies. Yield increases are differentiated by crop and region, but typically are about 0.9% per year in the BAU scenario. This rate of yield increase over time is kept constant for all crops except jatropha, which is currently at an early stage of development so a higher rate of increase was thought possible from 2025 onwards. Full details of assumptions about planting rates, yields and yield increases are given in below.

BAU + high investment

This scenario is also based on the Hoogwijk A1 Global Economic scenario.

We have assumed this scenario provides opportunities for development of bioenergy, both domestically and through investment from richer countries. There is good technology transfer, enabling yield improvements in all countries. Facilitating trade is important, so product quality standards are developed to allow commodity trading of various grades of fuel. These standards also ensure consistent product quality, which together with reliable delivery, encourages investment by demand side sector. Developing countries are assumed to have the capacity to implement sustainability requirements and demonstrate that they have been met. The UK is also assumed to develop good infrastructure to deal with large quantities of imports (e.g. facilities at ports).

Planting rates for energy crops increase more rapidly in this scenario; yield increases for both energy crops and biofuels crops are the same as in the BAU scenario.

In summary this scenario presents an optimistic view of the potential for bio-energy from the land available (but is not a theoretical maximum). Supply is increased substantially from the BAU scenario, due to increased planting and the removal of some barriers by investment, but a large proportion of land which could potentially be used still remains unplanted in some regions. By 2030, this is mainly due to general infrastructure and market constraints, rather than the planting rate constraint.

This scenario will still only produce a ‘realistically’ high level of supply. That is, while planting rates and yields increase more quickly that for BAU, the planting rates still constrain supply. Similarly, while barriers to development are lower than in the BAU case, there are still some.

Low development

For this scenario, we used the Hoogwijk A2 Regional-Economic scenario (Hoogwijk 2005).

Under this scenario we have assumed technology development is slower, and there is less intensification of agriculture and less improvement in yields. Growth in global GDP is lower than for the other scenarios (at 1.6 % per annum), and there is reduced international food trade. These traits combine to give lower potential land availability for bio-energy production.

In addition, we have assumed that there is less infrastructure development in developing countries under this scenario, as it will not be developed for food crops; and that developed countries do not invest in developing biomass supply in developing countries. Yields of energy crops only improve at 1.2% p.a. (compared to 1.6% in BAU) and yields of biofuels corps at half the rate assumed in the BAU scenario. Planting rates for energy crops are also lower.

The combination of lower initial land availability and more constraints on supply mean that this scenario gives the lowest potential for bio-energy production.

Global Demand scenario

Reference Demand Scenario

In order to understand what proportion of the feedstock resource in other countries might be traded we also need to take demand in the country of production and other countries into account. To do this we used the ‘reference’ demand, as predicted in the IEA World Energy Outlook 2009 (IEA, 2010), as a basis for our reference global bioenergy demand scenario. The demand for biofuels was cross checked against any mandates which have been set for biofuels use, and the demand updated to reflect any mandates which set legislative targets. For example, the EU biofuels demand was increased to ensure that the requirements of the Renewable Energy Directive would be met in 2020. We also reviewed whether countries had specific targets for the use of biomass in general, but while we identified some general targets for renewable energy use in some countries, and strategic intentions to increase the use of biomass, no specific quantitative targets were identified. The demand for biomass in the heat and power sector in the WEO forecast was therefore not adjusted.

High Biomass Demand Scenario

To test the sensitivity of results to the demand side assumptions, we also considered a high biomass demand scenario, in which there is a higher demand for biomass globally. This is based on the ‘450 scenario’ included in the IEA World Energy Outlook -“an alternative world, with an energy sector that is substantially cleaner, more efficient and more secure, and in which annual energy-related CO2 emissions peak just before 2020 before falling to put the world on track for stabilisation of the atmospheric concentration of greenhouse gases at 450 parts per million (ppm) of CO2 –equivalent”. Under this scenario, there is a substantial increase in the use of biofuels, principally second generation biofuels, and increased use of biomass for electricity generation.

Other Demand Side Assumptions

Further assumptions were made around:

- the split of demand between different sectors. This was based on the split in the IEA (2009) reference scenarios, adjusted for a number of countries/regions (e.g. Asia and Africa) to remove the influence of traditional biomass use (i.e. traditional household use of biomass, often collected informally, for heating and cooking);

- the proportion of demand in power, industry and ‘other’ sectors met with woody biomass. The increase in biomass use for electricity generation in the high biomass demand scenario is assumed to be met mainly (90%) by woody biomass;

- the split between 1G vs 2G biofuels and the proportion of 2G biofuels produced from woody biomass. This was based broadly on E4Tech (2008) with additional information from IEA (2010, 2010a). In the high biomass demand scenario, it is assumed that almost all of the increase in biofuels use is supplied by 2G biofuels and that much of this increase is supplied by woody biomass, on the basis that as low cost feedstocks, wastes and agricultural residues are utilised initially, and that they are a limited resource.

Matching international demand and supply

Combining the estimates of the international resource with the constraints information gives a constrained resource, which represents the amount of biomass that could be supplied to either the domestic or international market. The next step in the modelling is to subtract the domestic demand in each region for 1G biofuels and woody biomass from this resource. At the regional level, this may result in a surplus or deficit, indicating whether regions are likely to be net exporters or importers of biofuels and woody biomass. At the global level, this indicates the amount of biofuels and biomass which could be available to the international market, once forecast domestic demands have been met; i.e. how much more biomass could be available if countries wished to expand their use of biomass and biofuels.

It is unlikely that any one country would obtain all of this ‘surplus’, and it is therefore assumed that only a certain percentage of this surplus would be available to the UK. This percentage can be changed by the user in the model, but for the reference runs used to inform this study it has been set at 10%. This is based on examination of the modelling results that indicate that in the time period being considered, the EU is both one of the regions with the highest demand for biomass, and also that it will need to import significant amounts of biomass to meet this demand. We therefore believe that the EU is likely to be one of the key players in the international biomass market and that the UK will be competing with other EU countries to secure biomass supply. Overall the UK accounts for about 10% of EU energy demand and this value has therefore been chosen to allow an estimation of how much biomass supply the UK might secure.

Scenario Runs

A range of results were generated by combining the three core global supply scenarios, BAU, BAU – high investment and low development, with the two demand scenarios to create six sets of results. Within each set of results, two variants are possible, one where production of woody energy crops is maximised, and one where production of 1G feedstocks and 1G biofuels is maximised. This leads to 12 overall scenarios for global supply of biomass as shown in Table 36.

