Energy Research Partnership
Technology Report

BIO-ENERGY TECHNOLOGIES REVIEW - Appendices

Appendices Contents

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Appendix 2: Biomass Resource Assessments

A2.1 Introduction

The purpose of this appendix is to provide users of the biomass assessment data some grounding as to the way in which they are compiled, key issues / problems and dimensions to the projections.

Summarised below is a summary of recent analysis of global biomass assessments. The narrative is extracted and edited from a Biomass Energy Europe (BEE) paper - `*A Review and Harmonisation of Biomass Resource Assessments*'[1]. The reason for the selection of the BEE reference is the fact that the mandate of BEE has been to harmonise the diverging methodologies behind biomass assessments and therefore relevant the work undertaken in this review. The UKERC 2010 Working paper on UK bio-energy resource also summaries these issues with specific reference to the UK biomass resource[2].

A2.2 State of the biomass assessment dataset

Biomass resource potential assessments for energy for the same geographic entity differ significantly from each other (Berndes et al., 2003; Ovando et al., 2008; Ericsson et al., 2006; Dornburg et al., 2008; and Cannell (2003)). The most important reasons for the considerable variation in the results are:

- The heterogeneity of methodologies and approaches that are used;
- The heterogeneity of datasets that are used;
- The use of different data and assumptions (due to missing empirical data) for certain aspects (*e.g.* conversion factors, waste fractions, yields);
- The heterogeneity of factors and assumptions used to consider the production and utilisation of biomass, *e.g.* sustainability, demand and competition with other sectors; and
- The heterogeneity of approaches used for the integration of technological learning curves, both in the production sector of biomass and in biomass-to-energy conversion.

Furthermore, the scope of existing biomass resource assessments vary with regard to the biomass categories considered, *e.g.* energy crops, forest residues or total potentials (for further details see section A2.6), the scale of the analysis (*e.g.* local, regional and global), the timeframe of the analysis, and the type of potentials considered (for further details see section A2.3). Finally, also meeting the criteria of sustainable production, as well as implementation aspects, can further limit usable biomass resources. As a consequence, different nomenclatures and categorizations, and the differing definitions of resource levels from bio-physical to implementation potential, hinder the comparability of the results of various assessments.

A2.3 Type of biomass potential

An important difference between existing biomass studies is the potential that is investigated. Four types of biomass potentials are distinguished:

- *Theoretical potential*: the overall maximum amount of terrestrial biomass which can be considered theoretically available for bio-energy production within fundamental bio-physical limits. In the case of biomass from crops and forests, the theoretical potential represents the maximum productivity under theoretically optimal management taking into account limitations that result from temperature, solar radiation and rainfall (Kheshgi et al., 2005; Sorensen 1999; and REFUEL 2008). In the case of residues and waste, the theoretical potential equals the total amount that is produced.

- *Technical potential*: The fraction of the theoretical potential which is available under the regarded techno-structural framework conditions and with the current technological possibilities, also taking into account

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[1] More information about the BEE project can be found on http://www.eu-bee.org/. Biomass Energy Europe (BEE): A Review and Harmonisation of Biomass Resource Assessments proceedings of 17th European Biomass Conference and Exhibition - From Research to Industry and Markets, Hamburg, Germany. 29 June - 3 July 2009 is available on the following link: http://www.eubee.com/default.asp?sivuID=24174&component=/modules/bbsView.asp&recID=14661

[2] http://www.ukerc.ac.uk/support/tiki-index.php?page=Biomass+Resources+and+Uses

spatial confinements due to competition with other land uses (food, feed and fibre reserves) and other non-technical constraints.

- *Economic potential*: The share of the technical potential which meets criteria of economic profitability within the given framework conditions.

- *Implementation potential*: The fraction of the economic potential that can be implemented within a certain time frame and under concrete socio-political framework conditions, including economic, institutional and social constraints and policy incentives. Studies that focus on the feasibility or on the economic, environmental or social impacts of bio-energy policies are also included in this category.

In theory, a fifth potential can be distinguished, which is the environmentally or ecologically sustainable potential, defined as the fraction of the theoretical potential which meets certain environmental criteria. However, the environmentally or ecologically sustainable potential is not investigated separately in the BEE project, because the environmental criteria are generally included together with other (technical, economic) constraints. It should be noted that the definitions of potentials in literature are often not fully consistent with the definitions presented above. Biomass energy assessments that focus on a certain type of potential often also include limitations that, according to the definitions above, are relevant for another type of potential. Further, several studies explicitly, or implicitly, analyse several types of potentials.

A2.4 Approaches Used in Biomass Resource Assessments

Three types of approaches can be distinguished:

- ***Resource-focussed assessments*** investigate the bio-energy resource base and the competition between different uses of the resources, *i.e.* the focus is on the biomass energy supply side. Resource focussed assessments generally investigate the theoretical and technical potentials, taking into account the demand for land and biomass for the production of food and materials as function of among others, population and income growth. Yet, environmental limitations or economic criteria are often also included; particularly the protection of biodiversity is usually included.

- ***Demand-driven assessments*** analyse the competitiveness of biomass-based energy systems, compared to conventional fossil fuel based energy systems as well as other renewable energy systems and nuclear energy, or estimate the production and use of biomass required to meet exogenous targets on climate-neutral energy supply, *i.e.* the focus is on the biomass energy demand side. Thus, demand driven studies typically focus on the economic and implementation potentials, more than on the theoretical and technical potentials. However, some studies start with an evaluation of the feasibility of the projected use of bio-energy, via reference to other studies or by estimating the technical biomass potential. Climate and energy policies are crucial in assumptions about population growth, economic development, technology development and the energy intensity of economic activities are important variables. Population growth and economic development are principal factors behind overall energy end-use. Further, some other studies use agricultural economics models to investigate the economics of the use of conventional agricultural crops for energy production.

- ***Integrated modelling assessments*** use integrated assessment models (IAMs), which are designed to assess policy options for climate change. IAMs include mathematical correlations between the socio-economic drivers of economic activity and energy use, which lead to emissions and other pressure on the environment leading to environmental changes, which lead to physical impacts on ecosystems, which lead to socioeconomic impacts and eventually return to cause changes in the socio-economic drivers. IAMs are unique because they combine information about economic, energy and climate variables across various scientific disciplines, time, and spatial scales. IAMs are particularly useful for the purpose of addressing policy questions, mostly by means of scenario analysis. Often IAMs consist of several linked models and tools.

A2.5 Methodologies used in biomass resource assessments

Of the 28 studies reviewed by the BEE a generalised overview of the different combinations of approaches and methodologies were identified - these included:

- ***Statistical analysis*.** The least complicated studies estimate the energy potential based on assumptions about the yield per hectare, based on expert judgement, field studies or a literate review, in combination with assumptions about the fraction of land available for energy crops or the fraction of forest biomass that is available for energy production to account for the use of land and biomass for other purposes and environmental or social barriers. Often results from other studies are thereby used, but some several other studies use scenario analysis. The potential of residues and waste is generally calculated based on projections of the production of food and wood, multiplied by residue and waste generation coefficients and multiplied by a factor that account for the fact that many residues and wastes cannot be collected in practice. Some studies also assess the use of residues for other purposes. This category of analysis is referred to as statistical analysis, because data for this type of analysis start from statistics.

- ***Spatially explicit analysis.*** The most advanced resource-focussed assessments include spatially explicit data on the availability of land and forests in combination with calculations of the yields of energy crops and forests, based on data on crop growth models that use spatially explicit data on climate, soil type and crop management. The availability of agricultural land for energy crop production is estimated taking into account the use of land for the production of food and other purposes, using scenario analysis that take into account agricultural policies, technological development, population growth, income growth, and so forth. A type of land that has received special attention in our research is degraded and marginal land, because this type of land is partially or not suitable for conventional agriculture and may not lead to competition with food. The same approach is applied when estimating the potential of forestry and forestry residues and agricultural residues and organic waste.

- ***Cost-supply analysis.*** Cost-supply analysis start from a bottom up analysis of the potential, based on assumptions on the availability of land for energy crop production, including crop yields, or based on assumptions on the availability of forestry and forestry residues. The demand of land and biomass for other purposes and environmental and other (social, technical) limitations are included, ideally by scenario analysis. The resulting bio-energy cost supply curves are then combined with estimates of the costs of other energy systems or policy alternatives, often with specific attention for policy incentives (*e.g.* tax exemptions, carbon credits, and mandatory blending targets). A good example is the REFUEL project (2008).

- ***Energy-economics and energy-system model analysis and other economic models.*** Several studies use energy-economics and energy-system models, but also other economic models are sometimes applied. Energy-economics and energy-system models mimic the dynamics of the demand and supply of energy, including bio-energy, by means of investigating economic and non-economic correlations. Most energy-economics and energy system models use scenarios, whereby typical scenario variables include the fundamental drivers of energy demand and supply, such as population growth and income growth, as well as technological developments, policy incentives. These variables are often integrated into a coherent set of scenario assumptions. Some models also include greenhouse gas and energy balances for different energy systems, which allows for the optimisation of costs towards greenhouse gas reduction or energy security target.

- ***Integrated modelling assessments**.* See Section A2.4.

A2.6 Type of biomass

The term biomass refers to three broad types of biomass, which are defined as follows:

- ***Forestry and forestry residues**.* Forestry biomass refers to harvests from natural forests, plantations (including short rotation forestry (SRF)) and other wooded land and trees outside forests (including orchards, vineyards). Forestry residues include both primary residues, *i.e.* leftovers from cultivation and harvesting activities (twigs, branches, thinning material *etc.*) and secondary residues, *i.e.* those resulting from any processing steps (sawdust, bark, black liquor *etc.*). Tertiary residues, *i.e.* used wood (wood in household waste, demolition wood etc.) tend to be considered in the category of "organic waste".

- ***Energy crops on agricultural land and marginal land.*** Energy crops include all crops with the purpose of producing biomass for energy use (including short rotation coppice (SRC)). Marginal land is not well defined in the literature, but the term marginal generally refers to the (low) productivity of the land.

- ***Agricultural residues and organic waste****.* Agricultural residues is the by-product of agricultural practice (cultivation of farms and harvesting activities), labelled as "primary" and processing of agricultural products, *e.g.* for food or feed production, labelled as "secondary". Organic waste is divided into materials produced from houses and from industrial and trade activities. Also sludge and biogas from sewage treatment plants as well as landfill gas are considered biomass from organic waste.

The lack of a coherent classification for biomass categories results in different boundary conditions for each biomass types and therefore the ability to compare the same feedstock streams from different studies becomes problematic.

A2.7 Relevant References

Berndes, G., M. Hoogwijk, and R. Van den Broek 2003 The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bio-energy, 2003. 25(1): p. 1-28.

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Sørensen, B., 1999 Long-term scenarios for global energy demand and supply: Four global greenhouse mitigation scenarios. 1999, Energy & Environment Group, Roskilde University, Denmark.: Roskilde.

REFUEL, Eyes on the track, mind on the horizon. 2008, Energy Research Centre of the Netherlands (ECN), Interational Institute for Applied Systems Analysis (IIASA), Utrecht University, COWI, Chalmers University of Technology, EC-BREC, Joanneum University: Petten, The Netherlands. p.48.

Appendix 3: Bio-energy Sustainability and Environmental Issues

A3.1 Land Use Change, Indirect Land Use Change and Soil Organic Carbon

A3.1.1 The Issue

Where bio-energy cropping occurs on land previously used for food, feed or fibre production, it displaces the previous production of food, feed or fibre. As demands for displaced production remain, it will be produced somewhere else, which might result in converting other land (and releasing carbon emissions) to producing the requisite amounts of food, feed, or fibre. These emissions from ***indirect*** land use changes (iLUC) are effectively caused by the bio-energy production displacing food production and can, in the net balance, negate any positive effects of replacing fossil fuels (IEA, 2009a). For example, Searchinger et al (2008) claimed that pay-back timeframes of 167 years for US corn ethanol and Fargonie et al (2008) 17 to 420 years for a variety of land types for corn ethanol.

The introduction of the iLUC to the biomass production debate has called into question the climate change credentials of bio-energy feedstock streams. Despite the compelling nature of the impacts suggested by Searchinger and Fargonie, the iLUC debate and its perceived impact on bio-energy value chains GHG balance remains controversial. On the one hand, the causes of land use change are highly complex which makes attributing / measurement of any iLUC to biomass for bio-energy production problematic and on the other the quantities of feedstocks diverted to bio-energy production may only be partly made up from yield increases on remaining land area allocated to food production. The state of the debate is summarised, below.

A3.1.2 Methodological Issues and Challenges

a. The causes of land use change (LUC) and indirect LUC are highly complex.