Table 36 Scenarios examined for global biomass supply

	Reference Global Biomass Demand		High Global Biomass Demand	
BAU	**Maximise Energy Crops**	**Maximise Biofuels**	**Maximise Energy Crops**	**Maximise Biofuels**
High Investment	**Maximise Energy Crops**	**Maximise Biofuels**	**Maximise Energy Crops**	**Maximise Biofuels**
Low development	**Maximise Energy Crops**	**Maximise Biofuels**	**Maximise Energy Crops**	**Maximise Biofuels**

Main Assumptions for Estimating Supply

International Agricultural residues

Technical Potential 85PJ/y in 2010, rising to 322 PJ/y in 2030 under BAU	Assumptions
	• Not all agricultural residues are relevant to UK because a large proportion are either too dispersed or too wet to be brought to the UK. Therefore have used international data on specific residues that can be aggregated and traded internationally. • The feedstocks of most relevance are those that are already traded for energy (usually co-firing), or that are traded as feed components. In addition some other food processing residues are considered if concentrated quantities of relatively dry residues that can be transported are available. These are the feedstocks we have considered for tradable supplies (see the table below). • Global estimates of 49-69EJ/y are based on theoretical estimates of all residues that could be used and include many residues that could not be traded internationally. We have therefore not used these estimates, although they do provide a valid approach to global energy use. • We have used country and international data on relevant residues to provide an indication of what might be available. We have then constrained this on the basis that a proportion (depending on crop) would be used in country. Key data sources included: NREL (2008), Kline *et al* (2007), who summarise agricultural residues in the Pacific and Caribbean basins; IEA country reports; EU reports on animal feed and AEA data. • We have not taken novel crops or future plantations into account. These may be a viable resource in the future but we have no data on which to judge them. • There is considerable uncertainty in the source data used. There has been no comprehensive review of the trade in agricultural residues and much of the information on this trade is subject to commercial sensitivities. • Production of agricultural residues varies considerable with time, depending on harvest conditions. For example the olive harvest can vary by over 30% from year to year. In addition the harvest of other crops can significantly impact on the availability of residues for energy, as feed suppliers substitute from one crop to another. For example issue with maize supply in 2007 led to increased use of palm kernel expeller the Australian feed market, decreasing the availability of this residue to the energy market. These factors make imported agricultural residues unreliable fuels on which to base energy strategies and a flexible approach to these feedstock is advisable. • For the scenario analysis we have assumed that high investment enables investment in infrastructure for processing, storage and transport of agricultural residues for trade. In the low investment scenario we assumed that none of these happened. • Physical constraint: Crops planted.

Commodity	Quantities produced globally	Comments and sources of information and comments on major resources
Olive oil residues	5Mt	Olive cake, 3Mt produced in EU.* Dependent on harvest, which can reduce yield by 30%. Already used for heat and power in country of production and for animal feed and fertiliser. 283,222 t imported to UK for co-firing in 2005*
Palm Kernel Expeller	2.5Mt	2.5Mt is quantity imported to EU for animal feed. It is probable that over 3.5Mt is produced annually. PKE supply chain dominated by a few major players. Perry and Rosillo-Calle (2006) estimated that PKE could reach 4.6Mt worldwide by 2016.
Palm kernel shell	5.2-8.7Mt	AEA information
Shea nut shells		5,420t imported to UK for cofiring in 2005*
Sunflower pellets		20,331t imported to UK for co-firing in 2005* Ukraine production: 67.8 $x10^6$ GJ/y (BEE 2008).
Tall oil		120,129t imported to UK for co-firing in 2005*
DDGS	14Mt (EU)	Estimate from EBB calculation of how much grain ethanol could be used for 2010 target.
Bagasse	1631PJ	Estimate for Australia 1029 GWh (286PJ); Brazil produces 27M odt/y and uses some of these for heat plant capacity 3857MW. Estimated potential of energy from bagasse in Brazil is 3307 PJ in 2020, up from 1345PJ in 2010 (IEA Task 40 report). Argentina and India may also be a significant producers (Kline *et al*, 2007)
Meals and cakes from oil seeds	99.7Mt	2008/9, protein equivalent output (FAO statistics). According to these figures 100% is used for animal feed or has some other market. FAO also estimate the total concentrated feed produced in the world to be 1250 Mt in 2005. Apart from residues, this includes the growing of crops for fodder and the use of feed wheat. This is dominated by oil cake, cereals and brans. The UK imports about 1.9Mt of soya cake, and 1.74Mt of other oil cake (HMRC data)

*Perry M and Rosillo-Calle F (2006) Co-firing report for UK. Available from IEA Task 40.

Note that the quantities produced globally are not all available to UK. Within this analysis a view was taken on the amount that could not be exported because it is widely dispersed or too wet to transport; the amount used in country and the amount that could be made available, given the infrastructure to export it.

Yield rates	Yields of residues vary with crop yields and harvest conditions. We have not assumed increased yields in the future as increased crop yields do not necessarily result in increased residues as well (frequently crop yields increase at the expense of yield of residues).
Cost	The major influences on the cost of agricultural residues are: Drying and processing necessary at source Bulk density and other conditions that influence transport Storage and handling.
Competing uses	Assumptions on competing uses: food and non-energy uses. Agricultural residues are currently traded for use in the animal feed market, as a fuel for co-firing and as a feedstock for other products (e.g. coir for matting). Use for trade in the UK will be subject to competition with all of these uses. We have

<table>
<tr><td></td><td>assumed that current feed and commodity markets will out compete energy use on the basis that these markets represent higher value to the traders.

Additionally a number of countries, notably in Eastern Europe, are waking to the potential that these residues represent and are interested in using them for energy. We have assumed a large proportion of many of these residues will be used at the food processing plant or locally for energy.

The Table appendixed to this summary shows the types of competition included in our analysis.</td></tr>
<tr><td>Constraints:</td><td>The main constraints considered are:
In country use
Competition from other markets</td></tr>
<tr><td>Results</td><td>Key results

The results show that the availability of agricultural residues increases with time for all three scenarios, but that this increase is greatest for the high investment scenario.

The increase is due to infrastructure investment that enables better collection, storage, processing and transport of the residues.

PJ availability for the three development scenarios examined are:

<table>
<tr><th>Year</th><th>2010</th><th>2015</th><th>2020</th><th>2025</th><th>2030</th></tr>
<tr><td>BAU</td><td>854</td><td>1419</td><td>1984</td><td>2602</td><td>3220</td></tr>
<tr><td>BAU + high inv.</td><td>854</td><td>1954</td><td>3055</td><td>4171</td><td>5286</td></tr>
<tr><td>Low development.</td><td>854</td><td>833</td><td>812</td><td>915</td><td>1017</td></tr>
</table>
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References

APEC Assessment of biomass resources from marginal lands in APEC economies

Bauen A., Woods J., Hailes R (2004) Bioelectricity Vision: Achieving 15% of Electricity from Biomass in OECD Countries by 2020. Report for WWF and Aebiom.

Biomass Energy Europe (BEE) 2008 Status of biomass resource assessments. V1.

Bradley D, Hektor B and Schouwenberg P (2010) World Bio-trade Equity Fund Study For IEA Task 40 Bio-trade

Faaij etal (2006) quoted in Heinimo J., Pakarinen V., Ojanen V and Kassi T (2007) IEA – scenario study on international biomass market in 2020. Available: www.doeia.fi/lutpub

FAO (2008) Commodity Market review 2007-8 Foreign direct investment and agri-food value chains in developing countries: a review of the main issues Ruth Rama and John Wilkinson

FAO SOFA 2009: livestock in the balance

Hoogwijk M, Faaij A, Van den Broek R, Berndes G, Gielen D, Turkenburg W. Exploration of the ranges of the global potential of biomass for energy. Biomass Bioenergy 2003; 25(2):119–33.

Kline K.L. Oladosu G. A., Wolfe A.K., Perlack R.D., McMahon M., Dale V.H. (2008) Biofuel Feedstock Assessment for selected countries (To support the US DOE study of “Worldwide Potential to Produce Biofuels, with a focus on U.S. Imports”)

NREL, 2008. Survey of Biomass Resource Assessments and Assessment Capabilities in APEC Economies.

Perlack R D., Wright L L., Turhollow A F., Graham R L., Stokes B J., Erbach D C (2005) Biomass as a feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion ton annual supply. www.osti.gov/bridge

Perry M and Rosillo-Calle F (2006) Co-firing report for UK. Available from IEA Task 40

Smeets E.M.W, Faaij A.P.C, Lewandowski I.M., Turkenburg W.C., (2007) A bottom-up assessment and review of global bio-energy potentials to 2050 Progress in Energy and Combustion Science 33 (2007) 56–106

Walter A and Dolzan P (2009) Brazil country report for IEA Bioenergy Task 40 Biomass and

De Wit M and Faaij A (2009) European biomass resource potential and costs. Bioenergy 34 (2010) 188-202

International wood feedstocks

The international wood feedstock analysis was done using Forest Research's Carbine model. This provides figures for OECD Annex 1 countries for forest residues, small round wood and sawmill residues. The remaining regions were estimated on the basis of FAOstat data, as indicated below.

Technical Potential	Assumptions • Figures for OECD Annex 1 countries from Forest Research Carbine model. These figures are modelled using national forest inventory and FAOstat timber statistics. • Other regions are estimated using FAOstat data and wood products are estimated using a factor which reflects management practice in similar regions in Carbine. • Carbine projections are based on historic trends in forestry management. It assumes that no forestry is taken out of management or brought into management unless there is an historic trend for the country that indicates that this is current forestry practice. For example, countries such as Australia where there are increases in plantations over the period of 1990-2008 are assumed to continue expanding forestry at the same rate. • Carbine assumes conversion losses in forest and processing. It also assumes includes algorithms that allow the split of harvested timber into products according to species and forest management practice. • Products assumed available for bioenergy are: saw log off cuts (including slab wood), small round wood and branch wood. Carbine also provides an estimate of bark, but we have assumed that this is not exported for energy. Physical constraints: Current forestry management continues along historic trends. Scenarios for business as usual, high investment and low investment were examined for their impact on the availability of feedstock.
Cost	Carbine assumes current management practice and costs.
Competing uses	Assumptions on competing uses: • Carbine takes account of the use of timber for sawlogs, paper and pulp and produces a residue figure for products that can be used for bioenergy. It does not take account of competition between uses of these residues for pulp, paper and panel board and bioenergy. Nor does it include use of these products for energy at the mill. • For each of the regions, consideration as given to the whether the infrastructure to develop and exploit the resource existed, and how easily it could be further developed. Consideration was also given as to how likely it was that the market conditions necessary to develop a supply chain and to set arrangement for trading of the resource were in place. For each region, an assessment was made as to where the barrier to development in these two areas were very high, high, medium or low, for 2010, 2020 and 2030. This assessment was then used to estimate the percentage of the resource which would be likely to reach the market. The total resource which it is considered could reach the market for use (domestic or international) in each scenario is shown below.

<table>
<tr><td>Constraints:</td><td>The main constraints considered are:

• In country use
• Competition from other markets
These constraints increase with time because of the development of demand in the Far East, Latin America and Europe.</td></tr>
<tr><td>Results</td><td>Global total resource for wood products: unconstrained and constrained resource (PJ)
<table>
<tr><th></th><th>2010</th><th>2015</th><th>2020</th><th>2025</th><th>2030</th></tr>
<tr><td colspan="6">Unconstrained resource, BAU, BAU +high development, and low development</td></tr>
<tr><td>SRW</td><td>3136</td><td>3239</td><td>3330</td><td>3422</td><td>3532</td></tr>
<tr><td>Forest residues</td><td>3292</td><td>3409</td><td>3557</td><td>3748</td><td>3957</td></tr>
<tr><td>Sawmill residues</td><td>2405</td><td>2526</td><td>2699</td><td>2913</td><td>3167</td></tr>
<tr><td colspan="6">Constrained resource BAU</td></tr>
<tr><td>SRW</td><td>773</td><td>954</td><td>1136</td><td>1372</td><td>1608</td></tr>
<tr><td>Forest residues</td><td>927</td><td>1130</td><td>1333</td><td>1647</td><td>1961</td></tr>
<tr><td>Sawmill residues</td><td>1183</td><td>1280</td><td>1378</td><td>1577</td><td>1776</td></tr>
<tr><td colspan="6">Constrained resource BAU+ high development</td></tr>
<tr><td>SRW</td><td>773</td><td>1154</td><td>1536</td><td>1584</td><td>1632</td></tr>
<tr><td>Forest residues</td><td>927</td><td>1348</td><td>1768</td><td>1874</td><td>1980</td></tr>
<tr><td>Sawmill residues</td><td>1183</td><td>1291</td><td>1400</td><td>1600</td><td>1801</td></tr>
<tr><td colspan="6">Constrained resource Low development</td></tr>
<tr><td>SRW</td><td>773</td><td>893</td><td>1012</td><td>1048</td><td>1084</td></tr>
<tr><td>Forest residues</td><td>927</td><td>1080</td><td>1233</td><td>1306</td><td>1380</td></tr>
<tr><td>Sawmill residues</td><td>1183</td><td>1212</td><td>1241</td><td>1373</td><td>1504</td></tr>
</table>
</td></tr>
</table>

International Energy crops

Unconstrained Potential	**Assumptions** *Land availability* The starting point for land availability are the estimates of 'spare' agricultural land and pasture land (i.e. not required for food and feed production) estimated by Hoogwijk (2005) for each of 12 regions of the world. Two scenarios of land

Total resource:

20 to 99 EJ in 2030 depending on land availability and development scenario

availability were used:

- AI: a scenario which assumes high investment and that yields for food crops increase rapidly and that population growth is relatively modest and therefore land availability is high. This is used in the Business as Usual (BAU) scenario and the BAU – high investment scenario.
- A2: lower growth in crop yields and higher population growth results in higher land requirements for food and feed and lower availability of ‘spare’ land. This is used in the low development scenario.

Additional constraints were imposed on the amount of land that was available based on work by Van Vuuren (2009), which considered the impact of water availability and land degradation on the suitability of such ‘spare’ land for crops. It was then assumed that land categorised by Van Vuuren as severely degraded, or with severe water scarcity were unsuitable for growing either energy crops or oil or starch or sugar crops for biofuels production. Land which was mildly degraded or with mild water scarcity was considered suitable for energy crops but not biofuels crops. Land with no degradation or water scarcity was considered suitable for either use.

Summary of land availability (Mha)	**BAU**		**Low development**	
	2020	**2030**	**2020**	**2030**
Total ‘spare’ arable land	603	885	386	447
Unsuitable for planting	154	235	112	127
Maximum suitable for energy crops	449	650	274	320
Of which: suitable for energy crops only	253	360	152	178
suitable for energy crops or biofuels crops	196	290	122	142

Two scenarios for future use of this ‘spare’ land are considered:

- **Maximum 1G crops:** production of arable crops for biofuels (wheat and OSR) are maximised and energy crops are only grown on land that is unsuitable for biofuels crops
- **Maximum energy crops:** enough biofuels feedstocks are grown to meet a certain level of demand for biofuels, but all other spare land is used for energy crops.