The causes of land use change have been summarised in table A3.1 extracted from Lambin et al (2007). As can be seen the causes of LUC are caused by multiple interacting factors with a variety of drivers, which tend to vary in space and time, according to both human and environmental conditions. Bio-energy feedstock production is only one of the many drivers.

Table A3.1: Summary of possible causes of land use change (after Lambin et al., 2007).

Major Causes	*Pathways to Land Use Change*
• Natural Variability • Economic and Technological factors • Demographic Factors • Institutional Factors • Cultural Factors • Globalisation	• Loss of land productivity on sensitive areas following inappropriate use. • Deforestation on forest frontiers by weak state economies, for geopolitical reasons or to promote interest groups. • The transition from communal to private land ownership in developing regions. • Ecological marginalization of the poor by land expropriation for large-scale agriculture, dams, forestry projects, tourism, and wildlife conservation. • The "tragedy of enclosure": decreased land availability by land zoning for forest reserves, wilderness areas or agro-industrial plantations. • Land use intensification in peri-urban and market-accessible areas of developing regions. • Urbanization-driven changes in regional consumption patterns and income distribution with impacts on rural land use. • New economic opportunities linked to new market outlets, changes in economic policies, or capital investments. • Policy interventions that drive modifications of landscapes and ecosystems. • The breakdown of traditional extended families and its impacts on resource use efficiency. • Macroeconomic shocks and structural adjustment policies with undesirable consequences on natural resources. • Delayed and ineffective social responses to deteriorating environmental situations, combined with absence of political will to mitigate damage and to alter the trajectory of change.

The complexity of the drivers of iLUC has therefore introduced the concept of causality i.e. a proportional attribution of land use change to a cause. In the case of Searchinger *et al* (2008) analysis, 100% of the indirect land-use-change GHG emissions are attributed to be from displaced production on ‘forest land’ to biofuels. This assumption, however, is challenged, for example in Brazil, by Brander et al 2008 (submission to RFA Review) and Volpi (Brazil Case Study for RFA Review), and Schmidt (2006) for oil palm production in Indonesia and Malaysia. They suggest that the causes of deforestation are historically tightly linked to timber extraction and now more recently in Brazil at least, cattle ranching and not primarily to agricultural production. It is, therefore considered erroneous to allocate a large share of the LUC emissions to new agricultural production (for bio-energy). Despite this, developing defensible methodologies for allocating causality to any one commodity remains extremely contentious and may need to be crop specific (Black and Woods, in Prep).

The key factors determining iLUC emissions include: Physical land use in all agriculturally active regions; impacts of co-products, agricultural intensification and area expansion; and changes in consumption (Netherlands Environmental Assessment Agency, 2010). This makes the complexity of attributing causality to any feedstock stream highly problematic.

b. Globally, regionally and locally - detailed knowledge of land use is extremely poor

Though we have a high level understanding as to global land availability and use[3] - the level of detail is limited and monitoring the changes is highly problematic. Land surveys, particularly those in remote areas and using remote sensing techniques, often suffer from the following issues (Young, 1999):

- An overestimation of cultivatable land due to the failure to take into account hills and rocky outcrops when mapping is reduced in scale;
- An underestimation of cultivatable land i.e, not taking in account of illegal land occupation and changes in forest cover; and
- A failure to take into account land required for other purposes i.e. the multi-functionality of land for used other than cultivation.

Remote sensing interpretations of apparent land cover often lacks adequate `ground truthing' due to the fact that it is difficult and extremely expensive. Furthermore, though remote sensing is able to estimate land cover type and changes in type - it is not able to elucidate the reason for the change. This results in inconsistent datasets which can in some cases be used to either validate or negate the impact of a single commodity to land use change. For example, Morton et al (2006) and Souza (2006) using a large scale remote sensing dataset concluded in Mato Grosso in Brazil that, due to the strong correlation between the soya bean price and rate of deforestation, crop expansion was one of the largest drivers of deforestation. Conversely, Brown et al (2005) in Vihena, Rondonia SW Amazon basin found that new soya bean fields are replacing already deforested or transformed lands and that expansion has been occurring as a consequence of the slight expansion of already existing fields, conversion of already deforested land and higher yields on already converted land. Furthermore, Brown et al., (2005) found when interviewing farmers that they tended to use savannah rather than forest, targeted cleared lands and left virgin forest alone. The Brown et al., (2005) study findings strongly validating the need to ground truth datasets.

The situation is compounded by the fact that land cover and use are constantly changing due to normal agricultural practices. For example, how does one accommodate the classification of the following change: crop land which becomes idle land and then naturally to grassland and in turn to secondary forest which is then returned to cropland. This makes the distinctions between classifications of land type blurred and at a global scale such data becomes homogenised.

As a result of these issues, the crop land data sets required for baseline assessments in iLUC calculations have large uncertainties and variability in the quantities of land in each class due to differing forest definitions and area. The situation is compounded by the fact that grasslands and pasture quality and use are even more uncertain, for example, globally idle land estimates range from 400 to 1,000 MHa. Indeed, it is considered that the uncertainties in baseline data can be more significant than estimated biomass for bio-energy production land use impacts (Kline, 2010).

c. The Use of Existing Models to assess and predict iLUC impacts have been questioned

Finally, in order to assess the impact of iLUC on bio-energy supply chain GHG balances a number of modelling exercises have been undertaken to derive quantitative data (e.g. JRC, 2010a and b). However, Lywood (2009),

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[3] Global land use: total land 13.4 Bha of which 4.6 Bha (34.4%) desert, mountain and ice; 4.1 Bha (30.5%) Forest and Savannah; 3.2 Bha (23.7 %) Pasture and Range; and 1.5 Bha (11.5 %) Arable Land. Approximately 10 Mha non-agricultural land (mostly forest) cultivated per annum (FAO STAT, 2010).

Tipper (2009) and Netherlands Environment Assessment Agency (2010) have questioned the use of modelling for the calculation of emissions from land use change; for example Tipper (2009) states the following:

- Very high modelling uncertainty resulting from multiple degrees of freedom, feedback loops and complex interactions means that models conclusions are weakly supported by evidence and may have limited application;
- Models are not able to take account of real market conditions and discontinuities (models tend to assume prices and conditions of other products and processes are at equilibrium; whereas in reality there are multiple iLUC effects occurring at any time - see table A3.1, above);
- Models do not take account of multiple factors in land use change decisions (e.g. land tenure, land price speculation, market information, proximity of roads); and
- Models are not based on actual land use change data and may either multiply (through double-counting) or under estimate actual emissions.

Furthermore, methodological variation in parameters and model types compounds the ability to derive comparable datasets. In a recent review by Woods et al (2010) on EC Biofuel land Use Modelling states that the models had the following differences in:

- Geographical Coverage;
- Sectoral Coverage: extent to which the energy industry is modelled, biofuels, fertilisers and livestock and animal feed;
- Crop types modelled: palm Oil, Soy;
- Modelling of co-products;
- Carbon pools and fluxes;
- Counterfactual scenario definitions;
- Future crop yield increases;
- Changes in crop rotation frequencies;
- Impact of technological advancement;
- Mix of feedstocks;
- Competitive uses for palm oil;
- Assumptions for fuel demand (ranging from 300 to 389.4 Mtoe);
- Biofuel incorporation levels (ranging from 2.3 to 5.3% increase from current levels); and
- Role of 2G biofuels (some models include 2G others do not).

A3.1.3 Areas of Controversy

Considering the uncertainties highlighted above, it is considered that there is questionable benefit in the derivation of an iLUC factor for bio-energy supply chains from present models and datasets. The models have been designed for other purposes such as the global trade of agricultural commodities - not land use. The results have been highly variable to the point of questioning their usefulness. For example, using the outputs from the review of iLUC models from Woods et al (2010) found that for IFPRI/MIRAGE derived ethanol and biodiesel GHG footprint incorporating iLUC ranged from 16.07 - 79.15g CO_2/MJ and 44.63 - 75.40 gCO_2/MJ, respectively and for JRC/IE from 56 - 359 CO_2/MJ to 34 - 801 CO_2/MJ, respectively[4]. Though more recent attempts have been made to make the process more transparent such as the use of causal descriptive approaches (E4Tech, 2010). However, even these acknowledge that there are significant knowledge gaps in assumptions.

The lack of reliable data on land-cover, use, productivity, soil qualities, stocks, fluxes, environmental services is such that it is widely acknowledged it is essential better data and that the following research areas be undertaken to improve the modelling:

- There is a need to improve the theoretical framework for initial conversion and LUC;
- Calibrate the various drivers of LUC at different scales;
- Update and verify input specifications (yields, energy prices, elasticity factors, available land);
- Develop scenario based models of causality for deforestation and initial conversion;
- Reduce bias of homogenised, average aggregate data at global scales;

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[4] The reference is for petroleum based products is 85.8 CO_2/MJ for the EU Renewable Energy Directive.

- Improve characterisation of land assets (amounts, location, yields); and
- Develop operational linkages among models at different scales.

To this end, collaboration is essential due to the scope of issues, complexity of the challenges and the need for co-operation to improve global datasets is an important first step (Kline, 2010).

The significance of LUC and iLUC remains extremely difficult to assess with present datasets and modelling techniques. However, it is widely acknowledged that the iLUC and LUC can be avoided as there is plenty of potential to increase agricultural production without increasing land area. This topic is discussed further in section A3.3 - Food and Fuel, below.

A3.1.4 State of the Debate

The state of the iLUC and LUC debate is best summarised as follows. The body of iLUC work based on modelling was based on the assumption that land conversion was based on bio-energy crops automatically encroaching on forest land, that intensive land use practices would be undertaken (i.e. soil tilling would take place which would result in oxidation of the SOC), the extrapolation of historical land use trends and used economic models designed for other purposes than for land use. This lack of study framing and use of inappropriate assumptions has resulted in a lack of objectivity in iLUC / LUC studies and an inevitable skewing in the likelihood that iLUC / LUC impacts would be found. It has been suggested that future model studies should consider what pre-conditions would be needed to mobilise biomass to avoid iLUC and incorporate the ability to use agricultural processes where carbon is locked, water recycling bio-diversity improved on degraded / marginal and idle lands - this may produce outputs which are very different (Faaj, pers coms).

The alternative approach to assessing ILUC is by descriptive-causal models. These models use cause and effect logic to describe the behaviour of a given system, based on observations of how the system functions. By providing a more transparent analysis which enables input and review from a broad range of stakeholders descriptive-causal models could be used to help increase understanding of ILUC and therefore improve upon the work based on economic models.

It is suggested that the agenda has now moved on from iLUC / LUC to how to intensify agriculture and use land more effectively. This is in line with Brander et al (2008), who effectively considered that the best way to avoid iLUC was to monitor all LUC. Though the definition of land use areas is poor and clear demarcation is not known precisely there is sufficient confidence of where the areas of marginal and idle land are. There should be an effort to focus on using land as efficiently as possible (across all commodities) and start implementing best practice on that land which is used for biomass production. To a certain extent the sustainability agenda which has been ruthlessly applied to the bio-energy feedstock debate has spilled over into the food commodity space – this is demonstrated by the situation with oil palm which was initially limited to issues surrounding biodiesel production but also consumed food producers and retail outlets such as Danone, E.Leclerc and Aldi (The Economist dated 26th June 2010).

In order to ensure the most effective use of land a number of tools are being developed to ensure that processes are in place to optimise efficiency. An example, is shown below - the IUCN 4 Step Approach to Land Use Planning (2009). UNEP are also developing a check list for undertaking effective due diligence when utilising land.

Land use planning: 4 Step approach from IUCN

Screening
- Review of publicly available maps
  - Global data on carbon, biodiversity and other values
  - *Identification of protected areas and broad zones of high and low risk*

Landscape-level assessment
- National/Regional consultation
  - Consultation with relevant institutions and experts
  - Identification of important features not identified in global maps
  - *Site selection*

Site level mapping
- Detailed site-level assessment & planning
  - Consultation with local people and field-based data collection
  - *Delineation, and management plan for no-go areas*
  - *Identification of appropriate areas for potential development*

Responsible management
- Implementation of responsible land management
  - Development of appropriate areas, involving stakeholders in decision making
  - On-going monitoring of impacts and adaptive management
  - *Compliance with international best practice*

Indeed the Brazilians have been undertaking Agro-Ecological zoning for sugar cane since the late 1990’s and now incorporate soy with a view to increasing to a number of other crop types in due course (MAPA/Embrapa, 2010). To this end, their land use breakdown is as follows:

- Non-Arable areas 502.2 Mha (59%);
- Pastures 172.3 Mha (20.2%);
- Annual and Permanent Food Crops 70.3 Mha (8.3%);
- Sugar cane for ethanol 4.2 Mha (0.5%);
- Oil Seed crops for biodiesel 2.2.Mha (0.3%); and
- 99.8 MHa (11.7%) available for expansion.