In the scenarios constructed, it is assumed that because of sustainability considerations, no ‘spare’ grassland is utilised for either biofuels or energy crops, but the model does include estimates of ‘spare’ pasture land, and the ability to specify use of a fraction of this, to allow the sensitivity of results to this to be assessed.

Yields:

Regional average yields for energy crops were derived from the results in Hoogwijk (2005), and the yield increase specified in Hoogwijk: 1.6% per year in the BAU scenario and 1.2% per year in the low development scenario. Regional yields in 2010 range from 5 odt/yr (e.g. in Southern Africa) to 10 odt/yr (in North America) and 11 odt/yr in Former Soviet Union. By 2030 these increased by 37% in the BAU scenario and 27% in the low development scenario.

Planting rates

In the same way as for the modelling of UK energy crop resource, an estimate has been made of the maximum rate at which planting of energy crops could occur, based on an assumption about the maximum rate at which the area planted each year could be expanded.

Expansion of planting areas (% p.a)	BAU	BAU- high investment	Low development
Developed economies	20%	20%	20%
Transition economies	10%	20%	8%
Emerging economies	5%	20%	2%

Overall these planting rates reduce the area available to energy crops substantially: to 15% of the maximum area available in 2020 and 34% of the maximum available are in 2030 in the BAU scenario.

Maximum areas which could be planted (Mha)	BAU	BAU- high investment	Low development
2020	48	66	23
2030	232	490	137

Competing uses

No competing uses assumed for feedstock, although this could potentially change if the biomaterials market developed in the future

As land availability estimates are based on estimates of 'spare' or land which is not required to meet food and feed requirements, there is no completion with food and feed. Competing use of the land for biofuels feedstocks production has been considered through the use of two scenarios.

The domestic demand for the energy crops resource is considered in a separate part of the modelling where estimates of future biomass demand globally are matched against the estimates of resource to determine where there is a surplus which could potentially be traded. In addition an assumptions is made about the amount of international surplus available for trade that the UK could secure.

Constraints:

Constrained resource:

10 to 20 EJ in 2030 depending on land availability and development scenario

For each of the regions, consideration as given to the whether the infrastructure to develop and exploit the resource existed, and how easily it could be further developed. Consideration was also given as to how likely it was that the market conditions necessary to develop a supply chain and to set arrangement for trading of the resource were in place. For each region, an assessment was made as to where the barrier to development in these two areas were very high, high, medium or low, for 2010, 2020 and 2030. This assessment was then used to estimate the percentage of the resource which would be likely to reach the market. This value was used unless the constraints implied by the planting rate was higher, in which case the lower value (i.e. that which the planting rate dictates could be achieved) was used as the resource estimate. The total resource which it is considered could reach the market for use (domestic or international) in each scenario is shown below. Depending on year and scenario between about 40 and 70% of the total resource estimated above.

Potential resource (EJ)	**BAU**		**High investment**		**Low development**	
	2020	**2030**	**2020**	**2030**	**2020**	**2030**
Maximum energy crops	8	21	12	85	4	34
Minimum energy crops	8	34	10	42	4	13

International Biofuels

Unconstrained Potential

Total resource: 9 to 24 EJ in 2030 depending on land availability and development scenario

Assumptions

Land availability

As for international energy crops the starting point for land availability are the estimates of 'spare' agricultural land and pasture land (i.e. not required for food and feed production) estimated by Hoogwijk (2005) for each of 12 regions of the world. Two scenarios of land availability were used:

- AI: a scenario which assumes high investment and that yields for food crops increase rapidly and that population growth is relatively modest and therefore land availability is high. This is used in the Business as Usual (BAU) scenario and the BAU – high investment scenario.
- A2: lower growth in crop yields and higher population growth results in higher land requirements for food and feed and lower availability of 'spare' land. This is used in the low development scenario.

Additional constraints were imposed on the amount of land that was available based on work by Van Vuuren (2009), which considered the impact of water availability and land degradation on the suitability of such 'spare' land for crops. It was assumed that only land categorised by Van Vuuren as not being degraded and where there was no water scarcity were suitable for the types of crops (oil and sugar and starch) which could be grown as feedstocks for 'first generation' (1G) biofuels.

Summary of land availability (Mha)(excluding grassland)	BAU and BAU high investment		Low development	
	2020	2030	2020	2030
Total 'spare' arable land	450	650	274	320
Suitable for 1G biofuels crops	253	360	152	178

Two scenarios for future use of this 'spare' land are considered:

- **Maximum 1G crops:** production of arable crops for biofuels (wheat and OSR) are maximised and energy crops are only grown on land that is unsuitable for biofuels crops
- **Maximum energy crops:** enough biofuels feedstocks are grown to meet a certain level of demand for biofuels, but all other spare land is used for energy crops

In the scenarios constructed, it is assumed that because of sustainability considerations, no 'spare' grassland is utilised for either biofuels or energy crops, but the model does include estimates of 'spare' pasture land, and the ability to specify use of a fraction of this, to allow the sensitivity of results to this to be assessed.

Current (2010) biofuels production is assumed to be on existing arable land, but not to be in competition with food and feed production,

Biofuels crops

One bioethanol and one biodiesel crop was chosen per region. This was the current dominant biofuels crops, or the best prospect in those regions currently without large scale production. The choice was based on views expressed in three recent publications (Kline, 2008; OFID, 2009; ADAS, 2008); (and utilising AEA expert judgement).

Available land was split between the biodiesel and bioethanol crops based on data from the FAPRI forecasts of biofuels feedstock production for countries where this data was available, For other crop/regions, data was taken from FAPRI information on relative crop areas.

Yields:

Current yields were taken from RFA guidance on estimating greenhouse gas emissions associated with biofuels production; these were supplemented where necessary with values for the relevant crop/region combination from the FAPRI data set. These values were found to be largely consistent with values in the Kline, OFID and ADAS studies.

There was no evidence that yields will not continue to increase in a linear fashion with time, so the rate of yield increase over time is kept constant for most crops. The exception was jatropha, which is currently at an early stage of development, so a higher rate of increase was thought possible from 2025 onwards. There is evidence for potential for different increases in yield rates between crops and between regions, and some differentiation was therefore made. However, on average a yield increase of about 0.9% per year is thought feasible for the BAU (and high investment) scenario. This assumes that crop inputs remain optimal and that there is continued research and development of agricultural crops and techniques. For the low investment scenario the rate of increase of yield is halved.

Conversion efficiencies

Conversion efficiencies (litres of biofuels produced from a tonne of feedstock) are based on the values in the latest RFA Guidance. Production of first generation biofuels is a relatively mature technology and three are limited opportunities for improvement. A low rate of improvement 0.05%/ year) in the conversion technology efficiencies is therefore assumed, and is taken from modelling work recently completed for the DfT on production of biofuels.

Sustainability

Biofuels used in UK are required to meet the sustainability requirements set out in the Renewable Energy Directive (RED) (EC 2009). As well as specifying that biofuels feedstocks should not be grown on converted land that previously had a high carbon stock, RED also specifies minimum GHG savings (compared to fossil fuels) that biofuels must achieve. As we make the assumption that biofuels are grown on land that is ‘spare’ agricultural land, all biofuels would meet the first specification. To assess whether the required GHG savings would be achieved, typical values of savings for biofuel production form crop/region combinations in the model were evaluated. Where savings were below the required minimum, it is assumed that a fraction of the biofuel production might (e.g. through the use of lower inputs, higher yields or using less carbon intensive fuel sources for processing) achieve higher savings that could meet the required criteria. The estimate of the fraction of biofuel production that was assumed to be RED compliant was based on knowledge of opportunities for reducing GHG emissions from production and of how close the typical saving value was to the required criteria.

The total resource which could be produced is estimated as:

<table>
<tr>
<td></td>
<td>
<table>
<tr><th>Potential resource (EJ)</th><th>BAU</th><th></th><th>High investment</th><th></th><th>Low development</th><th></th></tr>
<tr><td></td><td>2020</td><td>2030</td><td>2020</td><td>2030</td><td>2020</td><td>2030</td></tr>
<tr><td>Maximum 1G biofuels</td><td>15.9</td><td>24.5</td><td>15.9</td><td>24.5</td><td>8.4</td><td>10.4</td></tr>
<tr><td>Maximum energy crops</td><td>15.6</td><td>23.4</td><td>15.6</td><td>18.3</td><td>8.8</td><td>8.8</td></tr>
</table>
In the BAU and low investment scenarios, the expansion of energy crops is heavily constrained by achievable planting rates, so there is little difference between the two land use scenarios. It is only in the high investment scenario where the area used for energy crops expands that the production of biofuels is compromised.
</td>
</tr>
<tr>
<td>Competing uses</td>
<td>As land availability estimates are based on estimates of ‘spare’ or land which is not required to meet food and feed requirements, there is no completion with food and feed. Competing use of the land for woody energy crops has been considered through the use of two scenarios.

The domestic demand for biofuels is considered in a separate part of the modelling where estimates of future biofuels demand globally are matched against the estimates of resource to determine where there is a surplus which could potentially be traded. Demand for biofuels for ‘international use’ e.g. in aviation is also considered. In addition an assumption is made about the amount of international surplus available for trade that the UK could secure. This can be set by the model user, and for the reference runs produced for this study was set at 10%.</td>
</tr>
<tr>
<td>Constraints:

Constrained resource:4 to 15 EJ in 2030 depending on land availability and development scenario</td>
<td>For each of the regions, consideration as given to the whether the infrastructure to develop and exploit the resource existed, and how easily it could be further developed. Consideration was also given as to how likely it was that the market conditions necessary to develop a supply chain and to set arrangement for trading of the resource were in place. For each region, an assessment was made as to where the barrier to development in these two areas were very high, high, medium or low, for 2010, 2020 and 2030. This assessment was then used to estimate the percentage of the resource which would be likely to reach the market. The total resource which it is considered could reach the market for use (domestic or international) in each scenario is shown below. Depending on year and scenario between about 44% and 66% of the total resource estimated above.
<table>
<tr><th>Potential resource (EJ)</th><th>BAU</th><th></th><th>High investment</th><th></th><th>Low development</th><th></th></tr>
<tr><td></td><td>2020</td><td>2030</td><td>2020</td><td>2030</td><td>2020</td><td>2030</td></tr>
<tr><td>Maximum energy crops</td><td>7.9</td><td>14.5</td><td>8.1</td><td>14.9</td><td>4.0</td><td>5.0</td></tr>
<tr><td>Minimum energy crops</td><td>7.9</td><td>14.0</td><td>8.0</td><td>11.3</td><td>4.0</td><td>3.9</td></tr>
</table>
</td>
</tr>
</table>

Detailed Assumptions for Estimating Global Supply

This section contains details of input data used in estimating supply;

Land Availability

Tables 37 and Table 38 show the area of abandoned land and grass land, derived from Hoogwijk (2005) and Van Vuuren (2009) which are released from agricultural production and potentially could be used for growing energy crops and 1G biofuels crops, under firstly the BAU and BAU + high investment scenario and secondly the low development scenario. The total area is split into land which was mildly degraded or with mild water scarcity, which was considered suitable for energy crops but not biofuels crops, and land with no degradation or water scarcity which was considered suitable for either use. Figures for abandoned grassland are also shown here. The modeling we carried out assumed that no abandoned grassland was used to grow either energy crops or 1G biofuels, due to sustainability concerns, but the model allows the user to specify a percentage of grassland which can be used.

Biofuel Crop yields and yield increases

Table 39 shows the representative bioethanol and biodiesel crops chosen for each region, together with the crop yield and crop yield increases.

Energy Crop Yields

Table 40 shows the woody energy crop yields assumed for 2010. Yields grow by 1.6%p.a in the BAU and BAU + high investment scenario and 1.2% p.a. in low investment. Table 5.5 shows the maximum area it is assumed can be planted with woody energy crops, in each of the three scenarios due to the constraints on planting rate.

Table 40 Woody Energy Crop Yields in 2010

Region	*Yield odt/ha*
Canada	189
USA	189
Central America	170
South America	170
North Africa	89
West Africa	139
East Africa	111
South Africa	89
Western Europe	189
East Europe	189
Former USSR	205
Middle East	89
South Asia	164
East Asia	164
South East Asia	164
Oceania	172
Japan	172

Sustainability Standards for Biofuels

Table 42 shows the typical greenhouse (GHG) gas savings for biofuels from each crop/region, based on data from the Renewable Fuels Agency Website. These are typical values, and in any region, it is likely that some biofuels production will deliver greater savings than this, and some lower. Based on the difference between the typical savings and the GHG saving criteria in the Renewable Energy Directive, (35% in 2015 and 50% in the next modeling year of 2020), and the opportunities for reducing GHG emissions from the biofuels production, A judgement was made as to how much biofuel production from that region might comply with the RED criteria in each year.

Constraints on Global Supply

Tables 43-46 show level of constraints assumed for infrastructure and trade/market mechanisms for each of the regions for each feedstock.

Table 37 Land availability by region under BAU and BAU + high investment scenarios

Region	Abandoned Agricultural Land (Mha)										Abandoned Grassland (Mha)									
	Suitable for 1G and energy crops					Suitable for energy crops only					Suitable for 1G and energy crops					Suitable for energy crops only				
	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Canada	12	13	14	15	15	12	13	14	15	16	3	4	4	4	4	3	4	4	4	5
USA	26	29	32	33	35	28	30	33	35	37	16	17	19	20	21	16	18	20	21	22
Central America	1	4	7	10	13	1	2	4	6	8	1	4	8	11	15	1	3	5	7	9
South America	5	25	45	66	86	3	16	29	42	55	3	15	27	40	52	2	10	18	25	33
North Africa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West Africa	13	13	13	13	13	6	6	6	6	6	18	18	18	18	18	8	8	8	8	8
East Africa	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
South Africa	2	2	3	3	3	1	1	1	1	1	1	2	2	2	2	1	1	1	1	1
Western Europe	9	10	11	12	12	7	8	9	9	10	4	5	5	5	5	3	4	4	4	4
East Europe	6	6	7	7	8	10	11	12	13	13	0	0	0	0	0	0	0	0	0	0
Former USSR	50	54	58	68	78	34	37	40	46	53	14	15	16	19	22	10	10	11	13	15
Middle East	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
South Asia	0	0	0	1	1	1	2	3	5	7	0	0	0	1	1	1	2	3	6	8
East Asia	5	10	15	27	39	7	14	22	39	56	1	3	4	8	11	2	4	6	11	16
South East Asia	0	0	0	0	1	0	0	0	0	1	1	1	2	4	6	1	1	2	4	6
Oceania	36	42	48	52	56	17	20	23	25	27	23	27	31	34	37	11	13	15	16	18
Japan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
World	166	209	253	307	360	128	162	196	243	290	88	113	138	166	195	60	79	97	121	145