Of the land that is available for expansion their Agro-Ecological zoning for sugarcane has identified 64 MHa available i.e. 15 times the area that is presently planted. The ability to delimit the land uses to this level of detail is paramount in the ability to ensure that policies that stimulate land use change do not result in unintended consequences.

This methodology has been undertaken in other nation states by the Brazilians (*e.g.* El Salvador, Dominican Republic, Haiti, Senegal, Guatemala and Saint Kitts and Nevis).

A3.2 Soil Quality

A3.2.1 The Issue

The total amount of carbon stored in global soil stock to a depth of 1 m - Soil Organic Carbon (SOC) - (1,500 Gt) contains over twice as much as that in the atmosphere (720 Gt). Intensive tillage methods which turn the soil over result in the oxidation of this SOC. It is the basis upon which the LUC debate is based in that the removal of vegetation and oxidation of this SOC results in the release of substantial quantities of carbon which takes a protracted period of time to `pay-back'. Furthermore, irresponsible agricultural practices are blamed for the large amount of land being degraded as a result of erosion, loss of fertility and desertification. According to the semi-quantitative *Global Assessment of Soil Degradation (GLASOD)* about 300 Mha, or 5% of the formerly usable land in developing countries, has been lost by severe soil degradation up to the present day. The current rate of loss is not less than 5 Mha per year (FAO STAT, 2009, after Conway, In Prep).

However, the cultivation of bio-energy crops on marginal or idle land have been shown to have the potential environmental benefit of improving management of land use with better soil restoration[5], the creation of vegetation filters and possible reduction of wildfire risk. Many of the woody crops proposed for biomass dedicated for bio-energy production would actually involve no-till and no-till cover crops (i.e. the soil is not turned over but saplings are placed individually in the soil), limited fertiliser application and cropping regimes would greatly reduce the SOC loss and reduce GHG balance paybacks to 3 -14 years (*e.g*. Kim et al., 2009) as opposed to the 17 to 420 years (Fargione et al., 2008) and 167 years (Searchinger et al., 2008) proposed. Indeed some no-till studies indicate that SOC improves (Galbraith, 2005).

The management of soil quality is integral to the sustainable use of land for all agricultural biomass - food, feed, fibre and energy.

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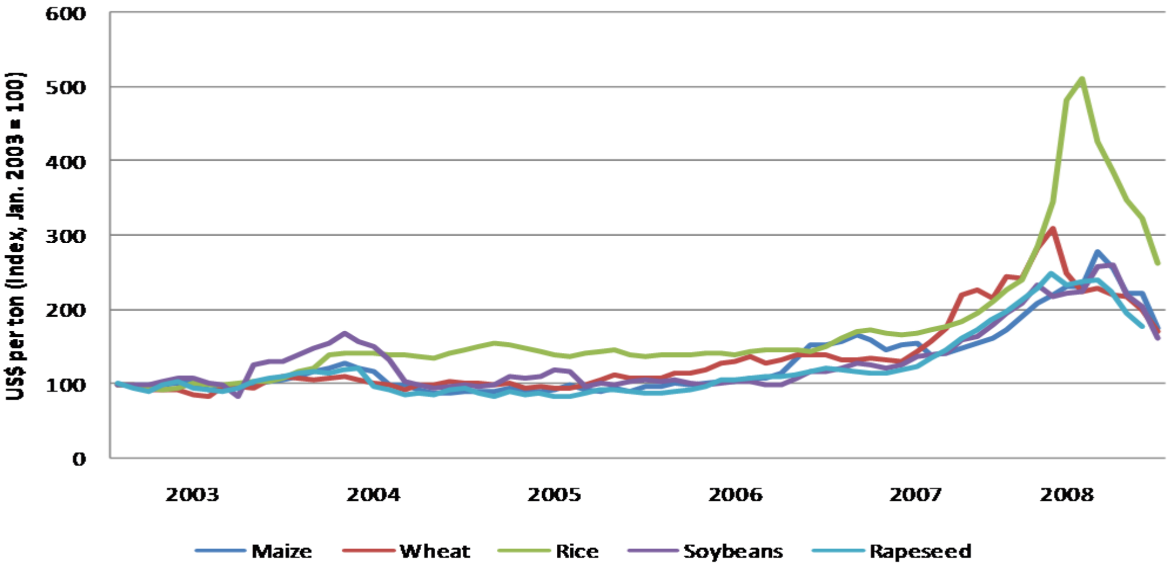
[5] Bio-energy crop production can improve the soil structure and fertility of degraded lands (IEA, 2009a)

A3.3 Food and Fuel

A3.3.1 The Issue

The issue of iLUC, LUC and food and fuel debate are closely linked in that it is the diversion of land for food crops to grow crops for energy (LUC) and the removal of commodities from food to energy supply chains that can result in reduced availability and an increase in the price of food commodities. This in turn is assumed to result in the generation of iLUC to grow food commodities to compensate for the short fall in their availability. The modelling of iLUC / LUC is intimately linked to the availability of food from land for agricultural production, crop yield improvements, population growth and changes in consumption patterns etc. However, the link with the rapid increase in global food commodity prices in 2007/08 during the rapid roll out of biofuel mandates brought the food and fuel debate to prominent public attention (see figure A3.1, below). It was claimed that the biofuel mandates resulted in food shortages and pushed between 30 to 100 M people into poverty. Widespread food riots were also reported in Haiti, Egypt and Bangladesh. Reports at the time attributed the impact of biofuels mandates to between 3 % (US DoA, 2008), 20-30% (IFPRI, 2008) and 75% (World Bank, 2008).

Figure A3.1: Fluctuation in food commodity prices from 2003 taking in the 2007/08 food price spike to present. Note that the production of bio-ethanol and bio-diesel continues to increase (18% between 2008-09) and yet food commodity prices have fallen. After the Economist



A3.3.2 Methodological Issues and Challenges

However, in retrospect with the mandates for biofuels and bio-energy still in place food commodity prices have fallen. To this end, it is considered that other factors contributed to the 2007/08 food crisis; these include:

- Changing dietary habits of emerging economies. There is a direct relationship between increasing wealth (GDP) and a shift to more grain intensive foods. For example, in China in 1985 the average consumer ate 20 kg of meat. In 2008 they ate 50 kg. Protein from meat is one of the most inefficient methods of producing protein. It takes 3, 8 and 20 kg to produce a kg of chicken, pork and beef, respectively. In EU the average person eats 84 kg of meat and in the US the average stands at 108 kg per year. As a result of this, global meat consumption is expected to grow by 55 M tonnes to 310 M tonnes in the next decade. In order to meet this demand will require an increase in feed of around 50 to 640 M tonnes / year (OECD-FAO, 2008 after Conway, In Prep).
- Adverse weather and natural disasters impacted on harvests in 2000, 2002, 2003 and droughts in Australia and floods in SE Asia in 2006 impacted on stocks, see below.
- Reduce food reserves due to the removal of production subsidies and production not keeping up with demand. Grain stocks and oil seeds stock to use percentages were between 21 to 28% between1980 to

2000 and but due to poor harvest resulted in demand exceeding supply in 7 of the 8 years from 2000 in 2007 stock fell to 14% of use (Piesse et al, 2008).

- Domestic policy responses by grain exporting nations resulted in some placing tariffs on or banning exports altogether (e.g. Argentina, India, Pakistan, Russia and Vietnam) exacerbating the shortages in nations which were dependent on food imports.
- Reducing increases in yields. The reduced investment in agricultural R&D has resulted in diminishing yields. Between 1970 to 90 global aggregate yields increased by between 2% per year. Yield increases between 1990 and 2007 averaged 1.1% are recorded; this has been less than demand increases. Stable food prices in the last 30 years has led to complacency and therefore a reduction in funding (|F, 2007)
- High oil prices have an impact along the agricultural chain from fertilisers to mechanised establishment and harvesting activities to transport. According to Conway (In Prep) *`In the US, combined energy, chemical and fertiliser costs account for around 16%, 27% and 34% of production costs for soybean, wheat and maize, respectively. With the US providing 40% of the worlds grain crops these increases are reflected in world food commodity prices. In developing nations, energy intensity increases with irrigation needs – especially where watertables are depleting increasing the need for deeper pumping. In 2008, a key fertiliser input (diammonium phosphate (DAP))for developing nations increased six fold as a result of increased energy costs (it was also assisted by shortages of sulphur and phosphate which are vital for DAP manufacture). The cost of DAP fell in 2008 but again remain higher than in 2006.'* The increased role of commodities for agricultural needs is reflected in BHP's recent move into the agricultural supply chain with its intention to take over Potash Crops (Economist dated 19th August 2010).
- Increased investment in commodities. Investment in commodity Index funds were up 66% in 2006. It is thought that investors have heavily targeted food commodities to gain increased returns due to the poor performance of traditional markets (after Accenture 2008).

It is noteworthy that the role of speculators in price spikes for a broad basket of commodities, including agricultural products, though cited by some (e.g. Langeveld et al, 2010), has been largely negated in recent reports (For example OECD, 2009 and Amenc et al., 2008).

A3.3.3 Areas of Controversy

However, despite the fact that prices fell at the end of 2008 they were still 20% higher than 2006. Indeed, projections by the FAO and OECD estimate that globally food prices will be 10 to 20% higher in real terms relative to 1997-2006 for the next 10 years. The debate remains as to whether or not there will be sufficient land available for bio-energy production and food.

In the last 30 years, the world population has increased by 123% from 3 Bn to 6.7 Bn. In that same period, according to the UN's Food and Agricultural Organisation (FAO) land use for crop production has only grown marginally with total agricultural area expanding from 4.51 to 4.93 BHa and arable area from 1.27 to 1.41 BHa (FAOSTAT, 2009, after Royal Society, 2009). This is due to the increase in food production being predominantly from yield increases (80%) and only 20% from area expansion (Smith et al., 2010).

With the world population set to increase by another 3 Bn in the next 40 years, it is anticipated that there will be a need for another 45-70% increase in food production. It therefore appears that the global food supply chain faces the choice of either expanding the area of agricultural land for gross production or increase the yields on existing agricultural land yet further. There is substantial variation in how the increase in crop production might occur from region to region but according to Smith et al (2010) in a review of 8 modelling / scenario studies the role of yield and intensity increases will remain the dominant driver at 80% relative to land expansion. Though the following issues will have to be considered:

- Historically, there is evidence that the intensification of agriculture (modelled from 1961 to present) resulting in yield improvements is the optimum way to reduce GHG emissions from agriculture relative to an `unimproved' Business as Usual case (Burney et al., 2010). This is backed by another study which suggests that the removal of crop protection measures results in 265% expansion of arable land needed to grow the equivalent food that is grown now (Avery, US Hudson Institute 2009, after Crute, 2009). This is contrary to the claimed benefits of organic farming techniques (Soil Association, 2009).

- The past increase in agricultural production intensity, though impressive and beneficial in terms of reducing GHG emissions, has been achieved at an environmental cost and pressures on land remain[6]. Present intensive agricultural practices have resulted in soil loss, over reliance on GHG intensive products and when washed into water systems oxygen depleting fertilisers, chemically harmful pesticides and are water intensive resulting in possible irreversible denudation of the water tables in key agricultural belts (Conway, 1997).
- It is argued that intensity increases are possible sustainably but that it will require international effort and a rebalancing of agricultural research funding[7] (Royal Society, 2009).
- There is also a growing consensus that there is capacity in the existing food production supply chain by improvement of efficiency through the closure of yield gaps through better agronomic practices[8] and in the agricultural supply chain, the minimisation of waste from field to markets[9] thereby getting more of the food grown to the market[10] and consumers (Lynd, 2010).

To this end, there is scope for cautious optimism and a recent study by Wirsenius, Azae and Berndes (2010) goes so far to suggest that there is opportunity for the food system to operate at lower land use from 5.4 BHa in a BUA scenario in 2030 to a possible 4.4 BHa.

A3.3.4 State of the Debate

Therefore, it is possible that there will be enough land for both food and energy crop production but the role of policy decisions in agriculture, forestry, energy and conservation sectors will have a substantial impact on land availability for food and fuels. Furthermore, policies addressing other drivers such as population growth, dietary preference, protected areas and forest policy will have significant impacts on the availability of land for food and fuel (Smith et al., 2010). There may, for example, be the need to consider the role of dedicated energy crops on to prime agricultural land.