Table 38 Land availability by region under low development scenarios

Region	Abandoned Agricultural Land (Mha)										Abandoned Grassland (Mha)									
	Suitable for 1G and energy crops					Suitable for energy crops only					Suitable for 1G and energy crops					Suitable for energy crops only				
	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Canada	8	8	8	9	11	9	9	9	10	11	3	3	3	3	4	3	3	3	3	4
USA	17	17	17	19	21	18	18	18	20	22	14	14	14	16	18	15	15	15	17	18
Central America	0	0	1	1	1	0	0	0	1	1	0	1	2	3	4	0	1	1	2	3
South America	0	0	1	1	1	0	0	0	1	1	0	6	13	19	26	0	4	8	12	16
North Africa	0	0	1	1	1	0	0	0	0	1	0	1	1	2	3	0	0	1	1	1
West Africa	6	6	6	6	6	3	3	3	3	3	42	42	42	42	42	19	19	19	19	19
East Africa	0	0	1	1	1	0	0	0	0	1	0	4	9	13	18	0	2	4	6	8
South Africa	0	0	1	1	1	0	0	0	0	1	0	3	6	8	11	0	1	3	4	5
Western Europe	12	12	12	13	15	9	9	9	10	12	5	5	5	5	6	4	4	4	4	5
East Europe	6	6	6	7	7	10	10	10	11	13	0	0	0	0	0	0	0	0	0	0
Former USSR	52	54	56	58	60	36	37	38	40	41	23	24	25	26	27	16	17	17	18	18
Middle East	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
South Asia	0	0	1	1	1	1	2	4	4	4	0	1	2	2	2	3	9	15	16	16
East Asia	1	4	8	8	8	2	6	11	11	11	3	10	17	18	18	4	14	25	25	26
South East Asia	0	1	2	2	2	0	1	2	2	2	2	5	9	9	10	2	5	9	10	10
Oceania	29	31	34	38	42	14	15	17	18	20	29	31	34	38	42	14	15	17	18	20
Japan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
World	132	142	152	165	178	101	111	122	132	142	120	151	182	206	229	78	109	140	155	171

Table 39 Assumptions for 1G biofuel feedstock crops

Region	Bioethanol crop	Yield 2010	Yield increase			Biodiesel crop	Yield 2010	Yield increase		
			BAU	BAU - high investment	Low development			BAU	BAU - high investment	Low development
		t/ha	% p.a.	% p.a.	% p.a.		t/ha	% p.a.	% p.a.	% p.a.
Canada	**corn**	10.3	1.2%	1.2%	0.60%	**OSR**	1.85	1.2%	1.2%	0.60%
USA	**corn**	8.6	1.2%	1.2%	0.60%	**soy**	2.85	0.9%	0.9%	0.45%
Central America	**sugar cane**	63.0	0.4%	0.4%	0.20%	**soy**	2.84	0.9%	0.9%	0.45%
South America	**sugar cane**	80.0	0.9%	0.9%	0.45%	**soy**	2.84	0.9%	0.9%	0.45%
North Africa	**none**					**none**				
West Africa	**none**					**jatropha**	2.27	0.5%*	0.5%*	0.25%**
East Africa	**none**					**jatropha**	2.27	0.5%*	0.5%*	0.25%**
South Africa	**sugar cane**	64.0	0.4%	0.4%	0.20%	**soy**	1.64	0.9%	0.9%	0.45%
Western Europe	**sugar beet**	65.0	1.0%	1.0%	0.50%	**OSR**	3.11	0.8%	0.8%	0.40%
East Europe	**wheat**	3.4	0.9%	0.9%	0.45%	**OSR**	3.11	1.2%	1.2%	0.60%
Former USSR	**wheat**	3.0	0.9%	0.9%	0.45%	**OSR**	1.42	1.2%	1.2%	0.60%
Middle East	**none**					**none**				
South Asia	**sugar cane**	68.7	0.9%	0.9%	0.45%	**jatropha**	2.27	0.5%*	0.5%*	0.25%**
East Asia	**corn**	5.5	0.9%	0.9%	0.45%	**jatropha**	2.27	0.5%*	0.5%*	0.25%**
South East Asia	**cassava**	16.0	0.8%	0.8%	0.40%	**palm**	19	0.5%*	0.5%*	0.25%**
Oceania	**wheat**	1.8	0.9%	0.9%	0.45%	**OSR**	1.4	0.5%*	0.5%*	0.25%**
Japan	**sugar cane**	54.0	0.9%	0.9%	0.45%	**none**				

Table 41 Maximum area which can be planted with energy crops due to planting rate constraints (Mha)

	Business as Usual (BAU)					*BAU – high investment*					*Low development*				
Region	*2010*	*2015*	*2020*	*2025*	2030	*2010*	*2015*	*2020*	*2025*	*2030*	*2010*	*2015*	*2020*	*2025*	*2030*
Canada	0	1	2	6	16	0	1	2	6	16	0	1	2	5	14
USA	0	2	5	15	38	0	2	5	15	38	0	1	4	11	29
Central America	0	0	1	2	3	0	0	1	4	9	0	0	0	0	0
South America	0	3	7	15	26	0	3	12	33	86	0	0	0	1	1
North Africa	0	0	0	1	2	0	0	1	2	5	0	0	0	1	1
West Africa	0	1	2	4	7	0	1	4	11	30	0	0	1	1	1
East Africa	0	1	2	3	5	0	1	3	8	22	0	0	0	1	1
South Africa	0	1	4	7	12	0	2	7	20	53	0	0	0	1	1
Western Europe	0	0	2	4	12	0	0	2	4	12	0	1	2	7	17
East Europe	0	0	1	4	11	0	0	1	4	11	0	0	2	5	12
Former USSR	0	2	6	12	23	0	2	8	24	64	0	1	3	7	12
MiddleEast	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
South Asia	0	0	1	1	1	0	0	1	3	8	0	0	0	0	1
East Asia	0	3	7	14	25	0	3	12	32	83	0	1	1	3	4
South East Asia	0	0	0	0	1	0	0	0	1	2	0	0	0	1	1
Oceania	0	2	7	20	51	0	2	7	20	51	0	2	6	15	40
Japan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
World	0	16	48	109	232	0	17	66	188	490	0	7	23	58	137