An example of the importance of policy in driving the ability to have enough land for the production of food and fuel is exemplified by Brazil - see Box 1, below and the implementation of appalling policy in reducing food production potential demonstrated by Zimbabwe where food production has declined by approximately 50% in the last decade. The ability to reconcile the intensification of agriculture in the Brazilian Cerredo is balanced against the biological diversity of the region (UNEP, 2007) and the ability to maintain these bio-diverse habitats (see section A3.4, below).

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[6] Annually, approximately 17 Mha of agricultural land is lost to erosion (5 Mha), salinisation (2 Mha) and urbanisation (10Mha) (FAO, 2009).

[7] In 1981, mid to high income countries accounted for 91% and low income countries accounted for 9% of the US$ 15.8 Bn in agricultural research. In 2000, of the US$ 23.4 Bn spent on agricultural research 89% was spent in high and mid income nations and 11% in low income nations. Low income nations are where population demands are the greatest and where the potential for yield enhancement is best.

[8] The photosynthetic efficiency (measured in radiation use efficiency (RUE)) is in theory 6% and 5.1% for C4 and C3 plants respectively. This efficiency is reduced when climate, soils, water availability etc is factored in and can be enhanced by the use of fertilisers, pesticides and agricultural practices. There is substantial capacity to reduce the yield gap, for example in Zambia sugar cane has a RUE of 1.8% whereas maize has a RUE of 0.1% suggesting that a 17 fold increase in yields is possible for Zambian maize with the adoption of appropriate techniques.

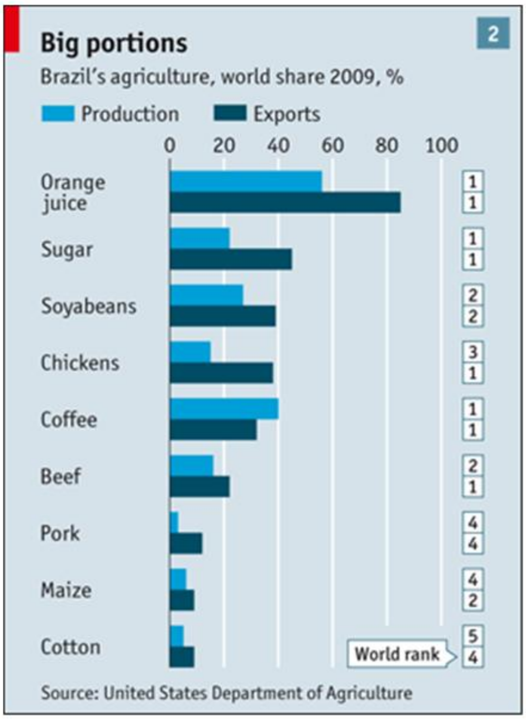
[9] Crop losses in developing countries varies from 5 to 100% (US National research Council, 1978 after Thompson). A survey of food facilities in the former Soviet Republics measured post harvest losses in Ukraine stores of between 40 to 25%. In developed nations with more efficient supply chains losses tend to be post-plate. Taking the UK, efficiency from field to store is good but it is estimated that 25% of food is thrown away after they leave the shop.

[10] The extent of food wastage suggests that there is some form of market failure in the present architecture of the global agricultural / food production system and the impact of commodity markets on commodity supply trends is little studied and deserves some attention. For example, the role of food subsides, present in 48 of the 54 countries that the World Bank tracks agricultural prices, has not been studied in terms of world food commodity price fluctuations. See also the Economist dated 9th September 2010 `Don't Starve thy Neighbour' which recommends 3 mechanisms to build confidence in world food markets (i) reduce food protectionism in the US, EU and Japan; (ii) export bans should incur penalties in the WTO; and (iii) there should be a Strategic Food Reserve managed by the UN World Food Programme.

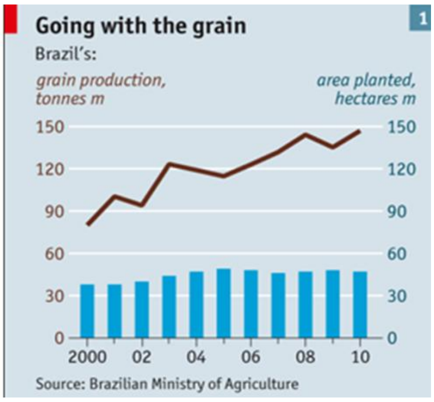
Box 1: The role of sound integrated agricultural policy in the formation of complementary role for food and bio-energy feedstock production (extracted from The Economist dated 26th August 2010).

In less than 30 years Brazil has turned itself from a food importer into one of the world's great breadbaskets (see chart 1). It is the first country to have caught up with the traditional "big five" grain exporters (America, Canada, Australia, Argentina and the European Union). It is also the first tropical food-giant; the big five are all temperate producers. The increase in Brazil's farm production has been stunning. Between 1996 and 2006 the total value of the country's crops rose from 23 billion reais (US$23 billion) to 108 billion reais, or 365%. Brazil increased its beef exports tenfold in a decade, overtaking Australia as the world's largest exporter. It has the world's largest cattle herd after India's. It is also the world's largest exporter of poultry, sugar cane and ethanol (see chart 2). Since 1990 its soya bean output has risen from barely 15M tonnes to over 60M. Brazil accounts for about a third of world soya bean exports, second only to America. In 1994 Brazil's soya bean exports were one-seventh of America's; now they are six-sevenths. Moreover, Brazil supplies a quarter of the world's soya bean trade on just 6% of the country's arable land.

Brazil has done all this without much government subsidy. According to the Organisation for Economic Co-operation and Development (OECD), state support accounted for 5.7% of total farm income in Brazil during 2005-07. That compares with 12% in America, 26% for the OECD average and 29% in the European Union. And Brazil has done it without deforesting the Amazon (though that has happened for other reasons). The great expansion of farmland has taken place 1,000 km from the jungle.



Source: United States Department of Agriculture



Source: Brazilian Ministry of Agriculture

Source: FAO

How did Brazil achieve this:

- Brazil has more spare farmland than any other country (see chart 3) and also has much in the way of water resources. According to the UN's World Water Assessment Report of 2009, Brazil has more than 8,000 billion cubic kilometres of renewable water each year, easily more than any other country. Brazil has almost as much farmland with more than 975 millimetres of rain each year as the whole of Africa and more than a quarter of all such land in the world;
- Since 1996 Brazilian farmers have increased the amount of land under cultivation by a third, mostly in the cerrado by pouring industrial quantities of lime) onto the soil to reduce levels of acidity;
- Embrapa (the Brazilian agricultural research establishment) went to Africa and brought back a grass called brachiaria. Patient crossbreeding created a variety, called braquiarinha in Brazil, which produced 20-25 tonnes of grass feed per hectare, many times what the native cerrado grass produces and three times the yield in Africa. That meant parts of the cerrado could be turned into pasture, making possible the enormous expansion of Brazil's beef herd. Thirty years ago it took Brazil four years to raise a bull for slaughter. Now the average time is 18-20 months;
- Most importantly, Embrapa turned soyabeans into a tropical crop;

- Embrapa has pioneered and encouraged new operational farm techniques. Brazilian farmers pioneered “no-till” agriculture, in which the soil is not ploughed nor the crop harvested at ground level;
- Embrapa’s latest trick is something called forest, agriculture and livestock integration: the fields are used alternately for crops and livestock but threads of trees are also planted in between the fields, where cattle can forage. This, it turns out, is the best means yet devised for rescuing degraded pasture lands.
- There were over 200,000 km of road infrastructure emplaced to improve networks and get crops from the field to port and markets.

Finally, a key factor in the success was the “system approach”, as its scientists call it: all the interventions worked together. Improving the soil and the new tropical soyabeans were both needed for farming the cerrado; the two together also made possible the changes in farm techniques which have boosted yields further.

A3.4 Bio-diversity and Eco-system Services

A3.4.1 The Issue

Expanding land for agricultural food commodities and bio-energy feedstocks may result in the losses of ecosystem and biodiversity services and loss of carbon sinks. Replacing the land with plantations for forest growth, has been proposed in many of the biomass assessments, yet these typically do not have the same biodiversity and carbon storage benefits as primary land (particularly forest land). Reduced biodiversity is also considered to impact on ecosystem resilience - the ability for ecosystems to resist environmental pressures. Though the relationship is not clearly understood it is thought that lower biodiversity leads to increased likelihood of abrupt shifts in ecosystem states (Gunderson et al., 2007).

The potential impact of invasive species is also a risk for many energy crops which may be grown in parts of the world in which they are not native. The potential benefits from increased productivity has to be balanced against the risk of damage to ecosystems (IUCN, 2009 and UNEP, 2010).

A3.4.2 Methodological Issues and Challenges

Biodiversity is a function of the number, abundance and identity of genotypes, populations, species, functional groups and traits and landscape units present in a given ecosystem (MEA, 2005). Biodiversity has an impact on carbon sequestered in a unit of land and local ecosystem services (flood prevention, freshwater filtration) of an ecological unit. The way in which bio-diversity impacts these crucial issues is poorly understood (Naeem et al., 2008).

The ability to substitute for the carbon sequestration of natural forests, their bio-diversity or the ecosystem services that they provide is extremely difficult. Nonetheless, it is widely acknowledged (MEA, 2005) that the functional composition of ecosystems are altering and that species and therefore biodiversity are being lost at an alarming rate due to the impact of LUC (Convention on Biodiversity, 2010); though attributing LUC to bio-energy feedstock production or indeed any individual agricultural commodity is problematic (section A3.1, above). Therefore there is pressure to retain rainforest land by using existing non-forest land more efficiently and therefore the push for the intensification of land use by modern agricultural techniques (see section A3.3 above). However, with the historical use of tilling, irrigation and fertilizer and agro-chemical use, along with declining habitat heterogeneity from increased field sizes, the use of large monocultures and the modification of natural habitats by humans places pressures on biodiversity. The importance of biodiversity for the maintenance of pollination services within ecosystems and food productivity is also gaining attention, for example:

- Estimates show that 35% of global food production is directly consumed by humans comes from crops that benefit from flower visitation - mainly from bees and other insects (Klien et al., 2007). These crops also provide essential vitamins, nutrients and fibre;
- Under experimental conditions fruit and seed yields increase by between 5 to 50% when flower visitors are present;
- Flower visitors are also important for diary and meat industries, since many forage crops benefit from insect pollination for seed production (Delphane and Mayer, 2007 after Klein et al., 2009); and
- Based on 16 crops on five continents wild bee pollinators decline in species richness and numbers with distance from natural habitats (Ricketts et al., 2008).

The lack of understanding of the role and mechanisms involved in biodiversity and ecosystem services is matched by the difficulty in measuring and valuing their properties. The most common technique is the use of biodiversity indicators. However, biodiversity indicators are numerous and often location specific:

- Key indicator species can be used to represent species or taxa that are less well known and often means selecting species that are more well know up the food chain. For example, a top predator which may indicate the presence of a broad base of prey species and their various food sources and habitat requirements;
- There are also `keystone’ indicators which rely on specific interactions / species / habitats and can be indicative of their presence;
- There are also those categories of indicators which are used to assess the state of biodiversity, pressures and responses of ecosystems;

- There are levels of indicators for the measurement of different scales – local, national, regional and global which is complicated by the fact that different organisations have their own indicators e.g. The WWF and the Living Planet Index;
- A basket of indicators is often used which are linked to key sensitivities and policy issues relevant an ecosystem that is being measured; these may not be comparable with other ecosystems in other areas; and
- There is a move to tie biodiversity indicators to an ecosystem approach which is considered to be even more abstract (UKERC, 2010).

A3.4.3 Areas of Controversy

The important role that biodiversity plays in stabilising ecosystems, and the importance of ecosystem function in the role of agriculture and the biosphere as a whole, makes the protection of bio-diverse regions and the avoidance of LUC for mono-culture development is vital - even for subsequent plantation development. This, however, leads to the need to intensify agricultural practices on those lands that have been converted which has historically resulted in the demise of biodiversity - jeopardising the resilience of those existing agricultural ecosystems. This suggests that there is a need for revision of present intensive agricultural systems to accommodate ecosystem issues (Conway, 1997). The difficulty in measuring biodiversity and ecosystem services exacerbates the situation as the ability to collect data which is of a transferable nature and assess status is problematic.

A3.4.4 State of the Debate

Policy measures which incorporate a component of bio-diversity protection (e.g. Reduced Emissions from Deforestation and Degradation[11]) are considered vital to maintain units of land which optimise carbon sequestration and ecosystem services. The ability to implement these policies is somewhat problematic due to a lack of governance in those parts of the world where these ecosystems predominate. For example, a report by CIFOR (2009) in Indonesia found that an analogous REDD system has been fraught with problems including corruption and the miss-appropriation of funds - even resulting in the acceleration of deforestation in some cases (CIFOR, 2009).

The mitigation of the impact of invasive species requires the use of planning tools to avoid the unintended consequence of the introduction of destructive crop types (UNEP, 2010); this too requires project level governance and oversight which is dependent on national governance systems.

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[11] The following issues as considered to be important in the incorporation of biodiversity in the design of climate change mitigation initiatives (after Diaz et al, 2008):

- Protection of primary forests is the best C sequestration option;
- The maximisation of short-term C sink strength is the best option for long term C sequestration;
- Mixed forest systems are considered more stable in the likelihood of environmental variability and direction change than mono-cultures and they are likely to sequester more carbon securely in the longer term.
- Plantations established with the specific purpose of carbon sequestration or bio-energy production can be compatible with biodiversity conservation.
- Decisions on species and genotype richness and composition of protected or newly established plantations pr agro-forestry systems should be tailored to local context.

A3.5 Water Use

A3.5.1 The Issue

Agriculture utilises 70% of all freshwater consumed by humans (In Developing nations it is 82% and in Developed nations it is 30% (WBCSD, 2005)). Many of areas of crop production are now maintaining food production through unsustainable extractions of water from rivers and groundwater. In China ground water extraction exceeds replenishment by 25% and in NW India it is 56% (FAO, AQUASTAT 2009). There is a concern that the growth of biomass for bio-energy supply chains will place additional pressure on freshwater resources. The issue is likely to be of pressing concern with the impact of climate change on water availability (IPCC, 2007 and Smakhtin, 2004). Though water is integral to biomass production along the entire supply chain its impact at the feedstock production stage is described here.

Finally, the availability of water and the efficiency with which it is recycled is dependent upon the availability of ecosystem services which are potentially under pressure due to LUC issues (see section A3.4, above) making the issue related to the effectiveness of managing the health of ecosystems.

The key issues with water and biomass production are highlighted below.

A3.5.2 Methodological Issues and Challenges

a. There is no widely accepted method of measuring water impact or metrics.

The development of methodology and protocols for the measurement of water impact is at an early stage (Gerbens-Leenes, 2008) with present outputs often varying by orders of magnitude (see for example www.waterootprint.org). Furthermore, the use of the appropriate metrics to assess water scarcity is still in debate (- see for example Mulder et al., 2010). This situation is augmented by the fact that water impact is dependent on contextual issues (see (c) below) and therefore confuses the debate - making the development of effective `one size sits all' policies problematic.

b. Globally, regionally and locally - detailed knowledge of water availability is extremely poor

There is little accurate and reliable information on water availability at a local and regional level and globally. This is a function of water management issues tending to be poorly co-ordinated at a national level (institutional responsibility is often fragmented with no overarching control) and this situation is replicated at an international level.

c. Knowledge of water needs at a local and regional level, for feedstock type and along bio-energy pathways is poor

The water needs of bio-energy and agricultural crops varies considerably as a function of local climate, crop type, soil type and conditions and agricultural practices. There is the concern that the use of primary agricultural land for biomass dedicated to bio-energy requires less water input but will displace food production and the use of marginal lands will require greater inputs including substantially greater water needs (though this can be mitigated by the use of low water demand crops such as Japtropha). The increase in the use of fertiliser on marginal lands may also lead to Nitrate runoff contamination of water courses which impact on water quality.

Taking point (a), above into account work by Hoogeveen et al., (2009) suggests that sugarcane and maize have a water footprint of 2,000 litres/litre and 1,400 litres / litre for ethanol, respectively. In a study of 12 bio-energy chains by Gebens-Leenes et al (2008) suggests that the water footprint of bioelectricity is more efficient than first generation biofuels production due to the use of the whole crop rather than just a proportion of the crop with a footprint of 140,000l/GJ for electricity generated from sugarcane, sugar beet and maize.

Comparison of bio-energy chains and fossil fuel waterfootprints vary between 70 to 400 times larger (UNEP, 2010) to 5-% to 10% of that for fossil fuels (Sandia, 2007) - highlighting the contextual nature of these footprints and that the accuracy of these figures is subject to much uncertainty.

There are a number of ways of mitigating the impact of bio-energy chains on water availability - these are as follows: For quantity - selecting the appropriate feedstock, using water as efficiently as possible in cultivation; and for quality: using sustainable agricultural practices and fostering market and regulatory mechanisms to reduce agrochemical use (UNEP, 2010).

A3.5.3 Areas of Controversy

There is a line of argument developing for bio-energy and water use which is similar to that taken for LUC and the food and fuel debate - that water is an increasingly limited resource which should be prioritised for human needs (based on the projection that in 2025, 1.8 billion people will live in places with an `absolute water scarcity' of which 1.2 billion will live in areas experiencing water stress (UNEP, 2007 - Global Environmental Outlook 4)) and food production rather than fuel production.

A3.5.4 State of the Debate

The role of water in bio-energy chains is highly complex and has largely been overlooked in the bio-energy debate (UNEP, 2010). There is a need to implement mitigation systems for bio-energy chains as well as conduct further research on the water requirements and impacts of different bio-energy pathways.

Furthermore, the debate has also carried over to the conventional energy sector as the intersection of water and energy production has become increasingly evident. For example, in the US recent work by Sandia (Hightower et al., 2008) suggests the following:

- that thermo-electric power generation accounted for 50% of fresh and saline water withdrawals (totalling 746 billion litres per day in 2004) and is the second biggest consumer (39%) after agricultural irrigation (40%) for fresh water;
- future energy development such as biofuels, hydrogen, oil shale development, carbon sequestration and nuclear power development could significantly increase water use and consumption; and
- water resource development - distribution, treatment and transmission is one of the biggest energy users.

The work concluded that `*as future demands for energy and water continue to increase [along with population increases which in turn will increase electricity and water consumption], competition for water between energy, domestic, agricultural, and industrial sectors, could significantly impact on the reliability and security of future energy production and electricity power generation*.'

Thereby highlighting how the sustainability debate for bio-energy feedstock chains is as relevant to the conventional energy sector as a whole.

A3.6 Social Sustainability

A3.6.1 The Issue

The development of biomass supply chains of the magnitude required to support some of the scenarios in section 3 suggests the need for the establishment of a robust global agricultural sector supporting both food production and biomass for bio-energy supply; sections A3.1 and A3.3 have suggested that with careful policy this will be possible. If so then it would also provide a socio-economic benefit in that a significant opportunity to promote rural diversification in developing nations may result. Farmers, having faced stagnant commodities for decades (since the mid-80's) may benefit from higher international agricultural commodity prices, provided that local markets are efficient enough to pass on the increases to small producers. Therefore large scale biomass production could provide opportunities for poverty reduction by stimulating stagnant agricultural sectors, thus creating jobs for agricultural workers and markets for small farmers (Oxfam, 2007 after Chatham House, 2008)[12]. The development of international markets and therefore trade in biomass would also provide opportunity for technology transfer and efficiency gains in the agricultural supply chain resulting in the closure of yield gaps from mechanisation and better practices (section A.3.3), the minimisation of waste from field to markets and wealth transfer from exports.

This would, however, probably require significant reorganisation of the international trade system (Doornbosch and Steenblik, 2007). Furthermore, improved agricultural production, once food requirements had been met, could in turn lead to efficient regional bio-energy industries. It is in equatorial regions and developing nations where land availability, agricultural inputs and labour is cheap and where biomass may be efficiently produced allowing economic development.

A3.6.2 Methodological Issues and Challenges

The ability to ensure that welfare benefits from the generation of a robust international biomass market are transferred to facilitate poverty alleviation is extremely difficult as four decades of underperforming international development programmes will testify (World Bank, 2009). Intra state governance issues underlie the ability for equity to be distributed amongst the most socially disadvantaged.

Furthermore, the ability to measure social performance is open to substantial subjectivity which is difficult to quantify and comparability is problematic. For example, is using the net number of jobs created for any one project a good proxy for success? It can be argued that the creation of skilled or permanent jobs might reasonably be valued more highly than unskilled migrant jobs; calculating this metric necessitates taking a stance on the nature of the jobs created and their perceived relative value. There may also be difficulties in making casual links between some welfare benefits such as the impact of replacing traditional open fire stoves with cleaner alternatives on the reduction of indoor air pollution and health benefits; this would require a substantial dataset to prove categorically (Diaz-chavez, 2010 after UKERC 2010).

Despite these challenges, it is considered that the certification and verification systems ongoing worldwide are already influencing the policy regarding the sustainable production and use of bio-energy. Though the main criticism for many of these systems is the lack of reward or penalties for non-compliance the main concerns lay on the current reporting methodologies that do not adequately reflect the actual impacts of increased production of bio-energy (BEST, 2010).

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[12] Targeting the world's small holders in developing countries would greatly assist in development by:

- Reduce poverty: three quarters of those making do on US$1 per day live in the countryside and depend on the health of the small holder farming;
- Assists the environment - smallholders manage a disproportionate share of the worlds water and vegetation cover so increasing their productivity would be environmentally more compatible than cutting down new rainforest; and
- Efficient in terms of return on investment. It is easier to boost grain yields in Africa from two tonnes per hectare to four than raise yields in Europe from 8 to 10. The opportunities are greater and the law of diminishing returns has not set in; and
- The World bank estimates that growth from agriculture generates at least twice as much poverty reduction as growth from other sectors (World Bank, 2009).

A3.6.3 Areas of Controversy

The food price shocks of 2007-08 has promoted some food importing countries to secure their own food supplied along the whole supply chain (rather than purchasing on the open market which was shut off to them by export embargos being imposed by food exporting countries at the height of the 2007-08 food crisis) resulting in both private sector and government to government agreements to lease tracts of rich agricultural land for food production for direct export. For example, Morgan Stanley purchased 40,000 Ha in Ukraine in March 2009; in the Sudan, South Korea has signed deals for 690,000 Ha, the UAE for 400,000 Ha and Egypt another 400,000 Ha for wheat; and it is estimated that China has signed similar deals covering 2 Mha since 2007 (Economist, 21st May 2009). In total it is estimated that between 75 to 80 MHa of land in poor countries have been subject to transactional talks since 2006 - which is equivalent to 80% of the agricultural land in Europe (IFPRI, 2009). The motivation for such radical actions highlights the importance that nation states are placing on food security and their concerns as to the ability for global food commodity markets to provide reliable and economically viable supplies. Though there may be benefits in terms of technological transfer (see above) there are concerns how these deals will impact local populations - their land rights as well as the ability for wealth transfer to filter down to the benefit of the nations as a whole (FoE, 2010). The net benefit of these deals is the topic of much research with work by IFPRI (2009), Chatham House and IIED (2009) and World Bank (2010).

A3.6.4 State of the Debate

Tools and methodologies to meet the new demands with the awareness of the social and economic impacts are evolving and will need to develop and be collected as the market continues to develop (GBEP, 2011).

A3.7 Air Quality

A3.7.1 The Issue

As far as this review is aware, the impact of bio-energy use on air quality, beyond the health effects of traditional biomass use, has not been fully evaluated. The limited work that has been undertaken suggests electricity generated from biomass has generally lower emissions than from fossil fuels, particularly coal, with corresponding air quality benefits. The EU's Biocosts (1998) study concluded that, whilst in general, overall emissions are lower, particularly SO_2, for the bio-energy systems, emissions of specific pollutants can be higher e.g. carbon monoxide (CO) and NO_x.

Understanding the potential health and developmental impacts of an increasing demand for bio-fuels is complicated and prone to uncertainty. This uncertainty, which exists to a greater extent than with bio-electricity production, results from the wider range of potential biomass feedstocks and the influence of innovation on the development cycle of next-generation technologies as applied throughout the biomass production, conversion and use chain. The concerns are exemplified in recent work by Jacobson (2007) which suggested that ethanol may increase the incidents of cancer. It is this that this section will focus.

The use of biofuels, particularly bioethanol, has a number of properties that offer potential emission reductions for several local air pollutants when burning it either as a pure fuel or in blends with diesel or petrol. For example, bioethanol does not contain olefins, aromatics or sulphur, which have negative impacts on air quality (though ethanol denaturants can contain these components) and the oxygen content of ethanol leads to an easier and complete burn reducing unburn't hydrocarbons and CO in exhaust fumes. Though actual emissions depend on a number of factors and as a result, reported emissions vary significantly, most studies report improved emissions performance compared to petrol. Studies can show increases in some air pollutants relative to petrol but they have been within allowable limits.