Table 42 Assumptions on Sustainability of Biofuels

Region	*Crop*	*Typical GHG saving for crop/region*	% of supply that is RED compliant				
			2010	*2015*	*2020*	*2025*	*2030*
Bioethanol Production							
Canada	corn	40%	100%	100%	20%	30%	40%
USA	corn	40%	100%	100%	20%	30%	40%
Central America	sugar cane	71%	100%	100%	100%	100%	100%
South America	sugar cane	71%	100%	100%	100%	100%	100%
South Africa	sugar cane	62%	100%	100%	100%	100%	100%
Western Europe	sugar beet	55%	100%	100%	100%	100%	100%
East Europe	wheat	18%	100%	5%	10%	15%	20%
Former USSR	wheat	7%	100%	5%	10%	15%	20%
South Asia	sugar cane	62%	100%	100%	100%	100%	100%
East Asia	corn	40%	100%		20%	30%	40%
South East Asia	casava	45%	100%	100%	20%	30%	40%
Oceania	wheat	18%	100%	5%	10%	15%	20%
Japan	sugar cane	62%	100%	100%	100%	100%	100%
Biodiesel production							
Canada	OSR	44%	100%	100%	20%	30%	40%
USA	soy	40%	100%	100%	20%	30%	40%
Central America	soy	40%	100%	100%	20%	30%	40%
South America	soy	42%	100%	100%	20%	30%	40%
West Africa	jatropha	66%	100%	100%	100%	100%	100%
East Africa	jatropha	66%	100%	100%	100%	100%	100%
South Africa	soy	40%	100%	100%	20%	30%	40%
Western Europe	OSR	38%	100%	100%	20%	30%	40%
East Europe	OSR	38%	100%	100%	20%	30%	40%
Former USSR	OSR	27%	100%	10%	10%	15%	20%
South Asia	jatropha	66%	100%	100%	100%	100%	100%
East Asia	jatropha	66%	100%	100%	100%	100%	100%
South East Asia	palm	36%	100%	100%	25%	38%	50%
Oceania	OSR	18%	100%	5%	5%	7%	10%

Table 43 Infrastructure constraint analysis for global biomass supply for wood and agricultural residue supply

(a) Small round wood and forest residues

Key

Level of Barrier/constraint	Abbrev	Restriction on supply
Not available at all	NA	100%
Very high	VH	95%
High	H	75%
Medium	M	50%
Low	L	20%

Infrastructure	Small roundwood							Forestry residues						
	Present	Continuing Trends		Globalisation		Regionalisation		Present	Continuing Trends		Globalisation		Regionalisation	
Supply Regions	**2010**	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**	**2010**	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**
US	H	M	L	L	L	M	M	H	M	L	L	L	M	M
Canada	H	M	L	L	L	M	M	H	M	L	L	L	M	M
Mexico	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Brazil	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Argentina	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Other South and Central America	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Middle East	VH	H	H	M	M	H	H	VH	H	H	M	M	H	H
Northern Africa	VH	H	H	M	M	H	H	VH	H	H	M	M	H	H
Sub-Saharan Africa	VH	H	H	M	M	H	H	VH	H	H	M	M	H	H
EU	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Other Europe and Eurasia	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Russia	VH	H	M	M	M	H	H	VH	H	M	M	M	H	H
India	H	H	H	H	H	H	H	H	H	H	H	H	H	H
China	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Indonesia and Malaysia	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Other Asia	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Japan	H	M	L	L	L	M	M	H	M	L	L	L	M	M
Australia and New Zealand	M	M	L	L	L	M	M	M	M	L	L	L	M	M

Table 43 Continued (b) Agricultural residues and sawmill co-products

Infrastructure	Sawmill coproducts							Agricultural Residues						
	Present	Continuing Trends		Globalisation		Regionalisation		Present	Continuing Trends		Globalisation		Regionalisation	
Supply Regions	2010	2020	2030	2020	2030	2020	2030	2010	2020	2030	2020	2030	2020	2030
US	L	L	L	L	L	L	L	NA	NA	NA	H	H	NA	NA
Canada	L	L	L	L	L	L	L	NA	NA	NA	VH	VH	NA	NA
Mexico	M	M	L	M	L	M	M	NA	NA	VH	H	H	NA	NA
Brazil	M	M	L	M	L	M	M	VH	H	H	H	M	VH	H
Argentina	M	M	L	M	L	M	M	VH	H	H	H	M	VH	H
Other South and Central America	M	M	L	M	L	M	M	VH	H	H	H	M	VH	H
Middle East	VH	VH	VH	M	M	H	H	NA	NA	NA	NA	NA	NA	NA
Northern Africa	VH	VH	VH	M	M	H	H	VH	VH	VH	VH	VH	NA	NA
Sub-Saharan Africa	VH	VH	VH	M	M	H	H	VH	VH	H	VH	H	VH	VH
EU	L	L	L	L	L	L	L	H	M	M	M	M	H	H
Other Europe and Eurasia	M	M	M	M	M	M	M	H	H	M	H	M	H	H
Russia	H	M	M	M	M	H	M	VH	VH	VH	VH	H	NA	NA
India	M	M	L	M	L	M	M	H	H	H	H	H	H	H
China	M	M	L	M	L	M	M	NA	NA	NA	NA	NA	NA	NA
Indonesia and Malaysia	M	M	L	M	L	M	M	H	H	M	H	M	H	H
Other Asia	M	M	L	M	L	M	M	H	H	M	H	M	H	H
Japan	L	L	L	L	L	L	L	NA	NA	NA	NA	NA	NA	NA
Australia and New Zealand	L	L	L	L	L	L	L	H	H	M	M	M	H	H

Table 44 Infrastructure constraint analysis for global biomass supply for (a) wood energy crops and 1G Bioethanol

Key as for Table 43.

	Woody energy crops							1G Bioethanol						
	Present	Continuing Trends		Globalisation		Regionalisation		Present	Continuing Trends		Globalisation		Regionalisation	
	2010	2020	2030	2020	2030	2020	2030	2010	2020	2030	2020	2030	2020	2030
Canada	L	L	L	L	L	L	L	L	L	L	L	L	L	L
USA	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Central America	M	M	L	M	L	M	M	L	L	L	L	L	L	L
South America	M	M	L	M	L	M	M	M	M	L	M	L	M	M
North Africa	VH	VH	VH	M	M	VH	VH	VH	H	H	M	M	H	H
West Africa	VH	VH	VH	M	M	VH	VH	VH	H	H	M	M	H	H
East Africa	VH	VH	VH	M	M	VH	VH	VH	H	H	M	M	H	H
South Africa	VH	VH	VH	M	M	VH	VH	VH	H	H	M	M	H	H
Western Europe	L	L	L	L	L	L	L	L	L	L	L	L	L	L
East Europe	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Former USSR	M	M	M	M	L	M	M	M	M	M	M	L	M	M
MiddleEast	VH	VH	VH	M	M	H	H	VH	VH	VH	M	M	H	H
South Asia	M	M	L	M	L	M	M	M	M	L	M	L	M	M
East Asia	M	M	L	M	L	M	M	M	M	L	M	L	M	M
South East Asia	M	M	L	M	L	M	M	M	M	L	M	L	M	M
Oceania	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Japan	L	L	L	L	L	L	L	L	L	L	L	L	L	L