Using emissions inventories, emissions data from previous studies, population data and health effects data along with an urban air pollution model to estimate health effects Jacobson (2007) suggested that the health impact of switching from gasoline to E85 in 2020 in Los Angeles (USA) would result in the following:

- Large increases in aldehyde emissions will lead to increased ground level ozone formation;
- There will be greater incidence of ozone-related mortality, hospitalisation and asthma;
- There will be little change to cancer risk; and
- E85 likely to cause at least as much damage as future gasoline vehicles.

These findings are at odds from previous studies and though the reliability of the model and independence of the data set has not been substantiated the finding, again, questions the use of biofuels in the transport sector as an environmentally beneficial strategy.

A3.7.2 Methodological Issues, Challenges and Areas of Controversy

The apparent inconsistencies in reported emissions impacts of ethanol fuel make it difficult to draw firm conclusions from the body of available study reports. In many cases there has been conflicting evidence even of the directional change in emissions (AEA, 2009). These inconsistencies may partly reflect a number of study-specific factors, but the varying levels of transparency between studies limits analysis of trends. The specifications for the ethanol, petrol and diesel fuels used in the different studies may have been different. Perhaps more importantly, the specifications for the emissions control measures (*e.g.* catalytic converters, engine design features) employed on the test vehicles may also have been different. Variations in methodology (such as drive cycles used and test procedures) could also account for some of the apparent inconsistencies. Nevertheless, analysis of the different studies does suggest that, depending on particular conditions, both increases and decreases in emissions of some major air pollutants may be observed when substituting ethanol for petrol or diesel. It is of great importance to understand what those particular circumstances are, and further research is clearly needed in this area.

A3.7.3 State of the Debate

As bioethanol use grows worldwide, improved emission control measures may be necessary to ensure that aldehyde emissions are kept within acceptable limits. Recent work in this area recommends (BEST, 2010):

- Measuring “non-bioethanol HC” should be a complement for bioethanol vehicles. This makes it possible to better judge how dangerous these emissions are to human health and the environment. It would give bioethanol cars the same fair treatment as biomethane/CNG cars, for which both “nonmethane HC” and total HC are measured.
- Comparative evaluation on the harmfulness of regulated and unregulated emissions from petrol, diesel and bioethanol vehicles,
- If deemed necessary, research and development to develop improved vehicle design, exhaust aftertreatment and other measures.

A3.8. Summary

The key cross-cutting themes that these sustainability issues posses include:

- They are extremely complex and interlinked with their impacts ranging from local to global;
- some of the specific subject areas are poorly understood, with consensus lacking on methodological issues, uncertainties in data and gaps in understanding; and
- the bio-energy sustainability debate highlights the fact that we need to be more aware of the way in which we manage and utilise of our natural resources - especially land.

It is noteworthy that with regards land use, there are innovative management systems being developed that seek to address a number of sustainability issues which provide an opportunity for the utilisation of land in a more sustainable manner - even to enhance their C sink properties (*e.g.* Bogdanski et al., 2010 and Lal et al 2009).

Finally, it is worth emphasising sections A3.1 to A3.6 are a summary of a highly complex set of issues which warrant reviews in their own right. A number of studies have been undertaken prior and whilst this Review has been undertaken which are recommended to gain greater breadth and depth of understanding of these issues. These include:

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- FAO (2009) Small Scale Bio-energy Initiatives: brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa. Food and Agricultural Organisation of the United Nations, Rome pp142 available at: http://www.fao.org/docrep/011/aj991e/aj991e00.HTM; and
- Foresight (2011) The future of food and farming: Challenges and choices for global sustainability. Government Office for Science pp211 available at: http://www.bis.gov.uk/assets/bispartners/foresight/docs/food-and-farming/11-546-future-of-food-and-farming-report.pdf.

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Appendix 4: Innovation Needs for Energy Crops and Algae

These are extracted from the Bio-energy Technological Innovation Needs Assessments (E4Tech, 2011):

Energy Crops: Most innovation needs for new energy crops are in the Breeding R&D component

Component	Key innovation needs
Breeding R&D	▪ Increase energy output of plants (e.g. amount of sugar, cellulose, oil produced) – By increasing the total biomass yield – By increasing the energy content of the yield ▪ Increase the range over which energy crops can be grown – Increasing the yield stability of a chosen crop over a wider geographical range e.g. use of poorer land – Development of regionally adapted crops ▪ Reduce inputs and carbon intensity per unit feedstock – By developing plants that require less fertiliser, less water, fewer agrochemicals and reduced management – Reducing carbon intensity of feedstock e.g. through no-till approaches ▪ Increase accessibility of useful plant components – By manipulating plants so that they produce cell walls that can be deconstructed more easily, thereby making the useful components more accessible – By making plants that produce the enzymes that will hydrolyse their own cells or assist the release useful compounds
Plant Material Supply	▪ No major innovation needs
Growing and Harvesting	▪ Increased yields and reduced inputs are primarily addressed at the Breeding R&D stage, though can also be optimised through timing of fertiliser application and harvesting ▪ Refine methods of disease and pest control in plantations ▪ Examine the effect of stem moisture content on the harvesting performance and product quality
Distribution	▪ Develop optimum harvesting, storage and transport models to match feedstock with application

Micro-Algae: Innovation needs in microalgae focus on strain selection and development, proof of concept at scale, and cost reduction

Sub-area	Key innovation needs
R&D Strain Development	▪ Identification of new algal strains ▪ Optimisation of strains through breeding or genetic modification to achieve – Improved biomass yields i.e. higher photosynthetic conversion efficiency – Higher lipid productivity – Robustness for production at scale ▪ Potential for strain selection to produce oils that are more easily separable, or can be used as fuels directly with no downstream processing
Cultivation	▪ Scale up of current concepts, with improved system design and capex reductions in major system components e.g. photobioreactors, liners ▪ Optimisation of operation to – Maximise yields e.g. through monitoring, control of grazers – Reduce costs e.g. automation to reduce labour costs – Reduce of energy, water and fertiliser requirements e.g. through recycling, use of wastewater ▪ Assessment of environmental impacts at a whole system level ▪ System design and engineering ▪ Algae for wastewater treatment
Harvesting and Lipid Extraction	▪ Development of new technologies with increased extraction efficiency, lower costs e.g. new centrifuge processes, use of enzymes ▪ Valorisation of co-products e.g. commercialisation of biomass residue in animal feed
Downstream Processing	▪ Few innovation needs: FAME biodiesel is commercial, and to HVO is early commercial stage

Macro-Algae: Innovation needs in macroalgae focus on strain selection and development, proof of concept at scale, and cost reduction

Sub-area	Key innovation needs
R&D Strain Development	▪ Identification of new algal strains ▪ Optimisation of strains through breeding or genetic modification to achieve ▪ Improved biomass yields i.e. higher photosynthetic conversion efficiency ▪ Desired composition e.g. high carbohydrate content ▪ Robustness for production at scale ▪ Reduced inputs such as fertiliser
Cultivation	▪ Design and demonstration of systems proposed at scale e.g. near/offshore, horizontal and vertical line. ▪ Re-use of infrastructure (offshore wind and oil and gas) as support for lines. There is a strong need to reduce system capital costs to make macroalgae cost effective with other forms of biomethane ▪ More detailed analysis of potential locations for macroalgae production ▪ Accurate assessment of costs and environmental impacts at a whole system level
Harvesting and Treatment	▪ Automation of harvesting through dedicated vessels, particularly important in developed countries with higher labour costs ▪ Reducing the water content (currently 75-90%) to enable cheaper transport to processing facilities ▪ Valorisation of co-products
Downstream Processing	▪ Production of AD biogas offshore to reduce costs of transporting wet biomass ▪ Optimise anaerobic digestion and fermentation processes for macroalgae feedstock

Appendix 5: Innovation Needs for Combined Heat and Power, Combustion, Gasification, Drop-In Fuels and Non-Fungible Fuels

These are extracted from the Bio-energy Technological Innovation Needs Assessments (E4Tech, 2011):

Heat and Combined Heat and Power (CHP): Innovation needs in heat and CHP as it is commercialised will be focused on cost reduction and reliability improvements.

Component	Key innovation needs
Feedstock	▪ Feedstock supply is outside the scope of this TINA. However, as supply chains are established , better quality woodchips will lead to combustion efficiency improvements (via lower moisture contents, increased chip uniformity, fewer contaminants). Higher efficiencies result in less feedstock required per unit of power output, and lower conversion plant component costs.
Design and Installation	▪ Transition from bespoke biomass heating systems to more standardised designs will decrease design costs while higher installed volumes will also decrease risk premiums presently built into civil contracts. ▪ Sizing of system to achieve full-load efficiencies. In particular, appropriate sizing of buffer tanks to prevent rapid cycling of the boiler during low load cycles. ▪ Better integration with other heat technologies – solar hot water, heat pumps using integrated valves and controls.
Controls	▪ Ability to adjust for various feedstock qualities and moisture contents. ▪ Increase automation of the systems and early fault detection.
Feedstock Storage and Recovery	▪ Smaller systems are usually designed to use a homogeneous feedstock supply (e.g. pellets). This allows for a simpler design reducing both system capex and opex. However, pellets are much more expensive than alternative options such as wood chips. By increasing the tolerance for feedstock parameters (e.g. size, moisture content) – the overall levelised costs of a system can be reduced.
Biomass Conversion	▪ Biomass combustion (e.g. boilers, stoves) is a fully mature technology competitive with other forms of heat production depending on specific circumstances of feedstock costs and availability. Biomass gasification is an earlier stage technology with higher capital costs but potential for higher efficiencies, particularly for CHP applications. However, gasifier costs need to be reduced to become competitive with combustion and other heat technologies ▪ Most current systems are designed in high labour cost EU regions (e.g. Austria) and are often bespoke designs. Standardising on biomass heating models and moving to low labour cost regions (e.g. Eastern Europe, Turkey) would reduce unit cost of the technology ▪ RD&D inputs could target reducing air pollutants in both small and large scale heat plants. Current EU legislation attempts to limit particulate matter concentrations as does the US Clean Air Act. Electrostatic and ceramic filters are available but the cost of these needs to be reduced (currently adds c.15% to overall system costs) ▪ Most systems do not function well during rapid cycling or lower loads and are often supplemented with a small gas boiler. Increasing the efficiency and reliability across the full range of duty cycles will remove this requirement. Currently many boilers claim to be able to turn down to 30% of nominal output, but only under ideal conditions (e.g. high quality feedstock) ▪ Reduction in physical size (footprint) of biomass boilers to allow for greater use in dense urban environment ▪ Introduction of condensing biomass boilers could potentially increase the system efficiency
Energy Collection	▪ Greater use of plastic over more expensive steel particularity in piping ▪ Improved materials for steam & gas turbines allowing for higher pressure and temperatures to be achieved
Operation and Maintenance	▪ No major technological innovation needs identified

Combustion: Innovation needs in the combustion process summary

Component	Key innovation needs
Feedstock	▪ Feedstock supply is outside the scope of the combustion TINA. However, as supply chains are established , better quality woodchips will lead to combustion efficiency improvements (via lower moisture contents, increased chip uniformity, fewer contaminants). Higher efficiencies result in less feedstock required per unit of power output, and lower conversion plant component costs

Drying and Sizing	▪ Low grade waste heat, from the steam turbine, can be used for feedstock drying. Most commercial dryers for fossil fuels operate at over 100°C, fewer biomass specific dryers in the 50-70°C range are available ▪ Many plant stoppages are due to clogging of feeding mechanisms, either due to inhomogeneous feedstock or foreign objects. This can be avoided by screening, purchase of the correct equipment, and its correct operation – i.e. no innovation required
Boiler	▪ Past combustion plants were mainly based on fixed grate technology. However, Circulating Fluidised Bed (CFB) technology, using a flowing bed of inert particles, is becoming increasingly common, due to higher efficiencies, combustion stability, greater flexibility to taking mixtures of feedstocks, and lower emissions. CFB technology is also more compact, and easier to apply at large scale ▪ CFB and fixed bed research is continuing to better understand ash behaviours, especially with high ash content feedstocks, as equipment corrosion and bed material agglomeration are still issues. Increasing maximum steam temperatures allow higher plant efficiencies to be reached, but this is requiring development of new alloys and boiler materials
Power Generation	▪ Steam turbine technology is fully commercial, with few innovation opportunities

Gasification: Innovation needs in the gasification process summary

Component	Key innovation needs
Feedstock	▪ Feedstock supply is outside the scope of the gasification TINA. However, increasing wood chip quality as supply chains are established will have a positive efficiency effect (via lower moisture contents, increased chip uniformity, fewer contaminants). Higher efficiencies result in less feedstock required per unit of power output, and lower conversion plant component costs
Drying and Sizing	▪ Many plant stoppages are due to clogging of feeding mechanisms, either due to inhomogeneous feedstock or foreign objects. This can be avoided by screening, purchase of the correct equipment, and its correct operation – i.e. no innovation is required, only learning-by-doing
Gasifier	▪ Only fluidised bed and entrained flow gasifier technologies can reach multi-MW scales. These technologies are only at the pre-commercial stage for heat and power applications, although the development of BTL by 2020 will produce relevant experience. Efficiency, reliability and capital costs require improvement through ‘proof of value’ demonstration ▪ Air is unlikely to be used in BIGCC, due to the large presence of inert N_2 that would require removal downstream. Therefore, R&D is ongoing to lower oxygen separation costs before gasification, or optimise indirectly heated steam gasifiers. Successful operation at high pressure would also allow smaller downstream equipment, and capital cost savings ▪ Understanding slagging behaviours, equipment corrosion and fluidised bed material agglomeration are also still issues, especially with high ash content feedstocks
Gas Clean Up	▪ Syngas cleanup needs for gas turbines are stricter than for gas ICEs, but much less onerous than for fuel catalysis (BTL). Tar and particle removal could be improved via hot gas or plasma cleanup.
Power Generation	▪ Combined cycle technology is commercial for natural gas, however, syngas has a lower calorific value, and hydrogen turbines are still in development. Demonstration trials are therefore ongoing to optimise gas turbine technology for specific syngas compositions, and improve tolerance to variations and contaminants. Large-scale stationary fuel cells are also still in development

Drop-In Fuels: Innovation needs in BTL focus on commercialisation of the whole integrated system at scale

Component	Key innovation needs
Sizing & drying	▪ Established technologies, limited cost reduction possible
Gasification	▪ Gasifier chemistry is well understood and the technology is currently nearing commercialisation. Further improvements being made in gasifier design, process design, dealing with tar and carbon, increasing gasifier efficiency and improving the quality of the syngas. ▪ Gasification has been proven at scale for coal, but large biomass gasifiers used to date for power and heat production have not shown proven reliability. Further work needed on demonstration of the gasifier types suitable for BTL applications at scale, and application to a range of feedstocks
Syngas cleaning & conditioning	▪ Although current technologies exist for gas clean up, e.g. wet gas scrubbing, they have efficiency and cost penalties, and so new options have been developed, e.g. hot gas clean up and plasma clean up.Progress has been achieved through research on these options, but opportunities remain in improving the processes and demonstration at scale
FT synthesis	▪ The FT catalysts used to produce diesel/naphtha/gasoline from syngas have been commercially used by the petrochemicals industry for the production of GTL and CTL. The FT catalysts are still being optimised for biosyngas ▪ Novel reactor technologies can be used at much smaller scales than current technology, with higher yields, efficiency and reduced equipment costs
Integration	▪ Integration of biomass gasification with the FT process requires most development, and is most likely to take place during the development of the demonstration plant itself. ▪ Large opportunity for optimised heat integration, balance of plant optimisation and control systems. Steam heating can be achieved via efficient heat recovery (less biomass or fuel use for drying), and steam used for electricity generation ▪ Cost reductions available by optimising system design for either large-scale use of specific biomass types, or heterogeneous inputs such as wastes

Drop-In Fuels: For upgraded pyrolysis oils, the principal innovation needs are in the upgrading step

Component	Key innovation needs
Pyrolysis	▪ Pyrolysis oil is denser than the biomass feedstock, so can be transported more cost effectively. A potential deployment model could involve several small-scale pyrolysis plants sited locally to feedstock supplies, with the raw pyrolysis oil then transported to a large centralised upgrading plant. In this case, since the pyrolysis and upgrading steps are likely to be in separate locations, there is little opportunity for optimised integration across the components ▪ Pyrolysis technology is at the early commercial stage for heat, power and chemicals. There is some further scope for improvement which includes further research into: • Reactor design which addresses issues such as heat transfer and reaction rates and the removal of impurities • Improving oil quality – developments which reduce suspended chars, alkali metals, water and viscosity of the oil, increasing the pH of the oil and improving the yield of pyrolysis oil over gas and char. This could be done through new pyrolysis processes (e.g. microwave pyrolysis) and through optimising the combination of feedstock composition and pyrolysis process. • Use of catalysts in the pyrolysis reaction to help optimise the reaction and oil quality and potentially yield other useful products, such as aromatics.
Upgrading	▪ A range of routes are under investigation for upgrading pyrolysis oil, either in a dedicated unit, or in a conventional refinery. These all involve removal of oxygen, and include: ▪ Hydrotreating (use of catalyst at high pressure in the presence of hydrogen) – the main issues to be overcome here are catalyst deactivation and reactor clogging. Large hydrogen requirements also add to the GHG impacts of this option ▪ Catalytic upgrading – this process requires catalyst and process development in order to reduce coking and to improve catalyst regeneration and optimise products formed. ▪ Fractionation to remove fractions of the pyrolysis oil that are high in oxygen content, e.g. carboxylic acid fraction. ▪ Co-processing of pyrolysis oil in conventional refinery units could allow use of existing infrastructure

	and commercial technologies, along with any spare hydrogen, giving significant cost savings compared to dedicated upgrading units using hydrodeoxygenation

Drop-In Fuels: For novel drop-in-fuels, innovation is needed from the R&D stage

Component	Key innovation needs
Conversion	▪ Basic process development and proof of concept ▪ For biological routes: selection and optimisation of the bacteria used, for example through prospecting for new strains, selective breeding, genetic modification or synthetic biology (rational design of microorganisms whose metabolism is engineered towards the production of specific molecules) ▪ For catalytic and chemical routes: catalyst design and optimisation ▪ Scale up and cost reduction – most of these routes are at an early stage of development, with high current costs ▪ Integration with co-product production and potential for biorefineries ▪ Evaluation and development/adaptation for a wider range of feedstocks e.g. many developers are currently focusing on sugars from sugar cane or corn. Deployment in the EU is more likely to use energy crop or wood feedstocks ▪ Life cycle analysis to prove GHG reductions versus conventional fuels

Non-Fungible Fuels: Innovation needs in biological routes to lignocellulosic ethanol focus on cost reduction and consolidation of processing steps

'Proving stages'	Key innovation needs
Pre-treatment	▪ None of the pre-treatment processes currently in use are ideal in terms of the cost or GHG intensity associated with them. Those being developed include: ▪ Biological pre-treatment – in particular, the use of white-rot fungi which produce lignin-degrading enzymes. Has low energy requirements and needs mild conditions, but is slow ▪ Chemical pre-treatment – acid and alkali treatment is used commercially. Novel options could use moderate temperature and pressure e.g. near critical or supercritical fluids, ionic liquids ▪ Physical/chemical pre-treatment – steam explosion is common, R&D is required to reduce the generation of/ remove inhibitors produced ▪ Most developers are currently focusing on feedstocks such as straw and grasses. Further development to enable use of wood, and heterogeneous waste streams is needed
Hydrolysis & Fermentation	▪ Conventional types of cellulose hydrolysis (e.g. acid hydrolysis) are fairly commercial and there are few remaining R&D challenges. Enzymatic hydrolysis of cellulose, which could be more cost-effective, is at the early demonstration stage, and requires cost reduction, higher tolerance to products, improved specificity, increased yield of sugars, and separation and re-use of enzymes ▪ Fermentation of C6 sugars is fully commercial. There are no commercially available fermentation routes from C5 sugars to ethanol, although some claim this is no longer a research challenge. Work has focused on finding or manipulating organisms (e.g. yeasts or bacteria) to metabolise the C5 sugars. This is now being demonstrated, but performance is not yet clear ▪ Development of Consolidated BioProcessing (CBP), which unifies enzyme production, hydrolysis & fermentation into one processing step, reduces costs overall. This is at an early stage of development and is being led by lignocellulosic ethanol producers, e.g. Mascoma. The challenge is to find or design microbes which produce both the enzymes for cellulosic breakdown and fermentation and which are capable of doing so in the presence of the reaction products
Separation	▪ Distillation is fully commercial, but energy intensive ▪ Several new membrane chemistries are being investigated, along with induced phase separation, which are thought to have the potential for >50% energy savings compared to distillation, and less wastewater

Non-Fungible Fuels: Innovation needs in lingo-cellulosic butanol focus on improving the existing process, or proving new pathways

‘Proving stages’	Key innovation needs

Pre-treatment	▪ None of the pre-treatment processes currently in use are ideal in terms of the cost or GHG intensity associated with them. Those being developed include:
	  ▪ Biological pre-treatment – in particular, the use of white-rot fungi which produce lignin-degrading enzymes. Has low energy requirements and needs mild conditions, but is slow
	  ▪ Chemical pre-treatment – acid and alkali treatment is used commercially. Novel options could use moderate temperature and pressure e.g. near critical or supercritical fluids, ionic liquids
	  ▪ Physical/chemical pre-treatment –steam explosion is common, R&D is required to reduce the generation of/ remove inhibitors produced
	▪ Most developers are currently focusing on feedstocks such as straw and grasses. Further development to enable use of wood, and heterogeneous waste streams is needed

Hydrolysis & Fermentation	▪ Fermentation to butanol is still at a research stage, although there are processes which have been used in the past, e.g. the acetone butanol ethanol (ABE) process
	▪ Some of those working in this area are looking at improving and re-commercialising the ABE process, although there are others looking at different routes to butanol, either through genetic manipulation of microbes that can already produce butanol, or of host microbes such as E. coli
	▪ R&D is particularly required in the following areas:
	  ▪ increasing butanol yield (proportion of feedstock converted to butanol)
	  ▪ increasing butanol concentration (in one pass through of the process)
	  ▪ increase productivity of process (how quickly butanol is produced)
	▪ Breakthroughs in these R&D areas are likely to require careful selection of appropriate microbes, genetic improvement of microbes to grow better and to have greater product tolerance, as well as improving growth conditions for the microbes
	▪ Consolidated BioProcessing (CBP), which unifies enzyme production, hydrolysis & fermentation could also be possible for butanol

Separation	▪ Butanol cannot be separated using the simple distillation process used for ethanol ▪ Precipitation, chemical based techniques, membrane separation, ion exchange and gas/liquid filtration could be used

Non-Fungible Fuels: Innovation needs in DME are similar to BTL, and focus on improving the existing process, or proving new pathways

‘Proving stages’	Key innovation needs
Sizing & drying	▪ Established technologies, limited cost reduction possible
Gasification	▪ Gasifier chemistry is well understood and the technology is currently nearing commercialisation. Further improvements being made in gasifier design, process design, dealing with tar and carbon, increasing gasifier efficiency and improving the quality of the syngas. ▪ Gasification has been proven at scale for coal, but large biomass gasifiers used to date for power and heat production have not shown proven reliability. Further work needed on demonstration of the gasifier types suitable for BTL applications at scale, and application to a range of feedstocks
Syngas cleanup & conditioning	▪ Although current technologies exist for gas clean up, e.g. wet gas scrubbing, they have efficiency and cost penalties, and so new options have been developed, e.g. hot gas clean up and plasma clean up. ▪ Progress has been achieved through research on these options, but opportunities remain in improving the processes and demonstration at scale
DME synthesis	▪ DME catalysts are still being optimised for biosyngas composition
Integration	▪ Integration of biomass gasification with the DME process requires most development, and is most likely to take place during the development of the demonstration plant itself. ▪ Large opportunity for optimised heat integration, balance of plant optimisation and control systems. Steam heating can be achieved via efficient heat recovery (less biomass or fuel use for drying), and steam used for electricity generation. ▪ Cost reductions available by optimising system design for either large-scale use of specific biomass types, or heterogeneous input

Appendix 6: International Bio-energy / Biotechnology Markets, Research Coordination and Extent of UK Collaboration

Summary information from the review of International bio-energy / biotechnology markets to assess the relative strengths and areas where the UK should seek to collaborate with other countries. Information was obtained from the BIS/FCO Science and Innovation Network survey undertaken in August 2010.

Table A6.1: International Biotechnology Markets, Co-ordination / Capacity and UK Collaboration.