Table 44 continued. (b) 1G Biodiesel

	1G Biodiesel						
	Present	Continuing Trends		Globalisation		Regionalisation	
	2010	2020	2030	2020	2030	2020	2030
Canada	L	L	L	L	L	L	L
USA	L	L	L	L	L	L	L
Central America	L	L	L	L	L	L	L
South America	M	M	L	M	L	M	M
North Africa	VH	H	H	M	M	H	H
West Africa	VH	H	H	M	M	H	H
East Africa	VH	H	H	M	M	H	H
South Africa	VH	H	H	M	M	H	H
Western Europe	L	L	L	L	L	L	L
East Europe	L	L	L	L	L	L	L
Former USSR	M	M	M	M	L	M	M
MiddleEast	VH	VH	VH	M	M	H	H
South Asia	M	M	L	M	L	M	M
East Asia	M	M	L	M	L	M	M
South East Asia	M	M	L	M	L	M	M
Oceania	L	L	L	L	L	L	L
Japan	L	L	L	L	L	L	L

Table 45 Trade market mechanism constraints analysis for global biomass supply for wood and agricultural residue supply

(a) Small round wood and forestry residues

Key as for Table 43

Trade/Market Mechanisms	Small roundwood							Forestry residues						
	Present	Continuing Trends		Globalisation		Regionalisation		Present	Continuing Trends		Globalisation		Regionalisation	
Supply Regions	2010	2020	2030	2020	2030	2020	2030	2010	2020	2030	2020	2030	2020	2030
US	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Canada	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Mexico	L	L	L	L	L	H	H	L	L	L	L	L	H	H
Brazil	L	L	L	L	L	H	H	L	L	L	L	L	H	H
Argentina	L	L	L	L	L	H	H	L	L	L	L	L	H	H
Other South and Central America	L	L	L	L	L	H	H	L	L	L	L	L	H	H
Middle East	H	H	H	M	M	H	H	H	H	H	M	M	H	H
Northern Africa	H	H	H	M	M	H	H	H	H	H	M	M	H	H
Sub-Saharan Africa	H	H	H	M	M	H	H	H	H	H	M	M	H	H
EU	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Other Europe and Eurasia	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Russia	H	M	M	M	M	H	H	H	M	M	M	M	H	H
India	L	L	L	L	L	H	H	L	L	L	L	L	H	H
China	L	L	L	L	L	H	H	L	L	L	L	L	H	H
Indonesia and Malaysia	L	L	L	L	L	H	H	L	L	L	L	L	H	H
Other Asia	L	L	L	L	L	H	H	L	L	L	L	L	H	H
Japan	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Australia and New Zealand	L	L	L	L	L	L	L	L	L	L	L	L	L	L

Table 45 continued

(b) Sawmill co-products and agricultural residues

Trade/Market Mechanisms	Sawmill coproducts							Agricultural Residues						
	Present	Continuing Trends		Globalisation		Regionalisation		Present	Continuing Trends		Globalisation		Regionalisation	
Supply Regions	2010	2020	2030	2020	2030	2020	2030	2010	2020	2030	2020	2030	2020	2030
US	L	L	L	L	L	L	L	NA	NA	NA	H	H	NA	NA
Canada	L	L	L	L	L	L	L	NA	NA	NA	H	H	NA	NA
Mexico	L	L	L	L	L	M	M	NA	NA	NA	VH	VH	NA	NA
Brazil	L	L	L	L	L	M	M	VH	H	H	M	M	H	H
Argentina	L	L	L	L	L	M	M	VH	H	H	M	M	H	H
Other South and Central America	L	L	L	L	L	M	M	VH	H	H	H	M	VH	H
Middle East	H	H	H	M	M	H	H	NA	NA	NA	NA	NA	NA	NA
Northern Africa	H	H	H	M	M	H	H	VH	VH	VH	VH	VH	NA	NA
Sub-Saharan Africa	H	H	H	M	M	H	H	VH	H	H	H	M	VH	VH
EU	L	L	L	L	L	L	L	H	M	M	L	L	H	H
Other Europe and Eurasia	M	M	M	M	M	M	M	H	M	M	M	M	H	H
Russia	H	M	M	M	M	H	H	VH	H	H	M	M	VH	VH
India	L	L	L	L	L	M	M	H	H	H	H	H	H	H
China	L	L	L	L	L	M	M	NA	VH	VH	VH	VH	VH	VH
Indonesia and Malaysia	L	L	L	L	L	M	M	H	H	M	H	M	H	H
Other Asia	L	L	L	L	L	M	M	H	H	M	H	M	H	H
Japan	L	L	L	L	L	L	L	NA	NA	NA	NA	NA	NA	NA
Australia and New Zealand	L	L	L	L	L	L	L	H	M	M	M	M	VH	H

Table 46 Trade market mechanism constraints analysis for global biomass supply for (a) wood energy crops and 1 G bioethanol

Key as for Table 43

	Woody energy crops							1G Bioethanol						
	Present	Continuing Trends		Globalisation		Regionalisation		Present	Continuing Trends		Globalisation		Regionalisation	
	2010	2020	2030	2020	2030	2020	2030	2010	2020	2030	2020	2030	2020	2030
Canada	L	L	L	L	L	L	L	L	L	L	L	L	L	L
USA	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Central America	L	L	L	L	L	M	M	L	L	L	L	L	M	M
South America	L	L	L	L	L	M	M	L	L	L	L	L	M	M
North Africa	H	H	H	M	M	H	H	H	H	H	M	M	H	H
West Africa	H	H	H	M	M	H	H	H	H	H	M	M	H	H
East Africa	H	H	H	M	M	H	H	H	H	H	M	M	H	H
South Africa	H	H	H	M	M	H	H	H	H	H	M	M	H	H
Western Europe	L	L	L	L	L	L	L	L	L	L	L	L	L	L
East Europe	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Former USSR	H	M	M	M	M	H	H	H	M	M	M	M	H	H
MiddleEast	H	H	H	M	M	H	H	H	H	H	M	M	H	H
South Asia	L	L	L	L	L	M	M	L	L	L	L	L	M	M
East Asia	L	L	L	L	L	M	M	L	L	L	L	L	M	M
South East Asia	L	L	L	L	L	M	M	L	L	L	L	L	M	M
Oceania	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Japan	L	L	L	L	L	L	L	L	L	L	L	L	L	L

Table 46 continued (b) 1 G biodiesel.

	1G Biodiesel						
	Present	Continuing Trends		Globalisation		Regionalisation	
	2010	2020	2030	2020	2030	2020	2030
Canada	L	L	L	L	L	L	L
USA	L	L	L	L	L	L	L
Central America	L	L	L	L	L	M	M
South America	L	L	L	L	L	M	M
North Africa	H	H	H	M	M	H	H
West Africa	H	H	H	M	M	H	H
East Africa	H	H	H	M	M	H	H
South Africa	H	H	H	M	M	H	H
Western Europe	L	L	L	L	L	L	L
East Europe	L	L	L	L	L	L	L
Former USSR	H	M	M	M	M	H	H
MiddleEast	H	H	H	M	M	H	H
South Asia	L	L	L	L	L	M	M
East Asia	L	L	L	L	L	M	M
South East Asia	L	L	L	L	L	M	M
Oceania	L	L	L	L	L	L	L
Japan	L	L	L	L	L	L	L

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