	State of Market	Co-ordination / Capacity	Existing Collaboration / Notes
United States	- US is a global leader in bio-energy. It has a strong agricultural sector, large industrial sectors in agriculture, chemicals and oil and has world class universities. - Bio-energy R&D driven by Federal funding for 2010 from the DoE and DoA is around US$1 Bn, tax credits and requirements for the Renewable Fuel Standard 2 (RFS2). Biofuels is the focus of the investment in bio-energy with corn ethanol capacity standing at 40.7 B litres. 2G capacity stands at 96.5 M litres. Landscape for biogas and biomass-generated electricity and heat less developed. Tend to be driven by state Renewable Portfolio Standard 2009 1.3% of electricity derived from biomass. 151 AD systems, 130 for electrical and heat Patchwork of activity due to state system. Funding available from a number of sources: The Recovery and Reinvestment Act, Tax Credits, Small Business Innovation Research Solicitation, USDA Biomass Crop Assistance Program, DoE Loan Guarantee Program, Various State funding, venture capital and Private Sector.	Key players in the space include US Dept of Energy, Dept of Agriculture and Environmental Protection Agency. In May 2009 interagency group on biofuels convened to develop roadmap to fulfil RFS by 2022. National Science Foundation funds basic science. There are a number of corporate players. Produced a number of strategies and roadmaps related to biomass - DOE and DOA has one of the most sophisticated biosciences programmes in the world. - 60% of LC capacity for ethanol is based in the US. - Waste: Major players in waste to energy based in US (has Tax credit for waste to fuels). - Algae - One of the largest investors in algae and nation with the most start ups. Emerging areas include use of Synthetic Biology to develop single cell bioreactors and the DoE funding of the Joint Centre for Artificial Photosynthesis with US$122 over 5 years.	- In 2000, the US DoE and DTI signed a memorandum of understanding. While the MoU will expire in late 2010, efforts to sign a new agreement between DECC and the DoE. - The University of Nottingham/BSBEC and the DoE Joint Bio-energy Institute (JBEI) signed an MoU on collaboration in July 2010, with support from UK Science & Innovation Network. - In 2009, the University of Portsmouth and the University of Maine received a BBSRC UK-US partnering award of £24,000 for project entitled: “New insights into using lignocellulose degradation mechanisms for biofuel generation by sharing expertise in wood-degrading animals and fungi”. - In 2007, the BBSRC made a UK-US partnering award (£44.8K) for the Institute of Grassland & Environmental Research to collaborate with the US Samuel Roberts Nobel Foundation on "the underpinning genetics of biomass yield, quality and sustainability in Miscanthus and switchgrass". - Imperial College, Georgia Tech and ORNL were part of the Atlantic partnership. This established collaborative ties between the Porter Alliance (Imperial) & bio-energy researchers at the partner institutions. Funding has recently come to an end. - Many individual researcher-to-researcher links. Potentially bio-energy related: - In autumn 2010, the BBSRC and NSF held a joint `ideas lab’, a week long facilitation workshop on the topic of `Enhancing Photosynthesis’. The 2 finders will make up to $8 M available to find proposals arising from the meeting. - In spring 2009, the EPSRC and NSF held a sandpit on “New Directions in Synthetic Biology”. Funding of up to £5.5 million was allocated to proposals stemming from the workshop

Brazil	Brazil has a strong agricultural sector due to large endowments of land and water. Seeking to increase renewable sources for electricity generation. Second larger producer of ethanol after US 24B litres. Seeking to increase to 65 B litres by 2020. 90% of vehicles manufactured in Brazil FFV. 5% of electricity from bagasse. Seeking US$ 33 Bn in new investments in bioethanol over next 4 years incl 126 production plants. PROINFA targets renewable energy programs incl bio-energy.	Key players in the space include Min Science and Technology, Min of Agriculture, Livestock and Food Supply, National Council for Science and Technological Development, State of Sao Paulo Research Foundation, Research and Projects Financing (Innovation Agency), Brazilian Development Bank and Brazilian Agricultural Research Corporation (Embrapa) abd Centre for Research and Development, Petrobras (CENEPES). - Looking at Sugar cane to diesel. - Waste - There are several biodiesel plant investments using MSW and vegetable oil and waste - Algae - some indications of work taking place in this space. Emerging areas include productivity improvement, decreased soil stress, species adaption. 2G LC plants, GM sugar cane, advanced conversion concepts and advanced gasification.	***Information requested from Science and Innovation Network in Brazil not forthcoming.***

China	China energy consumption increasing at almost 9% pa^{-1} with increased proportion of imported energy especially oil. Seeking to increase renewable portfolio from nuclear, wind, PV and bio-energy. Energy Security is a key driver. Main source of feedstock likely to be agricultural crop residue / waste. Feedstock from food crops not attractive due to need for food. China is the third largest user of ethanol. Most is used in pharmaceutical and beverage industries. Ambition that biofuels will meet 15% of transport needs by 2020. Present capacity for biomass power generation 5.5GW. After the US has the most LC ethanol plants planned.	Key players: Min of Finance, National Energy Administration, Min of Science and Technology, Min of Agriculture, The National Energy Authority, Chinese Academy of Sciences and Provincial Governments, Large Scale companies and research institutions. Produced a number of strategic documents related to science and technology rather than bio-energy specifically. No. of research programmes 973 Projects and 863 Projects. - Waste - Much waste. Biodiesel dominated by use of vegetable oil. Lack of defined standards impacting development. - Algae - work is starting e.g. PetroSun and PetroAlgae. Also tapping into deposits of algae on coast Emerging areas focus on development of new feedstocks such as Jatropha and algae.	China has no energy ministry. Bio-energy Research is fragmented and uncoordinated across the nation and has yet to feature in the national energy system. Collaboration of Chinese and UK Institutes are bottom up and depends on personal contacts. There is no governmental collaboration agreement. No sustainable funding to encourage research collaboration. EPSRC energy joint call was suspended from 2008. Competition from other bio-energy experts from US, Germany, Japan, Sweden etc - Optimisation of biomass/coal co-firing through integrated measuring and computational modelling between Chinese Academy of Engineering and Uni of Nottingham, Leeds and Kent. - BMT-CES: Biofuel Micro-Trigeneration with Cryogenic Energy Storage between Chinese Academy of Science and Uni Leeds, Ulster and Newcastle. - Impact of DMF on Engine Performance and Emissions as a New Generation of Sustainable Biofuel between Uni of Birmingham and Wuhan University Technology. - BioProcess Intensification between Jiangnan University and Newcastle. - Using sugar cane residue to power sugar refineries by British Sugar. - Research on butanol – Shangdong Academy of Sciences and Green Biologics - The technology of utilising biomass efficiently - Zhjiang and Uni of Kent. - Developing a Sustainable Biodiesel Production Platform Based on Jatropha Curcas between Sichuan University and Uni Kent. - In May 2009 the Carbon Trust signed an agreement with the China Energy Conservation Investment Corporation (CECIC) to develop and deploy low carbon technologies in China. - EU Framework Directives - have been the main financial tools through which the European Union supports research and development activities covering almost all scientific disciplines.

Other	The drivers for bio-energy development vary between countries. But most common is energy security mainly to reduce oil imports. Greenhouse gas emission reduction is a driver for some, but in developing countries rural development is often stated. In most countries bio-energy is currently a significant proportion of the total energy supply from renewables, mainly for heating, cooking (including biogas) and electricity. This includes developed countries, although the overall contribution to the energy supply is often small. This proportion is expected to decrease as other renewables are deployed more widely. Targets for bio-energy are not universal and may only be ambitions. Bio-energy is often included in renewables targets, with no specific objectives defined. Where targets they are mainly short-term going out to 2020. None go out to 2030. Targets/ambitions are split between biofuels and electricity/heat production, depending on the policy drivers. It is also affected by domestic feedstock supplies, such as availability of wood and wood waste. Biogas varies widely. Some countries, such as China, have already implemented a widespread scheme for biogas production at domestic and small scale. Mainly as anaerobic digestion is a more mature technology. Industry involvement appears to be greatest where there are clear targets.	R&D is usually split between a number of government ministries and research funding bodies, because of the diversity of the R&D needs. Some have bio-energy roadmaps and have set up bodies to advise/lead on bio-energy development. These national programmes provide a more focussed and comprehensive approach to the technology development across the supply chain. Some are set up to deliver on specific objectives , such as biofuel supply, others provide a wider view of bio-energy end uses and development. Canada - Waste from forest residues due to fact has 10% of worlds forests. Bio-energy mechanism to support forestry sector. Japan - leading in MSW combustion plants	Collaboration between UK and Singapore in bio-energy (as a component of renewable / clean) energy with a view for Singapore to build science and engineering expertise and then act as a launchpad for new forms of development in the region.

Appendix 7: UK Capacity Assessment for Advanced Biofuels (work undertaken with the NNFCC extracted from NNFCC, 2011)

Download from the ERP website: http://www.energyresearchpartnership.org.uk/bio-energy as a separate annex with the file name `NNFCC Annex to Appendix 7 UK Capabilities'. This document titled `UK Capabilities in Advanced Biofuels by Dr Claire Smith' is extracted from Appendix 2 of a Department for Transport Report on UK Biofuels which was co-written by the NNFCC and a number of other organisations including the ERP in early 2011.

Appendix 8: Summary of UK Government Support and Sustainability Requirements for Biomass

Extracted from a DECC presentation delivered at the SUPERGEN Bio-energy II Researchers conference on 15th April 2011.

Renewables Obligation - electricity production

- Obligation on all electricity suppliers to supply a specific proportion of electricity from eligible renewable sources.
- Supports dedicated biomass, co-firing, energy from waste, anaerobic digestion, sewage gas, landfill gas, gasification, pyrolysis.
- Paid for by suppliers – ultimately by consumers.
- Open to March 2017 to new investment (20 year support).
- Banding introduced from April 2009 and extended to 2037 – will know 2013 rates this autumn.
    - Including consideration of conversion
    - Aim is delivery of renewable electricity target 2020
    - Looking at outstanding grandfathering issues

Feed in Tariff - electricity production below 5MWe

- Introduced in 2010 to support small, distributed generation.
- Provides a guaranteed payment to the generator for each unit of power.
- Aimed at the non-energy professional – domestic, small businesses
- The FIT support includes anaerobic digestion. Government recent consultation on increased support for on-farm:
    - ≤250kW: 14p/kWh
    - >250 - ≤500kW: 13p/kWh
    - (These compare with previous tariff rate from 1 April of 12.1p/kWh for AD up to 500 kW.)
- AD >500kW support

Renewable heat incentive (RHI)

- Introduced in March 2011 to support renewable heat in buildings and homes
- First phase targeted at non-domestic sector – from large scale industrial heating to small businesses and community projects
- Including solid and gaseous biomass, on-site use of biogas for heat, energy from waste and injection of biomethane into the grid;
- Quarterly payments over twenty year period
- Biomass installations of 1 MWth capacity and above will be required to report on the sustainability of their biomass feedstock

- Government will also introduce *Renewable Heat Premium Payments* for the domestic sector.
- Ring-fenced funding of around £15 million, used to make premium payments to households who install renewable heating.
- Will subsidise the cost of installing renewable heating systems, including biomass boilers
- Second phase of RHI support including long-term tariff support for the domestic sector to be introduced in 2012.

Sustainability constraints

- Acceptable sustainability of bio-energy introduces production limitations.
- UK technical potential estimated at around 100 TWh by 2020
- About half could come from wastes
- UKERC see ~7.5 Mt of short rotation energy crops from marginal land (ALC grades 4 and 5) as a realistic production estimate13.
- Equivalent to about ~4% of current UK electricity /~1% of energy demand.)
- Imports are desirable, if available.

Feedstock sustainability criteria

- Introducing formal sustainability criteria for bioliquids within the Renewables Obligation (RO) to comply with the RED
- Introduced “voluntary” sustainability criteria for solid and gaseous biomass within the RO from April 2011

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[13] Aylott et al. (2010) Biofuels 1(5), 719-727.

- .....making them formal requirements in April 2013
- Introduce similar requirements within the RHI
- Introduce requirements into the Feed-In-Tariff when and if there is a need.
- Address large scale electricity through planning (and LCA).

Renewable Energy Directive

- Minimum GHG emissions saving of 35% compared to fossil fuel, increasing in 2017 to 50%; and in 2018 increases to 60% for new installations (equates to 285 kg CO_2/MWh or lower).
- For bioliquids, Member States can only provide support that meet these, but cannot impose tougher criteria
- The RED Criteria for Bioliquids (& Biofuels) are 3-fold:
  - General restrictions on use of raw materials from land important on carbon or biodiversity grounds - e.g. Primary forest, peatlands, highly biodiverse grasslands
  - If crop is grown in EU must meet CAP cross-compliance requirements
- Requirement to report against these from April 2011
- For generators of ≥1MW, in April 2013, receipt of ROCs depend on meeting criteria
- Biomass and biogas from waste or landfill/ sewage gas will be excluded from requirements